4.5.0 Transit Mixed Concrete

"Transit mixing" refers to concrete that is mixed, either wet or dry, en route to a job site. A transit mix truck carries a mixer and a water tank from which the driver can, at the proper time, introduce the required amount of water into the mix. The truck picks up the dry ingredients at the batch plant together with a slip which tells how much water to introduce to the mix upon arrival at the site. The mixer drum is kept revolving en route and at the job site so that the dry ingredients do not segregate. Transit mix trucks are part of the battalion's equipment inventory and are widely used on all but the smallest concrete jobs assigned to a battalion. A large concrete job is shown in *Figure 6-14*.

Figure 6-14 – Large concrete job.

Test your Knowledge (Select the Correct Response)

5. You are to mix a 1:2:4 batch of concrete by hand. After putting part of the sand onto a mixing platform, in what order should you add and mix the other ingredients?

   A. Cement, water, aggregate, sand
   B. Cement, sand, water, aggregate
   C. Aggregate, sand, cement, water
   D. Cement, sand, aggregate, water

5.0.0 FORMWORK

Most structural concrete is made by placing or casting plastic concrete into spaces enclosed by previously constructed forms. The plastic concrete hardens into the shape outlined by the forms. The size and shape of the formwork is always based on the project plans and specifications.

Forms for all concrete structures must be tight, rigid, and strong. If the forms are not tight, there will be excessive leakage at the time the concrete is placed. This leakage can result in unsightly surface ridges, ***honeycombing***, and sand streaks after the concrete has set. The forms must be able to safely withstand the pressure of the concrete at the time of placement, as well as the live load, which includes personnel and equipment. Do not take shortcuts. Proper form construction material and adequate bracing in place prevent the forms from collapsing or shifting during placement of the concrete.

Forms or form parts are often omitted when a firm earth surface exists that is capable of supporting or molding the concrete. In most footings, the bottom of the footing is cast directly against the earth and only the sides are molded in forms. Many footings are cast with both the bottom and the sides against the natural earth. In these cases, the specifications usually call for larger footings. A foundation wall is often cast between a form on the inner side and the natural earth surface on the outer side.

5.1.0 Form Materials

Forms are generally constructed from earth, metal, wood, fiber, or fabric.

5.1.1 Earth

Use earthen forms in subsurface construction where the soil is stable enough to retain the desired shape of the concrete. The advantages of earthen forms are that less excavation is required and there is better settling resistance. The obvious disadvantage is a rough surface ***finish***, so the use of earthen forms is generally restricted to footings and foundations. Always take precautions to avoid collapse of the sides of trenches.

5.1.2 Metal

Use metal forms where high strength is required or where the construction is duplicated at more than one location. They are initially more expensive than wood forms, but may be more economical if they can be reused repeatedly. Originally, all prefabricated metal forms were made of steel. These forms were heavy and hard to handle. Aluminum forms, which are lightweight and easier to handle, are replacing steel.

Prefabricated metal forms are easy to erect and strip. The frame on each panel is designed so that the panels can be easily and quickly fastened and unfastened. Metal forms provide a smooth surface finish so that little concrete finishing is required after the forms are stripped. They are easy to clean, and maintenance is minimal. Care should be taken when ***stripping*** metal forms to ensure they are not damaged.

Metal wood forms are just like metal forms except for the face. It is made with a sheet of B grade exterior plywood with waterproof glue.

5.1.3 Wood

Wooden forms are by far the most common type used in building construction. They have the advantage of economy, ease in handling, ease of production, and adaptability to many desired shapes. Added economy may result from reusing form lumber later for roofing, bracing, or similar purposes. Lumber should be straight, structurally sound, strong, and only partially seasoned. Kiln dried timber has a tendency to swell when soaked with water from the concrete. If the boards are tight jointed, the swelling will cause bulging and distortion. When green lumber is used, make allowance for shrinkage, or keep the forms wet until the concrete is in place. Soft woods, such as pine, fir, and spruce, make the best and most economical form lumber since they are light, easy to work with, and available in almost every region.

Lumber that comes in contact with concrete should be surfaced at least on one side and both edges. The surfaced side is turned toward the concrete. The edges of the lumber may be square, shiplap, or tongue and groove. The latter makes a more watertight joint and tends to prevent warping.

Plywood can be used economically for wall and floor forms if it is made with waterproof glue and identified for use in concrete forms. Plywood is more warp resistant and can be reused more often than lumber. Plywood is made in 1/4, 3/8, 1/2, 9/16, 5/8 and 3/4 inch thicknesses and in widths up to 48 inches. Although longer lengths are manufactured, 8 foot lengths are the most common. The 5/8 and 3/4 inch thicknesses are most economical; thinner sections require additional solid backing to prevent bulging. The 1/4 inch thickness is useful for forming curved surfaces.

5.1.4 Fiber

Fiber forms are prefabricated from impregnated waterproofed cardboard and other fiber materials. Successive layers of fiber are first glued together and then molded in the desired shape. Fiber forms are ideal for round concrete columns and other applications where preformed shapes are feasible since they require no form fabrication at the job site. This saves considerable time and money.

5.1.5 Fabric

Fabric forming is made of two layers of nylon fabric. These layers are woven together, forming an envelope. Structural mortar is injected into these envelopes, forming nylon encased concrete pillows. These are used to protect the shorelines of waterways, lakes and reservoirs and as drainage channel linings.

Fabric forming offers exceptional advantages in the structural restoration of bearing piles under waterfront structures. A fabric sleeve with a zipper closure is suspended around the pile to be repaired, and mortar is pumped into the sleeve. This forms a strong concrete jacket.

5.1.6 Stay-in-Place

Systems of finished stay-in-place concrete forms are used for load bearing and non-load bearing concrete walls, above and below grade applications. These systems are very versatile and can be used for a wide variety of applications. Forms are available in different wall types and can incorporate integrated adjustable door jambs, window jambs, and trim.

5.2.0 Form Design

Forms for concrete construction must support the plastic concrete until it has hardened. Stiffness is an important feature in forms. Failure to provide form stiffness may cause unfortunate results. Forms must be designed for all the weight to which they are likely to be subjected. This includes the dead load of the forms, the plastic concrete in the forms, the weight of the workmen, the weight of equipment and materials, and the impact due to ***vibration***. These factors vary with each project, but none should be ignored. Ease of erection and removal is also an important factor in the economical design of forms.

Displacement of forms due to loading and impact shock from workmen and equipment can be avoided by using platform and ramp structures independent of the formwork.

When concrete is placed in forms, it is in a plastic state and exerts hydrostatic pressure on the forms. The basis of form design is the maximum pressure developed by concrete during placing. The maximum pressure developed depends on the ***placing rate*** and the temperature. The rate at which concrete is placed affects the pressure because it determines how much ***hydrostatic head*** builds up in the form. The hydrostatic head continues to increase until the concrete takes its initial set, usually in about 90 minutes. At low temperatures, the initial set takes place much more slowly. This makes it necessary to consider the temperature at the time of placing. By knowing these two factors and the type of form material to be used, you can calculate a tentative design.

5.3.0 Form Construction

Strictly speaking, it is only those parts of the form work that directly mold the concrete that are correctly referred to as the forms. The rest of the formwork consists of various bracing and tying members. The following discussion on forms provide illustrations to help you understand the names of all the formwork members. Study these illustrations carefully so that you will understand the material in the next section.

5.3.1 Foundation Forms

The portion of a structure that extends above the ground level is called the superstructure. The portion below the ground level is called the substructure. The parts of the substructure that distribute building loads to the ground are called foundations.

Footings are installed at the base of foundations to spread the loads over a larger ground area. This prevents the structure from sinking into the ground. It’s important to remember that the footings of any foundation system should always be placed below the frost line. Forms for large footings, such as bearing wall footings, column footings, and pier footings, are called foundation forms. Footings, or foundations, are relatively low in height since their primary function is to distribute building loads. Because the concrete in a footing is shallow, pressure on the form is relatively low. A form design based on high strength and rigidity considerations is generally not necessary. *Figure 6-15* shows a foundation form for a small structure.

Figure 6-15 – Foundation forms.

Simple Foundation – Whenever possible, excavate the earth and use it as a mold for concrete footings. Thoroughly moisten the earth before placing the concrete. If this is not possible, you must construct a form. Because most footings are rectangular or square, you can build and erect the four sides of the form in panels.

1. Make the first pair of opposing panels as shown in *Figure 6-16 (a)* to exact footing width.
2. Nail vertical ***cleats*** to the exterior sides of the sheathing. Use at least 1 by 2 inch lumber for the cleats, and space them 2 1/2 inches from each end of the exterior sides of the panels *(a)*, and on 2 foot centers between the ends.
3. Nail two cleats to the ends of the interior sides of the second pair of panels (*Figure 6-16 (b)*). The space between these panels should equal the footing length plus twice the sheathing thickness.

Figure 6-16 – Typical foundation form for a large footing.

4. Nail cleats on the exterior sides of the panels *(b)* spaced on 2 foot centers.
5. Erect the panels into either a rectangle or square and hold them in place with form nails. Make sure that all reinforcing bars are in place.
6. Drill small holes on each side of the center cleat on each panel. These holes should be less than 1/2 inch in diameter to prevent paste leakage.
7. Pass No. 8 or No. 9 black annealed iron wire through these holes and wrap it around the center cleats or erect the panels into either a rectangle or square and hold them in place with form nails. Make sure that all reinforcing bars are in place.
8. Drill small holes on each side of the center cleat on each panel. These holes should be less than 1/2 inch in diameter to prevent paste leakage.
9. Pass No. 8 or No. 9 black annealed iron wire through these holes and wrap it around the center cleats of the opposing panels to hold them together as shown in *Figure 6-16*. Mark the top of the footing on the interior side of the panels with grade nails.

For forms 4 feet square or larger, drive stakes against the sheathing, as shown in *Figure 6-16*. Both the stakes and the 1 by 6 tie braces nailed across the top of the form keep it from spreading apart.

If a footing is less than l foot deep and 2 feet square, you can construct the form from 1 inch sheathing without cleats. Simply make the side panels higher than the footing depth, and mark the top of the footing on the interior sides of the panels with grade nails. Cut and nail the lumber for the sides of the form, as shown in *Figure 6-17.*

Figure 6-17 – Typical small footing form.

Foundation and Pier Forms Combined – You can often place a footing and a small pier at the same time. A pier is a vertical member that supports the concentrated loads of an arch or bridge superstructure. It can be either rectangular or round. Build a pier form as shown in *Figure 6-18*. The footing form should look like the one in *Figure 6-18*. You must provide support for the pier form while not interfering with concrete placement in the footing form.

Nail 2 by 4s or 4 by 4s across the footing form, as shown in *Figure 6-18*. These serve as both supports and tie braces. Nail the pier form to these support pieces.

Figure 6-18 – Footing and pier form.

Bearing Wall Footings – *Figure 6-19* shows a typical footing formwork for a bearing wall, and *Figure 6-20* shows bracing methods for a bearing wall footing. A bearing wall, also called a load bearing wall, is an exterior wall that serves as an enclosure and also transmits structural loads to the foundation. The form sides are 2 inch lumber whose width equals the footing depth. Stakes hold the sides in place while spreaders maintain the connect distance between them. The short braces at each stake hold the form in line.

Figure 6-19 – Bearing wall footing form.

A keyway is made in wet concrete by placing a 2 by 2 inch board along the center of the wall footing form, shown in *Figure 6-20*. After the concrete is dry, the board is removed. This leaves an indentation, or key, in the concrete.

When you pour the foundation wall, the key provides a tie between the footing and the wall. Although not discussed in this training manual, there are several commercial keyway systems available for construction projects.

Figure 6-20 – Methods of bracing bearing wall footing forms and placing a keyway.

5.3.2 olumns

Square column forms are made of wood. Round column forms are made of steel or cardboard impregnated with waterproofing compound.

Figure 6-21 shows an assembled column and footing form.

1. Construct the footing forms.
2. Build the column form sides.
3. Nail the yokes to them.

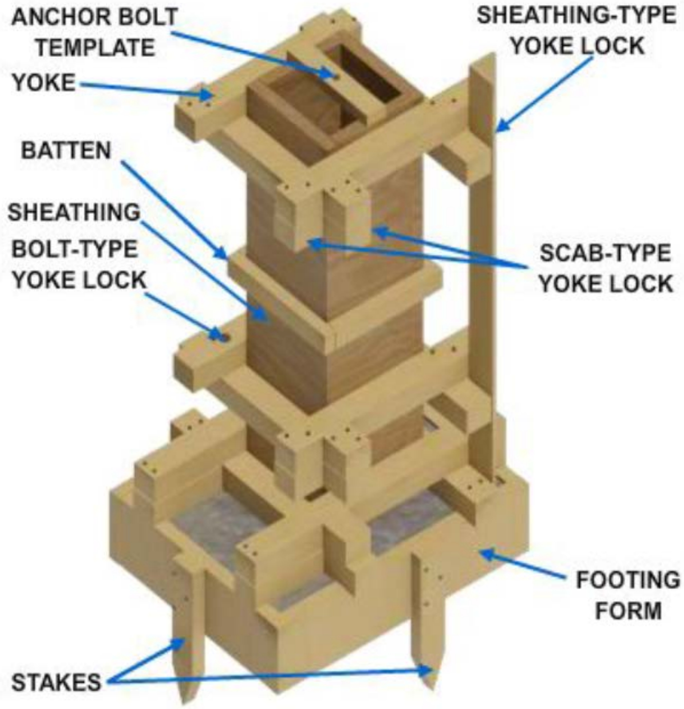

Figure 6-21 – Form for a concrete column.

Figure 6-22 shows a column form with two styles of yokes. *View A* shows a commercial type called a scissor clamp. *View B* shows yokes made of all-thread bolts and 2 by material. Since the rate of placing concrete in a column form is very high and the bursting pressure exerted on the form by the concrete increases directly with the rate of placing, a column form must be securely braced, as shown by the yokes in the figure. Since the bursting pressure is greater at the bottom of the form than at the top, yokes are placed closer together at the bottom.

Figure 6-22 – Column form with with scissors clamp or yolk and wedge.

The column form should have a cleanout hole cut in the bottom to remove construction debris. Nail the pieces that you cut to make the cleanout hole to the form. You can replace them right before placing concrete in the column. The intention of the cleanout is to ensure that the surface which bonds with the new concrete is clear of all debris.

5.3.3 Wall Forms

Wall forms, as shown in *Figure 6-23*, may be built in place or prefabricated, depending on the form shape and whether the form will be reused. Some of the elements that make up wooden forms are sheathing, studs, walers, braces, shoe plates, spreaders, and tie wires.

Figure 6-23 –Form for a concrete wall.

Construction sheathing forms the surfaces of the concrete. It should be as smooth as possible, especially if the finished surfaces are to be exposed. Since the concrete is in a plastic state when placed in the form, the sheathing should be watertight. Tongue and groove sheathing gives a smooth, watertight surface. You can also use plywood or hardboard, and tongue and groove sheathing is the most widely accepted construction method.

The weight of the plastic concrete causes sheathing to bulge if it is not reinforced. As a result, run studs vertically to add rigidity to the wall form. Studs are generally made from 2 by 4 or 3 by 6 material.

Studs also require reinforcing when they extend over 4 or 5 feet. Double walers supply this reinforcing. They also serve to tie prefabricated panels together and keep them in a straight line. They run horizontally and are lapped at the corners of the forms to add rigidity. Walers are usually made of the same material as the studs.

The shoe plate is nailed into the foundation or footing. It is carefully placed to maintain the correct wall dimension and alignment. The studs are tied into the shoe and spaced according to the correct design.

Small pieces of wood, known as spreaders, are cut the same length as the thickness of the wall and are placed between the forms to maintain proper distance between forms. Spreaders are not nailed but are held in place by friction and must be removed before the concrete covers them. Attach a wire securely to each spreader so the spreaders can be pulled out after the concrete has exerted enough pressure on the walls to allow them to be easily removed. Tie wire is designed to hold forms securely against the lateral pressure of unhardened concrete. Always use a double strand of tie wire.

Bracing – Many types of braces can be used to add stability and bracing to the forms. The most common type is a diagonal member and horizontal member nailed to a stake and to a stud or waler, as shown in *Figure 6-24*. The diagonal member should make a 30° angle with the horizontal member. You may add additional bracing to the form by placing vertical members (strongbacks) behind the walers or by placing vertical members in the corner formed by intersecting walers. Braces are not part of the form design and do not provide any additional strength.

Reinforcement – Wall forms are usually reinforced against displacement using ties. Two types of simple wire ties used with wood spreaders are shown in *Figure 6-24*. The wire is passed around the studs, the walers, and through small holes bored in the sheathing. Each spreader is placed as close as possible to the studs. *View A* shows the tie set taut by the wedge. *View B* shows the tie set taut by twisting with a small toggle.

Figure 6-24 – Wire ties for wall forms.

As the concrete reaches the level of each spreader, knock the spreader out and remove it.

Figure 6-25 shows an easy way to remove the spreaders by drilling holes and placing a wire through them. The parts of the wire that are inside the forms remain in the concrete; the outside surplus is cut off after the forms are removed.

Wire ties and wooden spreaders have been largely replaced by various manufactured devices which combine the functions of the tie and the spreader.

Figure 6-25 – Removing wood spreaders.

Figure 6-26 shows one of these. It is called a snap tie. These ties are made in various sizes to fit various wall thicknesses. The tie holders can be removed from the tie rod. The rod goes through small holes bored in the sheathing and also through the walers, which are usually doubled for that purpose. Tapping the tie holders down on the ends of the rod brings the sheathing to bear solidly against the spreader washers. You can prevent the tie holder from coming loose by driving a duplex nail in the provided hole.

After the concrete has hardened, the tie holders can be detached to strip the forms. After stripping the forms, use a special wrench to break off the outer sections of rods. The rods break off at the breaking points, located about 1 inch inside the surface of the concrete. Small surface holes remain, which can be plugged with grout if necessary.

Figure 6-26 – Snap tie.

Determining the Load on a Snap Tie – Use these steps to determine the total load on a snap tie:

1. Figure the contributing area of form. Multiply the distance between the ties horizontally by the vertical distance between ties.
2. Multiply the contributing area of form by the unit pressure per square foot (PSFT) of the concrete on that area of form as shown in *Table 6-5*.

Table 6-5 – Unit Pressure per Square Foot.

Rate of Placement R. ft. per hr.	P. maximum lateral pressure, psf for temperatures indicated.					
	90°F	**80°F**	**70°F**	**60°F**	**50°F**	**40°F**
1	250	262	278	300	350	375
2	350	375	407	450	510	600
3	450	488	536	600	690	825
4	550	600	664	750	870	1050
5	650	712	793	900	1050	1275
6	750	825	921	1050	1230	1500
7	850	938	1050	1200	1410	1725
8	881	973	1090	1246	1466	1795
9	912	1008	1130	1293	1522	1865
10	943	1043	1170	1340	1578	1935

The following examples walk you through the process of checking the load on snap ties. The safe load on snap ties is 2,250 pounds per square foot (psf).

Example 1:

1. 8’ of foam panel with snap ties at 24” on center (o.c.) (8 ties per 4’ x 8’ panel) as shown in *Figure 6-32*
2. Poured at 5’ per hour (rate of pour) at a 70° temperature
3. Contributing area of form = 2’0” x 2’0” = 4 square feet
4. 5’ rate of pour at 70 = 793 pounds of pressure per square foot (PSFT)
5. 4 (area of form) x 793 (unit pressure per square foot.) = 3,172 psf pressure of load on snap tie

Figure 6-27 – Contributing area.

CAUTION

This exceeds the safe capacity of the snap tie and must be reduced either by slowing the rate of concrete poured per hour or by reducing the snap tie spacing (increasing the number of snap ties).

Example 2:

1. 8’ of foam panel with snap ties at 16” o.c. (18 ties per 4’ x 8’ panel)
2. Poured at 5’ per hour (rate of pour at a 70° temperature)
3. Contributing area of form = 1.33 x 1.33 = 1.8 square feet
4. 5’ rate of pour at 70 = 793 PSFT
5. 1.8 (area of form) x 793 (unit pressure per sq. ft.) = 1,427 psf pressure of load on snap tie

This is well within the 2,250 psf safe load on snap ties.

Spacing Snap Ties – Some alternatives for spacing snap ties on a 4’ x 8’ sheet are shown in *Figure 6-28*.

Figure 6-28 – Alternative snap tie spacing for 4' x 8' sheets.

Snap Tie Systems – There are a number of snap tie systems you can use; they are shown in *Figures 6-29 through 6-32*.

Figure 6-29 – Single waler system using a Jahn bracket.

Figure 6-30 – 3/4" Plywood, double 2 x 4 waler with hair pin.

Figure 6-31 – 3/4” Plywood, double 2 x 4 waler with hair pin (with strongback).

Figure 6-32 – Plywood (3/4” or 1 1/8”) only, hair pin only.

Another type of wall form tie is the tie rod, shown in *Figure 6-33*. This rod consists of an inner section that is threaded on both ends and two threaded outer sections. Place the inner section with the cone nuts set to the thickness of the wall between the forms, and the outer sections through the walers and sheathing and thread them into the cone nuts. Then thread the clamps on the outer sections to bring the forms to bear against the cone nuts.

After the concrete hardens, loosen the clamps and remove the outer sections of rod by threading them out of the cone nuts. After stripping the forms, remove the cone nuts from the concrete by threading them off the inner sections of the rod with a special wrench. Plug the cone shaped surface holes that remain with grout. The inner sections of the rod remain in the concrete. The outer sections and the cone nuts may be reused indefinitely.

Figure 6-33 – Tie rod.

Wall forms are usually constructed as separate panels.

1. Make the panels by first nailing sheathing to the studs.
2. Next, connect the panels, as shown in *Figure 6-34*.

Figure 6-35 shows the form details at the wall corner.

Figure 6-34 – Joining wall form panels together in line.

Figure 6-35 – Joining wall form panels at a corner.

When placing concrete panel walls and columns at the same time, construct the wall form as shown in *Figure 6-36*. Make the wall form shorter than the distance between the column forms to allow for a wood strip that acts as a wedge. When stripping the forms, remove the wedge first to aid in form removal.

Figure 6-36 – Form for panel wall and columns.

5.3.4 Stair Forms

Concrete stairway forms require accurate layout to ensure accurate finish dimensions for the stairway. Always reinforce stairways with rebars (reinforcing bars) that tie into the floor and landing. Form them or after the concrete for the floor slab has set. Ge sure to anchor stairways formed after the slab has set to a wall or beam by tying the stairway rebars to rebars projecting from the walls or beams, or by providing a keyway in the beam or wall.

You can use various stair forms, including prefabricated forms. For moderate width stairs joining typical floors, a design based on strength considerations is generally not necessary.

Figure 6-37 shows one way to construct forms for stair widths up to and including 3 feet.

1. Make the sloping wood platform that serves as the form for the underside of the steps from 3/4 inch plywood. The platform should extend about 12 inches beyond each side of the stairs to support the stringer bracing blocks.
2. Shore up the back of the platform with 4 by 4 supports, as shown in *Figure 6-39*. The post supports should rest on wedges for easy adjustment and removal.

Figure 6-37 – Stairway form.

3. Cut 2 by 12 planks for the side stringers to fit the treads and risers.
4. Bevel the bottom of the 2 by 12 risers for easy form removal and finishing.

5.3.5 Beams and Girders

The type of construction used for beam and girder forms depends upon whether the forms are to be removed in one piece or whether the sides are to be stripped and the bottom left in place until the concrete has hardened enough to permit removal of the shoring.

The latter type of form is preferred, and details for this type are shown in *Figure 6-38*. Although beam and girder forms are subjected to very little bursting pressure, they must be shored up at frequent intervals to prevent sagging under the weight of fresh concrete.

Figure 6-38 – Typical beam and girder form.

The bottom of the form should be the same width as the beam and in one piece for the full width. The sides of the form should be 1 inch thick tongue and groove sheathing and should lap over the bottom as shown in *Figure 6-38*. Nail the sheathing to 2 by 4 inch studs placed on 3 foot centers. Nail a 1 by 4 inch piece along the studs.

These pieces support the joist for the floor panel, as shown in *Figure 6-39, Detail E*. Do not nail the beam sides of the form to the bottom. They are held in position by continuous strips, as shown in *Detail E*. The crosspieces nailed on top serve as spreaders. After erection, the slab panel joists hold the beam sides in position. Girder forms are the same as beam forms except that the sides are notched to receive the beam forms. Nail temporary cleats across the beam opening when handling the girder form.

The entire method of assembling beam and girder forms is illustrated in *Figure 6-39*. The connection of the beam and girder is illustrated in *Detail D*. The beam bottom butts up tightly against the side of the girder form and rests on a 2 by 4 inch cleat nailed to the girder side. *Detail C* shows the joint between the beam and slab panel, and *Details A and B* show the joint between the girder and column. The clearances given in these details are needed for stripping and also to allow for movement caused by the weight of the fresh concrete. The 4 by 4 posts shown in *Detail E*, used for shoring the beams and girders, should be spaced to provide support for the concrete and forms. Wedge them at the bottom to obtain proper elevation.

Figure 6-39 – Assembly of beam and floor forms.

Figure 6-40 shows how the same type of forming can be done by using quick beams, scaffolding, and I-beams, if they are available. This type of system can be set up and taken down in minimum time.

Figure – 6-40 – Beam and floor forms.

5.3.6 Oiling and Wetting Forms

Never use oils or other form coatings that may soften or stain the concrete surface, prevent the wet surfaces from water curing, or hinder the proper functioning of sealing compounds used for curing. If you cannot obtain standard form oil or other form coating, you can wet the forms to prevent sticking in an emergency.

Oil for Wood Forms – Before placing concrete in wood forms, treat the forms with a suitable form oil or other coating material to prevent the concrete from sticking to them. The oil should penetrate the wood and prevent water absorption. Almost any light bodied petroleum oil meets these specifications. On plywood, shellac works better than oil in preventing moisture from raising the grain and detracting from the finished concrete surface. Several commercial lacquers and similar products are also available for this purpose. If you plan to reuse wood forms repeatedly, a coat of paint or sealing compound will help preserve the wood. Sometimes lumber contains enough tannin or other organic substances to soften the concrete surface. To prevent this, treat the form surfaces with whitewash or limewater before applying the form oil or other coating.

Oil for Steel Forms – Oil wall and steel column forms before erecting them. You can oil all other steel forms when convenient, but you should oil them before placing the reinforcing steel. Use specially compounded petroleum oils, not oils intended for wood forms. Synthetic castor oil and some marine engine oils are examples of compound oils that give good results on steel forms.

Applying Oil – The successful use of form oil depends on how you apply it and the condition of the forms. They should be clean and have smooth surfaces. Because of this, do not clean forms with wire brushes, which can mar their surfaces and cause concrete to stick. Apply the oil or coating with a brush, spray, or swab.

CAUTION

Cover the form surfaces evenly, but do not allow the oil or coating to contact construction joint surfaces or any reinforcing steel in the formwork. Remove all excess oil.

Other Coating Materials – Asphalt paint, varnish, and boiled linseed oil are also suitable coatings for forms. Plain fuel oil is too thin to use during warm weather, but mixing one part petroleum grease to three parts fuel oil provides adequate thickness.

5.3.7 Form Failure

Even when all form work is adequately designed, many form failures occur because of human error, improper supervision, or use of damaged materials. The following list highlights some, but not all, of the most common construction deficiencies that supervisory personnel should consider when working with concrete:

- Inadequately tightened or secured form ties
- Inadequate diagonal bracing of shores
- Use of old, damaged, or weathered form materials
- Use of undersized form material
- Shoring not plumb
- Failure to allow for lateral pressures on form work
- Failure to inspect form work during and after concrete placement to detect abnormal deflections or other signs of imminent failure

Formwork and other work that needs to be completed before concrete is poured has to be verified before the concrete is poured. A concrete placement clearance form, shown in *Figure 6-41*, gives a thorough checklist to fill out before delivering and ***pouring*** concrete.

CONCRETE PLACEMENT CLEARANCE FORM

PART I Date

Project Number Title Location

Date/Time Desired QTY Strength (PSI)

Slump (in) ________________________ Max Aggregate Size ______________________ Admixtures __________________

Type of Placement ( ) Roof ( ) Slab ( ) Wall ( ) Other

Finish Required (Type) Tolerance ( ) +/- 1/4 in. ( ) Other

PART II		Conforms to Requirements		Item		Conforms to Requirements	
Item	N/A	Crew-leader	QC Insp		N/A	Crew-Leader	QC Insp
Subgrade Prep				Electrical			
Elevation				Conduit inst/stubbed up			
Dimension				Sleeves (foundations)			
Compaction				Pull cords			
Capillary Barr (sand)				Mechanical			
Vapor Barrier				Sleeves (foundations)			
Misc. (Insect, Drain rack, etc.)				Sub slab piping pressure tested			
Forms				Floor Drains (elevation & location)			
Elevation				Floor Cleanouts (elevation & location)			
Dimensions				Stubups (location, type)			
Alignment							
Bracing							
Condition							
Keyways				Placing/finishing Equipment			
Water Stop				Screed Boards Set			
Embedded Items				Screed Boards Checked			
Anchor Bolts				Placing Tools Set			
Sleeves				Placing Tools Checked			
Misc.				Finishing Tools Set			
Reinforcing				Finishing Tools Checked			
Size				Curing Materials			
Location and Spacing				Testing Materials (cylinders, Slump cone, etc.) arranged For on site			
Chairs (meshups)							
Bracing							

Submitted: ______________________________ ________________
Crewleader Date

Approved: ______________________________ ________________
QC Inspector Date

Scheduled For: ______________________________

Remarks

Figure 6-41 – Form for Concrete Placement Clearance.

There are many reasons why forms fail. It is the Builder's responsibility to ensure that the forms are correctly constructed according to design, and that proper techniques are followed.

Test your Knowledge (Select the Correct Response)

6. The parts of the substructure that distribute building loads to the ground are called

   A. footings
   B. superstructures
   C. pier footings
   D. foundations

7. Yokes are placed closer together at the bottom of column forms because

   A. the yokes are easier to nail
   B. the bursting pressure is greater at the bottom
   C. you can stand on the yokes to work on the rest of the column
   D. the placing of concrete is very low

6.0.0 REINFORCED CONCRETE

Concrete is strong under compression, but relatively weak under tension; the reverse is true for steel. When the two are combined, one makes up for the deficiency of the other. When steel is embedded in concrete in a manner that assists it in carrying imposed loads, the combination is known as reinforced concrete. The steel may consist of ***welded-wire fabric*** or expanded metal mesh, but more often, it consists of reinforcing bars, commonly known as rebar.

6.1.0 Welded Wire Fabric

Welded wire fabric, often referred to as wire mesh, comes in rolls and sheets. You must cut these to fit your individual application and tie together, or lap, them to form a continuous sheet of fabric.

Specifications and designs are usually used when wire fabric is being lapped. As a rule of thumb, one complete lap is usually sufficient with a minimum of 2 inches between laps. Whenever the rule of thumb is not allowed, use the end lap or side lap method.

In the end lap method, lap the wire mesh by overlapping one full mesh measured from the end of the longitudinal wires in one piece to the end of the longitudinal wires in the adjacent piece. Then tie the two pieces with a snap tie at 1 1/2 foot centers.

In the side lap method, place the two longitudinal side wires one alongside and overlapping the other. Then tie the two pieces with a snap tie every 3 feet.

6.2.0 Reinforcing Steel

Before placing reinforcing steel in forms, complete all form oiling. As mentioned earlier, oil or other coating should not contact the reinforcing steel in the formwork. Oil on reinforcing bars reduces the bond between the bars and the concrete. Use a piece of burlap to clean the bars of rust, scale, grease, mud, or other foreign matter. A light film of rust or mill scale is not objectionable.

Rebars must be tied together for the bars to remain in a desired arrangement during pouring. Tying is also a means of keeping laps or splices in place. Laps allow bond stress to transfer the load from one bar, first into the concrete, and then into the second bar.

6.3.0 Methods of Tying

Several types of ties can be used with rebar. Some are more effective than others. The views in *Figure 6-42* illustrate the six types used by the Seabees: (A) snap, or simple, tie, (B) wall tie, (C) double strand tie, (D) saddle tie, (E) saddle tie with twist, and (F) cross, or figure eight, tie. As a Builder, you will probably be concerned only with the snap and saddle ties. As a professional, you should be familiar with all six types.

6.3.1 Snap, or Simple, Tie

To use the snap, or simple, tie *(View A)*, simply wrap it once around the two crossing bars in a diagonal manner with the two ends on top. Then twist the ends together with a pair of side cutters until they are very tight against the bars. Finally, cut off the loose ends. This tie is used mostly on floor slabs.

6.3.2 Wall Tie

To make the wall tie *(View B)*, take one and one half turns around the vertical bar, then one turn diagonally around the intersection. Twist the two ends together until the connection is tight, then cut off the excess. The wall tie is used on light vertical mats of steel.

Figure 6-42 – Types of ties.

6.3.3 ouble-Strand Single Tie

The double strand tie *(View C)* is a variation of the simple tie. It is favored in some localities and is especially used for heavy work.

6.3.4 Saddle Tie

Pass the wires of the saddle tie *(View D)* halfway around one of the bars on either side of the crossing bar and bring them squarely or diagonally around the crossing bar. Then twist the ends together and cut them off.

6.3.5 Saddle Tie with Twist

The saddle tie with twist *(View E)* is a variation of the saddle tie. Carry the tie wire completely around one of the bars, then squarely across and halfway around the other, either side of the crossing bars, and finally bring the ends together and twist them either squarely or diagonally across. The saddle tie with twist is used for heavy mats that are to be lifted by crane.

6.3.6 oss, or Figure-Eight, Tie

The cross, or figure eight, tie *(View F)* has the advantage of causing little or no twist in the bars.

6.4.0 Location for Reinforcing Steel

The proper location for reinforcing bars is given on the drawings. To ensure that the structure can withstand the loads it must carry, place the steel in exactly the position shown. Secure the bars in position so that they will not move when the concrete is placed. Accomplish this by using the reinforcing bar supports shown in *Figures 6-43, 6-44, and 6-45*.

Figure 6-43 – Devices used to support horizontal reinforcing.

Figure 6-44 – Precast concrete block used for reinforcing steel support.

Figure 6-45 – Beam-reinforcing steel hung in place.

Footings and other principal structural members that are against the ground should have at least 3 inches of concrete between steel and ground.

CAUTION

If the concrete surface is to be in contact with the ground or exposed to the weather after removal of the forms, the protective covering of concrete over the steel should be 2 inches for bars larger than No. 5 and 1 1/2 inches for bars No. 5 or smaller. The protective covering may be reduced to 1 1/2 inches for beams and columns and 3/4 inch for slabs and interior wall surfaces, but it should be 2 inches for all exterior wall surfaces.

The clear distance between parallel bars in beams, footings, walls, and floor slabs should be a minimum of 1 inch, or one and one third times the largest size aggregate particle in the concrete. In columns, the clear distance between parallel bars should be a minimum of one and one half times the bar diameter, one and one half times the maximum size of the coarse aggregate, or not less than 1 1/2 inches.

The support for reinforcing steel in floor slabs is shown in *Figure 6-46*. The height of the slab bolster is determined by the concrete protective cover required. Concrete blocks made of sand-cement mortar can be used in place of the slab bolster. Never use wood blocks for this purpose. Bar chairs, like those shown in *Figure 6-46*, are available from commercial sources in heights up to 6 inches. If you require a height greater than 6 inches, make the chair of No. 0 soft annealed iron wire. Tie the bars together at frequent intervals with a snap tie to hold them firmly in position.

Figure 6-46 – Reinforcing steel for a floor slab.

Steel for column ties can be assembled into cages by laying the vertical bars for one side of the column horizontally across a couple of sawhorses. Slip the proper numbers of ties over the bars, add the remaining vertical bars, and then space out the ties as required by the placing plans. Wire a sufficient number of intersections together to make the assembly rigid. This allows you to hoist and set it as a unit.

After raising the column form, tie it to the dowels or reinforcing steel carried up from below. This holds it firmly in position at the base. Erect the column form and tie the reinforcing steel to the column form at 5 foot intervals, as shown in *Figure 6-47*.

Figure 6-47 – Securing a column with reinforcing steel against displacement.

The use of metal supports to hold beam reinforcing steel in position is shown in *Figure 6-48*. Note the position of the beam bolster. The stirrups are tied to the main reinforcing steel with a snap tie. Whenever possible, assemble the stirrups and main reinforcing steel outside the form and then place the assembled unit in position.

Precast concrete blocks, as shown in *Figure 6-44*, may be substituted for metal supports or, if none of the types of bar supports described above seem suitable, you may use the method shown in *Figure 6-45*.

Figure 6-48 – Beam-reinforcing steel supported on beam bolsters.

Placement of steel in walls is the same as for columns except that the steel is erected in place and not preassembled. Tie horizontal steel to vertical steel at least three times in any bar length. Steel in place in a wall is shown in *Figure 6-49*. Remove the wood block when the form has been filled up to the level of the block. For high walls, use ties in between the top and bottom.

Figure 6-49 – Steel in place in a wall.

Steel is placed in footings very much as it is placed in floor slabs. You may use stones, rather than steel supports, to support the steel at the proper distance above the subgrade. Steel mats are generally preassembled and placed in small footings after the forms have been set. A typical arrangement is shown in *Figure 6-50*. Steel mats in large footings are generally constructed in place.

Figure 6-50 – Steel in place in a footing.

Figure 6-51 – Welded wire mesh fabric.

Welded wire fabric (WWF) as shown in *Figure 6-51* is also used as limited reinforcement for concrete footings, walls, and slabs, but its primary use is to control crack widths due to temperature changes. Form construction for each job has its peculiarities. Certain natural conditions prevail in all situations. Wet concrete always develops hydrostatic pressure and strain on forms. Be sure to properly secure all stakes, braces, walers, ties, and shebolts before placing concrete.

6.4.1 Splicing Reinforcing Bar

Because rebar is available only in certain lengths, it must be spliced together for longer runs. Where splices are not dimensioned on the drawings, lap the bars not less than 30 times the bar diameter, or not less than 12 inches, whichever is more.

The stress in a tension bar can be transmitted through the concrete and into another adjoining bar by a lap splice of proper length. The lap is expressed as the number of bar diameters. If the bar is No. 2, make the lap at least 12 inches. Tie the bars together with a snap tie as shown in *Figure 6-52.*

Figure 6-52 – Bars spliced by lapping.

Test your Knowledge (Select the Correct Response)

8. Concrete footings should have what minimum concrete thickness between the ground and steel?

   A. 6 inches
   B. 8 inches
   C. 3 inches
   D. 4 inches

7.0.0 CONCRETE CONSTRUCTION JOINTS

Concrete structures are subjected to a variety of stresses. These stresses are the result of shrinkage and differential movement. Shrinkage occurs during hydration, and differential movement is caused by temperature changes and different loading conditions. These stresses can cause cracking, spalling, and scaling of concrete surfaces and, in extreme cases, can result in failure of the structure.

7.1.0 Types of Joints

Stresses in concrete can be controlled by the proper placement of joints in the structure. We'll discuss three basic types of joints: ***isolation joints***, ***control joints***, and construction joints.

7.1.1 Isolation Joints

Isolation joints are used to separate (isolate) adjacent structural members. An example is the joint that seperates the floor slab from a column. An isolation joint allows for differential movement in the vertical and horizontal plane and expansion/contraction due to loading conditions or uneven settlement. In this context, they allow for differential movement as a result of temperature changes, as in two adjacent slabs. All isolation joints extend completely through the member and have no load transfer devices built into them. Examples of these are shown in *Figures 6-53, 6-54 and 6-55.*

Figure 6-53 – Typical isolation and control joints.

Figure 6-54 – Isolation joints at columns and walls.

Figure 6-55 – Expansion/contraction joint for a bridge.

7.1.2 ontrol Joints

Movement in the plane of a concrete slab is caused by drying shrinkage and thermal contraction. Some shrinkage is expected and restrained from curling; cracking will occur wherever the restraint imposes stress greater than the tensile strength. Control joints shown in *Figure 6-56* are cut into the concrete slab to create a plane of weakness. Cracking should occur at a designated place rather than randomly. These joints run in both directions at right angles to each other. Control joints in interior slabs are typically cut 1/3 to 1/4 of the slab thickness and then filled with joint filler. See *Table 6-6* for suggested control joint spacings. Temperature steel (welded wire fabric) can be used to restrict crack width.

Figure 6-56 – Control joints.

Table 6-6 – Suggested Spacing of Control Joints

Slab Thickness (in.)	Less than 3/4 in. Aggregate: Spacing (ft.)	Larger than 3/4 in. Aggregate: Spacing (ft.)	Slump Less than 4 in.: Spacing (ft.)
5	10*	13	15
6	12	15	18
7	14	18	21
8	16	20	24
9	18	23	27
10	20	25	30

In driveways and sidewalks, space contraction joints at intervals about equal to the slab width. Drives and walks wider than 10 to 12 feet should have a longitudinal joint down the center. In patio slabs, joints should not be more than 10 ft apart in both directions. As with floor slabs, make the panels as nearly square as possible. As a general rule, the smaller the panel, the less likelihood of random cracking.

Contraction joints should also be located at re-entrant corners; otherwise cracks are likely to radiate from the corners. The part of a concrete slab within a very sharp corner is likely to crack. Avoid such sharp corners if possible, but if you cannot avoid them, make sure that the subgrade is well compacted and locate contraction joints where cracking is most likely to occur. Reinforcing steel is sometimes added to hold cracks closed tight at sharp or re-entrant corners.

Surface irregularities along the plane of the crack are usually sufficient to transfer loads across the joint in slabs on grade.

7.1.3 onstruction Joints

Make construction joints, shown in *Figures 6-57, 6-58, 6-59, and 6-60*, where the concrete placement operations end for the day or where one structural element is cast against previously placed concrete. These joints allow some load to be transferred from one structural element to another through the use of keys or, for some slabs and pavement, dowels. Note that the construction joint extends entirely through the concrete element.

Figure 6-57 – Vertical bulkhead in wall using keyway.

Figure 6-58 – Keyed wall construction joint.

Figure 6-59 – Construction joint between wall and footing with a keyway.

Figure 6-60 – Types of construction joints.

Test your Knowledge (Select the Correct Response)

9. Control joints for interior slabs are typically cut to what depth?

   A. 1 inch
   B. 2 inches
   C. 1/3 to 1/4 of the slab thickness
   D. 2/3 to 7/8 of the slab thickness

8.0.0 SAWING CONCRETE

8.1.0 The Concrete Saw

The concrete saw shown in *Figure 6-61* is used to cut longitudinal and transverse joints in finished concrete pavements. The saw is small and one person can operate it. Once the cut has been started, the machine provides its own tractive power. Use a water spray to flush the saw cuttings from the cutting area and to cool the cutting blade.

Figure 6-61 – Concrete saw.

Several types of blades are available. The most common blades have either diamond or Carborundum cutting surfaces. The diamond blade is used for cutting hard or old concrete; the Carborundum blade for cutting green concrete (under 30 hours old). Let's take a closer look at these two blades.

8.2.0 Diamond Blades

Diamond blades have segments made from a sintered mixture of industrial diamonds and metal powders, which are brazed to a steel disk. They are generally used to cut old concrete, asphalt, and green concrete containing the harder aggregates. Diamond blades must always be used wet. Many grades of diamond blades are available to suit the conditions of the job.

Twelve inch diameter diamond blades are the most popular size. This size makes a cut about 3 1/4 inches deep. Larger size blades are used for deeper cuts.

8.3.0 Carborundum Blades

Low cost, abrasive blades are now widely used to cut green concrete made with soft aggregates, such as limestone, dolomite, coral, or slag. These blades are made from a mixture of silicon carbide grains and a resin bond. This mixture is pressed and baked. In many cases, some of the medium hard aggregates can be cut by the step cutting method. This method uses two or more saws to cut the same joint, each cutting only a part of the total depth. This principle is also used on the longitudinal saw, which has two individually adjustable cutting heads. When a total depth of 2 1/2 inches is to be cut, the leading blade cuts the first inch and the trailing blade, which is slightly narrower, cuts the remaining depth.

Abrasive blades come in 14 and 18 inch diameters. They are made in various thicknesses to cut joints from 1/4 inch to 1/2 inch wide.

8.3.1 When to Use

When is the best time to saw green concrete? In the case of abrasive blades, there is only one answer; as soon as the concrete can support the equipment and the joint can be cut with a minimum of chipping. In the case of diamond blades, there are two factors to consider. In the interest of blade life, sawing should be delayed, but control of random cracking requires sawing at the transverse joints as early as possible. Where transverse joints are closely spaced and on large projects, cut every second or third joint initially and the rest later.

Saw joints as soon as the concrete is hard enough not to be torn or damaged by the blade, but before random cracks can form in the concrete slab. With wet cut saws, this condition usually occurs from 4 to 12 hours after finishing is complete, although sawing as late as 24 hours may be successful under some conditions.

For proper operation and maintenance of the concrete saw, follow the manufacturer's manual.

9.0.0 PLACING CONCRETE

You cannot obtain the full value of well designed concrete without using proper placing procedures. Good concrete placing and ***consolidation*** techniques produce a tight bond between the paste and aggregate and fill the forms completely. Both of these factors contribute to the full strength and best appearance of concrete. The following are some of the principles of concrete placement:

9.1.0 Segregation

Avoid segregation during all operations, from the mixer to the point of placement, including final consolidation and finishing.

9.2.0 Consolidation

Thoroughly consolidate the concrete, working solidly around all embedded reinforcement and filling all form angles and corners.

9.3.0 Bonding

When placing fresh concrete against or upon hardened concrete, make sure that a good bond develops.

9.4.0 Temperature Control

Take appropriate steps to control the temperature of fresh concrete from mixing through final placement. Protect the concrete from temperature extremes after placement.

9.5.0 Maximum Drop

To save time and effort, you may be tempted to simply drop the concrete directly from the delivery chute regardless of form height. Unless the free fall into the form is less than 4 feet, use vertical pipes, suitable drop chutes, or baffles. *Figure 6-62* suggests several ways to control concrete fall. Good control prevents honeycombing and other undesirable results.

9.6.0 Layer Thickness

Try to place concrete in even horizontal layers. Do not attempt to puddle or vibrate it into the form. To prevent honeycombing and voids, place each layer in one operation and consolidate it before placing the next layer. This is particularly critical in wall forms containing considerable reinforcement. Use a mechanical vibrator or a hand spading tool for consolidation. Take care not to over vibrate. This can cause segregation and a weak surface. Do not allow the first layer to take its initial set before adding the next layer. Layer thickness depends on the type of construction, the width of the space between forms, and the amount of reinforcement.

9.7.0 Compacting

(Note: This is different from soil compaction.) First, place concrete as nearly as possible into its final position. Then, work the concrete thoroughly around reinforcement and imbedded fixtures, into the corners, and against the sides of the forms. Because paste tends to flow ahead of aggregate, avoid horizontal movements that result in segregation.

9.8.0 Placing Rate

To avoid excessive pressure on large project forms, the filling rate should not exceed 4 vertical feet per hour, except for columns. Coordinate the placing and compacting so that the concrete is not deposited faster than it can be compacted properly. To avoid cracking during settlement, allow an interval of at least 4 hours, preferably 24 hours, between placing slabs, beams, or girders, and placing the columns and walls they support.

9.9.0 Placement in Wall Forms

When constructing walls, beams, or girders, place the first batches of each layer at the ends of the section, then proceed toward the center to prevent water from collecting at the form ends and corners. For walls, stop off the inside form at the construction level. Overfill the form for about 2 inches and remove the excess just before the concrete sets to ensure a rough, clean surface. Before placing the next lift of concrete, deposit a 1/2 to 1 inch thick layer of sand-cement mortar. Make the mortar with the same water content ratio as the concrete and with a 6 inch slump to prevent stone pockets and help produce a watertight joint. *View 1 of Figure 6-62* shows the proper way to place concrete in the lower portion of high wall forms. Note the different types of drop chute that can be used to place concrete through port openings and into the lower portion of the wall. Space the port openings at about 10-foot intervals up the wall. The method used to place concrete in the upper portion of the wall is shown in *View 2 of Figure 6-62*. When placing concrete for walls, be sure to remove the spreaders as you fill the forms.

Figure 6-62 – Concrete placing techniques.

9.10.0 Placement of Slabs

When constructing slabs, place the concrete at the far end of the slab first, and then place subsequent batches against previously placed concrete, as shown in *View 3 of Figure 6-62*. Do not place the concrete in separate piles and then level the piles and work them together. Also, don't deposit the concrete in piles and then move them horizontally to their final position. These practices can result in segregation.

9.11.0 Placing Concrete on Slopes

View 4 of Figure 6-62 shows how to place concrete on slopes. Always deposit the concrete at the bottom of the slope first, and then proceed up the slope placing each new batch against the previous one. When consolidated, the weight of the new concrete increases the compacting of the previously placed concrete.

Test your Knowledge (Select the Correct Response)

10. What is the maximum concrete placing rate for a large pour?

    A. 3 vertical feet every 30 minutes
    B. 4 vertical feet every 30 minutes
    C. 3 vertical feet per hour
    D. 4 vertical feet per hour

10.0.0 CONSOLIDATING CONCRETE

Except for concrete placed underwater, you must compact or consolidate all concrete after placement.

10.1.0 Purpose of Consolidation

Consolidation eliminates rock pockets and air bubbles and brings enough fine material both to the surface and against the forms to produce the desired finish. You can use hand tools such as spades, puddling sticks, or tampers, but mechanical vibrators are best. Any compacting device must reach the bottom of the form and be small enough to pass between reinforcing bars. The process involves carefully working around all reinforcing steel with the compacting device to assure proper embedding of reinforcing steel in the concrete. Since the strength of the concrete member depends on proper reinforcement location, be careful not to displace the reinforcing steel.

10.2.0 Vibration

Vibrators consolidate concrete by pushing the coarse aggregate downward, away from the point of vibration. Vibrators allow placement of mixtures that are too stiff to place any other way, such as those having a 1 or 2 inch slump. Stiff mixtures are more economical because they require less cement and present fewer segregation or bleeding problems. Do not use a mix so stiff that it requires too much labor to place it.

10.2.1 Mechanical Vibrators

The best compacting tool is a mechanical vibrator, shown in *Figure 6-63*. The best vibrators available in engineering construction battalions are called internal vibrators because the vibrating element is inserted into the concrete.

When using an internal vibrator, insert it at approximately 18-inch intervals into air-entrained concrete for 5 to 10 seconds and into nonair-entrained concrete for 10 to 15 seconds. The exact period of time to leave a vibrator in the concrete depends on its slump. Overlap the vibrated areas somewhat at each insertion. Whenever possible, lower the vibrator into the concrete vertically and allow it to descend by gravity.

Figure 6-63 – Using a vibrator to consolidate concrete.

The vibrator should not only pass through the layer just placed, but penetrate several inches into the layer underneath to ensure a good bond between the layers.

Vibration does not normally damage the lower layers, as long as the concrete disturbed in these lower layers becomes plastic under the vibrating action. You know that you have consolidated the concrete properly when a thin line of mortar appears along the form near the vibrator, the coarse aggregate disappears into the concrete, or the paste begins to appear near the vibrator head. Then, withdraw the vibrator vertically at about the same gravity rate at which it descended.

Some hand spading or puddling should accompany all vibration. To avoid the possibility of segregation, do not vibrate mixes that you can consolidate easily by spading. Also, don't vibrate concrete that has a slump of 5 inches or more. Do not use vibrators to move concrete in the form.

10.2.2 Vibrating (consolidating) the Concrete

When surface vibrating slabs up to 6 inches thick, provided they are not reinforced or contain only light mesh, use low-frequency vibrating screeds — 3000 to 6000 vibrations per minute. This will provide adequate consolidation depth without creating an objectionable layer of fines at the surface. High frequency, low amplitude screeds are satrifatory when applied solely to accommodate the finishing operation. 6 to 8 inch slabs that are not reinforced may be consolidated by either surface or internal vibration.

For slabs more than 8 inches thick or thinner slabs containing embedments or substantial reinforcement, it is recommended to use an internal vibration. When an internal vibrator *(Figure 6-64),* is inserted into fresh concrete, the concrete near the vibrator tends to act like very thick liquid in the field of action area that is affected by the vibrator. By watching the way the concrete acts near the vibrator you can judge the size of the field of action. Big high-powered vibrators have larger fields of action than do small vibrators. A vibrator's field of action is larger in high slump (very wet) concrete than it is in stiffer concrete. To consolidate concrete completely, you must be sure that the fields of action overlap from one insertion point to another.

Figure 6-64 – Consolidation by an internal vibrator and a spading tool.

The head of an internal vibrator should be completely immersed during vibration. For thick slabs it is possible to insert a vibrator vertically, for thinner slabs it should be inserted at an angle or even horizontally. Note that letting the vibrator contact the subgrade could contaminate the concrete with foreign material. The vibrator should remain in the concrete until the surface of the field takes on a sheen look. There are several precautions when consolidating concrete:

- DO NOT use a vibrator to move concrete horizontally ("run the concrete") because the coarse aggregates will separate from the mortar.
- DO NOT leave a vibrator in the concrete too long in concrete mixes which have a slump of more than 3 inches, this will cause segregation. If in doubt about the adequacy of compaction, it is generally better to vibrate more in stiffer mixes because the danger of overvibrating stiff mixes is minimal.

- DO NOT let a vibrator run very long when it is not in concrete — it may burn out. Concrete acts as a coolant for the vibrator.
- DO NOT use an electrically powered internal vibrator without wearing good rubber gloves and rubber boots — there is a shock or burn hazard.

10.2.3 Hand Methods

Manual consolidation methods require spades, puddling sticks, or various types of tampers. To consolidate concrete by spading, insert the spade along the inside surface of the forms as shown in *Figure 6-64*, through the layer just placed, and several inches into the layer underneath. Continue spading or puddling until the coarse aggregate disappears into the concrete. Do not attempt on large placements.

Test your Knowledge (Select the Correct Response)

11. When using a vibrator on air-entrained concrete, you should insert the vibrator into the concrete (a) what approximate distance for (b) what length of time?

    A. (a) 6 inches (b) 25 to 30 seconds
    B. (a) 18 inches (b) 5 to 10 seconds
    C. (a) 24 inches (b) 25 to 30 seconds
    D. (a) 36 inches (b) 5 to 10 seconds

11.0.0 FINISHING CONCRETE

The finishing process provides the final concrete surface. There are many ways to finish concrete surfaces, depending on the effect required. Sometimes you only need to correct surface defects, fill bolt holes, or clean the surface. Unformed surfaces may require only ***screeding*** to proper contour and elevation, or a ***broomed***, floated, or trowelled finish may be specified in the specifications.

11.1.0 Screeding

The top surface of a floor slab, sidewalk, or pavement is rarely placed at the exact specified elevation. Screeding brings the surface to the required elevation by striking off the excess concrete. Two types of screeds are used in concrete finishing operations: the hand screed and the mechanical screed.

11.1.1 Hand Screed

Hand screeding requires a tool called a straightedge. This is actually a templet, usually a 2 by 4; having a straight lower edge to produce a flat surface or a curved lower edge to produce a curved surface. Move the screed back and forth across the concrete using a sawing motion, as shown in *Figure 6-65*. With each sawing motion, move the screed forward an inch or so along the forms. This forces the concrete built up against the

Figure 6-65 – Screeding operation.

screed face into the low spots. If the screed tends to tear the surface, as it may on air-entrained concrete due to its sticky nature, either reduce the rate of forward movement or cover the lower edge of the screed with metal. This stops tearing the tearing action in most cases.

You can hand screed surfaces up to 30 feet wide, but the efficiency of this method diminishes on surfaces more than 10 feet wide. You must screed the surface a second time to remove the surge of excess concrete caused by the first screeding.

A mechanical screed as shown in *Figure 6-66* usually consists of a beam (or beams) with a gasoline engine or electric motor and a vibrating mechanism mounted in the center of the beam. Most mechanical screeds are quite heavy and usually equipped with wheels to help move them around. You may occasionally encounter lightweight screeds not equipped with wheels. These are easily lifted by two crewmembers and set back for the second pass if required.

The speed at which to pull the screed is directly related to the slump of the concrete; the less the slump, the slower the speed; the more the slump, the faster the speed. On the finishing pass of the screed, there should be no transverse (crosswise) movement of the beam; the screed is merely drawn directly forward riding on the forms or rails. For a mechanical screed, a method is provided to quickly start or stop the vibration. This is important to prevent over vibration when the screed might be standing still.

11.1.2 Mechanical Screed

The mechanical screed is being used more and more in construction for striking off concrete slabs on highways, bridge decks, and deck slabs. This screed incorporates the use of vibration and permits the use of stronger, and more economical, low-slump concrete. It can strike off this relatively dry material smoothly and quickly. The advantages of using a vibrating screed are greater density and stronger concrete. Vibrating screeds give a better finish, reduce maintenance, and save considerable time due to the speed at which they operate. Vibrating screeds are also much less fatiguing to operate than hand screeds.

Figure 6-66 – Mechanical screed.

Figure 6-67 – Concrete placement.

Concrete is usually placed 15 to 20 feet ahead of the screed and shoveled as close as possible to its final resting place. The screed is then put into operation and pulled along by two crewmembers, one at each end of the screed. It is important to keep sufficient concrete in front of the screed. Should the concrete be below the level of the screed beam, voids or bare spots will appear on the concrete surface as the screed passes over the slab. Should this occur, place a shovelful or so of concrete on the bare spot, and lift up the screed and ease it back past this spot for a second pass. In rare cases, the screed crew will work out the void or bare spot with a hand-operated bull float, rather than make a second pass with the screed.

The vibration speed will need to be adjusted for particular mixes and different beam lengths. Generally, the stiffer the mix and the longer the beam, the greater the vibration speed required. The speed at which the screed is moved also affects the resulting finish of the slab. After a few minutes of operation, a satisfactory vibration pulling speed can be established. After the vibrating screed has passed over the slab, the surface is then ready for broom or burlap finishing.

Where possible, it is advisable to lay out or engineer the concrete slab specifically for use of a vibrating screed. Lay out forms in lanes of equal widths, so that the same length screed can be used on all lanes or slabs. If possible, any vertical columns should be next to the forms, so that the screed can easily be lifted or maneuvered around the column.

There are three important advantages of using a vibrating finishing screed. First, it allows the use of low-slump concrete, resulting in stronger slabs. Second, it increases the density of the concrete, resulting in a superior wearing surface. And third, in the case of floor slabs, troweling can begin sooner since you can use drier mixes, which set up more quickly.

11.2.0 Hand Tamping

Hand tamping, or jitterbugging with a tool, as shown in *Figure 6-68*, is done after the concrete has been screeded. Hand tamping is used to compact the concrete into a dense mass and to force the larger particles of coarse aggregate slightly below the surface. This enables you to put the desired finish on the surface. Use the tamping tool only with a low slump concrete (1”-2”), and bring just enough mortar to the surface for a proper finish. After using the jitterbug, you can go directly to using the bull float.

Figure 6-68 – Hand tamp (Jitterbug)

11.3.0 Floating

If a smoother surface is required than the one obtained by screeding, work the surface sparingly with a wood or aluminum magnesium float, as shown in *Figure 6-69*, or with a finishing machine.

Figure 6-69 – Floats.

Figure 6-70 – Hand float in use.

In *Figure 6-70*, the aluminum magnesium float is shown in use.

A long handled wood float is used for slab construction, as shown in *Figure 6-71.* The aluminum float, which is used in the same way as the wood float, gives the finished concrete a much smoother surface. To avoid cracking and dusting of the finished concrete, begin aluminum floating when the water sheen disappears from the freshly placed concrete surface. Do not use cement or water as an aid in finishing the surface.

Figure 6-71 – Long handled float in use.

Floating has three purposes: (1) to embed aggregate particles just beneath the surface; (2) to remove slight imperfections (high and low spots); and, (3) to compact the concrete at the surface in preparation for other finishing operations.

Begin bull floating immediately after screeding while the concrete is still plastic and workable. Do not overwork the concrete while it is still plastic because you may bring an excess of water and paste to the surface. This fine material forms a thin, weak layer that will scale or quickly wear off under use. To remove a coarse texture as the final finish, you usually have to float the surface a second time after it partially hardens.

11.4.0 Edging

As the sheen of water begins to leave the surface, ***edging*** should begin. Finish with an edger, as shown in *Figure 6-72*, all edges of a slab that do not abut another structure.

Figure 6-72 – Edger.

An edger dresses corners and rounds or bevels the concrete edges. Edging the slab helps prevent chipping at the corners and helps give the slab a finished appearance. *Figure 6-73* shows an edger in use.

Figure 6-73 – Edger in use.

Figure 6-74 – Troweling.

Figure 6-75 – Trowel.

11.5.0 Troweling

If a dense, smooth finish is desired, floating must be followed by steel troweling, as shown in *Figure 6-74*. Troweling should begin after the moisture film or sheen disappears from the floated surface and when the concrete has hardened enough to prevent fine material and water from being worked to the surface. Delay this step as long as possible. Troweling too early tends to produce crazing and lack of durability. Too long a delay in troweling, however, results in a surface too hard to finish properly. The usual tendency is to start to trowel too soon. Troweling should leave the surface smooth, even, and free of marks and ripples. Spreading dry cement on a wet surface to take up excess water is never a good practice where a wear resistant and durable surface is required. Avoid wet spots if possible. When they do occur, do not resume finishing operations until the water has been absorbed, has evaporated, or has been mopped up.

11.5.1 Steel Trowel

An unslippery, fine textured surface can be obtained by troweling lightly over the surface with a circular motion immediately after the first regular troweling. In this process, kepp the trowel flat on the surface of the concrete. Where a hard steel troweled finish is required, follow the first regular troweling by a second troweling. The second troweling should begin after the concrete has become hard enough so that no mortar adheres to the trowel, and a ringing sound is produced as the trowel passes over the surface. During this final troweling, the trowel should be tilted slightly and heavy pressure exerted to thoroughly compact the surface. Hairline cracks are usually due to a concentration of water and extremely fine aggregates at the surface. This results from overworking the concrete during finishing operations. Such cracking is aggravated by drying and cooling too rapidly. Cracks that develop before troweling can usually be closed by pounding the concrete with a hand float.

11.5.2 Mechanical Troweling Machine

Figure 6-76 – Mechanical troweling machine.

The mechanical troweling machine shown in *Figure 6-76* is used to good advantage on flat slabs with a stiff consistency. Mechanical trowels come with a set of float blades that slip over the steel blades. With these blades, you can float a slab with the mechanical trowels. The concrete must be set enough to support the weight of the machine and the operator. Machine finishing is faster than hand finishing, but it cannot be used with all types of construction. Refer to the manufacturer's manual for operation and maintenance of the machine you are using.

11.6.0 Brooming

Brooming the concrete before it has thoroughly hardened can produce a nonskid surface. Brooming is carried out after the floating operation. For some floors and sidewalks where scoring is not desirable, a hair bristle brush can produce a similar finish after the surface has been troweled once. Where rough scoring is required, use a stiff broom made of steel wire or coarse fiber. When brooming, make sure that the direction of the scoring is at right angles to the direction of the traffic.

11.7.0 Grinding

When grinding of a concrete floor is specified, start it after the surface has hardened sufficiently to prevent dislodgement of aggregate particles and continue it until the coarse aggregate is exposed. The machines used should be of an approved type with stones that cut freely and rapidly. Keep the floor wet during the grinding process, and remove the cuttings by squeegeeing and flushing with water.

After the surface is ground, air holes, pits, and other blemishes are filled with a thin grout composed of one part No. 80 grain carborundum grit and one part Portland cement. Spread this grout over the floor and work it into the pits with a straightedge. Next, rub the grout into the floor with the grinding machine. When the fillings have hardened for 17 days, the floor receives a final grinding to remove the film and to give the finish a polish. Then remove all surplus material by washing thoroughly. When properly constructed of good-quality materials, ground floors are dustless, dense, easily cleaned, and attractive in appearance.

11.8.0 Sack-Rubbed Finish

A sack-rubbed finish is sometimes necessary when the appearance of formed concrete falls considerably below expectations. Perform this treatment after completing all required patching and correction of major imperfections. Thoroughly wet the surfaces and commence sack rubbing immediately.

The mortar used consists of one part cement; two parts, by volume, of sand passing a No. 16 screen; and enough water so that the consistency of the mortar will be that of thick cream. It may be necessary to blend the cement with white cement to obtain a color matching that of the surrounding concrete surface. Rub the mortar thoroughly over the area with clean burlap or a sponge rubber float, so that it fills all pits. While the mortar in the pits is still plastic, ruab the surface over with a dry mix of the same material. This removes all excess plastic material and places enough dry material in the pits to stiffen and solidify the mortar. The filings will then be flush with the surface. No material should remain on the surface above the pits. ***Curing*** of the surface is then continued.

11.9.0 Rubbed Finish

A rubbed finish is required when a uniform and attractive surface must be obtained. A surface of satisfactory appearance can be obtained without rubbing by using plywood or lined forms. Do the first rubbing with coarse carborundum stones as soon as the concrete has hardened so that you do not pull out the aggregate. Then cure the concrete until final rubbing. Finer carborundum stones are used for the final rubbing. The concrete should be kept damp while being rubbed. Any mortar used in this process and left on the surface should be kept damp for 1 to 2 days after it sets to cure properly. Keep the mortar layer to a minimum thickness as it is likely to scale off and mar the appearance of the surface.

11.10.0 Exposed Aggregate Finish

An exposed aggregate finish provides a nonskid surface. To obtain this, you must allow the concrete to harden sufficiently to support the finisher. Expose the aggregate by applying a retarder over the surface and then brushing and flushing the concrete surface with water. Since timing is important, use test panels to determine the correct time to expose the aggregate.

11.11.0 Curing Concrete

Adding water to Portland cement to form the water-cement paste that holds concrete together starts a chemical reaction that turns the paste into a bonding agent. This reaction, called hydration, produces a stone-like substance, the hardened cement paste. Both the rate and degree of hydration, and the resulting strength of the final concrete, depend on the curing process that follows placing and consolidating the plastic concrete. Hydration continues indefinitely at a decreasing rate as long as the mixture contains water and the temperature conditions are favorable. Once the water is removed, hydration ceases and cannot be restarted.

Curing is the period of time from consolidation to the point where the concrete reaches its design strength. During this period, you must take certain steps to keep the concrete moist and as near 73°F as practical. The properties of concrete; such as freeze and thaw resistance, strength, watertightness, wear resistance, and volume stability; cure or improve with age as long as you maintain the moisture and temperature conditions favorable to continued hydration.

The length of time that you must protect concrete against moisture loss depends on the type of cement used, mix proportions, required strength, size and shape of the concrete mass, weather, and future exposure conditions. The period can vary from a few days to a month or longer. For most structural use, the curing period for cast-in-place concrete is 3 days to 2 weeks. This period depends on such conditions as temperature, cement type, mix proportions, and so forth. Bridge decks and other slabs exposed to weather and chemical attack usually require longer curing periods. *Figure 6-77* shows how moist curing affects the compressive strength of concrete.

Figure 6-77 – Moist curing effect on compressive strength of concrete.

11.11.1 Curing Methods

Several curing methods will keep concrete moist and, in some cases, at a favorable hydration temperature. They fall into two categories: those that supply additional moisture and those that prevent moisture loss. *Table 6-7* lists several of these methods and their advantages and disadvantages.

Table 6-7 – Curing Methods.

METHOD	ADVANTAGE	DISADVANTAGES
Sprinkling with Water or Covering with Burlap	Excellent results if kept constantly wet	Likelihood of drying between sprinklings; difficult on vertical walls
Straw	Insulator in winter	Can dry out, blow away, or burn
Moist Earth	Cheap but messy	Stains concrete; can dry out; removal problem
Ponding on Flat Surfaces	Excellent results, maintains uniform temperature	Requires considerable labor; undesirable in freezing weather
Curing Compounds	Easy to apply and inexpensive	Sprayer needed; inadequate coverage allows drying out; film can be broken or tracked off before curing is completed; unless pigmented, can allow concrete to get too hot
Waterproof Paper	Excellent protection, prevents drying	Heavy cost can be excessive; must be kept in rolls; storage and handling problem
Plastic Film	Absolutely watertight, excellent protection. Light and easy to handle.	Should be pigmented for heat protection; requires reasonable care and tears must be patched; must be weighed down to prevent blowing away

Methods that supply additional moisture include sprinkling and wet covers. Both these methods add moisture to the concrete surface during the early hardening or curing period. They also provide some cooling through evaporation. This is especially important in hot weather.

Sprinkling continually with water, shown in *Figure 6-78*, is an excellent way to cure concrete. If you sprinkle at intervals, do not allow the concrete to dry out between applications. The disadvantages of this method are the expense involved and the volume of water required.

Figure 6-78 – Sprinkling concrete with water.

Wet covers, such as straw, earth, burlap, cotton mats, and other moisture retaining fabrics, are used extensively in curing concrete. Lay the wet coverings as soon as the concrete hardens enough to prevent surface damage. Leave them in place and keep them moist during the entire curing period.

If practical, horizontal placements can be flooded by creating an earthen dam around the edges and submerging the entire concrete structure in water.

Methods that prevent moisture loss include laying waterproof paper, plastic film, or liquid membrane forming compounds, and simply leaving forms in place. All prevent moisture loss by sealing the surface.

A sheet of plastic, as shown in *Figure 6-79*, can be used to cure horizontal surfaces and structural concrete having relatively simple shapes. The plastic should be large enough to cover both the surfaces and the edges of the concrete. Wet the surface with a fine water spray before covering. Lap adjacent plastic 12 inches or more and weigh their edges down to form a continuous cover with closed joints. Leave the coverings in place during the entire curing period.

Figure 6-79 – Curing concrete with plastic.

Plastic form materials are sometimes used to cure concrete. They provide lightweight, effective moisture barriers that are easy to apply to either simple or complex shapes.

Some thin plastic sheets may discolor hardened concrete, especially if the surface was steel troweled to a hard finish. The coverage, overlap, weighing down of edges, and surface wetting requirements of plastic film are similar to those of waterproof paper.

Curing compounds are suitable not only for curing fresh concrete, but to further cure concrete following form removal or initial moist curing. You can apply them with spray equipment, such as hand operated pressure sprayers, to odd slab widths or shapes of fresh concrete, and to exposed concrete surfaces following form removal. If there is heavy rain within 3 hours of application, you must respray the surface. You can use brushes to apply curing compound to formed surfaces, but do not use brushes on unformed concrete because of the risk of marring the surface, opening the surface to too much compound penetration, and breaking the surface film continuity. These compounds permit curing to continue for long periods while the concrete is in use. Because curing compounds can prevent a bond from forming between hardened and fresh concrete, do not use them if a bond is necessary.

Forms provide adequate protection against moisture loss if you keep the exposed concrete surfaces wet. Keep wood forms moist by sprinkling, especially during hot, dry weather.

11.12.0 Form Removal

Forms should, whenever possible, be left in place for the entire curing period. Since early form removal is desirable for their reuse, a reliable basis for determining the earliest possible stripping time is necessary. Some of the early signs to look for during stripping are no excessive deflection or distortion and no evidence of cracking or other damage to the concrete due to the removal of the forms or the form supports. In any event, never strip forms until the concrete has hardened enough to hold its own weight and any other weight it may be carrying. The surface must be hard enough to remain undamaged and unmarked when reasonable care is used in stripping the forms.

11.12.1 Curing Period

Haunch boards (side forms on girders and beams) and wall forms can usually be removed after 1 day. Column forms usually require 3 days before the forms can be removed. Removal of forms for soffits on girders and beams can usually be done after 7 days. Floor slab forms (over 20 foot clear span between supports) usually require 10 days before removing the forms. Specifications dictate when forms can be removed, usually after a gain of 70% of 28 day strength requirement. This is proven through a compressive strength break test.

11.12.2 Inspections

After removing the forms, inspect the concrete for surface defects. These defects may be rock pockets, inferior quality ridges at form joints, bulges, bolt holes, and form stripping damage. Experience has proved that no steps can be omitted or carelessly performed without harming the serviceability of the work. If repairs are not properly performed, the repaired area may later become loose, crack at the edges, and not be watertight. Repairs are not always necessary, but when they are, do them immediately after stripping the forms, within 24 hours.

Defects can be repaired in various ways. Let’s look at some common defects you may encounter when inspecting new concrete and how repairs can be made.

Ridges and bulges – Ridges and bulges can be repaired by careful chipping followed by rubbing with a grinding stone.

Honeycomb – Defective areas, such as honeycomb, must be chipped out of the solid concrete. Cut the edges as straight as possible at right angles to the surface or slightly undercut them to provide a key at the edge of the patch. If a shallow layer of mortar is placed on top of the honeycomb concrete, moisture will form in the voids and subsequent weathering will cause the mortar to span off. Fill shallow patches with mortar placed in layers not more than 1/2 inch thick. Give each layer a scratch finish to match the surrounding concrete by floating, rubbing, or tooling or on formed surfaces by pressing the form material against the patch while the mortar is still in place.

Large or deep patches can be filled with concrete held in place by forms. Reinforce and dowel these patches to the hardened concrete as shown in *Figure 6-80*. Patches usually appear darker than the surrounding concrete. Use some white cement in the mortar or concrete used for patching if appearance is important. A trial mix will help to determine the proportion of white and gray cements to use. Before placing mortar or concrete in patches, keep the surrounding concrete wet for several hours. Then brush a grout of cement and water mixed to the consistency of paint into the surfaces to which the new material is to be bonded. Start curing as soon as possible to avoid early drying. Damp burlap, tarpaulins, and membrane curing compounds are useful for this purpose.

Figure 6-80 – Repair of large volumes of concrete.

Snap tie holes – Snap tie holes should be filled with small amounts of non shrink grout carefully packed into place. The grout should be mixed as dry as possible, with just enough water so it compacts tightly when forced into place. Tie rod holes extending through the concrete can be filled with grout with a pressure gun similar to an automatic grease gun.

Rock pockets – Rock pockets should be completely chipped out. The chipped out hole should have sharp edges and be so shaped that the grout patch will be keyed in place as shown in *Figure 6-81*. The surface of all holes that are to be patched should be kept moist for several hours before applying the grout. Grout should be placed in these holes in layers not over 1/4 inch thick and be well compacted. To reduce the amount of shrinkage and to make a better patch, allow the grout to set as long as possible before using it. Scratch each layer rough to improve the bond with the succeeding layer and smooth the last layer to match the adjacent surface.

Figure 6-81 – Repairing concrete with dry packed mortar.

Where absorptive form lining has been used, the patch can be made to match the rest of the surface by pressing a piece of form lining against the fresh patch.

View A of Figure 6-76 shows an incorrectly installed patch. Feathered edges around a patch lack sufficient strength and will eventually break down. *View B* shows a correctly installed patch. The chipped area should be at least 1 inch deep with the edges at right angles to the surface. The correct method of screeding a patch is shown in V*iew C*. The new concrete should project slightly above the surface of the old concrete. It should be allowed to stiffen and then troweled and finished to match the adjoining surfaces.

Figure 6-82 – Patching concrete.

Test your Knowledge (Select the Correct Response)

12. Which of the following advantages results from edging concrete slabs?

    A. Dressed corners
    B. Less corner chipping
    C. A finished appearance
    D. All of the above

13. When a dustless, dense, easily cleaned floor is required, what finishing product should you use?

    A. Sack rubbing
    B. Power troweling
    C. Steel troweling
    D. Grinding

14. Under ordinary circumstances, the forms for floor slabs can be removed after what minimum time?

    A. 1 day
    B. 6 days
    C. 10 days
    D. 14 days

15. After forms are removed, a pressure gun may be used to repair which of the following defects?

    A. Honeycomb
    B. Joints
    C. Tie-rod holes
    D. Rock pockets

12.0.0 PRECAST and TILT-UP CONCRETE

Concrete cast in the position it is to occupy in the finished structure is called cast-in-place concrete. Concrete cast and cured elsewhere is called precast concrete. Tilt-up concrete is a special type of precast concrete in which the units are tilted up and placed using cranes or other types of lifting devices.

Wall construction is frequently done with precast wall panels originally cast horizontally, sometimes one above the other, as slabs. This method has many advantages over the conventional method of casting in place in vertical wall forms. Since a slab form requires only edge forms and a single surface form, the amount of formwork and form materials required is greatly reduced. The labor involved in slab form concrete casting is much less than that involved in filling a high wall form. One side of a precast unit cast as a slab may be finished by hand to any desired quality of finishing.

The placement of reinforcing steel is much easier in slab forms, and it is easier to attain thorough filling and vibrating. Precasting of wall panels as slabs may be expedited by mass production methods not available when casting in place.

Relatively light panels for concrete walls are precast as slabs, as shown in *Figure 6-83*.

Figure 6-83 – Precast wall panels in stacks of three each.

The panels are set in place by cranes, using spreader bars as shown in *Figure 6-84*.

Figure 6-84 – Precast panels being erected by use of crane and spreader bars.

Figure 6-85 shows erected panels in final position.

Figure 6-85 – Precast panels in position.

12.1.1 Casting

The casting surface is very important in making precast concrete panels. In this section, we will cover two common types: earth and concrete. Regardless of which method you use, you must cast the slab in a location that will permit easy removal and handling.

Castings can be made directly on the ground with cement poured into forms. These earth surfaces are economical but only last for a couple of concrete pours. Concrete surfaces, since they can be reused repeatedly, are more practical.

When building casting surfaces, keep the following points in mind:

- The subbase should be level and properly compacted.
- The slab should be at least 6 inches thick and made of 3,000 psi or higher reinforced concrete. Large aggregate, 2 ½ to 3 inches maximum, may be used in the casting slabs.
- If pipes or other utilities are to be extended up through the casting slab at a later date, they should be stopped below the surface and the openings temporarily closed. For wood, cork, or plastic plugs, fill almost to the surface with sand and top with a thin coat of mortar that is finished flush with the casting surface.
- It is important to remember that any imperfections in the surface of the casting slab will show up on the cast panels. When finishing the casting slab, you must ensure there is a flat, level, and smooth surface without humps, dips, cracks, or gouges. If possible, cure the casting surface keeping it covered with water. If you use a curing compound or surface hardener, make sure that it will not conflict with the later use of ***bond breaking agents***.

12.2.0 Forms

The material most commonly used for edge forms is 2 by lumber. The lumber must occasionally be replaced, but the steel or aluminum angles and charnels may be reused many times. The tops of the forms must be in the same plane so that they may be used for screeds. They must also be well braced to remain in good alignment.

Edge forms should have holes in them for rebar or for expansion/contraction dowels to protrude. These holes should be ¼ inch larger in diameter than the bars. At times, the forms are spliced at the line of these bars to make removal easier.

The forms, or rough bucks, for doors, windows, air conditioning ducts, and so forth are set before the steel is placed and should be on the same plane as the edge forms.

12.3.1 Bond Breaking Agents

Bond breaking agents are one of the most important items of precast concrete construction. The most important requirement is that they break the bond between the casting surface and the cast panel. Bond breaking agents must also be economical, fast drying, easily applied, easily removed, or leave a paintable surface on the cast panel, if desired. They are broken into two general types: sheet materials and liquids.

There are many bond breaking agents commercially available. Obtain the type best suited for the project and follow the manufacturer's application instructions. If commercial bond breaking agents are not available, several alternatives can be used.

- Paper and felt effectively prevent a bond with a casting surface, but usually stick to the cast panels and may cause asphalt stains on the concrete.
- Plywood, fiberboard, and metal effectively prevent a bond when oiled and can be used many times. Their initial cost is high and they leave joint marks on the cast panels.
- Canvas gives a very pleasing texture and is used where cast panels are lifted at an early stage. It should be either dusted with cement or sprinkled with water just before placing the concrete.
- Oil gives good results when properly used, but is expensive. The casting slab must be dry when the oil is applied, and the oil must be allowed to absorb before the concrete is placed. Do no use oil if the surface is to be painted, and never use crankcase oil.
- Waxes, such as spirit wax (paraffin) and ordinary floor wax, give good to excellent results. One mixture that may be used is 5 pounds of paraffin mixed with 1 ½ gallons of light oil or kerosene. The oil must be heated to dissolve the paraffin.
- Liquid soap requires special care to ensure it is not used in excess amounts or the surface of the cast panel will be sandy.

Apply these materials after the side forms are in place and the casting slab is clean but **before** placing any reinforcing steel. To ensure proper adhesion of the concrete, keep all bond breaking materials off the reinforcing steel.

12.4.0 Reinforcements and Inserts

Reinforcing bars (rebar) should be assembled into mats and placed into the forms as a unit. This allows for rapid assembly on a jig and reduces walking on the casting surface, which has been treated with the bond breaking agent.

Use extra rebars at openings. Place them parallel to and about 2 inches from the sides of openings or diagonally across the corners of openings.

The bars may be suspended by conventional methods, such as with high chairs or from members laid across the edge forms. Do not use high chairs if the bottom of the cast panel is to be a finished surface. Another method is to first place half the thickness of concrete, place the rebar mat, and then complete the pour. Perform this method quickly to avoid a cold joint between the top and bottom layers.

When welded wire fabric (WWF) is used, dowels or bars must still be used between the panels and columns. WWF is usually placed in sheets covering the entire area and then clipped along the edges of the openings after erection.

If utilities are going to be flush mounted or hidden, pipe, conduit, boxes, sleeves, and so forth should be put into the forms at the same time as the reinforcing steel. If the utilities pass from one cast panel to another, the connections must be made after the panels are erected but before the columns are poured. If small openings are to go through the panel, a greased pipe sleeve is the easiest method of placing an opening in the form. For larger openings, such as air conditioning ducts, forms should be made in the same reamer as doors or windows.

After rebar and utilities have been placed, all other ***inserts*** should be placed. These will include lifting and bracing inserts, anchor bolts, welding plates, and so forth. You need to make sure these items are firmly secured so they won't move during concrete placement or finishing.

12.5.0 Pouring, Finishing, and Curing

With few exceptions, placing cast panels can be done in the same manner as other pours. Since the panels are poured in a horizontal position, you can use a stiffer mix. Use a minimum of six sacks of cement per cubic yard with a maximum of 6 gallons of water per sack of cement along with well graded aggregate. As pointed out earlier, you will have to reduce the amount of water used per sack of cement to allow for the free water in the sand. Large aggregate, up to 1 ½ inches in diameter, may be used effectively. Work the concrete into place by spading or vibration, and take extra care to prevent honeycomb around the outer edges of the panel.

Normal finishing methods should be used, but many finishing styles are available for horizontally cast panels. Some finishing methods include patterned, colored, exposed aggregate, broomed, floated, or steel troweled. Regardless of the finish used, finishers must be cautioned to do the finishing of all panels in a uniform manner. Spots, defects, uneven brooming, or troweling, and so forth will be highly visible when the panels are erected.

Without marring the surface, curing should be started as soon as possible after finishing. Proper curing is important, so cure cast panels just like any other concrete to achieve proper strength. Curing compound, if used, prevents bonding with other concrete or paint.

12.6.0 Lifting Equipment and Attachments

Tilt-up panels can be set up in many different ways and with various kinds of power equipment. The choice depends upon the size of the job. Besides the equipment, a number of attachments are used.

12.6.1 Equipment

The most popular power equipment is a crane. But other equipment used includes a winch and an A frame, used either on the ground or mounted on a truck. When a considerable number of panels are ready for tilting at one time, power equipment speeds up the job.

12.6.2 Attachments

Many types of lifting attachments are used to lift tilt-up panels. Some of these are locally made and are called hairpins; other types are available commercially. Hairpin types are made on the job site from rebar by making 180° bends in the ends of two vertical reinforcing bars. The hairpins are then placed in the end of the panel before the concrete is poured. These lifting attachments must protrude from the top of the form for attaching the lifting chains or cables, but go deep enough into the panel form so they won't pull out.

Among the commercial types of lifting attachments, you will find many styles with greater lifting capacities that are more dependable than hairpins if properly installed. These are used with lifting plates. For proper placement of lifting inserts, refer to the plans or specs.

12.6.3 Spreader Bars

Spreader bars, shown in *Figure 6-80*, may be permanent or adjustable, but must be designed and made according to the heaviest load they will carry plus a safety factor. They are used to distribute the lifting stresses evenly, reduce the lateral force applied by slings, and reduce the tendency of panels to bow.

12.7.0 Point Pickup Methods

Once the concrete has reached the desired strength, the panels are ready to be lifted. The strength of the inserts is governed by the strength of the concrete.

CAUTION

An early lift may result in cracking the panel, pulling out the insert, or total concrete failure. Taking the time to wait until the concrete has reached its full strength prevents problems and minimizes the risk of injury.

There are several pickup methods. The following are just some of the basics. Before using these methods on a job, make sure that you check plans and specs to see if these are stated there. *Figure 6-86* shows four different pickup methods: 2, 2-2, 4-4, and 2-2-2.

Figure 6-80 – Different types of pickup points.

The 2-point pickup is the simplest method, particularly for smaller panels. Fasten the pickup cables or chains directly from the crane hook or spreader bar to two pickup points on or near the top the precast panel.

The 2-2 point pickup is a better method and is more commonly used. Variations of the 2-2 are the 4-4 and 2-2-2, or combinations of pickup points as designated in the job site specifications. These methods use a combination of spreader bars, sheaves, and equal length cables. The main purpose is to distribute the lifting stress throughout the panel during erection. Remember, the cables must be long enough to allow ample clearance between the top of the panel and the sheaves or spreader bar.

12.8.1 Erecting, Bracing, and Jointing Panels

Erecting is an important step in the construction phase of the project. Before you start the erecting phase, and for increased safety, make sure all your tools, equipment, and braces are in proper working order. All personnel must be well informed and the signalman and crane operator understand and agree on the signals to be used. During the erection of the panels, make sure that the signalman and line handler are not under the panel and that all unnecessary personnel and equipment are away from the lifting area. After the erection is done, make sure that all panels are properly braced and secured before unhooking the lifting cables.

Bracing is an especially important step. After all the work of casting and placing the panels, you want them to stay in place. The following are some steps to take before lifting the panels:

- Install the brace inserts into the panels during casting if possible.
- Install the brace inserts into the floor slab either during pouring or the day before erection.
- Install solid brace anchors before the day of erection.
- If brace anchors must be set during erection, use a method that is fast and accurate.

Although there are several types of bracing, pipe or tubular braces are the most common. They usually have a turnbuckle welded between sections for adjustment. Some braces are also made with telescoping sleeves for greater adaptability. *Figure 6-80* shows tube type braces used to hold up panels. Cable braces are normally used for temporary bracing and for very tall panels. Their flexibility and tendency to stretch make them unsuitable for most projects. Wood bracing is seldom used except for low, small panels or for temporary bracing.

Jointing the panels is simple. Just tie all the panels together, covering the gap between them. You can weld, bolt. Or pour concrete columns or beams. Steps used to tie the panels should be stated in the plans and specs.

Summary

Concrete is a very important construction material, since it is comparatively economical and easy to make, offering continuity, solidity, and the ability to bond with other materials. The keys to good quality concrete are the raw materials required to make concrete and the mix design as specified in the project specifications, which includes methods and mixing times. Tilt-up construction involves several considerations, including what projects it might be suitable for and lifting methods needed to put these pieces in place.

Review Questions (Select the Correct Response)

1. **(True or False)** Concrete has high ability to resist stretching, bending, and twisting.

   A. True
   B. False

2. What principle factor controls the strength of concrete?

   A. Dryness
   B. Water-cement ratio
   C. Age
   D. Reinforcement

3. **(True or False)** The major factor controlling the durability of concrete is its strength.

   A. True
   B. False

4. If more water is added to a concrete mix than is needed to hydrate the cement, the concrete becomes less ________.

   A. porous
   B. brittle
   C. fluid
   D. watertight

5. The production of good concrete is impossible unless good quality materials are used in the mix, and this mix is properly ________.

   A. cured and dried
   B. puddled and dried
   C. worked and cured
   D. fortified and cured

6. Portland cement is manufactured from finely ground limestone mixed with which of the following materials?

   A. Clay
   B. Shale
   C. Marl
   D. Any of the above

7. For highway construction, Type III Portland cement is sometimes preferred to Type I because Type III has which of the following characteristics?

   A. Finer finish
   B. Requires less working
   C. Shorter curing time
   D. Longer curing time

8. What type of cement was developed for use in areas subject to severe frost and ice conditions?

   A. Air entrained
   B. Keene's
   C. Type V
   D. Type IV

9. **(True or False)** Aggregate is the material combined with cement and water to make concrete.

   A. True
   B. False

10. Concrete is denser and stronger when which of the following conditions is met?

   A. All voids are filled
   B. Voids are large and unfilled
   C. Aggregate particles are not solidly bonded
   D. Aggregate particles are not coated with a cement-water paste

11. **(True or False)** When performing a sieve analysis of aggregate, you should determine the percentage of material retained on the sieve.

   A. True
   B. False

12. **(True or False)** To prevent aggregate from segregating during stockpiling, you should build up piles in layers by dumping successive loads alongside each other.

   A. True
   B. False

13. In concrete, how is laitance produced?

   A. Water collects under the surface of the cement.
   B. Cement is hydrated with saltwater.
   C. Cement is hydrated with minimum water.
   D. Cement is hydrated with excess water.

14. The proportion of air-entraining agent added to a concrete mix should fall within what range?

    A. 1% to 2% only
    B. 1% to 3%
    C. 3% to 7%
    D. 8% to 10%

15. **(True or False)** The accepted use for retarders is to increase the rate of hydration.

    A. True
    B. False

16. What is the main reason to store cement should in a dry place?

    A. To prevent it from becoming concrete while in storage
    B. To prevent it from setting too fast and producing weak concrete
    C. To prevent it from setting too slowly and producing weak concrete
    D. To avoid warehouse pack

17. When storing sacks of cement in a warehouse, what is the main reason to stack them close together?

    A. So they can draw moisture from each other
    B. To restrict the circulation of air between them
    C. To prevent warehouse pack
    D. To prevent them from getting mixed up

18. Before using warehouse-packed cement, what should you do to make it lump free?

    A. Restack the sacks to allow air to circulate around them
    B. Raise the temperature for 48 hours in the area where the sacks are stored
    C. Roll the sacks around
    D. Cover the sacks for 48 hours with tarpaulins

19. **(True or False)** In a field mix, the number of gallons of water per sack of cement must be increased to allow for the saturated surface-dry condition of the sand.

    A. True
    B. False

20. When available aggregate is 1 1/2 inches, what rule of thumb should you use to calculate materials required for a proper concrete mix?

    A. Rule 38 only
    B. Rule 41 only
    C. Rule 38 or 41 depending on whether mixing is done by hand or machine
    D. Rule 42

In answering questions 21 through 23, use the appropriate rule of thumb for a 1:2:5 concrete mix when 2-inch coarse aggregate is used.

21. How many bags of cement are required to make 1 cubic yard of concrete?

    A. 8
    B. 7 1/2
    C. 6
    D. 5 1/4

22. How many cubic feet of sand are required to make 1 cubic yard of concrete?

    A. 5
    B. 7 1/2
    C. 10 1/2
    D. 12

23. To make 40 cubic yards of concrete, how many cubic feet of (a) sand and (b) coarse aggregate are required?

    A. (a) 500 (b) 1,240
    B. (a) 480 (b) 1,200
    C. (a) 475 (b) 1,180
    D. (a) 420 (b) 1,050

24. For each layer of concrete placed in a mold for a slump test, how many times should you rod the mold?

    A. 25
    B. 50
    C. 75
    D. 100

25. After completing a concrete slump test, you tap the side of the mix and the concrete crumbles apart. What condition exists?

    A. Well-proportioned mix
    B. Undersanded mix
    C. Oversanded mix
    D. Fluid or runny mix

26. When incorrect concrete slump is detected, what action should you take to correct the problem?

    A. Decrease or increase the aggregate only
    B. Change the proportions of the fine coarse aggregate only
    C. Either A or B above
    D. Add water to the batch

27. The rated capacity of a concrete mixing machine is determined by what factor?

A. The cubic feet of the mixed concrete
B. The cubic feet of the dry ingredients
C. The cubic yards of the dry ingredients
D. The weight of the dry ingredients

28. **(True or False)** In cement batch-plant operations, the aggregate must pass through a weigh box before being discharged into the mixer.

A. True
B. False

29. In an 11-S concrete mixer, what maximum size aggregate can you use?

A. 3/4 in
B. 1 1/2 in
C. 3 in
D. 4 in

30. In an 11-S concrete mixer, when should water be added to the mix?

A. Just before the cement
B. Just before the sand
C. Just before the aggregate
D. After all the dry ingredients have been added

31. You are to charge the skip of an 11-S concrete mixer. In what order should you add the dry ingredients?

A. Cement, aggregate, sand
B. Aggregate, cement, sand
C. Sand, cement, aggregate
D. Aggregate, sand, cement

32. When using a large mixing machine, what minimum time should you mix 2 1/3 cubic yards of concrete?

A. 1 min, 15 sec
B. 1 min, 30 sec
C. 2 min, 15 sec
D. 2 min, 45 sec

33. It is now 12 noon and you just finished pouring concrete. You should make sure the inside of the mixing drum is cleaned no later than

A. 1220
B. 1230
C. 1300
D. 1330

34. When cleaning a mixing drum, you should place the coarse aggregate in the drum and turn for how long?

A. 5 min
B. 10 min
C. 15 min
D. 30 min

35. When concrete must be discharged more than 4 feet above the level of placement, why should it be dumped into an elephant trunk?

A. To reduce segregation
B. To prevent scattering
C. To accurately place it
D. To ensure workable consistency

36. It is now 12 noon and you begin mixing concrete in a mixing drum. The concrete should be dumped no later than what time?

A. 1230
B. 1300
C. 1330
D. 1500

37. What type of concrete mixer can mix concrete en route to the jobsite?

A. Ready mixer
B. Portable mixer
C. Transit-mix truck
D. Agitator truck

38. In building construction, what is the most common type of forming material?

A. Wood
B. Earth
C. Steel
D. Fiberboard

39. What type of joint should you use to make watertight concrete forms?

A. Shiplap
B. Tongue and groove
C. Square
D. Rough-sawed

40. The hydrostatic head exerted on forms during concrete-placing operations normally continues for what maximum time?

A. 1 1/2 hr
B. 6 hr
C. 24 hr
D. 72 hr

41. **(True or False)** Footings for any foundation system should always be placed below the frost line.

A. True
B. False

42. An exterior wall that serves as an enclosure and also transmits structural loads to the foundation is called

A. a pier
B. a load bearing wall only
C. a bearing wall only
D. both A and B

43. Which of the following phrases best defines the term "keyway" in a concrete footer?

A. The rebar that sticks out of the concrete
B. The 2-by-2 that goes across the forms
C. The 45˚ groove around the outside edge of the footer
D. The indentation in the center of the footer

44. Horizontal form members that tie prefabricated panels together are called______.

A. studs
B. shoe plates
C. walers
D. spreaders

45. **(True or False)** Braces are not part of concrete form design and provide no additional strength.

A. True
B. False

46. What type of form-tying device is used with cone nuts?

A. Tie wire
B. Snap tie
C. Shear tie
D. Tie rod

47. When constructing stair forms, you should extend the platform what approximate distance past the sides?

A. 6 in
B. 12 in
C. 16 in
D. 18 in

48. You are pouring concrete but a suitable bond-preventing compound is not available. To prevent the wood forms from bonding to the concrete, which of the following substances is a suitable alternative?

A. Wax
B. Lacquer
C. Marine engine oil
D. Water

49. Of the following, which is the best bond breaking agent to use on steel forms?

A. Light-bodied petroleum oil
B. Vegetable oil
C. Marine engine oil
D. Hydraulic oil

50. **(True or False)** A light film of rust or mill scale is acceptable on rebar.

A. True
B. False

51. Which of the following rebar ties should you use when a finished mat is to be lifted by crane?

A. Double-strand single tie
B. Saddle tie
C. Cross tie
D. Saddle tie with a twist

52. In floor slabs, all steel reinforcing bars should be separated by what minimum distance?

A. 1 in
B. 3/4 in
C. A distance equal to 1 1/3 times the diameter of the largest bar
D. A distance equal to 1 1/2 times the diameter of the smallest bar

53. When a column assembly of reinforcing bars is raised into place, the reinforcing steel is tied to the column form at intervals of

A. 5 ft
B. 2 ft
C. 3 ft
D. 4 ft

54. **(True or False)** In footing construction, stones may be used instead of steel supports under reinforcing bars.

A. True
B. False

55. A joint that separates a floor slab from a column is called

    A. a contraction joint
    B. an expansion joint
    C. an isolation joint
    D. a stress joint

56. A joint that allows the transfer of part of the load from one structural element to another through the use of keys or dowels is called a

    A. keyway
    B. tooled joint
    C. construction joint
    D. control joint

57. What type of blade is normally used to cut seasoned concrete?

    A. Abrasive
    B. Diamond
    C. Graphite
    D. Carbide

58. **(True or False)** High quality concrete requires both a well designed mix and good placing procedures.

    A. True
    B. False

59. What is the maximum distance concrete should be dropped from a chute?

    A. 5 ft
    B. 2.5 ft
    C. 3 ft
    D. 4 ft

60. When placing concrete on a slope, you should start at what position?

    A. Top only
    B. Bottom only
    C. Top or bottom
    D. Middle

61. What is the best tool for compacting concrete?

    A. Spade
    B. Puddling stick
    C. Tamper
    D. Mechanical vibrator

62. **(True or False)** It is permissible to use a mechanical vibrator to move concrete in forms.

A. True
B. False

63. Which of the following procedures is used to bring a concrete surface to the required elevation?

A. Consolidating
B. Screeding
C. Floating
D. Troweling

64. The speed at which a vibrating screed is pulled across concrete directly depends on which of the following factors?

A. The amount of concrete poured
B. The density of the concrete
C. The slump of the concrete
D. The length of the beam

65. **(True or False)** Troweling a vibrator screed finished floor slab is usually delayed because of the slow setup time needed for the concrete mix.

A. True
B. False

66. Which of the following finishing tools gives concrete a smooth, dense, finished surface?

A. Canvas belt
B. Wooden float
C. Steel trowel
D. Aluminum float

67. Which of the following processes produces a nonskid or rough concrete surface?

A. Skidding
B. Streaking
C. Brooming
D. Grinding

68. When mortar is being used in rubbing a concrete surface, how long should the surface be kept moist to cure?

A. 8 hours
B. 1 to 2 days
C. 3 to 4 days
D. 7 days

69. Concrete made with ordinary cement is generally cured for what minimum period?

A. 11 days
B. 7 days
C. 3 days
D. 14 days

70. **(True or False)** When curing flat surfaces, ponding allows the concrete to maintain a uniform temperature.

A. True
B. False

71. Which of the following materials is the best insulator?

A. Straw
B. Moist earth
C. Plastic film
D. Dry insulation

72. When plastic is used in the concrete curing process, what is the minimum overlap for adjacent sheets?

A. 12 in
B. 8 in
C. 16 in
D. 4 in

73. When patching concrete, you should apply mortar in layers NOT exceeding what maximum thickness?

A. 1 1/2 in
B. 2 in
C. 3/4 in
D. 1/2 in

74. Of the following surfaces, which is best for precast concrete?

A. Earth
B. Wood
C. Concrete
D. Tile

75. At what point in concrete casting should the bond-breaking agent be applied to a casting surface?

A. Before the edge forms are placed
B. After the edge forms are placed
C. After the steel is placed but before final preparation
D. Just before pouring the concrete

76. What is the simplest method for pickup of small cast panels?

A. 2 point
B. 2 x 4 point
C. 3 point
D. 4 x 4 point

77. What is the most common type of brace used in tilt-up concrete construction?

A. Wood
B. Cable
C. Angle iron
D. Tubular

78. **(True or False)** Because of their flexibility and tendency to stretch, cable braces are unsuitable for most projects.

A. True
B. False

79. In cast concrete, sand streaking is caused by

A. Too rapid casting
B. Casting against earth surface
C. Escape of moisture from loose forms
D. Escape of mortar from loose forms

80. Compared to cast-in-place panels, precast panels have what main advantage(s)?

A. Less forming material is required
B. Placing the rebar is easier
C. Thorough filling and vibrating are easier
D. All of the above

Trade Terms Introduced in this Chapter

Accelerators	Additives which, when added to paint, concrete, mortar, or grout mix, speed the rate of hydration and thereby cause it to set or harden sooner.
Admixture	An ingredient other than cement, aggregate, or water that is added to a concrete or mortar mixture to affect the physical or chemical characteristics of the concrete or mortar. The most common admixtures affect plasticity, air entrainment, and curing time.
Aggregate	Crushed rock or gravel screened to size for use in road surfaces, concrete, or bituminous mixes.
Air-entrained concrete	Concrete containing millions of trapped air bubbles.
Air-entraining agent	An admixture for concrete or mortar mixes that causes minute air bubbles to form within the mix. Air entrainment is desirable for workability of the mix and prevention of cracking in the freeze/thaw cycle.
Batch	The amount of concrete mixed at one time regardless of quantity.
Bond	The adhesion of cement paste to aggregate.
Bond breaking agents	Materials used to prevent adhesion between freshly placed concrete and the substrate.
Bracing	A temporary support for aligning vertical concrete work.
Broomed	Concrete that has been brushed with a broom when fresh in order to improve its traction or to create a distinctive texture.
Cement	Fuzed and pulverized limestone and clay.
Charging	The insertion of a predetermined mixture or quantity of materials into a concrete mixer.
Cleats	Small blocks of wood nailed to the surface of a wood member to stop or support another member.
Compacting	Eliminating voids in concrete by vibration, tamping, rolling, or some other method or combination of methods.
Compressive strength	The resistance capacity of any material, but especially structural members, to crushing force. Compressive strength is usually expressed as the maximum number of pounds per square inch that can be resisted without failure.
Consolidation	Compaction of freshly poured concrete by tamping, rodding, or vibrating to eliminate voids and to ensure total envelopment of aggregate and reinforcement.

Construction joints	Joints that run through concrete. Made by pouring sections of a structure at different times.
Control joints	A formed, sawed, or tooled groove in a concrete structure. The purpose of the joint is to create a weakened plane and to regulate the location of cracking resulting from the dimensional change of different parts of the structure. Also known as a contraction joint.
Curing	Maintaining the proper moisture and temperature after placing or finishing concrete to assure proper hydration and hardening.
Edging	The process of rounding to reduce the possibility of chipping or spalling exposed edges of concrete slabs.
Finish	The texture of a surface after compacting and finishing operations have been performed. (Examples are exposed aggregate, rubbed, and sack-rubbed.)
Finishing	Leveling, smoothing, compacting, and otherwise treating surfaces of fresh or recently placed concrete or mortar to produce the desired appearance and service.
Floating	The operation of finishing a fresh concrete or mortar surface by use of a float, preceding troweling when that is the final finish.
Forms	Temporary structures or molds for the support of concrete while it is setting and gaining sufficient strength to be self-supporting.
Formwork	The total system of support for freshly placed concrete, including the mold or sheathing which contacts the concrete, as well as all supporting members, hardware, and necessary bracing
Grout	A mixture of sand, cement, and water that can be poured.
Honeycombing	Sections of weak, porous concrete.
Hydrostatic head	The pressure in a fluid, expressed as the height of a column of fluid that will provide an equal pressure at the base of the column.
Insert	A unit of hardware embedded in concrete or masonry to provide a means for attaching something.
Isolation joints	Joints positioned so as to separate concrete from adjacent surfaces or into individual structural elements which are not in direct physical contact, such as an expansion joint.
Laitance	A milky deposit on the surface of new cement or concrete, usually caused by too much water.
Mixing time	The elapsed time for mixing a batch of concrete or mortar.

Particle size distributions	Tabulations of the result of mechanical analysis expressed as the percentage by weight passing through each of a series of sieves.
Placing Rate	The rate at which concrete is placed, generally expressed as feet per hour.
Pouring	The process of placing and consolidating concrete.
Precast concrete	Concrete structural components, such as piles, wall panels, beams, etc., fabricated at a location other than in-place.
Ready mixed concrete	Concrete manufactured for delivery to a purchaser in a plastic and unhardened state.
Rebar	A steel bar, usually with manufactured deformations, used in concrete and masonry construction to provide additional strength. Also known as reinforcing bar.
Reinforcement	Bars, wires, strands, and other slender members embedded in concrete such a manner that the reinforcement and the concrete act together in resisting forces.
Retarders	Admixtures which delay the setting of cement paste, and hence of mixtures such as mortar- or concrete-containing cement.
Rodding	Compaction of concrete by means of a tamping rod.
Screeding	The operation of forming a surface by striking off concrete lying above the desired plane or shape.
Segregation	The differential concentration of the components of mixed concrete, aggregate, or the like, resulting in nonuniform proportions in the mass.
Shrinkage	Concrete contraction due to curing and excess water in the mix.
Slump	A measure of consistency of freshly mixed concrete, mortar, or stucco equal to the subsidence measured to the nearest 1/4” (6 mm) of the molded specimen immediately after removal of the slump cone.
Slump test	A means of sample testing concrete for consistency; a measure of the plasticity of a concrete mix.
Stripping	The removal of mold forms from hardened concrete.
Tamping	The operation of compacting freshly poured concrete by repeated blows or penetrations with a tamping device.
Ties	Metal strips used to tie concrete forms together. (Types are cross, double-strand single, figure-eight, saddle, simple, snap, wall tie)
Tilt-up concrete	A method of concrete construction in which members are cast

horizontally at a location adjacent to their eventual position and tilted into place after removal of forms.

Troweling Smoothing and compacting the unformed surface of fresh concrete by strokes of a trowel.

Vibration Energetic agitation of freshly mixed concrete during placement by mechanical devices, either pneumatic or electric, that create vibratory impulses of moderately high frequency that assist in evenly distributing and consolidating the concrete in the formwork.

Welded-wire fabric A series of longitudinal and transverse wires of various gauges, arranged at right angles to each other and welded at all points of intersection; used for concrete slab reinforcement. Also known as welded-wire mesh.

Workability The property of freshly mixed concrete or mortar that determines the ease and homogeneity with which it can be mixed, placed, compacted, and finished.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Concrete and Masonry, FM 5-742, Headquarters, Department of the Army, Washington, D.C., 1985.

Concrete Formwork, Keel, Leonard, American Technical Publishers, Inc., Homewood, IL, 1988.

Design and Control of Concrete Mixtures, Portland Cement Association, Skokie, IL, 1988.

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American Concrete Institute, ACI Committee 309, technical committee document 309R-05, 2005, 35 pp. http://www.concrete.org/PUBS/newpubs/309.htm.

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Chapter 7

Fiber Line, Wire Rope, and Scaffolding

Topics

To hear audio, click on the box

Overview

As a Seabee Builder Petty Officer you will be put in charge, from time to time, of two important construction tasks. These tasks are setting up rigging to hoist loads and building ***scaffolding*** to support work above your crew's reach. You as crew leader will be expected to direct your crew in the correct performance of these tasks and above all in the safety of yourself and your crew. Safety is paramount while doing any job, but it is especially important when hoisting heavy loads and when working at heights on scaffolding.

This chapter presents information on how to use ***fiber line***, ***wire rope***, and timber in rigging and erecting ***hoisting*** devices, such as ***shear legs***, ***tripods***, blocks and tackles; and different types of scaffolds and ladders. It will also give you formulas for determining the safe working load of these materials.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Determine use, breaking strength, and care of ***lines*** and rope used for rigging
2. Determine use, breaking strength, and care of wire rope used for rigging
3. Identify components and operating characteristics of block and tackle units
4. Understand hoisting, hand signals used in lifting loads, and safety rules of lifting
5. Determine proper use of wood and prefabricated metal scaffolding

Prerequisites

None

This course map shows all of the chapters in Builder Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on this course map.

Expeditionary Structures	↑	B
Finishes		U
Moisture Protection		I
Finish Carpentry		L
Rough Carpentry		D
Carpentry Materials and Methods		E
Masonry		R
Fiber Line, Wire Rope, and Scaffolding		
Concrete Construction		B
Site Work		A
Construction Management		S
Drawings and Specifications		I
Tools		C
Basic Math		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 FIBER LINE

Fiber line is made from either natural or synthetic fiber. Natural fibers, which come from plants, include manila, sisal, and hemp. The synthetic fibers include nylon, polyester, and polypropylene,

1.1.0 Natural Fiber Ropes

The two most commonly used natural fiber ropes are manila and sisal, but the only type suitable for construction rigging is a good grade of manila. High quality manila is light cream in color, smooth, clean, and pliable. The quality of the line can be distinguished by varying shades of brown; Number 1 grade is very light in color, Number 2 grade is slightly darker, Number 3 grade is considerably darker. The next best line making fiber is sisal. Sisal fiber is similar to manila, but lighter in color. This type of fiber is only about 80 percent as strong as manila fiber.

1.2.0 Synthetic Fiber Ropes

Synthetic fiber rope, such as nylon and polyester, has rapidly gained wide use by the Navy. It is lighter in weight, more flexible, less bulky, and easier to handle and store than manila line. It is also highly resistant to mildew, rot, and fungus. Synthetic rope is stronger than natural fiber rope. For example, nylon is about three times stronger than manila. When nylon line is wet or frozen, the loss of strength is relatively small. Nylon rope will hold a load even though several strands may be frayed. Ordinarily, the line can be made reusable by cutting away the chafed or frayed section and splicing the good line together.

1.3.0 Fabrication of Line

The fabrication of line consists essentially of three twisting operations. First, the fibers are twisted to the right to form the ***yarns***. Next, the yarns are twisted to the left to form the strands. Finally, the strands are twisted to the right to form the line. *Figure 7-1* shows how the fibers are grouped to form a three strand line.

Figure 7-1 – Fiber groupings in a three-strand line.

The operation just described is the standard procedure, and the resulting product is known as a right-laid line. When the process is reversed, the result is a left-laid line. In either instance, the principle of opposite twists must always be observed. The two main reasons for the principle of opposite twists are to keep the line tight to prevent the fibers from unlaying with a load suspended on it and to prevent moisture penetration.

1.3.1 Types of Line Lays

There are three types of fiber line lays: hawser-laid, shroud-laid, and cable-laid lines. Each type is illustrated in *Figure 7-2*.

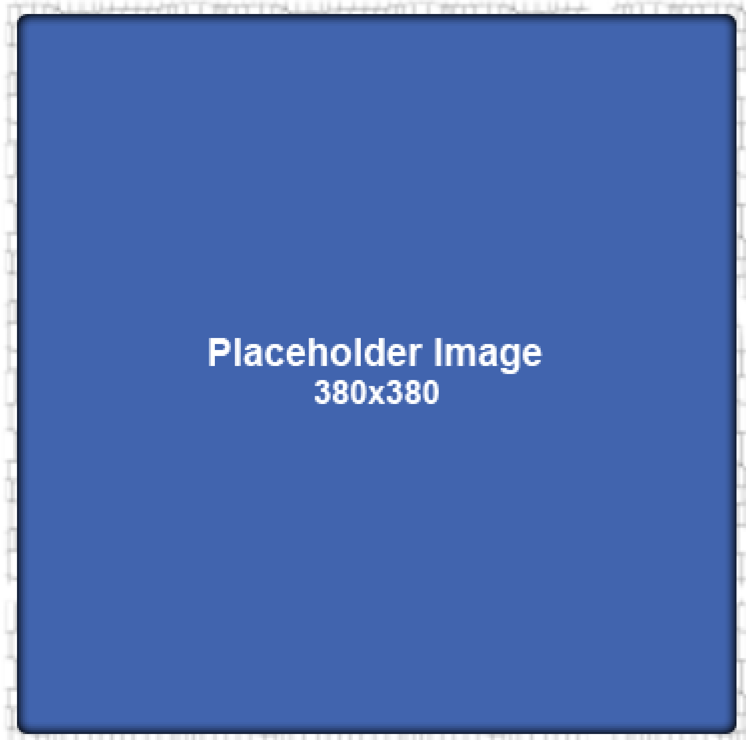

Figure 7-2 – Fiber line lays.

Hawser-laid line generally consists of three strands twisted together, usually in a right hand direction. A shroud-laid line ordinarily is composed of four strands twisted together, usually in a right hand direction around a center strand, or core, which is usually of the same material, but smaller in diameter than the four strands. Shroud-laid line is more pliable and stronger than hawser-laid line, but it has a strong tendency toward kinking. In most instances, it is used on ***sheaves*** and drums. This not only prevents kinking, but also makes use of its pliability and strength. Cable-laid line usually consists of three right-hand, hawser-laid lines twisted together in a left hand direction. It is especially safe to use in heavy construction work; if cable-laid line untwists, it will tend to tighten any regular right-hand screw connection to which it is attached.

1.3.2 Size Designation

Line that is 1 3/4 inches or less in circumference is called small stuff. The size is usually designated by the number of threads, or yarns, that make up each strand. You may use from six to 24 thread strands, but the most commonly used are nine to 21 thread strands, as shown in *Figure 7-3*. You may hear some small stuff designated by name without reference to size. One such type is marline; a tarred, two strand, left-laid hemp. Marline is the small stuff you will use most for seizing. When you need something stronger than marline, you will use a tarred, three-strand, left-laid hemp called houseline.

Figure 7-3 – Some commonly used sizes of manila line.

Line larger than 1 3/4 inches in circumference is generally size designated by its circumference in inches. A six-inch manila line, for instance, is constructed of manila fibers and measures six inches in circumference. 12 inches is about the largest manila carried in stock. Anything larger is used only on special jobs.

If you have occasion to order line, you may find that the catalogs, is designate it and you order it by diameter. The catalog may also use the term rope rather than line.

Pull rope yarns for temporary seizing, whippings, and lashings from large strands of old line that has outlived its usefulness. Pull your yarn from the middle, away from the ends, or it will get fouled.

1.4.1 Strength of Fiber Line

Overloading a line poses a serious threat to the safety of personnel, not to mention the heavy losses likely to result through damage to material. To avoid overloading, you must know the strength of the line with which you are working. This involves three factors: breaking strength, safe working load (SWL), and ***safety factor***.

Breaking strength refers to the tension at which the line will part when a load is applied. Rope manufacturers determine breaking strength through tests and provide tables with this information. In the absence of manufacturers' tables, a rule of thumb for finding the breaking strength of manila line is the formula:

$$BS = C^2 \times 900$$

BS equals the breaking strength in pounds and C equals the circumference in inches. To find BS, first square the circumference, then multiply the value obtained by 900. For example, with a three inch line you will get a BS of 8,100 pounds as follows:

$$BS = 3 \times 3 \times 900 = 8,100$$

The breaking strength of manila line is higher than that of sisal line because of the difference in the two fibers. The fiber from which a particular line is constructed has a definite bearing on its breaking strength. The breaking strength of nylon is almost three times that of manila line of the same size.

The best rule of thumb for breaking strength of nylon is as follows:

$$BS = C^2 \times 2{,}400$$

The symbols in the rule are the same as those for fiber line. For the 2 1/2 inch nylon line:

$$BS = 2.5 \times 2.5 \times 2{,}400 = 15{,}000 \text{ pounds}$$

Briefly defined, the safe working load of a line is the load that can be applied without damaging the line. Note that the safe working load is considerably less than the breaking strength. A wide margin of difference between breaking strength and safe working load is necessary. This difference allows for such factors as additional strain imposed on the line by jerky movements in hoisting or bending over sheaves in a pulley block.

You may not always have a chart available to tell you the safe working load for a particular line. Here is a rule of thumb that will adequately serve your needs on such an occasion:

$$SWL = C^2 \times 150$$

In this equation, SWL equals the safe working load in pounds, and C equals the circumference of the line in inches. Simply take the circumference of the line, square it, and then multiply by 150. For a 3 inch line:

$$SWL = 3 \times 3 \times 150 = 1{,}350 \text{ pounds}$$

The safe working load of a three inch line is equal to 1,350 pounds.

If a line is in good shape, add 30 percent to the SWL derived by means of the preceding rule; if it is in bad shape, subtract 30 percent from the SWL. In the example given above for the three inch line, adding 30 percent to the 1,350 pounds gives you a safe working load of 1,755 pounds. On the other hand, subtracting 30 percent from 1,350 pounds leaves you with a safe working load of 945 pounds.

Remember that the strength of a line decreases with age; use; and exposure to excessive heat, boiling water, or sharp bends. Especially with used line, give these and other factors affecting strength careful consideration and make proper adjustment in determining the breaking strength and safe working load capacity of the line. Manufacturers of line provide tables that show the breaking strength and safe working load capacity of line. Those tables are very useful in your work. You must remember that the values given in manufacturers' tables apply only to new line used under favorable conditions. For that reason, you must progressively reduce the values given in manufacturers' tables as the line ages or deteriorates with use.

Keep in mind that a strong strain on a kinked or twisted line will put a permanent distortion in the line. *Figure 7-4* shows what frequently happens when pressure is applied to a line with a kink in it. The kink that could have been worked out is now permanent, and the line is ruined.

Figure 7-4 – Results of a strong strain on a line with a kink in it.

The safety factor of a line is the ratio between the breaking strength and the safe working load. Usually, a safety factor of four is acceptable, but this is not always the case. In other words, the safety factor should never be less than three; it often must be well above four, possibly as high as eight or ten. For the best, average, or unfavorable conditions, the following safety factors may often be suitable:

- Best conditions (new line): four
- Average conditions (line used, but in good condition): six
- Unfavorable conditions (frequently used line, such as running rigging): eight

1.5.0 Handling and Care of Lines

If you expect the fiber line you work with to give safe and dependable service, make sure it is handled and cared for properly. Study the precautions and procedures given here and carry them out properly.

Cleanliness is part of the care of fiber line. Never drag a line over the deck or ground, or over rough or dirty surfaces. The line can easily pick up sand and grit, which will work into the strands and wear the fibers. If a line does get dirty, use only water to clean it. Do not use soap because it will remove oil from the line, which weakens it.

Avoid pulling line over sharp edges because the strands may break. When you encounter a sharp edge, place chafing gear; such as a board, folded cardboard, or canvas, or part of a rubber tire between the line and the sharp edge to prevent damaging the line.

Never cut a line unless you have to. When possible, use knots that you can easily untie.

Fiber line contracts, or shrinks, when it gets wet. If there is not enough slack in a wet line to permit shrinkage, the line is likely to become overstrained and weakened. If a taut line is exposed to rain or dampness, make sure the line, while still dry, is slacked to allow for shrinkage.

Inspect line carefully at regular intervals to determine whether it is safe. The outside of a line does not show the condition of the line on the inside. Untwisting the strands slightly allows you to check the condition of the line on the inside. Mildewed line gives off a musty odor. A trained observer can usually spot broken strands or yarns immediately. Look carefully to ensure there is no dirt or sawdust-like material inside the line. Dirt or other foreign matter inside reveals possible damage to the internal structure of the line.

A shrinking of circumference of the line is usually a sure sign that too much strain has been applied to the line.

For a thorough inspection, examine a line at several places along its length.

CAUTION

Only one weak spot anywhere in a line makes the entire line weak.

As a final check, pull out a couple of fibers from the line and try to break them. Sound fibers show a strong resistance to breakage.

If an inspection discloses any unsatisfactory conditions in a line, make sure to destroy the line or cut it up into small pieces as soon as possible. This precaution prevents the defective line from being used for hoisting.

Test your Knowledge (Select the Correct Response)

1. How many grades of manila lines are there?

   A. One
   B. Two
   C. Three
   D. Four

2. What term is line that is 1 3/4 inches or less in circumference called?

   A. Small stuff
   B. Hawser
   C. Rope
   D. Tarred line

2.0.0 WIRE ROPE

During the course of a project, Seabees often need to hoist or move heavy objects. Wire rope is used for heavy duty work. The following paragraphs discuss the characteristics, construction, and use of many types of wire rope. We will also discuss the safe working load, use of attachments and fittings, and procedures for the care and handling of wire rope.

2.1.0 Construction

Wire rope consists of three parts; wires, strands, and core, as shown in *Figure 7-5*. In the manufacture of rope, a number of wires are laid together to form the strand. Then a number of strands are laid together around a core to form the rope.

The basic unit of wire rope construction is the individual wire, which may be made of steel, iron, or other metal, in various sizes. The number of wires to a strand varies, depending on the purpose for which the rope is intended. Wire rope is designated by the number of strands per rope and the number of wires per strand. Thus a 1/2 inch 6 X 19 rope will have 6 strands with 19 wires per strand; but it will have the same outside diameter as a 1/2 inch 6 X 37 wire rope, which will have 6 strands with 37 wires of much smaller size per strand. Wire rope made up of a large number of small wires is flexible, but the small wires are easily broken, so the wire rope does not resist external abrasion. Wire rope made up of a smaller number of larger wires is more resistant to external abrasion but is less flexible.

Figure 7-5 – Parts of wire rope.

The core is the element around which the strands are laid to form the rope. It may be a hard fiber; such as manila, hemp, plastic, paper, or sisal; a wire strand, or an independent wire rope. Each type of core serves the same purpose, to support the strands laid around it.

A fiber core offers the advantage of increased flexibility. Also, it serves as a cushion to reduce the effects of sudden strain and acts as a reservoir for the oil to lubricate the wires and strands to reduce friction between them. Wire rope with a fiber core is used in places where flexibility of the rope is important.

A wire strand core not only resists heat more than a fiber core, but also adds about 15 percent to the strength of the rope. On the other hand, the wire strand makes the rope less flexible than does a fiber core.

An independent wire rope is a separate wire rope over which the main strands of the row are laid. It usually consists of six seven-wire strands laid around either a fiber core or a wire strand core. This core strengthens the rope more, provides support against crushing, and supplies maximum resistance to heat.

Wire rope may be made by either of two methods. If the strands or wires are shaped to conform to the curvature of the finished rope before laying up, the rope is called preformed. If they are not shaped before fabrication, the rope is called non-preformed. When cut, preformed wire rope tends not to unlay, and it is more flexible than non-preformed wire rope. With non-preformed wire rope, twisting produces a stress in the wires; and when it is cut or broken, the stress causes the strands to unlay.

WARNING

In non-preformed wire, unlaying is rapid and almost instantaneous, which could cause serious injury to someone not familiar with it.

The main types of wire rope used by the Navy consist of 6, 7, 12, 19, 24, or 37 wires in each strand. Usually, the rope has six strands laid around a fiber or steel center. Two common types of wire rope, 6 X 19 and 6 X 37 ropes, are illustrated in views A and B of *Figure 7-6*, respectively. The 6 X 19 type of rope, having six strands with 19 wires in each strand, is commonly used for rough hoisting and skidding work where abrasion is likely to occur. The 6 X 37 wire rope, having six strands with 37 wires in each strand, is the most flexible of the standard six-strand ropes. For that reason, it is particularly suitable when small sheaves and drums are to be used, such as on cranes and similar machinery.

Figure 7-6 – Two common types of wire rope.

2.2.0 Grades of Wire Rope

Wire rope is made in a number of different grades. Three of the most common are mild plow steel, plow steel, and improved plow steel.

Mild plow steel rope is tough and pliable. It can stand up under repeated strain and stress and has a tensile strength of from 200,000 to 220,000 pounds per square inch (psi). Plow steel wire rope is unusually tough and strong. It has a tensile strength, or resistance to lengthwise stress, of 220,000 to 240,000 psi. This rope is suitable for hauling, hoisting, and logging. Improved plow steel rope is one of the best grades of rope available, and most, if not all, of the wire rope in your work will probably be made of this material. It is stronger, tougher, and more resistant to wear than either plow steel or mild plow steel. Each square inch of improved plow steel can withstand a strain of 240,000 to 260,000 psi.

2.3.0 Measuring Wire Rope

The size of wire rope is designated by its diameter. The true diameter of a wire rope is the diameter of a circle that will just enclose all of its strands. Correct and incorrect methods of measuring wire rope are illustrated in *Figure 7-7*. In particular, note that the correct way is to measure from the top of one strand to the top of the strand directly opposite it. The wrong way is to measure across two strands side-by-side. Use calipers to take the measurement. If calipers are not available, an adjustable wrench will do.

To ensure an accurate measurement of the diameter of a wire rope, always measure the rope at three places, at least 5 feet apart. Use the average of the three measurements as the diameter of the rope.

Figure 7-7 – Correct and incorrect methods of measuring wire rope.

2.4.0 Safe Working Load

The term safe working load (SWL), in reference to wire rope, means the load that can be applied and still obtain the most efficient service from and prolong the life of the rope. Most manufacturers provide tables that show the safe working load for their rope under various conditions. In the absence of these tables, you must apply a formula to obtain the SWL. There are rules of thumb you can use to compute the strength of wire rope. The one recommended by the Naval Facilities Engineering Command (NAVFAC) is:

$$SWL = D^2 \times 8$$

D represents the diameter of the rope in inches, and SWL represents the safe working load in tons. This particular formula provides an ample safety margin to account for such variables as the number, size, and location of the sheaves and drums on which the rope runs. It also includes dynamic stresses, such as the speed of operation and the acceleration and deceleration of the load. All can affect the endurance and breaking strength of the rope. Let's work an example. Suppose you want to find the SWL of a two inch rope. Using the formula above, your figures would be:

$$SWL = 2^2 \times 8 = 4 \times 8 = 32$$

The answer is 32, meaning that the rope has a SWL of 32 tons.

It is very important to remember that any formula for determining SWL is only a rule of thumb. In computing the SWL of old rope, worn rope, or rope that is otherwise in poor condition, you should reduce the SWL as much as 50 percent, depending on the condition of the rope. Use the manufacturer's data concerning the breaking strength (BS) of wire rope if available. But if you do not have that information, one rule of thumb recommended is:

$$BS = C^2 \times 8{,}000 \text{ pounds}$$

Wire rope is measured by the diameter (D). To obtain the circumference (C) required in the formula, multiply D by pi (π), which is approximately 3.1416. Thus, the formula to find the circumference is:

$$C = D \times \pi$$

2.5.1 Wire Rope Failure

Wire can fail due to any number of causes. Here is a list of some of the common causes of wire rope failure.

- Using the incorrect size, construction, or grade of wire rope
- Dragging rope over obstacles
- Having improper lubrication
- Operating over sheaves and drums of inadequate size
- Overriding or cross winding on drums
- Operating over sheaves and drums with improperly fitted grooves or broken flanges
- Jumping off sheaves
- Subjecting it to acid fumes
- Attaching fittings improperly
- Promoting internal wear by allowing grit to penetrate between the strands
- Subjecting rope to severe or continued overload

2.6.0 Handling and Care of Wire Rope

To render safe, dependable service over a maximum period of time, wire rope must have the care and upkeep necessary to keep it in good condition. In this section, we'll discuss various ways of caring for and handling wire rope. Not only should you study these procedures carefully, you should also practice them on your job to help you do a better job now. In the long run, the life of the wire rope will be longer and more useful.

2.6.1 Coiling and Uncoiling

Once a new reel has been opened, it may be either coiled or faked down like line. The proper direction of coiling is counterclockwise for left-laid wire rope and clockwise for right-laid rope. Because of the general toughness and resilience of wire, it occasionally tends to resist being coiled down. When this occurs, it is useless to fight the wire by forcing down a stubborn turn; it will only spring up again. If it is thrown in a back turn, as shown in *Figure 7-8*, it will lie down properly. A wire rope, when faked down, will run right off like line; but when wound in a coil, it must always be unwound.

Figure 7-8 – Throwing a back turn to make wire lie down.

Wire rope tends to kink during uncoiling or unreeling, especially if it has been in service for a long time. A kink can cause a weak spot in the rope, which will wear out more quickly than the rest of the rope. A good method for unreeling wire rope is to run a pipe or rod through the center and mount the reel on drum jacks or other supports so the reel is off the ground or deck as shown in *Figure 7-9*. In this way, the reel will turn as you unwind the rope, and the rotation of the reel will help keep the rope straight. During unreeling, pull the rope straight forward, as shown in *Figure 7-9*, and try to avoid hurrying the operation. As a safeguard against kinking, never unreel wire rope from a stationary reel.

Figure 7-9 – Unreeling wire rope (left) and uncoiling wire rope (right).

To uncoil a small coil of wire rope, simply stand the coil on edge and roll it along the ground or deck like a wheel or hoop, as illustrated in *Figure 7-9*. Never lay the coil flat on the deck or ground and uncoil it by pulling on the end because that practice can kink or twist the rope.

Figure 7-10 – Drum windings diagram for selecting the proper lay of rope.

To rewind wire rope back onto a reel or a drum, you may have difficulty unless you remember that it tends to roll in the direction opposite the lay. For example, a right-laid wire rope tends to roll to the left.

Carefully study *Figure 7-10*, which shows drum-winding diagrams selecting the proper lay of rope. When putting wire rope onto a drum, you should have no trouble if you know the methods of overwinding and underwinding shown in the illustration. When you run wire rope off one reel onto another or onto a winch or drum, run it from top to top or from bottom to bottom, as shown in *Figure 7-11*.

Figure 7-11 – Transferring wire rope from reel to drum.

2.6.2 Kinks

If a wire rope should form a loop, never try to pull it out by putting strain on either part. As soon as you notice a loop, uncross the ends by pushing them apart. See steps 1 and 2 in *Figure 7-12*. This reverses the process that started the loop. Now, turn the bent portion over and place it on your knee or some firm object and push downward until the loop straightens out somewhat. See step 3 in *Figure 7-12*. Then, lay the bent portion on a flat surface and pound it smooth with a wooden mallet. See step 4 in *Figure 7-12*.

If a heavy strain has been put on a wire rope with a kink in it, the rope can no longer be trusted. Replace the wire rope altogether.

Figure 7-12 – The correct way to take out a loop in wire rope.

2.6.3 Lubrication

Clean used wire rope at frequent intervals to remove any accumulation of dirt, grit, rust, or other foreign matter. The frequency of cleaning depends on how much the rope is used. However, rope should always be well cleaned before lubrication. The rope can be cleaned with wire brushes, compressed air, or steam.

WARNING

Do not use oxygen in place of compressed air; it becomes very dangerous when it comes in contact with grease or oil.

The purpose is to remove all old lubricant and foreign matter from the valleys between the strands and from the spaces between the outer wires. This gives newly applied lubricant ready entrance into the rope. Wire brushing affords a good opportunity to find any broken wires that may otherwise go unnoticed.

Wire rope is initially lubricated by the manufacturer, but this initial lubrication isn't permanent and the user must make periodic reapplications. Each time a wire rope bends and straightens, the wires in the strands and the strands in the rope slide upon each other. To prevent the rope from wearing out from this sliding action, a film of lubricant is needed between the surfaces in contact. The lubricant also helps prevent corrosion of the wires and deterioration of fiber centers. A rusty wire rope is a liability! With wire rope, just as with any machine or piece of equipment, proper lubrication is essential to smooth, efficient performance.

The lubricant should be a good grade of lubricating oil, free from acids and corrosive substances. It must also be of a consistency that will penetrate to the center of the core, yet heavy enough to remain as a coating on the outer surfaces of the strands. Two good lubricants for this purpose are raw linseed oil and medium graphite grease. Raw linseed oil dries and is not greasy to handle. Graphite grease is highly resistant to saltwater corrosion. Of course, you may obtain and use other commercial lubricants. One of the best is a semi-plastic compound that is thinned by heating before being applied. It penetrates while hot, then cools to a plastic filler, preventing the entrance of water.

One method of applying the lubricant is by using a brush. Remember to apply the coating of fresh lubricant evenly and to work it in well. Another method involves passing the wire rope through a trough or box containing hot lubricant, shown in *Figure 7-13*. In this method, the heated lubricant is placed in the trough, the rope passes over a sheave, through the lubricant, and under a second sheave. Hot oils or greases have very good penetrating qualities. Upon cooling, they have high adhesive and film strength around each wire.

Figure 7-13 – Trough method of lubrication.

As a safety precaution, always wipe off any excess when lubricating wire rope. This is especially important where heavy equipment is involved. Too much lubricant can get on brakes or clutches, causing them to fail. The motion of machinery can throw excess oil onto crane cabs and catwalks, making them unsafe to work on.

2.6.4 Storage

Wire rope should not be stored in places where acid is or has been kept. The slightest trace of acid coming in contact with wire rope damages it at that particular spot. Many times, wire rope that has failed has been found to be acid damaged. The importance of keeping acid or acid fumes away from wire rope must be stressed to all hands.

It is especially important that wire rope be cleaned and lubricated properly before it is placed in storage. Corrosion of wire rope during storage can be virtually eliminated if the lubricant film is applied properly beforehand and if adequate protection is provided from the weather. Bear in mind that rust, corrosion of wires, and deterioration of the fiber core greatly reduce the strength of wire rope. It is not possible to state exactly the loss of strength that results from these effects. It is certainly great enough to require close observance of precautions prescribed for protection against such effects.

2.6.5 Inspection

Inspect wire rope at regular intervals, the same as fiber line. In determining the frequency of inspection, carefully consider the amount of use of the rope and the conditions under which it is used.

During an inspection, examine the rope carefully for fishhooks, kinks, and worn, corroded spots. Usually, breaks in individual wires are concentrated in those portions of the rope that consistently run over the sheaves or bend onto the drum. Abrasion or reverse and sharp bends cause individual wires to break and bend back. These breaks are known as fishhooks. When wires are only slightly worn, but have broken off squarely and stick out all over the rope, the condition is usually caused by overloading or rough handling. Even if the breaks are confined to only one or two strands, the strength of the rope may be seriously reduced. When 4 percent of the total number of wires in the rope have breaks within the length of one lay of the rope, the wire rope is unsafe. Consider a rope unsafe when three broken wires are found in one strand of 6 by 7 rope, six broken wires in one strand of 6 by 19 rope, or nine broken wires in one strand of 6 by 37 rope.

Overloading a rope also reduces its diameter. Failure to lubricate the rope is another cause of reduced diameter, since the fiber core will dry out and eventually collapse or shrink. The surrounding strands are thus deprived of support, and the rope's strength and dependability are correspondingly reduced. Rope with a diameter reduced to less than 75 percent of its original diameter should be removed from service.

A wire rope should also be removed from service when an inspection reveals widespread corrosion and pitting of the wires. Pay particular attention to signs of corrosion and rust in the valleys, the small spaces between the strands. Since such corrosion is usually the result of improper or infrequent lubrication, the internal wires of the rope are then subject to extreme friction and wear. This form of internal, and often invisible, destruction of the wire is one of the most frequent causes of unexpected and sudden failure of wire rope. The best safeguard is to keep the rope well lubricated and to handle and store it properly.

2.7.1 Wire Rope Attachments

Many attachments can be fitted to the ends of wire rope to connect it to other wire ropes, pad eyes, or equipment. The attachment used most often to attach dead ends of wire ropes to pad eyes or like fittings on earthmoving rigs is the wedge socket, shown in *Figure 7-14*. Apply the socket to the bitter end of the wire rope as shown in the figure.

To configure a wedge socket and attach to wire rope, follow the steps listed below:

1. Remove the pin and knock out the wedge.
2. Pass the wire rope up through the socket and lead enough of it back through the socket to allow a minimum of six to nine inches of the bitter end to extend below the socket.
3. Replace the wedge, and haul on the bitter end of the wire rope until the bight closes around the wedge, as shown in *Figure 7-15*. A strain of the standing part will tighten the wedge. You need at least six to nine inches on the dead end, the end of the line that doesn't carry the load.

Figure 7-14 – Parts of a wedge socket.

4. Place one wire rope clip on the dead end to keep it from accidentally slipping back through the wedge socket. The clip should be approximately three inches from the socket. Use one size smaller clip than normal so that the threads on the U-bolt are only long enough to clamp tightly on one strand of wire rope. The other alternative is to use the normal size clip and hop the dead end back as shown in *Figure 7-15*. Never attach the clip to the live end of the wire rope.

The advantage of the wedge socket is that it is easy to remove; just take off the wire clip and drive out the wedge. The disadvantage of the wedge socket is that it reduces the strength of wire rope by about 30 percent. Of course, reduced strength means less safe working load.

Figure 7-15 – Wedge socket attached properly.

To make an eye in the end of a wire rope, use new wire rope clips, like those shown in *Figure 7-16*.The U-shaped part of the clip with the threaded ends is called the U-bolt; the other part is called the saddle. The saddle is stamped with the diameter of the wire rope that the clip will fit. Always place a clip with the U-bolt on the bitter end, not on the standing part of the wire rope. If clips are attached incorrectly, the standing part or live end of the wire rope will be distorted or have mashed spots. An easy way to remember is never saddle a dead horse.

You also need to determine the correct number of clips to use and the correct spacing. Here are two simple formulas Remember D represents the diameter of the wire rope:

Figure 7-16 – Wire rope clips.

- Number of clips = 3 x D + 1
- Spacing between clips = 6 x D

Another type of wire rope clip is the twin-base wire clip, sometimes referred to as the universal or two-clamp, shown in *Figure 7-17*. Since both parts of this clip are shaped to fit the wire rope, correct installation is almost certain. This considerably reduces potential damage to the rope. The twin-base clip also allows for a clean 360° swing with the wrench when the nuts are being tightened. When an eye is made in a wire rope, a metal fitting (called a thimble) is usually placed in the eye, as shown in *Figure 7-16*, to protect the eye against wear. Clipped eyes with thimbles hold approximately 80 percent of the wire rope strength.

After the eye made with clips has been strained, retighten the nuts on the clips. Make occasional checks for tightness or damage to the rope caused by the clips.

Figure 7-17 – Twin-base wire clip.

Test your Knowledge (Select the Correct Response)

3. Which of the following is not part of a wire rope?

   A. Wires
   B. Fibers
   C. Strands
   D. Core

4. **(True or False)** Once a new reel of wire rope has been opened, it may be either coiled or faked down like line.

   A. True
   B. False

5. **(True or False)** Rope that has its diameter reduced to less than 90 percent of its original diameter should be removed from service.

   A. True
   B. False

3.0.0 Block and Tackle

A block, shown in *Figure 7-18*, consists of one or more sheaves fitted in a wood or metal frame supported by a shackle inserted in the strap of the block. A tackle, as shown in *Figure 7-19*, is an assembly of blocks and lines used to gain a ***mechanical advantage*** in lifting and pulling.

In a tackle assembly, the line is ***reeved*** over the sheave(s) of blocks. The two types of tackle systems are simple and compound. A simple tackle system is an assembly of blocks in which a single line is used, as shown in view A of *Figure 7-19*. A compound tackle system is an assembly of blocks in which more than one line is used, as shown in view B of *Figure 7-19*.

Figure 7-18 – Fiber line block.

Figure 7-19 – Types of tackle: simple (view A) and compound (view B).

3.1.0 Tackle Terms

To help avoid confusion in working with tackle, you need a working knowledge of tackle vocabulary. *Figure 7-20* will help you organize the various terms.

A fall is a lie, either a fiber line or a wire rope, reeved through a pair of blocks to form a tackle. The hauling part is the part of the fall leading from one of the blocks upon which the power is exerted. The standing part is the end of the fall, which is attached to one of the beckets. The movable or running block of a tackle is the block attached to the object to be moved. The fixed or standing block is the block attached to a fixed object or support. When a tackle is being used, the movable block moves, and the fixed block remains stationary. The term two-blocked means that both blocks of a tackle are as close together as they will go. You may also hear this term called block-and-block. To overhaul is to lengthen a tackle by pulling the two blocks apart. To round in means to bring the blocks of a tackle toward each other, usually without a load on the tackle; this is the opposite of overhaul.

Figure 7-20 – Parts of a tackle.

Don’t be surprised if your coworkers use a number of different terms for a tackle. For example, line and blocks, purchase, and block and falls are other typical names for tackle.

3.2.0 Block Nomenclature

The block(s) in a tackle assembly change(s) the direction of pull or mechanical advantage, or both. The name and location of the key parts of a fiber line block are shown in *Figure 7-21*.

The frame, or ***shell***, is made of wood or metal and houses the sheaves. The sheave is a round, grooved wheel over which the line runs. Ordinarily, blocks used in your work will have one, two, three, or four sheaves. Blocks can come with more than this number of sheaves; some come with 11 sheaves. The ***cheeks*** are the solid sides of the frame, or shell. The pin is a metal axle on which the sheave turns. It runs from cheek to cheek through the middle of the sheave. The becket is a metal loop formed at one or both ends of a block; the standing part of the line is fastened to this part. The straps hold the block together and support the pin on which the sheaves rotate. The swallow is the opening in the block through which the line passes. The breech is the part of the block opposite the swallow.

Figure 7-21 – Nomenclature of a fiber line block.

3.3.0 Construction of Blocks

Blocks are constructed for use with fiber line or wire rope. Wire rope blocks are heavily constructed and have a large sheave with a deep groove. Fiber line blocks are generally not as heavily constructed as wire rope blocks and have smaller sheaves with shallower wide grooves. Wire rope requires a large sheave to prevent sharp bending. Since fiber line is more flexible and pliable than wire rope, it does not require a sheave as large as the same size of wire rope.

Blocks fitted with one, two, three, or four sheaves are often referred to as single, double, triple, and quadruple blocks, respectively. Blocks are fitted with a number of attachments, the number depending upon their use. Some of the most commonly used fittings are ***hooks***, shackles, eyes, and rings. *Figure 7-22* shows two metal frame, heavy-duty blocks. Block A is designed for manila line, and block B is for wire rope.

Figure 7-22 – Metal frame, heavy-duty blocks.

3.4.0 Ratio of Block Size to Line or Wire Size

The size of fiber line blocks is designated by the length in inches of the shell or cheek. The size of standard wire rope blocks is controlled by the diameter of the rope. The size of nonstandard and special purpose wire rope blocks is found by measuring the diameter of one of its sheaves in inches.

Use care in selecting the proper size line or wire for the block you are using. If a fiber line is reeved onto a tackle whose sheaves are below a certain minimum diameter, the line will be distorted and will soon wear badly. A wire rope too large for a sheave tends to be pinched and damage the sheave. The wire will also be damaged because of too short a radius of the bend. A wire rope too small for a sheave lacks the necessary bearing surface, puts the strain on only a few strands, and shortens the life of the wire.

With fiber line, the length of the block used should be about three times the circumference of the line. An inch or so either way doesn't matter too much; for example, a three inch line may be reeved onto an eight inch block with no ill effects. As a rule, you are more likely to know the block size than the sheave diameter. The sheave diameter should be about twice the size of the circumference of the line used.

Wire rope manufacturers issue tables that give the proper sheave diameters used with the various types and sizes of wire rope they manufacture. In the absence of these, a rough rule of thumb is that the sheave diameter should be about 20 times the diameter of the wire. Remember that with wire rope, diameter rather than circumference is important. Also remember that this rule refers to the diameter of the sheave rather than to the size of the block.

3.5.0 Snatch Blocks and Fairleads

A ***snatch block***, as shown in *Figure 7-22*, is a single sheave block made so that the shell opens on one side at the base of the hook to permit a rope or line to be slipped over a sheave without threading the end of it through the block. Snatch blocks are ordinarily used where it is necessary to change the direction of the pull on a line.

Figure 7-23 – Top dead end snatch blocks.

Figure 7-24 shows a system for moving a heavy object horizontally away from the power source using snatch blocks. This is an ideal way to move objects in limited spaces. Note that the weight is pulled by a single luff tackle, which has a mechanical advantage of three (mechanical advantage is discussed below). Adding snatch blocks to rigging changes the direction of pull but does not affect the mechanical advantage. It is, therefore, wise to select the proper rigging system to use based upon the weight of the object and the type and capacity of the power that is available.

The snatch block used as the last block in the direction of pull to the power source is called the leading block. This block can be placed in any convenient location provided it is within 20 drum widths of the power source. This is required because the ***fairlead*** angle, or ***fleet angle***, cannot exceed 2° from the center line of the drum; therefore, the 20-drum width distance from the power source to the leading block will assure the fairlead angle. If the fairlead angle is not maintained, the line could jump the sheave of the leading block and cause the line on the reel to jump a riding turn.

Figure 7-24 – Moving a heavy object horizontally along floor with limited access using snatch blocks and fairleads.

3.6.0 Mechanical Advantage

The mechanical advantage of a tackle is the term applied to the relationship between the load being lifted and the power required to lift it. If the load and the power required to lift it are the same, the mechanical advantage is one. If a load of 50 pounds requires only 10 pounds to lift it, then you have a mechanical advantage of five to one, or five units of weight are lifted for each unit of power applied.

The easiest way to determine the mechanical advantage of a tackle is by counting the number of parts of the falls at the running block. If there are two parts, the mechanical advantage is two times the power applied, disregarding friction. A gun tackle, for instance, has a mechanical advantage of two. Lifting a 200 pound load with a gun tackle requires 100 pounds of power, disregarding friction.

To determine the amount of power required to lift a given load by means of a tackle, determine the weight of the load to be lifted and divide that by the mechanical advantage. For example, if it is necessary to lift a 600 pound load by means of a single luff tackle, first determine the mechanical advantage gained by the tackle. By counting the parts of the falls at the movable block, you determine a mechanical advantage of three. By dividing the weight to be lifted, 600 pounds, by the mechanical advantage in this tackle, three, we find that 200 pounds of power is required to lift a weight of 600 pounds using a single luff tackle.

Remember, a certain amount of the force applied to a tackle is lost through friction. Friction develops in a tackle from the lines rubbing against each other or against the shell of a block. You must add an adequate allowance for the loss from friction. Roughly 10 percent of the load must be allowed for each sheave in the tackle.

3.7.0 Types of Tackle

Tackles are designated in two ways: first, according to the number of sheaves in the blocks used to make the tackle, such as single whip or twofold purchase; and second, by the purpose for which the tackle is used, such as yard tackles or stay tackles. In this section, we'll discuss some of the different types of tackle in common use; single whip, runner, gun tackle, single luff, twofold purchase, double luff, and threefold purchase. The purpose of the letters and arrows in *Figures 7-25* through *7-31* is to indicate the sequence and direction in which the standing part of the fall is led in reeving. You may want to refer to these illustrations when we discuss reeving of blocks in the next sections.

Figure 7-25 – Single-whip and runner tackle.

A single whip tackle consists of one single sheave block or tail block fixed to a support with a rope passing over the sheave as shown in *Figure 7-25*. It has a mechanical advantage of one. Lifting a 100 pound load requires a pull of 100 pounds plus an allowance for friction.

A runner, as shown in *Figure 7-25*, is a single sheave movable block that is free to move along the line on which it is reeved. It has a mechanical advantage of two.

A gun tackle is made up of two single sheave blocks as shown in *Figure 7-26*. This tackle got its name in the old days because it was used to haul muzzle-loading guns back into the battery after they had been fired and reloaded. A gun tackle has a mechanical advantage of two. To lift a 200 pound load with a gun tackle requires 100 pounds of power, disregarding friction.

Figure 7-26 – Gun tackle.

By inverting any tackle, you always gain a mechanical advantage of one because the number of parts at the movable block increases. By inverting a gun tackle, for example, you gain a mechanical advantage of three, as shown in *Figure 7-27*. When a tackle is inverted, the direction of pull is difficult. You can easily overcome this by adding a snatch block, which changes the direction of the pull but does not increase the mechanical advantage.

Figure 7-27 – Inverted gun tackle.

A single-luff tackle consists of a double and single block, as shown in *Figure 7-28*, and the double-luff tackle has one triple and one double block, as shown in *Figure 7-29*. The mechanical advantage of the single is three; the mechanical advantage of the double is five.

Figure 7-28 – Single-luff tackle.

Figure 7-29 – Double-luff tackle.

A twofold purchase consists of two double blocks, as shown in *Figure 7-30*, whereas a threefold purchase consists of two triple blocks, as shown in *Figure 7-31*. The mechanical advantage of the twofold purchase is four; that of the threefold is six.

Figure 7-30 – Twofold purchase.

Figure 7-31 – Threefold purchase.

3.8.0 Reeving Tackle

In reeving a simple tackle, lay the blocks a few feet apart. Place the blocks down with the sheaves at right angles to each other and the becket ends pointing toward each other.

To begin reeving, lead the standing part of the falls through one sheave of the block that has the greatest number of sheaves. If both blocks have the same number of sheaves, begin at the block fitted with the becket. Then pass the standing part around the sheaves from one block to the other, making sure no lines are crossed, until all sheaves have a line passing over them. Now, secure the standing part of the falls at the becket of the block containing the least number of sheaves, using a becket hitch for a temporary securing or an eye splice for a permanent securing.

With blocks of more than two sheaves, lead the standing part of the falls through the sheave nearest the center of the block. This method places the strain on the center of the block and prevents the block from toppling and the lines from being cut by rubbing against the edges of the block.

Falls are generally reeved through eight or ten inch wood or metal blocks in such a manner as to have the lower block at right angles to the upper block. Two three-sheave blocks are the usual arrangement, and the method of reeving these is shown in *Figure 7-32*. The hauling part must go through the middle sheave of the upper block, or the block will tilt to the side and the falls jam when a strain is taken.

Figure 7-32 – Reeving a threefold purchase.

If a three and two-sheave block rig is used, the method of reeving is about the same as shown in *Figure 7-33,* but, in this case, the becket for the dead end must be on the lower, rather than the upper block.

Naturally, you must reeve the blocks before you splice in the becket thimble, or you will have to reeve the entire fall through from the opposite end.

3.9.0 Safe Working Load of Tackle

You know that the force applied at the hauling part of a tackle is multiplied as many times as there are parts of the fall on the movable block. Also, you must allow for friction, which adds roughly 10 percent to the weight to be lifted for every sheave in the system. If you are lifting a weight of 100 pounds with a tackle containing five sheaves, you must add 10 percent times five, or 50 percent, of 100 pounds to the weight in your calculations. In other words, you determine that this tackle is going to lift 150 pounds instead of 100 pounds.

Figure 7-33 – Reeving a double-luff tackle.

Disregarding friction, the safe working load of a tackle should be equal to the safe working load of the line or wire used multiplied by the number of parts of the fall on the movable block. To make the necessary allowance for friction, multiply this result by 10, and then divide what you get by 10 plus the number of sheaves in the system.

Suppose you have a threefold purchase with a mechanical advantage of 6, reeved with a line that has a safe working load of two tons. Disregarding friction, 6 times 2, or 12 tons, should be the safe working load of this setup. To make the necessary allowance for friction, multiply 12 by 10, this gives you 120. This you divide by 10 plus 6, the number of sheaves in a threefold purchase, or 16. The answer is 7 1/2 tons safe working load.

3.9.1 Lifting a Given Weight

To find the size of fiber line required to lift a given load, use this formula:

$$C = \sqrt{15 \ x \ P}$$

C in the formula is the circumference, in inches, of the line that is safe to use. The number 15 is the conversion factor. P is the weight of the given load expressed in tons. The radical sign over 15 x P indicates you are to find the square root of that product.

To square a number means to multiply that number by itself. Finding the square root of a number means finding the number that, multiplied by itself, gives the number whose square root you are seeking. Most pocket calculators today have a square root function. Now, let's determine what size fiber line you need to hoist a 5 ton load. First, circumference equals 15 times five, or:

$$C = 15 \text{ x } 5, \text{ or } 75$$

Next the number that multiplied by itself comes nearest to 75 is 8.6. A fiber line 8 1/2 inches in circumference will do the job.

The formula for finding the size of wire rope required to lift a given load is:

$$C = 2.5 \times P$$

C is the circumference, in inches, of the rope that is safe to use. The number 2.5 is the conversion factor. *P* is the weight of the given load expressed in tons. You work this formula in the same manner explained above for fiber line. One point you should be careful not to overlook is that these formulas call for the circumference of the wire. You are used to talking about wire rope in terms of its diameter, so remember that circumference is about three times the diameter, roughly speaking. You can also determine circumference by the following formula, which is more accurate than the rule of thumb:

$$C = D \times \pi$$

C is the circumference in inches; D is the diameter in inches. In using this formula, remember that π equals approximately 3.14.

3.9.2 Size of Line to Use in a Tackle

To find the size of line to use in a tackle for a given load, add one-tenth, 10 percent for friction, of its value to the weight to be hoisted for every sheave in the system. Divide the result you get by the number of parts of the fall at the movable block, and use this result as P in the formula.

$$C = \sqrt{15\ x\ P}$$

For example, let's say you are trying to find the size of fiber line to reeve in a threefold block to lift 10 tons. There are six sheaves in a threefold block. Ten tons plus one tenth for each of the six sheaves, a total of six tons, gives you a theoretical weight of 16 tons to be lifted. Divide 16 tons by six, the number of parts on the movable block in a threefold block, and you get about 2 2/3. Using this as P in the formula you get:

$$C = \sqrt{15\ x\ 2\ \ 2/3}$$

$$= \sqrt{40}$$

or about 6.3

The square root of 40 is about 6.3, so it will take a line of about 6 1/2 inches in this purchase to hoist 10 tons safely. As you seldom find three-sheave blocks that will take a line as large as 6 1/2 inches, you will probably have to rig two threefold blocks with a continuous fall, as shown in *Figure 7-34*. Each of these will have half of the load. To find the size of the line to use, calculate what size fiber line in a threefold block will lift five tons. It works out to about 4 1/2 inches.

Figure 7-34 – Rigging two tackles with continuous fall.

3.10.0 Tackle Safety Precautions

In hoisting and moving heavy objects with blocks and tackle, stress safety for people and materials.

Always check the condition of blocks and sheaves to make sure they are in safe working order before using them on a job. See that the blocks are properly greased. Also, make sure that the line and sheave are the right size for the job.

Remember that you must not use sheaves or drums that have become worn, chipped, or corrugated because they will damage the line. Always find out whether you have enough mechanical advantage in the amount of blocks to make the load as easy to handle as possible.

Sheaves and blocks designed for use with fiber line must not be used for wire rope since they are not strong enough for that service, and the wire rope does not fit the sheave grooves. Also, sheaves and blocks built for wire rope should never be used for fiber line.

3.11.0 Hooks and Shackles

Hooks and shackles are handy for hauling or lifting loads without tying them directly to the object with a line or wire rope. They can be attached to wire rope, fiber line, or blocks. Shackles should be used for loads too heavy for hooks to handle.

Hooks should be inspected at the beginning of each workday and before lifting a full rated load. *Figure 7-35* shows where to inspect a hook for wear and strain. Be especially careful during the inspection to look for cracks in the saddle section and at the neck of the hook.

Figure 7-35 – Hook inspection.

When the load is too heavy for you to use a hook, use a shackle. Shackles, like hooks, should be inspected on a daily routine and before lifting heavy loads.

Figure 7-36 shows the area to look for wear.

Figure 7-36 – Shackle inspection.

Figure 7-37 – Packing a shackle with washers.

You should never replace the shackle pin with a bolt. Never use as shackle with a bent pin, and never allow the shackle to be pulled at an angle; doing so will reduce its carrying capacity. Packing the pin with washers centralizes the shackle as shown in *Figure 7-37*.

If you need a hook or shackle for a job, always get it from Alpha Company. This way, you will know that it has been load tested.

Mousing is a technique often used to close the open section of a hook to keep slings, straps, and so on, from slipping off the hook as shown in *Figure 7-38*. To some extent, it also helps prevent straightening of the hook. Hooks may be moused with rope yarn, seizing wire, or a shackle. When using rope yarn or wire, make 8 to 10 wraps around both sides of the hook. To finish off, make several turns with the yarn or wire around the sides of the mousing, and then tie the ends securely as shown in *Figure 7-38*.

Figure 7-38 – Mousing.

Shackles are moused when there is danger of the shackle pin working loose and coming out because of vibration. To mouse a shackle, simply take several turns with seizing wire through the eye of the pin and around the bow of the shackle. *Figure 7-38* shows what a properly moused shackle looks like.

Test your Knowledge (Select the Correct Response)

6. How many types of tackle systems exist?

   A. Two
   B. Three
   C. Four
   D. Five

7. When using fiber line, the length of the block should be about how many times the circumference of the line?

   A. Two
   B. Three
   C. Four
   D. Five

8. What are the components of a single luff tackle?

   A. One triple and one double block
   B. Two double and one single block
   C. One double and one single block
   D. Two double blocks

4.0.0 HOISTING

Lifting any load safely takes two personnel, an equipment operator and a signalman. In the following paragraphs, we will discuss the importance of the signalman and a few of the safety rules all hands engaged in hooking on must observe.

4.1.0 Signalman

One person and one person only should be designated as the official signalman for the operator of a piece of hoisting equipment, and both the signalman and the operator must be thoroughly familiar with the standard hand signals. When possible, the signalman should wear some distinctive article of dress, such as a bright-colored helmet. The signalman must maintain a position from which he or she can see the load and the crew working on it and the operator can see him or her.

Figure 7-39 shows the standard hand signals for hoisting equipment. Some of the signals shown apply only to mobile equipment; others to equipment with a boom that can be raised, lowered, and swung in a circle. The signalman uses two-arm hoist and lower signals when he or she desires to control the speed of hoisting or lowering. The one-arm hoist or lower signal allows the operator to raise or lower the load. To dog off the load and boom means to set the brakes so as to lock both the hoisting mechanism and the boom hoist mechanism. The signal is given when circumstances require that the load be left hanging motionless.

Figure 7-39 – Hand signals.

With the exception of the emergency stop signal, which may be given by anyone who sees a necessity for it, and which the operator must obey instantly, only the official signalman gives the signals. The signalman is responsible for making sure that members of the crew remove their hands from slings, hooks, and loads before giving a signal. The signalman should also make sure that all persons are clear of bights and snatch block lines.

4.2.0 Attaching a Load

The most common way of attaching a load to a lifting hook is to put a sling around the load and hang the sling on the hook as shown in *Figure 7-40*.

Figure 7-40 – Ways of hitching on a sling.

A sling can be made of line, wire, or wire rope with an eye in each end, also called a strap, or an endless sling, shown in *Figure 7-41*. When a sling is passed through its own bight or eye, or shackled or hooked to its own standing part, so that it tightens around the load like a lasso when the load is lifted, the sling is said to be choked, or it may be called a choker, shown in *Figures 7-40* and *7-41*. A two-legged sling that supports the load at two points is called a bridle, shown in *Figure 7-42.*

Figure 7-41 – Ways of hitching on straps.

Figure 7-42 – Bridles.

4.3.1 Safety Rules

The following safety rules must be given to all hands engaged in hooking on. They must be strictly observed.

- The person in charge of hooking on must know the safe working load of the rig and the weight of every load to be hoisted. The hoisting of any load heavier than the safe working load of the rig is absolutely prohibited.
- When a cylindrical metal object, such as a length of pipe, a gas cylinder, or the like, is hoisted in a choker bridle, give each leg of the bridle a round turn around the load before hooking or shackling it to its own part or have a spreader bar placed between the legs. The purpose of this is to ensure that the legs of the bridle will not slide together along the load, upsetting the balance and possibly dumping the load.
- The point of strain on a hook must never be at or near the point of the hook.
- Before the hoist signal is given, the person in charge must be sure that the load will balance evenly in the sling.
- Before the hoist signal is given, the person in charge should be sure that the lead of the whip or falls is vertical. If it is not, the load will take a swing as it leaves the deck or ground.
- As the load leaves the deck or ground, the person in charge must watch carefully for kinked or fouled falls or slings. If any are observed, the load must be lowered at once for clearing.

- Use tag lines to guide and steady a load when there is a possibility that the load might get out of control.
- Before any load is hoisted, inspect it carefully for loose parts or objects that might drop as the load goes up.
- Clear all personnel from and keep them out of any area that is under a suspended load, or over which a suspended load may pass.
- Never walk or run under a suspended load.
- Do not place or leave loads at any point closer than four feet eight inches from the nearest rail of a railroad track or crane truck, or in any position where they would impede or prevent access to fire-fighting equipment.
- When materials are being loaded or unloaded from any vehicle by crane, the vehicle operators and all other persons, except the rigging crew, should stand clear.
- When materials are placed in work or storage areas, provide dunnage or shoring, as necessary, to prevent tipping of the load or shifting of the materials.
- All crew members must stand clear of loads that tend to spread out when landed.
- When slings are being heaved out from under a load, all crew members must stand clear to avoid a backlash, and to avoid a toppling or a tip of the load, which might be caused by fouling of a sling.

4.4.1 Shear Legs

The shear legs are formed by crossing two timbers, poles, planks, pipes, or steel bars and lashing or bolting them together near the top. A sling is suspended from the lashed intersection and used as a means of supporting the load tackle system, as shown in *Figure 7-43*. In addition to the name shear legs, this rig is often simply called a shears. It has also been called an A-frame.

The shear legs are used to lift heavy machinery and other bulky objects. They may also be used as end supports of a cableway and highline. The fact that the shears can be quickly assembled and erected is a major reason why they are used in field work.

Figure 7-43 – Shear legs.

A shears requires only two guy lines and can be used for working at a forward angle. The forward guy does not have much strain imposed on it during hoisting. This guy is used primarily as an aid in adjusting the drift of the shears and in keeping the top of the rig steady in hoisting or placing a load. The after guy is a very important part of the shears' rigging, as it is under considerable strain when hoisting. It should be designed for strength equal to one-half the load to be lifted. The same principles for thrust on the spars or poles apply, the thrust increases drastically as the shear legs go off the perpendicular.

The following are the steps for rigging the shears:

- Place your two spars on the ground parallel to each other and with their butt ends even.
- Put a large block of wood under the tops of the legs just below the point of lashing, and place a small block of wood between the tops at the same point to facilitate handling of the lashing.
- Separate the poles a distance equal to about one-third the diameter of one pole.
- As lashing material, use 18 or 21 thread small stuff. In applying the lashing, first make a clove hitch around one of the legs.
- Take about eight or nine turns around both legs above the hitch, working towards the top of the legs. Remember to wrap the turns tightly so that the finished lashing will be smooth and free of kinks.
- To apply the frapping, also known as tight lashings, make two or three turns around the lashing between the legs.
- With a clove hitch, secure the end of the line to the other leg just below the lashing as shown in *Figure 7-43*.
- Cross the legs of the shears at the top, and separate the butt ends of the two legs so that the spread between them is equal to one-half the height of the shears.
- Dig shallow holes, about one foot (30 cm) deep, at the butt end of each leg. The butts of the legs should be placed in these holes in erecting the shears. Placing the legs in the holes will keep them from kicking out in operations where the shears are at an angle other than vertical.
- Form the sling for the hoisting falls. To do this, take a short length of line, pass it a sufficient number of times over the cross at the top of the shears, and tie the ends together.
- Reeve a set of blocks and place the hook of the upper block through the sling, and secure the hook by mousing the open section of the hook with rope yarn to keep it from slipping off the sling.
- Fasten a snatch block to the lower part of one of the legs, as indicated in *Figure 7-43*.
- Secure the guys, one forward guy and one after guy, next to the top of the shears. Secure the forward guy to the rear leg and the after guy to the front leg using a clove hitch in both instances. If you need to move the load horizontally by moving the head of the shears, you must rig a tackle in the after guy near its anchorage.

4.5.0 Tripods

A tripod consists of three legs of equal length that are lashed together at the top as shown in *Figure 7-44*. The legs are generally made of timber poles or pipes.

Materials used for lashing include fiber line, wire rope, and chain. Metal rings joined with short chain sections are also available for insertion over the top of the tripod legs.

Compared to other hoisting devices, the tripod has a distinct disadvantage: it is limited to hoisting loads only vertically. Its use will be limited primarily to jobs that involve hoisting over wells, mine shafts, or other such excavations. A major advantage of the tripod is its great stability. In addition, it requires no guys or anchorages, and its load capacity is approximately one-third greater than shears made of the same size timbers. *Table 7-1* gives the load-carrying capacities of shear legs and tripods for various pole sizes.

Figure 7-44 – Tripod.

Table 7-1 – Load Carrying Capacities of Shear Legs and Tripods

Pole Size (Inches)	Length (Feet)	Working Capacity (Tons) Shear Legs (2) Poles	Working Capacity (Tons) Tripods (3) Poles
6 x 6	20	8	13
	25	5	7
	30	3	5
8 x 8	25	12	18
	30	8	13
	40	5	7
	50	3	5
10 x 10	20	35	52
	25	26	39
	30	17	26
	40	10	15
	50	7	10
12 x 12	30	35	52
	40	21	31
	50	14	21
	60	10	15

4.5.1 Rigging Tripods

The strength of a tripod depends largely on the strength of the material used for lashing, as well as the amount of lashing used. The following procedure for lashing applies to a line three inches in circumference or smaller. For extra heavy loads, use more turns than specified in the procedure given her. For light loads, use fewer turns than specified here.

As the first step in the procedure, take three spars of equal length and place a mark near the top of each to indicate the center of the lashing. Now, lay two of the spars parallel with their tops resting on a skid or block. Place the third spar between the two, with the butt end resting on a skid. Position the spars so that the lashing marks on all three spars are in line. Leave an interval between the spars equal to about one-half the diameter of the spars. This will keep the lashing from being drawn too tightly when you erect the tripod.

With the three inch line, make a clove hitch around one of the outside spars; put it about four inches above the lashing mark. Then make eight or nine turns with the line around all three spars as shown in view A of *Figure 7-45*. In making the turns, remember to maintain the proper amount of space between the spars.

Figure 7-45 – Lashings for a tripod.

Now, make one or two close frapping turns around the lashing between each pair of spars. Do not draw the turns too tightly. Finally, secure the end of the line with a clove hitch on the center spar just above the lashing; as shown in view A of *Figure 7-45*.

There is another method of lashing a tripod that you may find preferable to the method just given. You may use it in lashing slender poles up to 20 feet in length, or when some means other than hand power is available for erection.

First, place the three spars parallel to each other, leaving an interval between them slightly greater than twice the diameter of the line to be used. Rest the top of each pole on a skid so that the end projects about two feet over the skid. Then line up the butts of the three spars, as indicated in view B of *Figure 7-45*.

Next, make a clove hitch on one outside leg at the bottom of the position the lashing will occupy, which is about two feet from the end. Now, proceed to weave the line over the middle leg, under and around the other outside leg, under the middle leg, over and around the first leg, and so forth, until completing about eight or nine turns. Finish the lashing by forming a clove hitch on the other outside leg as shown in view B of *Figure 7-45*.

4.6.1 Erecting Tripods

In the final position of an erected tripod, it is important that the legs be spread an equal distance apart. The spread between legs must be no more than two-thirds or less than one-half the length of the leg. Small tripods, or those lashed according to the first procedure given in the preceding section, may be raised by hand. The following are the main steps:

- Raise the top ends of the three legs about 4 feet, keeping the butt ends of the legs on the ground.
- Cross the tops of the two outer legs, and position the top of the third or center leg so that it rests on top of the cross.
- You can readily attach a sling for the hoisting tackle by first passing the sling over the center leg, and then around the two outer legs at the cross. Place the hook of the upper block of a tackle on the sling, and secure the hook by mousing.
- You can now complete the raising operation. Raising an ordinary tripod, requires a crew of about eight. As the tripod is being lifted, spread the legs so that when it is in the upright position, the legs will be spread the proper distance apart.
- After getting the tripod in its final position, lash the legs near the bottom with line or chain to keep them from shifting, as shown in *Figure 7-44*.
- Where desirable, you can lash a leading block for the hauling part of the tackle to one of the tripod legs, as shown in *Figure 7-44*.

In erecting a large tripod you may need a small ***gin pole*** to aid in raising the tripod into position. The following are the steps in that procedure:

- To erect a tripod lashed according to the first procedure described in the preceding section, first raise the tops of the legs far enough from the ground to permit spreading them apart.
- Use guys or tag lines to help hold the legs steady as you raise them.
- With the legs clear of the ground, cross the two outer legs and place the center leg so that it rests on top of the cross.
- Attach the sling for the hoisting tackle. Here, as with a small tripod, simply pass the sling over the center leg and then around the two outer legs at the cross.

Test Your Knowledge (Select the Correct Response)

9. What two individuals are responsible for making a safe lift or hoist?

   A. Equipment operator and division chief
   B. Equipment operator and site supervisor
   C. Signalman and equipment operator
   D. Signalman and division chief

10. **(True or False)** A shears requires a minimum of three guy lines.

   A. True
   B. False

11. **(True or False)** A tripod is limited to hoisting only vertical loads.

A. True
B. False

5.0.0 SCAFFOLDING

As the working level of a structure rises above the reach of crew members on the ground or deck, temporary elevated platforms, called scaffolding, are erected to support the crew members, their tools, and materials.

There are two types of scaffolding in use today, wood and prefabricated. The wood types include the swinging scaffold, which is suspended from above, and the pole scaffold, which is supported on the ground or deck. The prefabricated type is made of metal and put together in sections, as needed.

5.1.0 Swinging Scaffold Construction

The simplest type of a swinging scaffold consists of an unspliced plank made from 2 x 8 inch (minimum) lumber. Place hangers between six and 18 inches from the ends of the plank. Ensure the span between hangers does not exceed 10 feet. Make sure also to secure the hangers to the plank to stop them from slipping off. *Figure 7-46* shows the construction of a hanger with a ***guardrail***. The guardrail should be made of 2 x 4 inch material between 36 and 42 inches high. Construct a midrail, if required, of 1 x 4 inch lumber.

Figure 7-1 – Typical hanger to use with plank scaffold.

Suspend swing scaffolds by wire or fiber line secured to the outrigger beams. Suspension ropes require a minimum safety factor of six. The blocks for fiber ropes should be the standard six inch size consisting of at least one double block and one single block. The sheaves of all blocks should fit the size of rope used.

Space the outrigger beams no more than the hanger spacing and construct them of no less than 2 x 10 inch lumber. The beam should not extend more than six feet beyond the face of the building. The inboard side should be nine feet beyond the edge of the building and securely fastened to the building.

Figure 7-47 shows a swinging scaffold you can use for heavy work with block and tackle.

Figure 7-47 – Swinging scaffold.

5.2.1 Pole Scaffold Construction

The poles on a job-built pole scaffold should not exceed 60 feet in height. If higher poles are required, an engineer must design the scaffolding.

- All poles must be setup perfectly plumb.
- The lower ends of poles must not bear directly on a natural earth surface. If the surface is earth, a board footing two inches thick and six to 12 inches wide, depending on the softness of the earth, must be placed under the poles.
- If poles must be spliced, splice plates must not be less than four feet long, not less than the width of the pole wide, and each pair of plates must have a combined thickness not less than the thickness of the pole. Adjacent poles must not be spliced at the same level.
- A ledger must be long enough to extend over two pole spaces, and it must overlap the poles at the ends by at least four inches. Ledgers must be spliced by overlapping and nailing at poles, never between poles. If platform planks are raised as work progresses upward, the ledgers and logs on which the planks previously rested must be left in place to brace and stiffen the poles. For a heavy-duty scaffold, ledgers must be supported by cleats, nailed or bolted to the poles, as well as by being nailed themselves to the poles.
- A single log must be set with the longer section dimension vertical, and logs must be long enough to overlap the poles by at least three inches. They should be both face nailed to the poles and toe nailed to the ledgers. When the inner end of the log butts against the wall, as it does in a single-pole scaffold, it must be supported by a 2 x 6 inch bearing block, not less than 12 inches long, notched out the width of the log and securely nailed to the wall. The inner end of the log

should be nailed to both the bearing block and the wall. If the inner end of a log is located in a window opening, it must be supported on a stout plank nailed across the opening. If the inner end of a log is nailed to a building stud, it must be supported on a cleat, the same thickness as the log, and nailed to the stud.

- A platform plank must never be less than two inches thick. Edges of planks should be close enough together to prevent tools or materials from falling through the opening. A ***toe board*** on each side of scaffold will prevent tools and materials from being accidently kicked over the side. A plank must be long enough to exceed over three logs, with an overlap of at least six inches, but not more than 12 inches.

5.3.0 Prefabricated Scaffold Erection

Several types of scaffolding are available for simple and rapid erection; one of these types is shown in *Figure 7-48*. The scaffold uprights are braced with diagonal members, and the working level covered with a platform of planks. All bracing must form triangles and the base of each column requires adequate footing plates for bearing area on the ground or deck. The steel scaffolding is usually erected by placing the two uprights on the ground or deck and inserting the diagonal members. The diagonal members have end fittings that permit rapid locking in position.

Figure 7-48 – Assembled prefabricated independent-pole scaffolding.

In tiered scaffolding, shown in *Figure 7-49*, the first tier is set on steel bases on the ground, and a second tier is placed in the same manner on the first tier with the bottom of each upright locked to the top of the lower tier. A third and fourth upright can be placed on the ground level and locked to the first set with diagonal bracing. The scaffolding can be built as high as desired, but high scaffolding should be tied to the main structure. Where necessary, scaffolding can be mounted on casters for easy movement.

Figure 7-49 – Tiered scaffolding.

Prefabricated scaffolding comes in three categories: light, medium, and heavy duty. Light duty has nominal two inch outside diameter steel tubing bearers. Posts are spaced no more than six to ten feet apart. Light-duty scaffolding must be able to support 25 pounds per square foot loads.

Medium duty scaffolding normally uses two inch outside diameter steel tubing bearers. Posts should be spaced no more than five to eight feet apart. If 2 1/2 inch outside diameter steel tubing bearers are used, posts are to be spaced six to eight feet apart. Medium duty scaffolding must be able to support 50 pounds per square foot loads.

Heavy duty scaffolding should have bearers of 2 1/2 inch outside diameter steel tubing with the posts spaced not mare than six feet to six feet six inches apart. This scaffolding must be able to support 75 pounds per square foot loads.

To find the load per square foot of a pile of materials on a platform, divide the total weight of the pile by the number of square feet of platform it covers.

5.4.0 Bracket Scaffolding

The bracket, or carpenter's scaffold, shown in *Figure 7-50*, is built of a triangular wood frame with not less than 2 x 3 inch lumber or metal of equivalent strength. Each bracket is attached to the structure in one of four ways: (1) a bolt, at least 5/8 inch, that extends through to the inside of the building wall; (2) a metal stud attachment device; (3) welded to a steel tank; or (4) hooked over a secured supporting member.

The brackets must be spaced no more than eight feet apart. No more than two persons should be on any eight foot section at any one time. Tools and materials used on the scaffold should not exceed 75 pounds.

Figure 7-50 – Carpenter's portable bracket for scaffolding.

The platform is built of at least two 2 x 10 inch nominal size planks. The planks should extend between six and twelve inches beyond each support.

5.5.1 Scaffold Safety

When working on scaffolding or tending others on scaffolding, observe all safety precautions. Builder petty officers must not only observe the safety precautions themselves, but must also issue them to their crew and ensure that the crew observes them. The following is a listing of the minimum safety precautions that must be followed.

- Always keep scaffolds clear of accumulations of tools, equipment, materials, and rubbish.
- Do not use a scaffold for the storage of materials in excess of those currently required for the job.
- Tools not in immediate use on scaffolds must be stored in containers to prevent tools left adrift from being knocked off. Tool containers must be lashed or otherwise secured to the scaffolds.
- Throwing objects to or dropping them from scaffolds is absolutely prohibited. Always use hand lines for raising or lowering objects that you cannot pass hand to hand.
- A standard guardrail and toe board should be provided on the open side of all platforms five feet or more above ground; otherwise, safety belts tied off to safety lines must be used.
- No person should remain on a rolling scaffold while it is being moved.

- Maintain all scaffolds in safe condition, and do not alter or disturb them while in use. Personnel must not use damaged or weakened scaffolds.
- Access to scaffolds must be by standard stairs or by fixed ladders only.
- When scaffolding is being dismantled, clean it and make it ready for storage or use. Never store scaffolding that is not ready for use.

Summary

Two materials can be used for rigging; fiber line and wire rope. Each of these materials has its uses, which factor in the breaking strength of the material. Care of fiber line and wire rope differs; it is important to understand these differences so you can properly care for them.

Block and tackle units increase the mechanical advantage of force used to hoist a load. The various components in use and how they are reeved determine the operating characteristics of block and tackle units. Calculating of the size and number of components to use is critical in maintaining the safety of the crew and the load being worked with.

Shear legs and tripods can be used for hoisting heavy loads. It is important for the well-being of the crew that there is a good understand of hand signals used in lifting loads, and safety rules of lifting.

Scaffolding is an important tool used when work rises above a level that can be reached by the crew from the ground. Scaffolding can be built from wood, or assembled from prefabricated metal scaffolding. In either case, the Builder chief petty officer must ensure that crewmembers follow safety precautions whenever they work on scaffolding.

Review Questions (Select the Correct Response)

1. What kind of fiber is best for making fiber line?

   A. Hemp
   B. Sisal
   C. Manila
   D. Cotton

2. Number one manila rope is what color?

   A. White
   B. Light brown
   C. Dark brown
   D. Black

3. Which of the following types of line is known for its strength, light weight, and flexibility?

   A. Nylon
   B. Hemp
   C. Manila
   D. Sisal

4. **(True or False)** In line fabrication, opposite twisting of fibers prevents moisture from entering the line and keeps the fibers from unlaying under a load.

   A. True
   B. False

5. What type of line is composed of four strands twisted together in a right-hand direction around a core?

   A. Hawser laid
   B. Shroud laid
   C. Cable laid
   D. Plain laid

6. Which of the following formulas should you use to find the approximate breaking strength (BS) of manila line?

   A. $BS = C^2 \times 900$
   B. $BS = C^2 \times 2{,}400$
   C. $BS = D^2 \times 900$
   D. $BS = D^2 \times 2{,}400$

7. For which of the following reasons is a wide margin between the safe working load and the breaking strength of fiber line desirable?

   A. To allow for the strain imposed only by jerky movements
   B. To allow for the strain imposed only when the line is bent over sheaves
   C. To allow for the strain imposed by jerky movements and when the line is bent over the sheaves
   D. To allow for the differences in the various types of fibers used

8. The safe working load (SWL) for a new fiber line can normally be increased by what percentage?

   A. 10 percent
   B. 20 percent
   C. 30 percent
   D. 40 percent

9. A used fiber line in good condition has what safety factor figured in?

   A. Eight
   B. Six
   C. Four
   D. Three

10. Of the following cleaners, which is the only one you should use to clean a muddy fiber line?

   A. Water
   B. Kerosene
   C. Linseed oil
   D. Liquid soap

11. Which of the following wire rope sizes is the most flexible?

   A. 6 x 14
   B. 6 x 19
   C. 6 x 21
   D. 6 x 37

12. The size of wire rope is designated by what characteristic?

   A. Circumference
   B. Diameter
   C. Weight per running foot
   D. Number of wires per strand

13. To measure the diameter of a wire rope, you should use which of the following methods?

    A. Measure in one place near the middle
    B. Measure in two places near the middle, 10 feet apart; then average the results
    C. Measure in three places, 3 feet apart; then average the results
    D. Measure in three places, 5 feet apart; then average the results

14. The bitter end of a wire rope should extend what minimum distance below a wedge socket?

    A. six inches
    B. four inches
    C. three inches
    D. two inches

15. What type of tackle system is an assembly of blocks in which more than one line is used?

    A. Compound
    B. Double whip
    C. Simple
    D. Tri-block

16. In a block and tackle assembly, the standing end of a line is attached to which of the following components?

    A. Breech
    B. Becket
    C. Sheave
    D. Strap

17. Why are blocks used in a tackle assembly?

    A. To change direction of pull only
    B. To provide a mechanical advantage only
    C. To change direction of pull and provide a mechanical advantage
    D. To provide an alternate means of using line

18. In a block and tackle, the opening in the block through which the line passes is known by which of the following terms?

    A. Swallow
    B. Cheek
    C. Breach
    D. Frame

19. In the absence of a reference table, a rule of thumb for determining the diameter of a wire rope sheave is that the sheave should have what approximate diameter?

    A. Ten times the diameter of the wire
    B. Twenty times the diameter of the wire
    C. Three times the circumference of the wire
    D. Four times the circumference of the wire

20. What type of block can be installed at any point on a wire rope or fiber line without having to thread the rope or line through the block?

    A. Swivel fairlead
    B. Swivel shackle
    C. Snatch
    D. Quick latch

21. When a snatch block is used in a rigging system, it provides what maximum number of mechanical advantages, if any?

    A. One
    B. Two
    C. Three
    D. None

22. What is the simplest method of determining the mechanical advantage of tackle?

    A. Count the sheaves at the running block
    B. Determine the diameter of the sheaves
    C. Count the standing parts at the stationary block
    D. Count the number of parts of the fall at the running block

23. Hooks and shackles should be inspected at what minimum interval?

    A. Daily
    B. Twice a week
    C. Weekly
    D. Monthly

24. When hoisting, what number of signalman should be assigned?

    A. One
    B. Two
    C. Three
    D. Four

25. When necessary, the EMERGENCY STOP signal should be given by which of the following individuals?

    A. The signalman only
    B. The crew leader only
    C. The project safety officer only
    D. Anyone who sees an emergency

26. What advantage does a tripod have over shear legs?

    A. It is more stable only
    B. It requires no guy lines only
    C. It has greater load capacity only
    D. All of the above

27. Tripod legs should be spread no more than what distance?

    A. One third the length of the legs
    B. One half the length of the legs
    C. Two thirds the length of the legs
    D. Three quarters the length of the legs

28. On a swinging scaffold, what are the minimum required sizes for (a) planks and (b) guard rails?

    A. (a) 2 x 8 inches (b) 1 x 4 inches
    B. (a) 2 x 4 inches (b) 2 x 4 inches
    C. (a) 2 x 10 inches (b) 2 x 8 inches
    D. (a) 2 x 8 inches (b) 2 x 4 inches

29. When splicing a vertical pole, what minimum length splice plate should you use?

    A. 8 feet
    B. 6 feet
    C. 3 feet
    D. 4 feet

30. Prefabricated scaffolding with 2 1/2 inch outside diameter steel tubing and post spacing not more than 6 1/2 feet apart is considered to be what duty scaffolding?

    A. Light
    B. Medium
    C. Heavy
    D. Extra heavy

Trade Terms Introduced in this Chapter

Cheeks	In general, the side of any feature, such as the side of a dormer.
Fairlead	A device such as a ring or a block of wood with a hole in it, through which cable or rope is led for alignment.
Fiber line	A thread-like structure of a plant that contributes to stiffness or strength.
Fleet Angle	In hoisting gear, the included angle between the rope, in its position of greatest travel.
Gin pole	An upright guy pole with hoisting tackle and foot-mounted snatch block. Used for vertical lifts.
Guardrail	(1) A horizontal rail of metal, wood, or cable fastened to intermittent uprights of metal, wood, or concrete around the edges of platforms or along the lane of a highway. (2) The rail that separates traffic entering or exiting through side-by-side automatic doors.
Hoisting	(1) Any mechanical device for lifting loads. (2) An elevator. (3) The apparatus providing the power drive to a drum, around which cable or rope is wound in lifting or pulling a load.
Hooks	(1) Any bent or curved device for holding, pulling, catching, or attaching. (2) A terminal bend in a reinforced bar. (3) Slang term for a crane.
Lines	Strands of natural or synthetic fiber twisted together, sometimes referred to as rope.
Mechanical advantage	The ratio of the weight lifted by a machine divided by the force applied.
Mousing	Turns of cordage around the opening of a block hook.
Reeved	Threading or placement of a working line.
Safety factor	The ratio of ultimate load, moment, or shear of a structural member to the working load, moment, or shear, respectively, assumed in design.
Scaffolding	A temporary structure for the support of deck forms, cart ways, and/or workers, such as an elevated platform for supporting workers, tools, and materials. Adjustable metal scaffolding is frequently adapted for shoring in concrete work.
Shear legs	A hoisting device constructed from two or more poles fastened near their apex, from which a pulley is hung to lift heavy loads
Sheaves	A grooved wheel used to support cable or change its direction

	of travel. (pronounced shiv)
Shell	The outer portion of a hollow masonry unit when laid. The outer section of a block.
Snatch block	A pulley or block with a side that can be opened to receive a rope or line.
Toe board	A vertical barrier at floor level erected along exposed edges of a floor opening, wall opening, platform, runway, or ramp to prevent falls of materials.
Tripods	A three legged, adjustable stand for an instrument.
Wire rope	A rope formed of wires wrapped around a central core; a steel cable.
Yarns	A continuous strand of twisted threads of natural or artificial material such as wool or nylon, used in making carpets.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Navy Occupational Safety and Health (NAVOSH) Program Manual for Forces Afloat, Volume I, Office of the Chief of Naval Operations (OP-45), Washington, D.C., 1989.

Safety and Health Requirements Manual, EM 385-1-1, U.S. Army Corps of Engineers, Washington, D.C. 1981.

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Chapter 8

Masonry

Topics

To hear audio, click on the box.

Overview

The Top 10 Reasons to Build with Masonry...

Christopher Huckabee, AIA, CEO, Huckabee & Associates

1. It's cost effective, beginning with the first day and over the life of the building.
2. One third of building costs are spent on Day 1; two thirds are spent maintaining the building. Masonry can substantially reduce maintenance over that lifetime.
3. It's easy to maintain, and requires no paint or harsh chemicals when properly designed for interior use.
4. It's safe from fire, tornado, and hurricane issues, to mold and other indoor air quality problems. Masonry is the solution.
5. It can be cleaned when it gets wet – no demolition required.
6. It's durable – try to kick a hole in a masonry wall. Try the same thing with wallboard.
7. It's environmentally friendly. When you use masonry, you don't spend your annual maintenance dollars on reconstruction costs.
8. It's beautiful – nothing looks like a masonry building.
9. It's flexible, adaptable and appropriate for most design solutions.
10. It's the best, most proven, wall system on the market today.

All quotes from Masonry Magazine August 2006 Edition

Originally, masonry was the art of building structures from stone. Today, it refers to construction consisting of units held together with ***mortar***, constructions such as ***concrete block***, stone, ***brick***, clay tile products, and, sometimes, glass ***block***. The characteristics of masonry work are determined by the properties of the masonry units and mortar and by the methods of bonding, reinforcing, anchoring, tying, and joining the units into a structure.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Identify basic masonry tools and equipment.
2. Identify components and requirements of concrete masonry construction.
3. Explain elements of concrete masonry.
4. Explain elements of brick masonry.

Prerequisites

None

This course map shows all of the chapters in Builder Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Expeditionary Structures	BUILDER BASIC
Finishes	
Moisture Protection	
Finish Carpentry	
Rough Carpentry	
Carpentry Materials and Methods	
Masonry	
Fiber Line, Wire Rope, and Scaffolding	
Concrete Construction	
Site Work	
Construction Management	
Drawings and Specifications	
Tools	
Basic Math	

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 MASONRY TOOLS and EQUIPMENT

Masonry involves the use of a wide selection of tools and equipment. A set of basic mason's tools, includes ***trowels***, a chisel, ***hammer***, and a ***jointer***.

1.1.0 Trowels

The trowels shown in *Figure 8-1* are used to pick up mortar from the board, throw it on the unit, spread the mortar, and tap the unit down into the bed. A common trowel is usually triangular, ranging in size up to about 11 inches long and from 4 to 8 inches wide. Generally, short, wide trowels are best because they do not put too much strain on the wrist. Trowels used to point and strike ***joints*** are smaller, ranging from 3 to 6 inches long and 2 to 3 inches wide. We will talk more about ***pointing*** and ***striking*** joints later in the chapter.

Figure 8-1 – Trowels.

1.2.0 Chisel

The chisel, or ***bolster***, shown in *Figure 8-2*, is used to smooth cut masonry units into parts. A typical chisel is 2 1/2 to 4 1/2 inches wide.

Figure 8-2 – Chisel or bolster.

1.3.0 Hammer

The ***mason's hammer***, shown in *Figure 8-3*, has a square face on one end and a long chisel on the other. The hammer weighs from 1 1/2 to 3 1/2 pounds. You use it to split and rough-break masonry units.

Figure 8-3 – Hammer.

1.4.0 Jointer

As its name implies, you use the jointer shown in *Figure 8-4* to make various mortar joints. There are several different types of jointer; rounded, flat, or pointed; depending on the shape of the mortar joint you want.

Figure 8-4 – Jointer.

1.5.0 Square

Use the square, shown in *Figure 8-5*, to measure right angles and to lay out corners. Squares are usually made of metal and come in various sizes.

Figure 8-5 – Square.

1.6.0 Mason's Level

The mason's level shown in *Figure 8-6* is used to establish plumb and level lines. A plumb line is absolutely vertical. A level line is absolutely horizontal. The level may be constructed of seasoned hardwood, various metals, or a combination of both. They are made as lightweight as possible without sacrificing strength to withstand fairly rough treatment. Levels may be equipped with single or double vials. Double vial levels are preferred since they can be used either horizontally or vertically.

Figure 8-6 – Mason's level.

Levels are shaped similar to rulers and have vials enclosed in glass. Inside each vial is a bubble of air suspended in either alcohol or oil. When a bubble is located exactly between the two center marks on the vial, the object is either level or plumb, depending on the position in which the mason is using the level. In a level, alcohol is the more suitable since oil is more affected by heat and cold. The term "spirit level" indicates that the vials contain alcohol. The vials are usually embedded in plaster or plastic so that they remain secure and true. Shorter levels are made for jobs where a longer level will not fit. The most popular of these are 24 and 18 inches long.

In a level constructed of wood, occasionally rub a small amount of linseed oil into the wood with a clean cloth. This treatment also stops mortar from sticking to the level. Do not use motor oil as it eventually rots the wood.

1.7.0 Straightedge

The ***straightedge***, shown in *Figure 8-7*, can be any length up to 16 feet. Thickness can be from 1 1/8 inches to 1 1/2 inches, and the middle portion of the top edge from 6 to 10 inches wide. The middle portion of the top edge must be parallel to the bottom edge. Use a straightedge to extend a level to plumb or level distances longer than the level length.

Figure 8-7 – Straightedge.

1.8.0 Miscellaneous Items

Other mason's tools and equipment include shovels, mortar hoes, wheelbarrows, chalk lines, plumb bobs, and a 200 foot ball of good quality ***mason's line***. Be sure to keep wheelbarrows and mortar tools clean; hardened mortar is difficult to remove. Clean all tools and equipment thoroughly at the end of each day or when the job is finished.

Figure 8-8 – Mortar mixing machine.

The ***mortar mixing machine*** shown in *Figure 8-8* is used for mixing large quantities of mortar. The mixer consists primarily of a metal drum containing mixing blades mounted on a chassis equipped with wheels for towing the machine from one job site to another. The mixer is powered by either an electric motor or a gasoline engine. After mixing, the mortar is discharged into a mortar box or wheelbarrow, usually by tilting the mixer drum. As with any machine, refer to the manufacturer's operator and maintenance manuals for proper operation. Be sure to follow safety requirements related to mixer operations.

Test your Knowledge (Select the Correct Response)

1. As a Builder, you should use a mason's hammer for which of the following tasks?

    A. Smooth-cutting concrete masonry units
    B. Chipping and rough cutting concrete masonry units
    C. Checking level courses
    D. Laying out corners

2.1.1 CONCRETE MASONRY

One of the most common masonry units is the concrete block. It consists of hardened cement and may be completely solid or contain single or multiple hollows. It is made from conventional cement mixes and various types of aggregate,including sand, gravel, crushed stone, air cooled slag, coal cinders, expanded shale or clay, expanded slag, volcanic cinders (pozzolan), pumice, and Scotia (refuse obtained from metal ore reduction and smelting). The term concrete block was formerly limited to only hollow masonry units made with such aggregates as sand, gravel, and crushed stone. Today, the term covers all types of concrete block, both hollow and solid, made with any kind of aggregate. Concrete blocks are also available with applied glazed surfaces, various pierced designs, and a wide variety of surface textures.

Concrete blocks are used in all types of masonry construction. The following are just a few of many examples:

- Exterior ***load-bearing walls*** (both below and above grade)
- Interior load-bearing walls
- ***Fire walls*** and ***curtain walls***
- Partitions and panel walks
- Backing for brick, stone, and other facings
- Fireproofing over structural members
- Fire safe walls around stairwells, elevators, and enclosures
- Piers and columns
- ***Retaining walls***
- Chimneys
- Concrete floor units

Although concrete block is made in many sizes and shapes, and in both modular and nonmodular dimensions, its most common unit size is 7 5/8 by 7 5/8 by 15 5/8 inches. This size is known as 8 by 8 by 16 inch block nominal size. All concrete block must meet certain specifications covering size, type, weight, moisture content, compressive strength, and other characteristics. Properly designed and constructed concrete masonry walls satisfy many building requirements, including fire prevention, safety, durability, economy, appearance, utility, comfort, and acoustics.

Figure 8-9 – Typical unit sizes and shapes of concrete masonry units.

2.1.1 Block Sizes and Shapes

Concrete masonry units are available in many sizes and shapes to fit different construction needs. Both full and half length sizes are shown in *Figure 8-9*. Because concrete block sizes usually refer to nominal dimensions, a unit actually measuring 7 5/8 by 7 5/8 by 15 5/8 inches is called an 8 by 8 by 16 inch block. When laid with 3/8 inch mortar joints, the unit occupies a space exactly 8 by 8 by 16 inches.

There are five main types of concrete masonry units:

1. Hollow load-bearing concrete block
2. Solid load-bearing concrete block
3. Hollow non-load bearing concrete block
4. Concrete building tile
5. Concrete brick

Load-bearing blocks are available in two grades, N and S. Grade N is for general use, such as exterior walls both above and below grade that may or may not be exposed to moisture penetration or weather. Both grades are also used for backup and interior walls. Grade S is for above grade exterior walls with a weather protective coating and for interior walls. The grades are further subdivided into two types. Type I consists of moisture controlled units for use in arid climates. Type II consists of non moisture controlled units.

American Society for Testing and Materials (ASTM) specifications define a solid concrete block as having a ***core*** area not more than 25 percent of the gross cross sectional area. Most concrete bricks are solid and sometimes have a recessed surface like the frogged brick shown in *Figure 8-9*. In contrast, a hollow concrete block has a core area greater than 25 percent of its gross cross sectional area, generally 40 percent to 50 percent.

Blocks are considered heavyweight or lightweight, depending on the aggregate used in their production. A hollow load-bearing concrete block 8 by 8 by 16 inches nominal size weighs from 40 to 50 pounds when made with a heavyweight aggregate such as sand, gravel, crushed stone, or air cooled slag. The same size block weighs only 25 to 35 pounds when made with coal cinders, expanded shale, clay, slag, volcanic cinders, or pumice. The choice of blocks depends on both the availability of the blocks and requirements of the intended structure.

Figure 8-10 – Masonry saw.

Blocks may be cut with a chisel, but they can be cut more conveniently and accurately with a power driven masonry saw, shown in *Figure 8-10*. Be sure to follow the manufacturer's manual for operation and maintenance. As with all electrically powered equipment, follow all safety guidelines.

2.2.0 Block Mortar Joints

The sides and the recessed ends of a concrete block are called the shell. The material that forms the partitions between the cores is called the ***web***. Each of the long sides of a block is called a ***face*** shell. Each of the recessed ends is called an end shell. The vertical ends of the face shells, on either side of the end shells, are called the edges. You can see the relationship of these components in a stretcher block in *Figure 8-11*.

Figure 8-11 – Components of a stretcher block.

Bed joints on first ***courses*** and bed joints in column construction are mortared by spreading a 1 inch layer of mortar. This procedure is referred to as full mortar bedding. For most other bed joints, only the upper edges of the face shells need to be mortared. This is referred to as face shell mortar bedding.

Head joints may be mortared by ***buttering*** both edges of the block being laid or by buttering one edge on the block being laid and the opposite edge on the block already in place.

2.3.0 Masonry Mortar

Properly mixed and applied mortar is necessary for good workmanship and good masonry service because it must bond the masonry units into a strong, well-knit structure. The mortar that bonds concrete block, brick, or clay tile will be the weakest part of the masonry unless you mix and apply it properly. When masonry leaks, it is usually through the joints. Both the strength of masonry and its resistance to rain penetration depend largely on the strength of the bond between the masonry unit and the mortar. Various factors affect bond strength, including the type and quantity of the mortar, its plasticity and workability, its water retentivity, the surface texture of the mortar bed, and the quality of workmanship in laying the units. You can correct irregular brick dimensions and shape with a good mortar joint.

2.3.1 Workability of Mortar

Mortar must be plastic enough to work with a trowel. You obtain good plasticity and workability by using mortar having good water retentivity, using the proper grade of sand, and thorough mixing. You do not obtain good plasticity by using a lot of cementitious materials. Mortar properties depend largely upon the type of sand the mortar contains. Clean, sharp sand produces excellent mortar, but too much sand causes mortar to segregate, drop off the trowel, and weather poorly.

2.3.2 Water Retentivity

Water retentivity is the mortar property of resistance to rapid loss of water to highly absorbent masonry units. Mortar must have water to develop the bond. If it does not contain enough water, the mortar will have poor plasticity and workability, and the bond will be weak and spotty. Sometimes, you must wet brick to control water absorption before applying mortar, but never wet concrete masonry units.

2.3.3 ortar Strength and Durability

The type of service that the masonry must give determines the strength and durability requirements of mortar. For example, walls subject to severe stress or weathering must be laid with more durable, stronger mortar than walls for ordinary service. *Table 8-1* gives mortar mix proportions that provide adequate mortar strength and durability for the conditions listed.

Table 8-1 – Recommended Mortar Mix Proportions by Unit Volume.

TYPE OF SERVICE	CEMENT	HYDRATED LIME	MORTAR SAND IN DAMP, LOOSE CONDITION
Ordinary	1 unit masonry cement[1]	1/2 to 1 1/4 units	2 1/4 to 3 units
	or		
	1 unit Portland cement		4 1/2 to 6 units
Isolated Piers Subject to Extremely Heavy Loads, Violent Winds, Earthquakes, or Severe Frost Action	1 unit masonry cement[1] plus 1 unit Portland cement	0 to 1/4 unit	4 1/2 to 6 units
	or		
	1 unit Portland cement		2 1/4 to 3 units

[1]ASTM Specification C91 Type II

2.3.4 Types of Mortar

The following mortar types are proportioned on a volume basis:

- Type M – One part Portland cement, one fourth part hydrated lime or lime putty, and three parts sand; or, one part Portland cement, one part type II masonry cement, and six parts sand. Type M mortar is suitable for general use but is recommended specifically for below grade masonry that contacts earth, such as foundations, retaining walls, and walks.
- Type S – One part Portland cement, one half part hydrated lime or lime putty, and four and one half parts sand; or, one half part Portland cement, one part type II masonry cement, and four and one half parts sand. Type S mortar is also suitable for general use, but is recommended where high resistance to lateral forces is required.
- Type N – One part Portland cement, one part hydrated lime or lime putty, and six parts sand; or, one part type II masonry cement and three parts sand. Type N mortar is suitable for general use in above grade exposed masonry that does not require high compressive or lateral strength.
- Type O – One part Portland cement, two parts hydrated lime or lime putty, and nine parts sand; or, one part type I or type II masonry cement and three parts sand. Type O mortar is recommended for load-bearing, solid unit walls when the

compressive stresses do not exceed 100 pounds per square inch (psi) and the masonry is not subject to freezing and thawing in the presence of a lot of moisture.

2.4.0 Mixing Mortar

The manner in which mortar is mixed has a lot to do with the quality of the final product. In addition to machine and hand mixing, you need to know the requirements for introducing various additives, including water, to the mix in order to achieve optimum results.

2.4.1 Machine Mixing

Machine mixing refers to mixing large quantities of mortar in a drum type mixer. Place all dry ingredients in the mixer first and mix them for 1 minute before adding the water. When adding water, you should always add it slowly. Minimum mixing time is 3 minutes. The mortar should be mixed until a completely uniform mixture is obtained.

2.4.2 Hand Mixing

Hand mixing involves mixing small amounts of mortar by hand in a mortar box or wheelbarrow. Take care to mix all ingredients thoroughly to obtain a uniform mixture. As in machine mixing, mix all dry materials together first before adding water. Keep a steel drum of water close at hand to use as the water supply. Also, keep all your masonry tools free of hardened mortar mix and dirt by immersing them in water when they are not in use.

2.4.3 Requirements

You occasionally need to mix lime putty with mortar. When you machine mix, use a pail to measure the lime putty. Place the putty on top of the sand. When hand mixing, add the sand to the lime putty. Wet pails before filling them with mortar and clean them immediately after emptying.

Mixing water for mortar must meet the same quality requirements as mixing water for concrete. Do not use water containing large amounts of dissolved salts, as salts weaken the mortars.

You can restore the workability of any mortar that stiffens on the mortar board due to evaporation by remixing it thoroughly. Add water as necessary, but discard any mortar stiffened by initial setting. Because it is difficult to determine the cause of stiffening, a practical guide is to use mortar within 2 1/2 hours of the original mixing. Discard any mortar you do not use within this time.

Do not use an antifreeze admixture to lower the freezing point of mortars during winter construction. The quantity necessary to lower the freezing point any appreciable degree is so large it will seriously impair the strength and other desirable properties of the mortar.

To avoid reinforcing steel (RST) corrosion, do not add calcium chloride unless specified by specifications.

2.5.0 Modular Planning

Concrete masonry walls should be laid out to make maximum use of full and half length units. This minimizes cutting and fitting of units on the job. Plan the length and height of walls, width and height of openings, and wall areas between doors, windows, and corners to use full size and half size units, which are usually available (*Figure 8-12*). This procedure assumes that window and door frames are of modular dimensions which fit modular full and half size units. Then, all horizontal dimensions should be in multiples of nominal full length masonry units.

Figure 8-12 – Planning concrete masonry wall openings.

Design both horizontal and vertical dimensions in multiples of 8 inches. *Table 8-2* lists nominal length of concrete masonry walls by stretchers.

Table 8-2 – Nominal Lengths of Concrete Masonry Walls in Stretchers.

Number of Stretchers	Nominal Length of Concrete Masonry Walls	
	Units 15 5/8” long and half units 7 5/8” long with 3/8” thick head joints	Units 11 5/8” long and half units 5 5/8” long with 3/8” thick head joints
1	1’4”	1’0”
1 1/2	2’0”	1’6”
2	2’	2’0”
2 1/2	3’4”	2’6”
3	4’0”	3’0”
3 1/2	4’8”	3’6”
4	5’4”	4’0”
4 1/2	6’0”	4’6”
5	6’8”	5’0”
5 1/2	7’4”	5’6”
6	8’0”	6’0”
6 1/2	8’8”	6’6”
7	9’4”	7’0”
7 1/2	10’0”	7’6”
8	10’8”	8’0”
8 1/2	11’4”	8’6”
9	12’0”	9’0”
9 1/2	12’8”	9’6”
10	13’4”	10’0”
10 1/2	14’0”	10’6”
11	14’8”	11’0”
11 1/2	15’4”	17’4”
12	16’0”	18’0”
12 1/2	16’8”	19’4”
13	17’4”	13’0”
13 1/2	18’0”	13’6”
14	19’4”	14’0”
14 1/2	20’0”	14’6”
15	20’0”	15’0”
20	26’8”	20’0”
NOTE: Actual wall length is measured from outside edge to outside edge of units and equals the nominal length minus 3/8” (one mortar joint).		

Table 8-3 lists nominal height of concrete masonry walls by courses. When using 8 by 4 by 16 units, plan the horizontal dimensions in multiples of 8 inches (half length units) and the vertical dimensions in multiples of 4 inches. If the thickness of the wall is greater or less than the length of a half unit, a special length unit is required at each corner in each course.

Table 8-3 – Nominal Heights of Modular Concrete Masonry Walls in Courses.

Number of Courses	Nominal Height of Concrete Masonry Walls	
	Units 7 5/8” high and 3/8” thick bed joints	Units 3 5/8” high and 3/8” thick bed joints
1	0’8”	0’4”
2	1’4”	0’8”
3	2’0”	1’0”
4	2’8”	1’4”
5	3’4”	1’8”
6	4’0”	2’0”
7	4’8”	2’4”
8	5’4”	2’8”
9	6’0”	3’0”
10	6’8”	3’4”
15	10’0”	5’0”
20	13’4”	6’8”
25	16’8”	8’4”
30	20’0”	10’0”
35	23’4”	11’8”
40	26’8”	13’4”
45	30’0”	15’0”
50	33’4”	16’8”

NOTE: For concrete masonry units 7 5/8” and 3 5/8” in height laid with 3/8” mortar joints. Height is measured from center to center of mortar joints.

Table 8-4 lists the average number of concrete masonry units by size and approximate number of cubic feet of mortar required per 100 square feet of concrete masonry wall.

Table 8-4 – Average Concrete Masonry Units and Mortar per 100 square feet of Wall.

Description, Size of Block (Inches)	Thickness Wall (Inches)	Number of Units Per 100 Square Feet of Wall Area	Mortar (Cubic Feet)
8 x 8 x 16	8	112.5	8.5
8 x 12 x 16	12	112.5	8.5
8 x 3 x 16	3	112.5	8.5
8 x 3 x 12	3	151.5	9.5
8 x 4 x 16	4	112.5	8.5
8 x 4 x 12	4	151.5	9.5
8 x 6 x 16	6	112.5	8.5

Table 8-5 lists the number of 16 inch blocks per course for any wall.

Table 8-5 – Number of 16 Inch Blocks per Course.

Length In Feet	Width in Feet																	
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
8	19	22	25	28	31	34	37	40	43	46	49	52	55	58	61	64	67	70
10	22	25	28	31	34	37	40	43	46	49	52	55	58	61	64	67	70	73
12	25	28	31	34	37	40	43	46	49	52	55	58	61	64	67	70	73	76
14	28	31	34	37	40	43	46	49	52	55	58	61	64	67	70	73	76	79
16	31	34	37	40	43	46	49	52	55	58	61	64	67	70	73	76	79	82
18	34	37	40	43	46	49	52	55	58	61	64	67	70	73	76	79	82	85
20	37	40	43	46	49	52	55	58	61	64	67	70	73	76	79	82	85	88
22	40	43	46	49	52	55	58	61	64	67	70	73	76	79	82	85	88	91
24	43	46	49	52	55	58	61	64	67	70	73	76	79	82	85	88	91	94
26	46	49	52	55	58	61	64	67	70	73	76	79	82	85	88	91	94	97
28	49	52	55	58	61	64	67	70	73	76	79	82	85	88	91	94	97	100
30	52	55	58	61	64	67	70	73	76	79	82	85	88	91	94	97	100	103
32	55	58	61	64	67	70	73	76	79	82	85	88	91	94	97	100	103	106
34	58	61	64	67	70	73	76	79	82	85	88	91	94	97	100	103	106	109
36	61	64	67	70	73	76	79	82	85	88	91	94	97	100	103	106	109	112
38	64	67	70	73	76	79	82	85	88	91	94	97	100	103	106	109	112	115
40	67	70	73	76	79	82	85	88	91	94	97	100	103	106	109	112	115	118
42	70	73	76	79	82	85	88	91	94	97	100	103	106	109	112	115	118	121
44	73	76	79	82	85	88	91	94	97	100	103	106	109	112	115	118	121	124
46	76	79	82	85	88	91	94	97	100	103	106	109	112	115	118	121	124	127
48	79	82	85	88	91	94	97	100	103	106	109	112	115	118	121	124	127	130
50	82	85	88	91	94	97	100	103	106	109	112	115	118	121	124	127	130	133
52	85	88	91	94	97	100	103	106	109	112	115	118	121	124	127	130	133	136
54	88	91	94	97	100	103	106	109	112	115	118	121	124	127	130	133	136	139
56	91	94	97	100	103	106	109	112	115	118	121	124	127	130	133	136	139	142
58	94	97	100	103	106	109	112	115	118	121	124	127	130	133	136	139	142	145
60	97	100	103	106	109	112	115	118	121	124	127	130	133	136	139	142	145	148

Always use outside measurements when calculating the number of blocks required per course. For example, a basement 22 feet by 32 feet should require 79 blocks for one complete course. Multiply 79 by the number of courses needed. Thus, a ten course basement requires a total of 790 blocks for a solid wall, from which deductions should be made for windows and doors. If any dimension is an odd number, use the nearest smaller size listed in the table. For example, for a 22 foot by 31 foot enclosure, use 22 feet by 30 feet and add one half block per row.

As a Builder, you might find yourself in the field without the tables handy, so here is another method. Use 3/4 times the length and 3/2 times the height for figuring how many 8 by 8 by 16 inch blocks you need for a wall. Let's take an example:

Given: A wall 20 feet long x 8 feet high

3/4 x 20 = 60 ÷ 4 = 15 (8" x 8" x16" block per course)

3/2 x 8 = 24 ÷ 2 = 12 courses high

15 x 12 = 180 total blocks

2.6.1 Estimating Mortar

You can use rule 38 for calculating the raw material needed to mix 1 yard of mortar without a great deal of paperwork. This rule does not accurately calculate the required raw materials for large masonry construction jobs. For larger jobs, use the absolute volume or weight formula. In most cases, and particularly in advanced base construction, you can use rule 38 to quickly estimate the quantities of the required raw materials. Builders have found that it takes about 38 cubic feet of raw materials to make 1 cubic yard of mortar.

In using rule 38 for calculating mortar, take the rule number and divide it by the sum of the quantity figures specified in the mix. For example, let's assume that the building specifications call for a 1:3 mix for mortar,

1. Add 1:3, which gives you 4.
2. Divide 38 by 4 to figure the prime number.

   38 ÷ 4 = 9 1/2 cubic feet
3. Compute your material requirements by multiplying the prime number by the ratio as follows:
   1 x 9 1/2 = 9 1/2 cubic feet of cement
   3 x 9 1/2 = 28 1/2 cubic feet of sand

Using these calculations, you find that you'll need 9 1/2 cubic feet (sacks) of cement and 28 1/2 cubic feet of sand to mix 1 cubic yard of mortar using a 1:3 mix. The sum of the two required quantities should always equal 38. This is how you can check whether you are using the correct amounts. In the above example, 9 1/2 sacks of cement plus 28 1/2 cubic feet of sand equal 38. Be careful with your calculations, as too much sand in your mortar can cause segregation.

2.7.0 Safe Handling of Material

When you handle cement or lime bags, wear goggles and snug fitting neckbands and wristbands. Always practice good personal cleanliness and never wear clothing that has become stiff with cement. Cement impregnated clothing irritates the skin and may cause serious infection. Report any susceptibility of the skin to cement and lime burns. Personnel who are allergic to cement or lime should be transferred to other jobs.

Do not pile bags of cement or lime more than 10 bags high on a pallet. The only exception is when storage is in bins or enclosures built for such storage. Place the bags around the outside of the pallet with the mouths of the bags facing the center. Be sure to cross pile the first five tiers of bags each way from any corner. Make a setback starting with the sixth tier to prevent piled bags from falling outward. If you have to pile bags above 10 tiers, make another setback. The back tier, when not resting against an interior wall of sufficient strength to withstand the pressure, should be set back on bag every five tiers, the same as the end tiers. During unpiling, keep the entire top of the pile level and maintain the necessary setbacks.

Lime and cement must be stored in a dry place. This helps prevent the lime from crumbling and the cement from hydrating before it is used.

Test your Knowledge (Select the Correct Response)

2. Excess sand in a mortar mix causes which of the following problems?

   A. Slow setting
   B. Segregation
   C. Stickiness
   D. Lumps

3. A single course in a 10 foot long block wall requires how many standard blocks?

   A. 5 1/2
   B. 6 1/2
   C. 7 1/2
   D. 8 1/2

4. Building specifications call for a 1:2 mortar mix. Using rule 38, how many sacks of cement are required to make up a 2 cubic yard mix?

   A. 7
   B. 13
   C. 20
   D. 26

3.0.0 CONCRETE MASONRY CONSTRUCTION

Good workmanship is a very important factor in building masonry walls. Make every effort to lay each masonry unit plumb and true. In the following paragraphs, we will discuss the basic steps in laying up masonry walls.

3.1.0 Steps in Construction

Start building a concrete masonry wall by locating the corners of the structure. In locating the corners, also make sure the footing or slab formation is level so that each Builder starts each section wall on a common plane. This also helps ensure that the bed joints are straight when the sections are connected. If the foundation is badly out of level, the entire first course should be laid before Builders begin working on other courses. If this is not possible, a level plane should be established with a transit or engineer's level.

Next chase out bond, or lay out, by placing the first course of blocks without mortar, as shown in *Figure 8-13*. Snap a chalk line to mark the footing and align the blocks accurately. Then, use a piece of material 3/8 inch thick to properly space the blocks. This helps you get an accurate measurement.

Figure 8-13 – Placing blocks without mortar (chasing the bond).

Figure 8-14 – Spreading and furrowing mortar bed.

Replace the loose blocks with a full mortar bed, spreading and furrowing it with a trowel to ensure plenty of mortar under the bottom edges of the first course, as shown in *Figure 8-14*.

Carefully position and align the corner block first, as shown in *Figure 8-15*. Lay the remaining first course blocks with the thicker end up to provide a larger mortar bedding area.

Figure 8-15 – Positioning and aligning corner block.

For the vertical joints, apply mortar only to the block ends by placing several blocks on end and buttering them all in one operation, as shown in *Figure 8-16*. Make the joints 3/8 inch thick. Then, place each block in its final position, and push the block down vertically into the mortar bed and against the previously laid block. This ensures a well filled vertical mortar joint.

Figure 8-16 – Laying first course of blocks for a wall.

After laying three or four blocks, use a mason's level as a straightedge to check correct block alignment, as shown in *Figure 8-17*.

Figure 8-17 – Leveling block for a wall.

Figure 8-18 - Plumbing block for a wall.

Use the level to bring the blocks to proper grade and plumb them by tapping with a trowel handle, as shown in *Figure 8-18*. Always lay out the first course of concrete masonry carefully and make sure that you properly align, level, and plumb it.

This assures that succeeding courses and the final wall are both straight and true.

Build up the corners of the wall, usually four or five courses high. This is also called laying up a lead. Step back each course one half block. For the horizontal joints, apply mortar only to the tops of the blocks already laid. For the vertical joints, you can apply mortar either to the ends of the new block or the end of the block previously laid, or both, to ensure well filled joints, as shown in *Figure 8-19*.

Figure 8-19 – Completed corner *leads*.

As you lay each course at the corner, check the course with a level for alignment, as shown in *Figure 8-20,* for level (*Figure 8-21*) *view B* and for plumb (*Figure 8-22*). Carefully check each block with a level or straightedge to make sure that all the block faces are in the same plane. This ensures true, straight walls.

Figure 8-20 – Checking for alignment.

Figure 8-21 – Checking for level.

Figure 8-22 – Checking for plumb.

The folding rule, shown in *Figure 8-23*, helps accurately place each masonry course.

Figure 8-23 – Using a folding rule to check course height.

Figure 8-24 – Checking horizontal block spacing.

Also check the horizontal block spacing by placing a level diagonally across the corners of the blocks, shown in *Figure 8-24*.

When filling in the wall between the corners, first stretch a mason's line along the extensor block edges from corner to corner for each course. Then lay the top outside edge of each new block to this line, as shown in *Figure 8-25*. How you grip a block before laying is important. First, tip it slightly toward you so that you can see the edge of the course below. Then place the lower edge of the new block directly on the edges of the block below, shown in *Figure 8-25*.

Figure 8-25 – Filling in the wall between corners.

Make all position adjustments while the mortar is soft and plastic. Any adjustments after the mortar stiffens will break the mortar bond and allow water to penetrate. Level each block and align it to the mason's line by tapping it lightly with a trowel handle.

Before installling the closure block, butter both edges of the opening and all four vertical edges of the closure block with mortar. Then lower the closure block carefully into place as shown in *Figure 8-26*. If any mortar falls out, leaving an open joint, remove the block and repeat the procedure.

Figure 8-26 – Installing a closure block.

Figure 8-27 – Cutting off excess mortar from the joints.

To assure a good bond, do not spread mortar too far ahead when actually laying blocks. If you do, the mortar will stiffen and lose its plasticity. The recommended width of mortar joints for concrete masonry units is 3/8 inch. When properly made, these joints produce a weathertight, neat, and durable concrete masonry wall. As you lay each block, cut off excess mortar from the joints using a trowel, as shown in *Figure 8-27*, and throw it back on the mortar board to rework into the fresh mortar. Do not rework any mortar dropped on the scaffold or floor.

Figure 8-28 – Tooled mortar joints for weathertight exterior walls.

Weathertight joints and the neat appearance of concrete masonry walls depend on proper striking, or tooling. After laying a section of the wall, tool the mortar joint when the mortar becomes thumb print hard. Tooling compacts the mortar and forces it tightly against the masonry on each side of the joint. Use either concave or V-shaped tooling on all joints, as shown in *Figure 8-28*.

Tool horizontal joints as shown in *Figure 8-29 A* with a long jointer first, followed by tooling the vertical joints as shown in *Figure 8-30*. Trim off mortar burrs from the tooling flush with the wall face using a trowel or a soft bristle brush or by rubbing with a burlap bag.

Figure 8-29 – Striking horizontal joints. **Figure 8-30 – Striking vertical joints.**

A procedure known as pointing may be required after jointing. Pointing is the process of inserting mortar into horizontal and vertical joints after the unit has been laid. Pointing is done to restore or replace deteriorated surface mortar in old work; this is called tuck pointing. Pointing may be necessary in freshly laid masonry to fill holes or correct defective joints.

You must prepare in advance for installing wood plates with anchor bolts on top of hollow concrete masonry walls. Place pieces of metal lath in the second horizontal mortar joint from the top of the wall under the cores that will contain the bolts, as shown in *Figure 8-31*. Use anchor bolts 1/2 inch in diameter and 18 inches long; space them not more than 4 feet apart. When you complete the top course, insert the bolts into the cores of the top two courses and fill the cores with concrete or mortar. The metal lath underneath holds the concrete or mortar filling in place. The threaded end of the bolt should extend above the top of the wall as shown in *Figure 8-32*.

Figure 8-31 – Placing metal lath under cores. **Figure 8-32 – Threaded bolt extends above wall top.**

3.2.0 Control Joints

Control joints, shown in *Figure 8-33*, are continuous vertical joints that permit a masonry wall to move slightly under unusual stress without cracking. There are a number of types of control joints built into a concrete masonry wall.

Figure 8-33 – Control joint made up with full and half length blocks.

The most preferred control joint is the Michigan type made with ***roofing felt***. A strip of felt is curled into the end core, covering the end of the block on one side of the joint (*Figure 8-34*). As the other side of the joint is laid, the core is filled with mortar. The filling bonds to one block, but the paper prevents bond to the block on the other side of the control joint.

Figure 8-34 – Control joint made with roofing felt.

Figure 8-35 shows the tongue and groove type of control joint. The special units are manufactured in sets consisting of full and half blocks. The tongue of one unit fits into the groove of another unit or into the open end of a regular flanged ***stretcher***. The units are laid in mortar exactly the same as any other masonry units, including mortar in the head joint. Part of the mortar is allowed to remain in the vertical joint to form a backing against which the caulking can be packed.

Figure 8-35 – Control joint blocks (top view).

Figure 8-36 shows a control joint that may be built with regular full and half length stretcher blocks with a Z shaped bar across the joint or a 10 or 12 inch pencil rod (1/4 inch smooth bar) across each face shell. If you use a pencil rod, it must be greased on one side of the joint to prevent bond. Place these rods every other course. Lay up control joints in mortar just as any other joint. If they are exposed to either the weather or to view, caulk them as well.

Figure 8-36 – Z bar joint (top view).

After the mortar is stiff, rake it out to a depth of about 3/4 inch to make a recess for the caulking compound. Use a thin, flat caulking trowel to force the compound into the joint as shown in *Figure 8-37*.

The location of control joints is established by the architectural engineer and should be noted in the plans and specifications.

3.3.0 Walls

Walls are differentiated into two types, load-bearing and non-load-bearing. Load-bearing walls separate spaces, and also provide structural support for whatever is above them. Non-load-bearing walls are solely partitions between spaces.

Figure 8-37 – *Raking* joint to prepare for caulking.

3.3.1 Load-bearing Walls

Do not join intersecting concrete block load-bearing walls with a masonry bond, except at the corners. Instead, terminate one wall at the face of the second wall with a control joint. Then, tie the intersecting walls together with Z shaped metal tie bars 1/4 by 1/4 by 28 inches in size, with 2 inch right angle bends on each end. Space the tie bars no more than 4 feet apart vertically and place pieces of metal lath under the block cores that will contain the tie bars ends (*Figure 8-38*). Embed the right-angle bends in the cores by filling them with mortar or concrete as shown in *Figure 8-39*.

Figure 8-38 – Z-shaped tie bar has right angle bends at each end.

Figure 8-39 – Filling core with mortar or concrete.

3.3.2 Nonload-bearing Walls

To join intersecting nonload-bearing block walls, terminate one wall at the face of the second with a control joint. Place strips of metal lath of 1/4 inch mesh galvanized hardware cloth across the joint between the two walls, as shown in *Figure 8-40,* in alternate courses. Insert one half of the metal stops into one wall as you build it, and then tie the other halves into the mortar joints as you lay the second wall, as shown in *Figure 8-41*.

Figure 8-40 – Metal lath spans the joint between the walls.

Figure 8-41 – Set lath in mortar joint as you construct the second wall.

3.4.0 Bond Beams, Lintels, and Sills

Bond beams are reinforced courses of block that bond and integrate a concrete masonry wall into a stronger unit. They increase the bending strength of the wall and are particularly needed to resist earthquake forces and the high winds of hurricanes.

They also exert restraint against wall movement, reducing the formation of cracks.

Bond beams are constructed with special shape masonry units (beam and lintel block) filled with concrete or grout and reinforced with embedded steel bars. These beams are usually located at the top of walls to stiffen them. Since bond beams have appreciable structural strength, they can be located to serve as lintels over doors and windows.

Figure 8-42 shows the use of lintel blocks to place a lintel over a metal door, using the door case for support. Lintels should have a minimum bearing of 6 inches at each end. A rule of thumb is to provide 1

Figure 8-42 – Lintel made from blocks.

inch of bearing for every foot of clear space. When bond beams are located just above the floor, they act to distribute the wall weight, making the wall a deep beam, thus helping avoid wall cracks if the floor sags. Bond beams may also be located below a window ***sill***.

Modular door and window openings usually require lintels to support the blocks over the openings. You can use precast concrete lintels, as shown in *Figure 8-43*, that contain an offset on the underside like the one in *Figure 8-44* to fit the modular openings. You can also use steel lintel angles installed with an offset on the underside, as shown in *Figure 8-45*, to fit modular openings. In either case, place a noncorroding metal plate under the lintel ends at the control joints to allow the lintel to slip and the control joints to function properly. Apply a full bed of mortar over the metal plate to uniformly distribute the lintel load.

Figure 8-43 – Precast concrete lintel.

Figure 8-44 – Precast concrete offset on lintel underside.

Figure 8-45 – Steel angles offset on lintel underside.

You usually install precast concrete sills as shown in *Figure 8-46*, following wall construction. Fill the joints tightly at the ends of the sills with mortar or a caulking compound.

Figure 8-46 – Installed precast concrete sills.

3.5.0 Piers and Pilasters

Piers are isolated columns of masonry; pilasters are columns or thickened wall sections built contiguous to and forming part of a masonry wall. Both piers and pilasters are used to support heavy, concentrated vertical roof or floor loads. They also provide lateral support to the walls. Piers and pilasters offer an economic advantage by permitting construction of higher and thinner walls. They may be constructed of special concrete masonry units, as shown in *Figure 8-47*, or standard units.

Figure 8-47 – Pilaster masonry units.

3.6.0 Reinforced Block Walls

Block walls may be reinforced vertically or horizontally. To reinforce vertically, place reinforcing rods called rebar into the cores at the specified spacing and fill the cores with a relatively high slump concrete. Place rebar at each corner and at both sides of each opening. Space vertical rebar a maximum of 32 inches on center in walls. Where splices are required, lap the bars 40 times the bar diameter. Place the concrete should in one continuous pour from foundation to plate line. A cleanout block may be placed in the first course at every rebar stud for cleaning out excess mortar and to ensure proper alignment and laps of rebars. Practical experience indicates that horizontal joint reinforcing can control cracking and achieve wall flexibility. The amount of joint reinforcement depends largely upon the type of construction.

Horizontal joint reinforcing, where required, should consist of not less than two deformed longitudinal No. 9 or heavier cold drawn steel wires. Truss type cross wires should be 1/8 inch diameter or heavier of the same quality. *Figure 8-48* shows joint reinforcement on 16 inch vertical spacing. The location and details of bond beams, control joints, and joint reinforcing should all be shown on the drawings.

Figure 8-48 – Masonry wall horizontal joint reinforcement.

3.7.0 Patching and Cleaning Block Walls

Always fill holes made by nails or line pins with fresh mortar and patch mortar joints. When laying concrete masonry walls, be careful not to smear mortar on the block surfaces. Once they harden, these smears cannot be removed, even with an acid wash, nor will paint cover them. Allow droppings to dry and harden.You can then chip off most of the mortar with a small piece of broken concrete block, as shown in *Figure 8-49*, or with a trowel, as shown in *Figure 8-50*. A final brushing of the spot removes practically all the mortar, as shown in *Figure 8-51*.

Figure 8-49 – Chipping off mortar with a piece of broken block.

Figure 8-50 – Chipping off mortar with a trowel.

Figure 8-51 – Final brushing of remaining spot.

3.8.0 Retaining Walls

The purpose of a retaining wall is to hold back a mass of soil or other material. As a result, concrete masonry retaining walls must have the structural strength to resist imposed vertical and lateral loads. The footing of a retaining wall should be large enough to support the wall and the load of the material the wall is to retain. The reinforcing must be properly located as specified in the plans. Make provisions to prevent the accumulation of water behind retaining walls. This includes the installation of drain tiles, ***weep holes***, or both.

3.9.0 Painting Concrete Masonry

Several finishes are possible on concrete masonry construction. The finish to use in any specific situation is governed by the type of structure in which the walls will be used and the climatic conditions to which they will be exposed.

Paints now commonly used on concrete masonry walls include Portland cement paint, latex paint, oil based paint, and rubber based paint. For proper application and preparation of the different types of paint, refer to the plans, specifications, or manufacturer's instructions.

Test your Knowledge (Select the Correct Response)

5. You are constructing a concrete block wall. After the corners are located, what is the next step?

   A. Spread and furrow the mortar bed for the first course.
   B. Attach the guide strings to the corner stakes.
   C. String out the blocks for the first course without mortar.
   D. Position the corner block.

6. You are building the corners of a concrete block wall. How should you ensure the horizontal blocks are correctly spaced?

   A. Place a level diagonally across the corners of the block.
   B. Place a level horizontally across the corners of the block.
   C. Place a level vertically across the corners of the block.
   D. Place a mason's line between the corners of the wall.

7. When reinforcing a block wall, where should you place rebars?

   A. At each corner
   B. At each side of a wall opening
   C. At points spaced no more than 32 inches on center in the wall
   D. All of the above

4.0.0 BRICK MASONRY

Brick masonry is construction in which uniform units called bricks, small enough to be placed with one hand, are laid in courses with mortar joints to form walls. Bricks are kiln baked from various clay and shale mixtures. The chemical and physical characteristics of the ingredients vary considerably. These characteristics and the kiln temperatures combine to produce brick in a variety of colors and hardnesses. In some regions, individual pits yield clay or shale which, when ground and moistened, can be formed and baked into durable brick. In other regions, clay or shale from several pits must be mixed.

4.1.0 Brick Terminology

Standard U.S. bricks are 2 1/4 by 3 3/4 by 8 inches nominal size. They may have three core holes or ten core holes. Modular U.S. bricks are 2 1/4 by 3 5/8 by 7 5/8 inches nominal size. They usually have three core holes. English bricks are 3 by 4 1/2 by 9 inches, Roman bricks are 1 1/2 by 4 by 12 inches, and Norman bricks are 2 3/4 by 4 by 12 inches nominal size. Actual brick dimensions are smaller, usually by an amount equal to a mortar joint width. Bricks weigh from 100 to 150 pounds per cubic foot, depending on their ingredients and duration of firing. Fired brick is heavier than under burned brick. The six surfaces of a brick are called cull, beds, side, end, and face, as shown in *Figure 8-52*.

Occasionally you will have to cut brick into various shapes to fill in spaces at corners and other locations where a full brick does not fit. *Figure 8-53* shows the more common cut shapes: half or bat, three quarter closure, quarter closure, king closure, queen closure, and split.

Figure 8-52 – Names of brick surfaces.

Figure 8-53 – Common cut brick shapes.

4.2.0 Types of Bricks

Brick masonry units may be solid, hollow, or architectural terra cotta. All types can serve a structural function, a decorative function, or a combination of both. The various types differ in their formation and composition.

Building brick, also called common, hard, or kiln-run brick, is made from ordinary clay or shale and fired in kilns. These bricks have no special shoring, markings, surface texture, or color. Because building bricks are generally used as the backing courses in either solid or cavity brick walls, the harder and more durable types are preferred.

Face brick is better quality and has better durability and appearance than building brick. Because of this, face bricks are used in exposed wall faces. The most common face brick colors are various shades of brown, red, gray, yellow, and white.

Clinker brick is over burned in the kiln. Clinker bricks are usually rough, hard, durable, and sometimes irregular in shape.

Pressed brick is made by a dry press process rather than by kiln firing. Pressed bricks have regular smooth faces, sharp edges, and perfectly square corners. Ordinarily, they are used like face brick.

Glazed brick has one surface coated with a white or colored ceramic glazing. The glazing forms when mineral ingredients fuse together in a glass-like coating during burning. Glazed bricks are particularly suited to walls or partitions in hospitals, dairies, laboratories, and other structures requiring sanitary conditions and ease of cleaning.

Fire brick is made from a special type of clay. This clay is very pure and uniform and is able to withstand the high temperatures of fireplaces, boilers, and similar constructions. Fire bricks are generally larger than other structural bricks and are often hand-molded.

Cored bricks have ten holes, two rows of five holes each, extending through their beds to reduce weight. Walls built from cored brick are not much different in strength than walls built from solid brick. Also, both have about the same resistance to moisture penetration. Whether cored or solid, use the more available brick that meets building requirements.

European brick has strength and durability about equal to U.S. clay brick. This is particularly true of the English and Dutch types.

Sand-lime brick is made from a lean mixture of slaked lime and fine sand. Sand-lime bricks are molded under mechanical pressure and hardened under steam pressure. They are used extensively in Germany.

4.3.0 Strength of Brick Masonry

The main factors governing the strength of a brick structure include brick strength, mortar strength and elasticity, bricklayer workmanship, brick uniformity, and the method used to lay the brick. In this section, we'll cover strength and elasticity. Workmanship is covered separately in the next section.

The strength of a single brick masonry unit varies widely, depending on its ingredients and manufacturing method. Brick can have an ultimate compressive strength as low as 1,600 psi. On the other hand, some well burned brick has compressive strength exceeding 15,000 psi.

Because Portland cement lime mortar is normally stronger than the brick, brick masonry laid with this mortar is stronger than an individual brick unit. The load carrying capacity of a wall or column made with plain lime mortar is less than half that made with Portland cement lime mortar. The compressive working strength of a brick wall or column laid with plain lime mortar normally ranges from 500 to 600 psi.

For mortar to bond to brick properly, sufficient water must be present to completely hydrate the Portland cement in the mortar. Bricks sometimes have high absorption rates, and, if not properly treated, can suck the water out of the mortar, preventing complete hydration. Here is a quick field test to determine brick absorptive qualities. Using a medicine dropper, place 20 drops of water in a 1 inch circle, about the size of a quarter, on a brick. A brick that absorbs all the water in less than 1 1/2 minutes will suck the water out of the mortar when laid. To correct this condition, thoroughly wet the bricks and allow the surfaces to air dry before placing.

4.4.0 Bricklaying Methods

Good bricklaying procedure depends on good workmanship and efficiency. Efficiency involves doing the work with the fewest possible motions. Each motion should have a purpose and accomplish a definite result. After learning the fundamentals, every Builder should develop methods for achieving maximum efficiency. The work must be arranged in such a way that the Builder is continually supplied with brick and mortar. The scaffolding required must be planned before the work begins. It must be built in such a way as to cause the least interference with other crewmembers.

Bricks should always be stacked on planks; they should never be piled directly on uneven or soft ground. Do not store bricks on scaffolds or runways. This does not prohibit placing normal supplies on scaffolding during actual bricklaying operations. Except where stacked in sheds, brick piles should never be more than 7 feet high. When a pile of brick reaches a height of 4 feet, it must be tapered back 1 inch in every foot of height above the 4 foot level. The tops of brick piles must be kept level, and the taper must be maintained during unpiling operations.

4.5.0 Masonry Terms

To efficiently and effectively lay bricks, you must be familiar with the terms that identify the position of masonry units and mortar joints in a wall. The following list, which references *Figure 8-54* through *Figure 8-60*, provides some of the basic terms you will encounter.

A course, shown in *Figure 8*-54, is one of several continuous, horizontal layers (or rows) of masonry units bonded together.

Figure 8-54 – Course.

A wythe, shown in *Figure 8-55*, is each continuous, vertical section of a wall; each section is one masonry unit thick. It is sometimes called a tier.

Figure 8-55 – Wythe.

A stretcher, shown in *Figure 8-56*, is a masonry unit laid flat on its bed along the length of a wall with its face parallel to the face of the wall.

Figure 8-56 – Stretcher.

A header, shown in *Figure 8-57*, is a masonry unit laid flat on its bed across the width of a wall with its face perpendicular to the face of the wall. It is generally used to bond two wythes.

Figure 8-57 – Header.

A rowlock, shown in *Figure 8-58*, is a header laid on its face or edge across the width of a wall.

Figure 8-58 – Rowlock.

A bull header, shown in *Figure 8-59*, is a rowlock brick laid with its bed perpendicular to the face of the wall.

A bull stretcher, also shown in *Figure 8-59*, is a rowlock brick laid with its bed parallel to the face of the wall.

Figure 8-59 – Bull header and bull stretcher.

A soldier, shown in *Figure 8*-60, is a brick laid on its end with its face perpendicular to the face of the wall.

4.6.1 Bonds

The term “bond”, as used in masonry, has three different meanings: structural bond, mortar bond, or pattern bond.

Structural bond refers to how the individual masonry units interlock or tie together into a single structural unit. You can achieve structural bonding of brick and tile walls in one of three ways:

- Overlapping (interlocking) the masonry units

Figure 8-60 – Soldier.

- Embedding metal ties in connecting joints
- Using grout to adhere adjacent wythes of masonry

Mortar bond refers to the adhesion of the joint mortar to the masonry units or to the reinforcing steel.

Pattern bond refers to the pattern formed by the masonry units and mortar joints on the face of a wall. The pattern may result from the structural bond, or may be purely decorative and unrelated to the structural bond. *Figure 8-44* shows the six basic pattern bonds in common use today: running, common or American, Flemish, English, stack, and English cross or Dutch bond.

The running bond, shown in *Figure 8-61*, is the simplest of the six patterns, consisting of all stretchers. Because the bond has no headers, metal ties usually form the structural bond. The running bond is used largely in cavity wall construction, brick veneer walls, and facing tile walls made with extra wide stretcher tile.

Figure 8-61 – Running bond.

The English bond, shown in *Figure 8-62*, consists of alternating courses of headers and stretchers. The headers center over and under the stretchers. The joints between stretchers in all stretcher courses do not align vertically. You can use blind headers in courses that are not structural bonding courses.

Figure 8-62 – English bond.

The common or American bond, shown in *Figure 8-63*, is a variation of the running bond, having a course of full length headers at regular intervals that provide the structural bond as well as the pattern. Header courses usually appear at every fifth, sixth, or seventh course, depending on the structural bonding requirements. You can vary the ***common bond*** with a Flemish header course. In laying out any bond pattern, be sure to start the corners correctly. In a common bond, use a three-quarter closure at the corner of each header course.

Figure 8-63 – Common or American bond.

In the Flemish bond, shown in *Figure 8-64*, each course consists of alternating headers and stretchers. The headers in every other course center over and under the stretchers in the courses in between. The joints between stretchers in all stretcher courses align vertically. When headers are not required for structural bonding, you can use bricks called blind headers. You can start the corners in two different ways. In the Dutch corner, a three quarter closure starts each course. In the English corner, a 2 inch or quarter closure starts the course.

Figure 8-64 – Flemish bond.

The stack bond, shown in *Figure 8-65*, is purely a pattern bond, with no overlapping units and all vertical joints aligning. You must use dimensionally accurate or carefully rematched units to achieve good vertical joint alignment. You can vary the pattern with combinations and modifications of the basic patterns shown in *Figures 8-61* through *8-66*. This pattern usually bonds to the backing with rigid steel ties or 8 inch thick stretcher units when available. In large wall areas or load-bearing construction, insert steel pencil rods into the horizontal mortar joints as reinforcement.

Figure 8-65 – Stack bond.

The English cross or Dutch bond, shown in *Figure 8-66*, is a variation of the English bond. It differs only in that the joints between the stretchers in the stretcher courses align vertically. These joints center on the headers in the courses above and below.

Figure 8-66 – English cross or Dutch bond.

When a wall bond has no header courses, use metal ties to bond the exterior wall brick to the backing courses. *Figure 8-67* shows three typical metal ties.

Figure 8-67 – Metal ties.

Install ***flashing*** at any spot where moisture is likely to enter a brick masonry structure. Flashing diverts the moisture back outside. Always install flashing under horizontal masonry surfaces, such as sills and copings; at intersections between masonry walls and horizontal surfaces, such as a roof and parapet or a roof and chimney; above openings, doors and windows, for example; and frequently at floor lines, depending on the type of construction. The flashing should extend through the exterior wall face and then turn downward against the wall face to form a drop.

Provide weep holes at intervals of 18 to 24 inches to drain water to the outside that might accumulate on the flashing. Weep holes are even more important when appearance requires the flashing to stop behind the wall face instead of extending through the wall. This type of concealed flashing, when combined with tooled mortar joints, often retains water in the wall for long periods and, by concentrating the moisture at one spot, does more harm than good.

4.7.0 Mortar Joints and Pointing

There is no set rule governing the thickness of a brick masonry mortar joint. Irregularly shaped bricks may require mortar joints up to 1/2 inch thick to compensate for the irregularities. Mortar joints 1/4 inch thick are the strongest. Use this thickness when the bricks are regular enough in shape to permit it.

A ***slushed joint*** is made simply by depositing the mortar on top of the head joints and allowing it to run down between the bricks to form a joint. You cannot make solid joints this way. Even if you fill the space between the bricks completely, there is no way you can compact the mortar against the brick faces; consequently a poor bond results. The only effective way to build a good joint is to trowel it.

The secret of mortar joint construction and pointing is in how you hold the trowel for spreading mortar. *Figure 8-68* shows the correct way to hold a trowel. Hold it firmly in the grip shown, with your thumb resting on top of the handle, not encircling it.

Figure 8-68 – Correct way to hold a trowel.

If you are right handed, pick up mortar from the outside of the mortar board pile with the left edge of your trowel as shown in *Figure 8-69*. A pickup for one brick forms only a small pile along the left edge of the trowel.

You can pick up enough to spread one to five bricks, depending on the wall space and your skill. A pickup for five bricks is a full load for a large trowel, as shown in *Figure 8-70*.

Figure 8-69 – Proper way to pick up mortar right-handed.

Figure 8-70 – Fully loaded trowel for five bricks.

If you are right handed, work from left to right along the wall. Holding the left edge of the trowel directly over the center line of the previous course, tilt the trowel slightly and move it to the right as shown in *Figure 8-71*.

Spread an equal amount of mortar on each brick until you either complete the course or the trowel is empty, as shown in *Figure 8-72*. Return any mortar left over to the mortar board.

Figure 8-71 – Working from left to right.

Figure 8-72 – Spreading mortar on three to five bricks at a time.

Do not spread the mortar for a bed joint too far ahead of laying; four or five brick lengths is best. Mortar spread out too far ahead dries out before the bricks become bedded and causes a poor bond, as shown in *Figure 8-73*. The mortar must be soft and plastic so that the brick will bed in it easily.

Figure 8-73 – A poorly bonded brick.

Spread the mortar about 1 inch thick and then make a shallow furrow in it as shown in *Figure 8-74*. A furrow that is too deep leaves a gap between the mortar and the bedded brick. This reduces the resistance of the wall to water penetration.

Use a smooth, even stroke to cut off any mortar projecting beyond the wall line with the edge of the trowel as shown in *Figure 8-75*. Retain enough mortar on the trowel to butter the left end of the first brick you will lay in the fresh mortar. Throw the rest back on the mortar board.

Figure 8-74 – Making a furrow. **Figure 8-75 – Cutting off excess mortar.**

Pick up the first brick to be laid with your thumb on one side of the brick and your fingers on the other, as shown in *Figure 8-76*. Apply as much mortar as will stick to the end of the brick and then push it into place.

Squeeze out the excess mortar at the head joint and at the sides as shown in *Figure 8-77.* Make sure the mortar completely fills the head joint. After bedding the brick, cut off the excess mortar and use it to start the next end joint. Throw any surplus mortar back on the mortar board where it can be restored to workability.

Figure 8-76 – Proper way to hold a brick when buttering the end. **Figure 8-77 – Making a head joint in a stretcher course.**

To insert a brick into a space left in a wall.

1. Spread a thick bed of mortar as shown in *Figure 8-78.*

2. *S*hove the brick into the wall space as shown in *Figure 8-79.*
3. Mortar squeezes out of all four joints as shown in *Figure 8-80*.

This way, you know that the joints are full of mortar at every point.

Figure 8-78 – Spreading a thick bed of mortar.

Figure 8-79 – Shoving the brick into place.

Figure 8-80 – Mortar squeezes out all four joints.

To make a cross joint in a header course:

1. Spread the bed joint mortar several brick widths in advance.
2. Spread mortar over the face of the header brick before placing it in the wall as shown in *Figure 8-81*.
3. Shove the brick into place, squeezing out mortar at the top of the joint.
4. Cut off the excess mortar as shown in *Figure 8-82*.

Figure 8-81 – Spreading mortar over brick face.

Figure 8-82 – Cutting off excess mortar.

To lay a closure brick in a header course:

1. Spread about 1 inch of mortar on the sides of the brick already in place as shown in *Figure 8*-83.
2. Spread about 1 inch of mortar on both sides of the closure brick as shown in *Figure 8-84*.
3. Lay the closure brick carefully into position without disturbing the brick already laid as shown in *Figure 8-85*.

Figure 8-83 – Spreading mortar on sides of brick already laid.

Figure 8-84 – Spreading mortar on both sides of closure brick.

Figure 8-85 – Laying the brick into position.

If you do disturb any adjacent brick, cracks will form between the brick and mortar, allowing moisture to penetrate the wall. To place a closure brick for a stretcher course, use the same techniques as for a header course:

1. Spread about 1 inch of mortar on the ends of the brick already in place as shown in *Figure 8-86*.
2. Spread about 1 inch of mortar on both ends of the closure brick as shown in *Figure 8-87*.
3. Lay the closure brick carefully into position without disturbing the brick already laid as shown in *Figure 8-88*.

Figure 8-86 – Spreading mortar on ends of brick already laid.

Figure 8-87 – Spreading mortar on both ends of closure brick.

Figure 8-88 – Laying the brick into position.

As mentioned earlier, filling exposed joints with mortar immediately after laying a wall is called pointing. You can also fill holes and correct defective mortar joints by pointing, using a pointing trowel.

4.8.1 Cutting Brick

To cut a brick to an exact line, you should use a chisel, as shown in *Figure 8-89*, or brick set. The straight side of the tool's cutting edge should face both the part of the brick to be saved and the bricklayer. One mason's hammer blow should break the brick. For extremely hard brick, first roughly cut it using the brick hammer head, but leave enough brick to cut accurately with the brick set.

Figure 8-89 – Cutting brick with a chisel.

Use a brick hammer for normal cutting work, such as making the closure bricks and bats around wall openings or completing corners. Hold the brick firmly while cutting it.

1. Cut a line all the way around the brick using light hammerhead blows.
2. A sharp blow to one side of the cutting line should split the brick at the cutting line, as shown in *Figure 8-90*.
3. Trim rough spots using the hammer blade, as shown in *Figure 8-91*.

Figure 8-90 – Striking brick to one side of cutting line.

Figure 8-91 – Trimming rough spots.

4.9.0 Finishing Joints

The exterior surfaces of mortar joints are finished to make brick masonry waterproof and give it a better appearance. If joints are simply cut to the face of the brick and not finished, shallow cracks will develop immediately between the brick and the mortar. Always finish a mortar joint before the mortar hardens too much. *Figure 8-92* shows several types of joint finishes, the most important of which are concave, flush, and weather.

Figure 8-92 – Joint finishes.

Of all joints, the concave is the most weather tight. After removing the excess mortar with a trowel, make this joint using a jointer that is slightly larger than the joint. Use force against the tool to press the mortar tightly against the brick on both sides of the mortar joint.

The flush joint is made by holding the trowel almost parallel to the face of the wall while drawing its point along the joint.

A weather joint sheds water from a wall surface more easily. To make it, simply push downward on the mortar with the top edge of the trowel.

4.10.0 Arches

A well constructed brick arch can support a heavy load, mainly due to the way weight is distributed over its curved shape. There are two common arch shapes; *Figure 8-93* shows an elliptical arch, and *Figure 8-94* shows a circular arch. Brick arches require full mortar joints. The joint width is narrower at the bottom of the arch than at its top, but it should not narrow to less than 1/4 inch at any point. As laying progresses, make sure the arch does not bulge out of position.

Figure 8-93 – Elliptical arch

Figure 8-94 – Circular arch

4.10.1 Templet

It is obviously impossible to construct an arch without support from underneath. These temporary wooden supports must not only be able to support the masonry during construction but also provide the geometry necessary for the proper construction and appearance of the arch. Such supports are called ***templets***.

Dimensions – Construct a brick arch over the templet, as shown in *Figure 8-95*, that remains in place until the mortar sets. You can obtain the templet dimensions from the construction drawings. For arches spanning up to 6 feet, use 3/4 inch plywood to make the templet. Cut two pieces to the proper curvature, and nail them to 2 by 4 spacers that provide a surface wide enough to support the brick.

Figure 8-95 – Using a templet to construct an arch.

Positioning – Use wedges to hold the templet in position until the mortar hardens enough to make the arch self supporting. Then drive out the wedges.

4.10.2 Layout

Lay out the arch carefully so that you don't have to cut any bricks. Use an odd number of bricks so that the ***key***, or middle, brick falls into place at the exact arch center, or crown. The key, or middle, brick is the last one laid. To determine how many bricks an arch requires, lay the templet on its side on level ground and set a trial number of bricks around the curve. Adjust the number of bricks and the joint spacing, not less than 1/4 inch, until the key brick is at the exact center of the curve. Then, mark the positions of the bricks on the templet and use them as a guide when laying the brick.

Test your Knowledge (Select the Correct Response)

8. Modular U.S. brick are what nominal size?

   A. 2 1/4 by 3 3/4 by 8 inches
   B. 2 1/4 by 3 5/8 by 7 5/8 inches
   C. 3 by 4 by 9 inches
   D. 2 3/4 by 4 by 12 inches

9. When stacking brick, you should start tapering back when the pile reaches what minimum height?

   A. 1 foot
   B. 2 feet
   C. 3 feet
   D. 4 feet

10. To tie brick on the outside face of a wall to the backing course when no header courses are to be installed, what should you use?

    A. Copings
    B. Metal ties
    C. Flashing
    D. Rebar

11. For weathertightness, what is the best type of joint finish?

    A. Flush
    B. Bead
    C. Concave
    D. Weather

Summary

Masonry is construction consisting of units held together with mortar, such as concrete block, stone, brick, clay tile products, and, sometimes, glass block. The characteristics of masonry work are determined by the properties of the masonry units and mortar and by the methods of bonding, reinforcing, anchoring, tying, and joining the units into a structure.

Masonry involves the use of a wide selection of tools and equipment, including trowels, chisels, hammers, and jointers.

One of the most common masonry units is the concrete block. There are all types of concrete block, both hollow and solid, made with any kind of aggregate. Concrete blocks are also available with applied glazed surfaces, various pierced designs, and a wide variety of surface textures.

Good workmanship is a very important factor in building masonry walls. It’s important to make every effort to lay each masonry unit plumb and true.

Brick masonry is construction in which uniform units called bricks, small enough to be placed with one hand, are laid in courses with mortar joints to form walls. Bricks are kiln baked from various clay and shale mixtures. The chemical and physical characteristics of the ingredients vary considerably. These characteristics and the kiln temperatures combine to produce brick in a variety of colors and hardnesses.

Review Questions (Select the Correct Response)

1. To smooth cut a concrete masonry unit, use which of the following tools?

   A. A mason’s hammer
   B. A brick chisel
   C. A brick trowel
   D. A pointing trowel

2. To finish a masonry joint, use which of the following tools?

   A. Trowel
   B. Bolster
   C. Mortar board
   D. Jointer

3. When placing masonry units, use a steel square for which of the following jobs?

   A. Leveling short columns
   B. Laying out corners
   C. Plumbing long stretches
   D. Finishing joints

4. **(True or False)** There are three main types of concrete masonry units.

   A. True
   B. False

5. Load-bearing concrete block used in above and below grade exterior walls that may or may not be exposed to moisture should be what grade?

   A. Grade M
   B. Grade N
   C. Grade O
   D. Grade S

6. A standard concrete masonry unit made with pumice has what approximate weight?

   A. 20 to 30 pounds
   B. 25 to 35 pounds
   C. 35 to 45 pounds
   D. 45 to 55 pounds

7. The sides and the recessed ends of a concrete block are called the

   A. Shell
   B. Face shell
   C. Edge
   D. Web

8. **(True or False)** Spreading a 1 inch layer of mortar on both bed joints of walls and columns is called face shell mortar bedding.

   A. True
   B. False

9. For above grade exposed masonry where high compressive and lateral strength is not required, use what type of mortar?

   A. Type M
   B. Type N
   C. Type O
   D. Type S

10. You should not temper mortar that has been mixed longer than what maximum time?

   A. 1 hour
   B. 2 1/2 hours
   C. 3 hours
   D. 4 1/2 hours

11. **(True or False)** You should only add calcium chloride should to mortar if it is specified in the specifications.

   A. True
   B. False

12. Using standard block, how many courses are required for a concrete block wall 10 feet high?

   A. 14
   B. 15
   C. 16
   D. 17

13. To lay 600 square feet of wall, you need approximately how many (a) 8 by 4 by 12 inch concrete blocks and (b) cubic feet of mortar?

A. (a) 520 (b) 15
B. (a) 680 (b) 15
C. (a) 770 (b) 24
D. (a) 900 (b) 24

14. How many cubic feet of sand are required to complete a 1:2 mix for 2 cubic yards of mortar?

A. 26
B. 51
C. 52
D. 104

15. When bags of cement or lime are stacked on pallets, a setback should begin at what tier?

A. Eighth
B. Sixth
C. Fifth
D. Fourth

16. A concrete block should be laid with what portion up?

A. The narrow end of the face shell
B. The web facing
C. The end shell
D. The thicker end of the face shell

17. What part(s) of a block wall is/are laid immediately after the first courses?

A. Corners
B. Second course
C. Lintels
D. Lateral supports

18. During the construction of a concrete block wall, you must butter all vertical edges of a block at what point?

A. When the corner blocks are being placed
B. When the closure block is being installed
C. When all stretchers are placed
D. When the second course is being laid

19. To ensure weathertight joints, at what point in construction should you start tooling mortar joints?

    A. Immediately after laying each course
    B. As soon as the mortar becomes thumbprint hard
    C. After the excess mortar falls off the block
    D. At the end of the workday

20. Any excess mortar remaining on a concrete block after the joints are tooled should be removed by what method?

    A. Rubbing with a burlap bag
    B. Flushing with water
    C. Striking the mortar with a small jointer
    D. Rubbing with a piece of broken concrete

21. The insertion of roofing felt in the end core of the concrete block in a control joint serves what purpose?

    A. It permits the wall to move without cracking
    B. It eliminates bonding of the mortar on both sides of the joint
    C. It prevents raking of the outside block
    D. It eliminates bonding of the mortar on one side of the joint

22. Intersecting bearing walls should be tied together by what means?

    A. Masonry bonds in alternate courses
    B. Hardware cloth placed across the courses
    C. Metal tie bars bent at right angles
    D. Anchor bolts located in alternate courses

23. Lintel blocks should extend past the edge of an opening to what minimum distance?

    A. 6 in
    B. 12 in
    C. 16 in
    D. 20 in

24. When reinforcing a block wall, you can ensure proper alignment of the rebar by performing what action?

    A. Placing a cleanout block at every stud in all courses
    B. Pouring concrete as each course is laid
    C. Placing a cleanout block at every stud in the first course
    D. Pouring concrete around the rebar as it is placed

25. **(True or False)** Weep holes in retaining walls are used to prevent water accumulation behind the wall.

A. True
B. False

26. The backing course for a cavity wall should be made with what type of brick?

A. Face
B. Building
C. Glazed
D. Fire

27. Where cleanliness and ease of cleaning are necessary, what type of brick should you use?

A. Face
B. Cored
C. Glazed
D. Sand-lime

28. For masonry structures that can withstand high temperatures without cracking or decomposing, you should use what type of brick?

A. Cored
B. Press
C. Clinker
D. Fire

29. **(True or False)** In masonry, a soldier is a row lock brick laid with its bed parallel to the face of the wall.

A. True
B. False

30. In brick walls, structural bonding takes place by what means?

A. Adhesion of grout to adjacent wythes of masonry
B. Metal ties embedded in connecting joints
C. Interlocking the masonry units
D. All of the above

31. The pattern formed by the masonry units and mortar joints on the face of a wall is called what type of bond?

A. Stack
B. Pattern
C. English
D. Running

32. Which of the following bonds is a variation of the running bond in which a header course appears at the fifth, sixth, or seventh course?

A. Running
B. Flemish
C. Common or American bond
D. Dutch bond

33. You must place a three-quarter brick at the corner of each header course in which of the following pattern bonds?

A. Common
B. English
C. Block
D. Stacked

34. Moisture is prevented from seeping under a horizontal masonry surface by the installation of

A. Sills
B. Copings
C. Parapets
D. Flashing

35. Water that accumulates on a flashing should be allowed to drain to the outside by what means?

A. Parapets
B. Concealed flashing
C. Weep holes
D. Sills

36. To ensure a good bond between mortar and brick, avoid which of the following joints?

A. Slushed
B. Bed
C. Cross
D. Header

37. Spread bed joint mortar what maximum number of bricks ahead?

A. 5
B. 7
C. 9
D. 11

38. For which of the following reasons should you form a shallow furrow in the mortar of a bed joint?

A. To maintain the required width of brick spacing
B. To conserve mortar
C. To keep a gap from forming and allowing water to enter the wall
D. To allow the mortar to dry slightly before placing the brick

39. To cut a brick to an exact line with a brick chisel or brick set, follow which of the following procedures?

A. Break the brick with one blow of the hammer
B. Let the straight side of the cutting edge face you
C. Let the straight side of the cutting edge face the part of the brick that is to be saved
D. All of the above

40. **(True or False)** When laying out a brick arch, you can make the key brick line up by using an even number of bricks.

A. True
B. False

Trade Terms Introduced in this Chapter

Bed joint	(1) The horizontal layer of mortar on which a masonry unit is laid. (2) In an arch, a horizontal joint or one that radiates between adjacent voussoirs.
Block	A usually hollow concrete masonry unit or other building unit, such as glass block.
Bolster	A mason's blocking chisel.
Bond beams	A horizontally reinforced concrete or concrete masonry beam built to strengthen and tie a masonry wall together. A bond beam is often placed at the top of a masonry wall with continuous reinforcing around the entire perimeter.
Brick	Solid blocks of fine clay.
Building brick	Brick that has not been treated for color or texture. Used as an all-purpose building material. Also known as common brick.
Buttering	Putting mortar on a brick or block with a trowel before laying.
Clinker brick	A hard brick that is usually formed with a distorted shape and is used for paving.
Common bond	Five stretcher courses with the sixth as an all header course.
Concrete block	A masonry building unit of concrete that has been cast into a standard shape, size, and style.
Core	(1) The void in a concrete masonry unit. (2) The rubble filling in a thick masonry wall.
Course	A single layer of bricks, stone, or other masonry.
Curtain walls	The exterior closure or skin of a building. A curtain wall is nonbearing and is not supported by beams or girders.
Face	(1) The surface of a wall, masonry unit, or sheet of material that is exposed to view or designed to be exposed in finish work. (2) To cover the surface layer of one material with another, as to *face* a wall with brick or fieldstone.
Face brick	(1) Brick manufactured to present an attractive appearance. (2) Any brick that is exposed, such as on a fireplace. Also known as facing brick.
Fire brick	A flame-resistant, refractory ceramic brick used in fireplaces, chimneys, and incinerators.

Fire walls	An interior or exterior wall that runs from the foundation of a building to the roof or above, constructed to stop the spread of fire.
Flashing	A thin, impervious sheet of material placed in construction to prevent water penetration or direct the flow of water. Flashing is used especially at roof hips and valleys, roof penetrations, joints between a roof and a vertical wall, and in masonry walls to direct the flow of water and moisture.
Glazed brick	Brick or tile with a surface produced by fusing it with a glazing material.
Hammer	A hand tool with a handle perpendicular to its head, for driving nails or other applications involving pounding or striking.
Joints	The mortar filled space between adjacent masonry units.
Jointer	(1) An offset metal tool used to smooth or indent mortar joints in masonry. (2) A bent strip of iron used in a wall to strengthen a joint.
Key	A brick whose proper fit in an arch is attained by tapering it toward one end.
Leads	Points at which block and brick are laid up a few courses and used as guides.
Load-bearing walls	A wall specifically designed and built to support an imposed load in addition to its own weight.
Mason's hammer	A steel hammer having one square face for striking and one curved chisel face for trimming masonry units.
Mason's line	A heavy string or cord used by masons to align courses of masonry.
Mortar	Sand, water, and cementing material in proper proportions.
Mortar mixing machine	A machine with paddles in a rotating drum for mixing and stirring mortar. Also known as a mill or mixer.
Load-bearing wall	Designed to carry no load other than its own weight.
Pointing	(1) The finishing of joints in a masonry wall. (2) The material with which joints in masonry are finished.

Pressed brick	Brick that is molded under mechanical pressure. The resulting product is sharp-edged and smooth, and is used for exposed surfaces.
Reinforced block walls	Masonry block walls with reinforced steel and grout placed in the voids to resist tensile, compressive, or shear stresses.
Retaining walls	(1) A structure used to sustain the pressure of the earth behind it. (2) Any wall subjected to lateral pressure other than wind pressure.
Roofing felt	A roof covering manufactured in rolls and made from asphalt-impregnated felt with a harder layer of asphalt applied to the surface of the felt. All or part of the “weather” side may be covered with aggregate of various sizes and colors.
Sand-lime brick	A concrete product made primarily from sand and lime which is hardened by autoclave curing.
Sill	A solid concrete masonry unit used as a sill for an opening.
Slushed joint	Distribution of grout with or without fine aggregate, as required, over a rock or concrete surface that is subsequently to be covered with concrete. The grouting is usually accomplished by brooming it into place to fill surface voids and fissures.
Square	A flat, metal L-shaped tool that constitutes an accurate right angle and is engraved with divisions and markings useful to a mason in laying out masonry.
Straightedge	A rigid, straight piece of wood or metal used to strike off or screed a concrete surface to proper grade, or to check the flatness of a finished grade.
Stretcher	A masonry unit laid with its length parallel with the face of the wall.
Striking	Cutting off the excess mortar at the face of a joint with a trowel stroke.
Templets	(1) A thin plate or board frame used as a guide in positioning or spacing form parts, reinforcement, or anchors. (2) A full size mold, pattern, or frame shaped to serve as a guide
Trowels	A flat, triangular lade tool used for applying mortar to masonry.
Web	The walls connecting the face shells of a hollow concrete masonry unit.
Weep holes	A small hole in a retaining wall located near the lower ground surface. The hole drains the soil behind the wall and prevents build-up of water pressure on the wall.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Concrete and Masonry, FM 5-742, Headquarters, Department of the Army, Washington, D.C., 1985.

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Chapter 9

Carpentry Materials and Methods

Topics

To hear audio, click on the box.

Overview

Woodworking is one of the most visible of the Builder trades. Quality woodworking begins with selection of the appropriate materials for the job; it's important for Builders to understand which wood is best for the job. You as the Builder select the methods to join the pieces of the job so the joints are sturdy and present a good appearance. You also choose the best fasteners to hold the job together.

Objectives

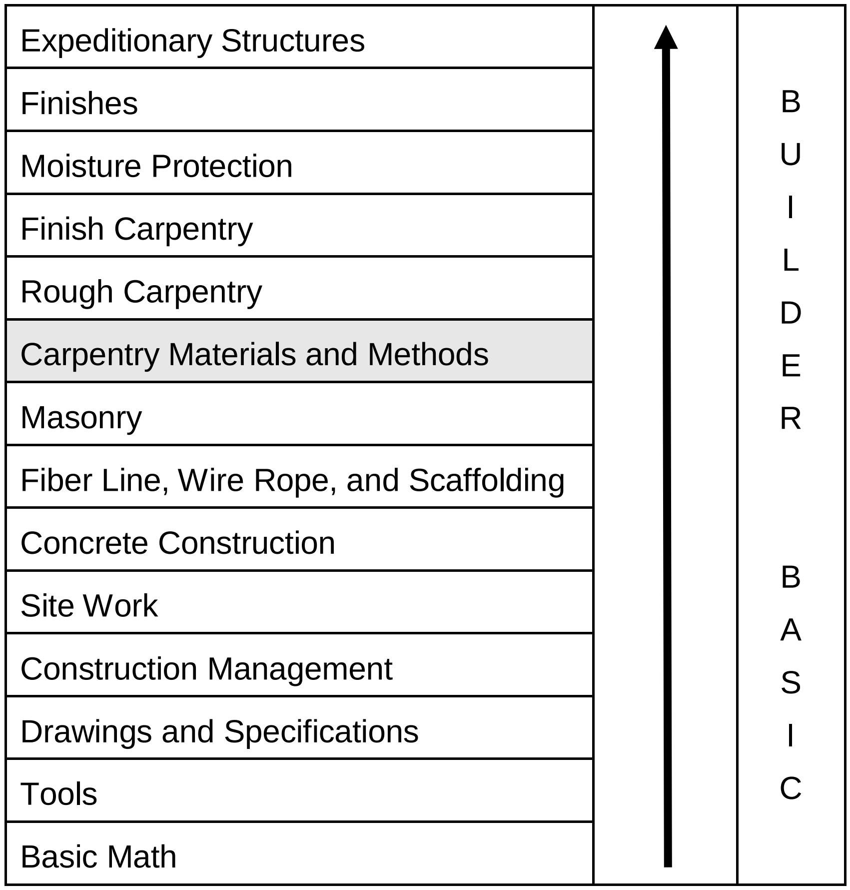
When you have completed this chapter, you will be able to do the following:

1. Identify the types, sources, uses, and characteristics of the common woods used on various construction projects.
2. Identify the various methods and joints associated with woodworking.
3. Identify the different types of fastening devices.

Prerequisites

None

This course map shows all of the chapters in Builder Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.



Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 TYPES of WOOD and USES

Of all construction materials, wood is probably the most often used and perhaps the most important. The variety of uses of wood is practically unlimited. Seabees accomplish few construction projects without using some type of wood. It is used for permanent structures as well as concrete forms, scaffolding, shoring, and bracing. The wood from these temporary structures is reusable again and again. The types, sources, uses, and characteristics of common woods are given in *Table 9-1*. The types of classifications of wood for a large project are usually designated in the project specifications and included in the project drawings.

Table 9-1 – Common Woods

TYPES	SOURCES	USES	CHARACTERISTICS
ASH	East of Rockies	Oars, boat thwarts, benches, gratings, hammer handles, cabinets, ball bats, wagon construction, farm implements	Strong, heavy, hard, tough, elastic, close straight grain, shrinks very little, takes excellent finish, lasts well
BEECH	East of Mississippi and Southeastern Canada	Cabinetwork, imitation mahogany furniture, wood dowels, capping, boat trim, interior finish, tool handles, turnery, shoe lasts, carving, flooring	Similar to birch but not so durable when exposed to weather, shrinks and checks considerably, close grain, light or dark red color
BIRCH	East of Mississippi River and North of Gulf Coast states, Southeast Canada, and Newfoundland	Cabinetwork, imitation mahogany furniture , wood dowels, capping, boat trim, interior finish, tool handles, turnery, carving	Hard, durable, fine grain, even texture, heavy, stiff, strong, tough, takes high polish, works easily, forms excellent base for white enamel finish, but not durable when exposed. Heartwood is light to dark reddish brown in color
BUTTERNUT	Southern Canada, Minnesota, Eastern U.S. as far South as Alabama and Florida	Toys, altars, woodenware, millwork, interior trim, furniture, boats, scientific instruments	Very much like walnut in color but softer, not as soft as white pine and basswood, easy to work, coarse grained, fairly strong
DOUGLAS FIR	Pacific Coast and British Columbia	Deck planking on large ships, shores, strongbacks, plugs, filling pieces and bulkheads of small boats, building construction, dimension timber, ***plywood***	Excellent lumber, strong, easy to work. Clear straight grained, soft but brittle. Heartwood is durable in contact with ground, best structural timber of northwest.
ELM	States East of Colorado	Agricultural implements, wheel-stock, boats, furniture, crossties, posts, poles	Slippery, heavy, hard, tough, durable, difficult to split, not resistant to decay
HICKORY	Arkansas, Tennessee, Ohio, and Kentucky	Tools, handles, wagon stock, hoops, baskets, vehicles, wagon spokes	Very heavy, hard, stronger and tougher than other native woods, but checks, shrinks, difficult to work, subject to

Table 9-1 – Common Woods

TYPES	SOURCES	USES	CHARACTERISTICS
			decay and insect attack
LIVE OAK	Southern Atlantic and Gulf Coasts of U.S., Oregon, and California	Implements, wagons, ship-building	Very heavy, hard, tough, strong, durable, difficult to work. Heartwood is light brown or yellow, sap wood is nearly white
MAHOGANY	Honduras, Mexico, Central America, Florida, West Indies, Central Africa, and other tropical sections	Furniture, boats, decks, fixtures, interior trim in expensive homes, musical instruments	Brown to red color, one of most useful of cabinet woods, hard, durable, does not split badly, open grained, takes beautiful finish when grain is filled but checks, swells, shrinks, warps slightly
MAPLE	All states East of Colorado and Southern Canada	Excellent furniture, high-grade floors, tool handles, ship construction, crossties, counter tops, bowling pins	Fine grained, grain often curly or "Birds' Eyes," heavy, tough, hard, strong, rather easy to work, but not durable. Heartwood is light brown, sap wood is nearly white
NORWAY PINE	States bordering Great Lakes	Dimension timber, masts, spars, piling, interior trim	Light, fairly hard, strong, not durable in contact with ground
PHILIPPINE MAHOGANY	Philippine Islands	Pleasure boats, medium-grade furniture, interior trim	Not a true mahogany, shrinks, expands, splits, warps, but available in long, wide, clear boards
POPLAR	Virginias, Tennessee, Kentucky, and Mississippi Valley	Low-grade furniture, cheaply constructed buildings, interior finish, shelving, drawers, boxes	Soft, cheap, obtainable in wide boards, warps, shrinks, rots easily, light, brittle, weak, but works easily and holds nails well, fine-textured
RED CEDAR	East of Colorado and North of Florida	Mothproof closets, lining for linen closets, sills, and other uses similar to white cedar	Very light, soft, weak, brittle, low shrinkage, great durability, fragrant scent, generally knotty, beautiful when finished in natural color, easily worked
RED OAK	Virginias, Tennessee, Arkansas, Kentucky, Ohio, Missouri, Maryland	Interior finish, furniture, cabinets, millwork, crossties when preserved	Tends to warp, coarse grain, does not last well when exposed to weather, porous, easily impregnated with preservative, heavy, tough, strong
REDWOOD	California	General construction, tanks, paneling	Inferior to yellow pine and fir in strength, shrinks and splits little, extremely soft, light, straight grained, very durable, exceptionally resistant to decay
SPRUCE	New York, New England, West Virginia, Central	Railway ties, resonance wood, piles, airplanes, oars, masts, spars, baskets	Light, soft, low strength, fair durability, close grain, yellowish, sap wood indistinct

Table 9-1 – Common Woods

TYPES	SOURCES	USES	CHARACTERISTICS
	Canada, Great Lakes states, Idaho, Washington, Oregon		
SUGAR PINE	California and Oregon	Same as white pine	Very light, soft, resembles white pine
TEAK	India, Burma, Thailand, and Java	Deck planking, shaft legs for small boats	Light brown color, strong, easily worked, durable, resistant to moisture damage
WALNUT	Eastern half of U.S. except Southern Atlantic and Gulf Coasts, some in New Mexico, Arizona, California	Expensive furniture, cabinets, interior woodwork, gun stocks, tool handles, airplane propellers, fine boats, musical instruments	Fine cabinet wood, coarse grained but takes beautiful finish when pores closed with wood filler, medium weight, hard, strong, easily worked, dark chocolate color, does not warp or check, brittle
WHITE CEDAR	Eastern coast of U.S., around Great Lakes	Boat planking, railroad ties, shingles, siding, posts, poles	Soft, lightweight, close grained, exceptionally durable when exposed to water, not strong enough for building construction, brittle, low shrinkage, fragment, generally knotty
WHITE OAK	Virginias, Tennessee, Arkansas, Kentucky, Ohio, Missouri, Maryland, and Indiana	Boat and ship stems, stern-posts, knees, sheer strakes, fenders, capping, transoms, shaft logs, framing for buildings, strong furniture, tool handles, crossties, agricultural implements, fence posts	Heavy, hard, strong, medium coarse grain, tough, dense, most durable of ***hardwoods***, elastic, rather easy to work, but shrinks and likely to check. Light brownish grey in color with reddish tinge, medullary rays are large and outstanding and present beautiful figures when quarter sawed, receives high polish
WHITE PINE	Minnesota, Wisconsin, Main, Michigan, Idaho, Montana, Washington, Oregon, California	Patterns, any interior job or exterior job that doesn't require maximum strength, window sash, interior trim, millwork, cabinets, cornices	Easy to work, fine grain, free of knots, takes excellent finish, durable when exposed to water, expands when wet, shrinks when dry, soft, white, nails without splitting, not very strong, straight grained
YELLOW PINE	Virginia to Texas	Most important lumber for heavy construction and exterior work, keelsons, risings, filling pieces, clamps, floors, bulkheads of small boats, shores, wedges, plugs, strongbacks, staging, joists, posts, piling, ties, paving blocks	Hard, strong, heartwood is durable in the ground, grain varies, heavy, tough, reddish brown in color, resinous, medullary rays well marked

1.1.0 Lumber

The terms wood, lumber, and timber are often spoken or written as if their meanings are alike or nearly so. In the Builder's language, the terms have distinct, separate meanings. Wood is the hard, fibrous substance that forms the major part of the trunk and branches of a tree. Lumber is wood that has been cut and surfaced for use in construction work. Timber is lumber that is 5 inches or more in both thickness and width.

1.2.0 Seasoning of Lumber

Seasoning lumber is removing moisture from the small and large cells of wood, or drying. The advantages of seasoning lumber are reducing its weight, increasing its strength and resistance to decay, and decreasing shrinkage, which helps to avoid checking and warping after placing the lumber. A seldom used and rather slow method of seasoning lumber is air drying in a shed or stacking in the open until dry. A faster method, known as kiln drying, has lumber placed in a large oven or kiln and dried with heat supplied by gas or oil fired burners. Lumber is dry enough for most uses when its moisture content has been reduced to about 12 to 15 percent. As a Builder, you will learn to judge the dryness of lumber by its color, weight, smell, and feel. After the lumber is cut, you will be able to judge the moisture content by looking at the shavings and chips.

1.3.0 Defects and Blemishes

A defect in lumber is any flaw that tends to affect the strength, durability, or utility value of the lumber. A blemish is a flaw that mars only the appearance of lumber. A blemish that affects the utility value of lumber, such as a tight knot that mars the appearance of lumber intended for fine cabinet work, is also considered a defect. Various flaws apparent in lumber are listed in *Table 9-2*.

Table 9-2 – Wood Defects & Blemishes

Common Name	Description
Bark Pocket	Patch of bark over which the tree has grown, and which it has entirely or almost entirely enclosed
Check	Separation along the lengthwise grain, caused by too rapid or nonuniform drying
Cross Grain	Grain does not run parallel to or spiral around the lengthwise
Decay	Deterioration caused by various fungi
Knot	Root section of a branch that may appear on a surface in cross section or lengthwise. A cross-sectional knot may become may be loose or tight. A lengthwise knot is called a spike knot.
Pitch Pocket	Deposit of solid or liquid pitch enclosed in the wood
Shake	Separation along the lengthwise grain that exists before the tree is cut. A heart shake moves outward from the center of the tree and is caused by decay at the center of the trunk. A wind shake follows the circular lines of the annual rings; its cause is not definitely known.
Wane	Flaw in an edge or corner of a board or timber. It is caused by the presence of bark

Table 9-2 – Wood Defects & Blemishes

Common Name	Description
	or lack of wood in that part.
Warp	Twist or curve caused by shrinkage that develops in a once flat or straight board.
Blue Stain	A blemish caused by a mold fungus; it does not weaken the wood.

1.4.0 Classification of Lumber

Trees are classified as either ***softwood*** or hardwood, as shown in *Table 9-3*. All lumber is therefore classified in the same way. The terms “softwood” and “hardwood” can be confusing since some softwood lumber is harder than some hardwood lumber. Generally, hardwoods are more dense and harder than softwoods. Lumber can be further classified by the name of the tree from which it comes. For example, Douglas fir lumber comes from a Douglas fir tree; walnut lumber comes from a walnut tree, and so forth.

Table 9-3 – Different Types of Softwoods and Hardwoods

Softwoods	Hardwoods
Douglas fir Southern pine Western larch	Basswood Willow American Elm
Hemlock White fir Spruce	Mahogany* Sweet gum White ash*
Ponderosa Pine Western red cedar Redwood	Beech Birch Cherry
Cypress White pine Sugar pine	Maple Oak* Walnut*

*Open-grained wood

The quality of softwood lumber is classified, according to its intended use, as being yard, structural, factory, or shop lumber. Yard lumber consists of those grades, sizes, and patterns generally intended for ordinary building purposes. Structural lumber is 2 or more inches in ***nominal*** thickness and width and is used where strength is required. Factory and shop lumber are used primarily for building cabinets and interior finish work.

Lumber manufacturing classifications consist of rough dressed (surfaced) and worked lumber. Rough lumber has not been dressed but has been sawed, edged, and trimmed. Dressed lumber is rough lumber that has been planed on one or more sides to attain smoothness and uniformity. Worked lumber, in addition to being dressed, has also been matched, shiplapped, or patterned. Matched lumber is tongue and groove, either sides or ends or both. Shiplapped lumber has been rabbeted on both edges to provide a close lapped joint. Patterned lumber is designed to a pattern or molded form.

1.4.1 Softwood Grading

The grade of a piece of lumber is based on its strength, stiffness, and appearance. A high grade of lumber has very few knots or other blemishes. A low grade of lumber may have ***knotholes*** and many loose knots. The lowest grades are apt to have splits, checks, honeycombs, and some warpage. The grade of lumber to be used on any construction job is usually stated in the specifications for a set of blueprints. Basic classifications of softwood grading include boards, dimension, and timbers. The grades within these classifications are shown in *Table 9-4*.

Table 9-4 – Softwood Lumber Grades

	BOARDS		
APPEARANCE			
SELECTS	B & Better C Select D Select	(IWP – Supreme) (IWP – Choice) (IWP – Quality)	
FINISH	Superior Prime E		
PANELING	Clear (Any Select or Finish Grade) No. 2, 3 Common selected for knotty paneling		
SIDING (Bevel, Bungalow)	Superior Prime	**Alternate Board Grades**	
BOARDS SHEATHING	No. 1 Common (IWP – Colonial) No. 2 Common (IWP – Sterling) No. 3 Common (IWP – Standard) No. 4 Common (IWP – Utility)	Select Merchantable Construction Standard Utility	
	DIMENSION		
LIGHT FRAMING 2 in. to 4 in. Thick 2 in. to 4 in. Wide	Construction Standard Utility Economy	This category is for use where high strength values are NOT required, such as studs, plates, sills, cripples, blocking, etc.	
	Stud Economy Stud	An optional all-purpose grade limited to 10 feet and shorter. Characteristics affecting strength and stiffness values are limited so that the Stud grade is suitable for all stud uses, including load bearing walls.	
STRUCTURAL LIGHT FRAMING 2 in. to 4 in. Thick 2 in. to 4 in. Wide	Select Structural No. 1 No. 2 No. 3 Economy	These grades are designed to fit those engineering applications where higher bending strength ratios require light framing sizes. Typical uses would be for trusses, concrete pier wall forms, etc.	
STRUCTURAL JOISTS & PLANKS 2 in. to 4 in. Thick 6 in. and Wider	Select Structural No. 1 No. 2 No. 3 Economy	These grades are designed especially to fit in engineering applications for lumber 6 inches and wider, such as joists, rafters, and general framing uses.	
	TIMBERS		
BEAMS & STRINGERS	Select Structural No. 1 No. 2 (No. 1 Mining) No. 3 (No. 2 Mining)	**POSTS & TIMBERS**	Select Structural No. 1 No. 2 (No. 1 Mining) No. 3 (No. 2 Mining)

Lumber is graded for quality in accordance with American Lumber Standards set by the National Bureau of Standards for the U.S. Department of Commerce. The major quality grades, in descending order of quality, are select lumber and common lumber. *Table 9-5* lists the subdivisions for each grade in descending order of quality.

Table 9-5 – Grades and Subdivisions of Lumber

SELECT LUMBER	
Grade A	This lumber is practically free of defects and blemishes.
Grade B	This lumber contains a few minor blemishes.
Grade C	This lumber contains more numerous and more significant blemishes than grade B. Those blemishes must be capable of being easily and thoroughly concealed with paint.
Grade D	This lumber contains more numerous and more significant blemishes than grade C, but it is still capable of presenting a satisfactory appearance when painted.
COMMON LUMBER	
No. 1	Sound, tight-knotted stock containing only a few minor defects. Must be suitable for use as watertight lumber.
No. 2	Contains a limited number of significant defects but no knotholes or other serious defects. Must be suitable for use as grain-tight lumber.
No. 3	Contains a few defects that are larger and coarser than those in No. 2 common; for example, occasional knotholes.
No. 4	Low-quality material containing serious defects like knotholes, checks, shakes, and decay.
No. 5	Capable only of holding together under ordinary handling.

1.4.2 Hardwood Grades

Grades of hardwood lumber are established by the National Hardwood Lumber Association. Firsts and Seconds (FAS) is the best grade. It specifies that pieces be no less than 6 inches wide by 8 feet long and yield at least 83 1/3 percent clear cuttings. The next lower grade is selects, which permits pieces 4 inches wide by 6 feet long. A still lower grade is No. 1 common. Lumber in this group is expected to yield 66 2/3 percent clear cuttings.

1.4.3 Lumber Sizes

Standard lumber sizes have been established in the United States for uniformity in planning structures and in ordering materials. Lumber is identified by nominal sizes. The nominal size of a piece of lumber is larger than the actual dressed dimensions.

Referring to *Table 9-6*, you can determine the common widths and thicknesses of lumber in their nominal and dressed dimensions.

Table 9-6 – Nominal and Dressed Sizes of Lumber

Nominal Size (Inches)	Dressed Size (Inches)
1 x 3	3/4 x 2 1/2
1 x 4	3/4 x 3 1/2
1 x 6	3/4 x 5 1/2
1 x 8	3/4 x 7 1/4
1 x 10	3/4 x 9 1/4
1 x 12	3/4 x 11 1/4
2 x 4	1 1/2 x 3 1/2
2 x 6	1 1/2 x 5 1/2
2 x 8	1 1/2 x 7 1/4
2 x 10	1 1/2 x 9 1/4
2 x 12	1 1/2 x 11 1/4
3 x 8	2 1/2 x 7 1/4
3 x 12	2 1/2 x 11 1/4
4 x 12	3 1/2 x 11 1/4
4 x 16	3 1/2 x 15 1/4
6 x 12	5 1/2 x 11 1/2
6 x 16	5 1/2 x 15 1/2
6 x 18	5 1/2 x 17 1/2
8 x 16	7 1/2 x 15 1/2
8 x 20	7 1/2 x 19 1/2
8 x 24	7 1/2 x 23 1/2

You can see in *Table 9-6* that nominal lumber sizes are a little larger than dressed lumber sizes. For softwood boards, there is a general rule to figure the dressed size of a piece of lumber, based on the nominal size. For boards with a nominal width up to and including one inch, the dressed size will be 1/4 inch smaller. For boards with a nominal width of two to six inches, the dressed size will be 1/2 inch smaller. For boards with a width larger than six inches, the dressed size will be 3/4 inch smaller. This rule may not be accurate in every case, so if there is any doubt about the size of a dressed piece of lumber, measure the piece.

1.4.4 Locally Procured Materials (Foreign Lumber)

You will have the opportunity to work on construction projects overseas. Be aware that the quantity and sizes of material, including lumber, will be different than what you work with in the United States. The Naval Facilities Engineering Command (NAVFAC) offices take this into account when they solicit project plans from the local engineering firms. The local Resident Officer in Charge of Construction (RIOCC) is well aware of the various products available in the project area and their intended use. The local Public Works Department or Supply Department is available for ensuring locally purchased material meets the specifications outlined for the project.

1.5.1 Engineered Wood Products

When Seabees first started building projects for the Navy, there were more abundant old-growth forests, which provided structural beams, timbers, joists, and other weight-bearing lumber. These old-growth forests have been reduced, driving up the cost of construction material and increasing conflict with forest conservation groups.

Lumber producers have developed laminating techniques that allow the use of younger trees to create a variety of building products. These products, called Engineered Wood Products, have a number of benefits over products fomr old-growth forests.

- They are made from more abundant young trees.
- The yield from a tree increases 30 to 50 percent.
- The engineered products are stronger than the natural products. A piece of engineered lumber the same size can bear more weight than its natural counterpart. Better yet, a smaller piece of engineered lumber can bear the same weight as a larger natural piece of lumber.
- Engineered lumber, with its greater strength, can span a greater distance than natural lumber.
- A length of engineered lumber is lighter than than the same length of natural lumber, which makes it easier to handle.
- Engineered lumber does not warp, crown, or twist, which helps it retain accurate dimensions.

There are five main categories of engineered wood products. These include ***laminated*** veneer lumber, parallel strand lumber, laminated strand lumber, wood I-beams, and glue-***laminated lumber*****,** also known as glue-lam.

1.5.1 Laminated Veneer Lumber (LVL)

LVL is similar to plywood because it is made from multiple layers of laminated thin wood veneer. Unlike plywood, the layers in LVL run in the same direction, parallel to the long direction, and do not have crossbands. The layers are glued with exterior grade adhesive, then pressed together and heated under pressure.

You can use LVL for permanent application in floor and roof beams, as well as door and window headers, or for temporary applications like scaffolding and concrete forms.

1.5.2 Parallel Strand Lumber (PSL)

PSL is made from long veneer strands. These strands are laid parallel to each other and bonded together with an adhesive in a specialized heating process.

You can use PSL as beams, posts, and columns. It is good for use in load-bearing applications.

1.5.3 Laminated Strand Lumber (LSL)

LSL is made from small logs that can't be used for standard lumber. The bark is removed from the logs, and then the logs are cut into short strands. The strands are dried, coated with resin, and pressed into long blocks called billets by a process that includes steam injection.

You can use LSL for millwork such as doors and windows, or other applications that require high-grade lumber. LSL does not have the load bearing capacity of PSL.

1.5.4 Wood I-Beams

The wood I-beam shown in *Figure 9-1* is a composite structural member made up of a web with flanges bonded to it with exterior type adhesives. The web is made of oriented strand board or plywood; the flanges are made of dimension lumber or laminated veneer lumber with grooves that fit over the web.

Like the steel I-beam that it resembles, the wood I-beam is exceptionally strong. You can use it for floor joists, rafters, and headers.

Figure 9-1 –Wood I-beam.

1.5.5 Glue-Laminated Lumber (Glulam)

The laminated lumber shown in *Figure 9-2* is made of several pieces of kiln-dried lumber held together as a single unit, a process called lamination. The pieces are nailed, bolted, or glued together with the grain of all pieces running parallel.

Figure 9-2 – Laminated lumber.

Glulam is very versatile; it can be shaped into forms from straight beams to complex curved members. You can use it for headers, floor girders, ridge beams, stair treads and stringers, purlins, cantilever beam systems, and arches.

Laminating greatly increases the load carrying capacity and rigidity of the wood. When extra length is needed, the pieces are spliced with the splices staggered so that no two adjacent laminations are spliced at the same point. Built up beams and girders are examples. They are built as shown in *Figure 9-3*, usually nailed or bolted together and spliced.

Figure 9-3 – Built up beam.

Lamination can be used independently or with other materials in the construction of a structural unit. Trusses can be made with lamination for the chords and sawed lumber for the web members as shown in *Figure 9-4*.

Figure 9-4 – Truss using laminated and sawed lumber.

Units such as plywood box beams and stressed skin panels can contain both plywood and lamination, as shown in Figure 9-5.

Probably the most common use of lamination is in the fabrication of large beams and arches. Beams with spans in excess of 100 feet and depths of 8 1/2 feet have been constructed using 2-inch boards. Laminations this large are factory produced. They are glued together under pressure. Most laminations are spliced using scarf joints as shown in Figure 9-6, and the entire piece is dressed to ensure uniform thickness and width.

Figure 9-5 – Stressed skin panel.

Figure 9-6 – Scarf joints.

The depth of the lamination is placed in a horizontal position and is usually the full width of the beam, as shown in *Figure 9-7*.

Figure 9-7 – Laminated beam.

1.6.0 Plywood

Plywood is constructed by gluing together a number of layers (plies) of wood with the grain direction turned at right angles in each successive layer. This design feature makes plywood highly resistant to splitting. It is one of the strongest building materials available to Seabees. An odd number (3, 5, or 7) of plies is used so that they will be balanced on either side of a center core and so that the grain of the outside layers runs in the same direction.

The outer plies are called faces or face and back. The next layers under these are called crossbands, and the other inside layer or layers are called the core, as shown in *Figure 9-8*. A plywood panel made of three layers would consist of two faces and a core.

There are two basic types of plywood, exterior and interior. Exterior plywood is bonded with waterproof glues. It can be used for siding, concrete forms, and other constructions where it will be exposed to the weather or excessive moisture. Interior plywood is bonded with glues that are not waterproof. It is used for cabinets and other inside construction where the moisture content of the panels will not exceed 20 percent.

Figure 9-8 – Grain directions in a sheet of plywood.

Plywood is made in thicknesses of 1/8 inch to more than 1 inch, with the common sizes being 1/4, 3/8, 1/2, 5/8, and 3/4 inch. A standard panel size is 4 feet wide by 8 feet long. Smaller size panels are available in the hardwoods.

Plywood can be worked quickly and easily with common carpentry tools. It holds nails well and normally does not split when nails are driven close to the edges. Finishing plywood presents no unusual problems; it can be sanded, texture coated with a permanent finish, or left to weather naturally.

There is probably no other building material as versatile as plywood. It is used for concrete forms, wall and roof sheathing, flooring, box beams, soffits, stressed skin panels, paneling, shelving, doors, furniture, cabinets, crates, signs, and many other items.

1.6.1 Softwood Plywood Grades

All plywood panels are quality graded based on products standards (currently PS 1/74). The grade of each type of plywood is determined by the kind of veneer (N, A, B, C, or D) used for the face and back of the panel and by the type of glue used in construction. The plywood veneer grades are shown in *Table 9-7*.

Table 9-7 – Plywood Veneer Grades

DESCRIPTION	
N	Special order “natural-finish” veneer. Select all heartwood or all sapwood. Free of open defects. Allows some repairs.
A	Smooth and paintable. Neatly made repairs permissible. Also used for natural finish in less demanding applications.
B	Solid surface veneer. Circular repair plugs and tight knots permitted.
C	Knotholes to 1 inch. Occasional knotholes 1/2 inch larger permitted providing

	total width of all knots and knotholes within a specified section does not exceed certain limits. Limited splits permitted. Minimum veneer permitted in exterior-type plywood.
C Plgd	Improved C veneer with splits limited to 1/8 inch in width and knotholes and borer holes limited to 1/4 inch by 1/2 inch.
D	Permits knots and knotholes to 2 1/2 inches in width and 1/2 inch larger under certain specified limits. Limited splits permitted.

Many species of softwood are used in making plywood. There are five separate plywood groups based on stiffness and strength. Group 1 includes the stiffest and strongest and group 5 the weakest woods. A list of groupings and associated woods is shown in *Table 9-8*.

Table 9-8 – Classification of Softwood Plywood Rates Species for Strength and Stiffness

GROUP 1	GROUP 2		GROUP 3	GROUP 4	GROUP 5
Apitong	Cedar,	Maple,	Alder,	Aspen,	Basswood
Beech,	Port	Black	Port	Bigtooth	Fir,
American	Orford	Mengkulang	Birch,	Quaking	Balsam
Birch,	Cypress	Meranti,	Paper	Cativo	Poplar,
Sweet	Douglas fir	Red	Cedar,	Cedar,	Balsam
Yellow	Fir,	Mersawa	Alaska	Incense	
Douglas fir	California	Pine,	Fir,	Western	
Kapur	Red	Pond	Subalpine	Red	
Keruing	Grand	Red	Hemlock,	Cottonwood,	
Larch,	Noble	Virginia	Eastern	Eastern	
Western	Pacific	Western	Maple,	Black	
Maple,	Silver	White	Bigleaf	Western poplar	
Sugar	Hemlock,	Spruce,	Pine,	Pine,	
Pine,	White	Red	Jack	Eastern	
Caribbean	Western	Sitka	Lodgepole	White	
Ocote	Lauan,	Sweetgum	Ponderosa	Sugar	
Pine,	Almon	Tamarack	Spruce		
South	Bagtikan	Yellow poplar	Redwood		
Loblolly	Mayapis		Spruce,		
Longleaf	Red Lauan		Black		
Shortleaf	Tangile		Engelmann		
Slash	White lauan		White		

1.6.2 Grade/Trademark Stamp

Construction and industrial plywood panels are marked with different stamps.

Construction Panels - Grading identification stamps, as shown in *Figure 9-9*, indicate the kind and type of plywood. The stamps are placed on the back and sometimes on the edges of each sheet of plywood.

For example, a sheet of plywood having the designation "A-C" would have A grade veneer on the face and C grade veneer on the back. Grading is also based on the number of defects, such as knotholes, pitch pockets, splits, discolorations, and patches in the face of each panel. Each panel or sheet of plywood has a stamp on the back that gives all the information you need. *Table 9-9* lists some uses for construction grade plywood.

Figure 9-9 – Standard plywood identification symbols.

Table 9-9 – Plywood Uses

SOFTWOOD PLYWOOD GRADES FOR EXTERIOR USES				
Grade (Exterior)	**Face**	**Back**	**Inner Plies**	**Uses**
A-A	A	A	C	Outdoor where appearance of both sides is important.
A-B	A	B	C	Alternate for A-A where appearance of one side is less important.
A-C	A	C	C	Siding, soffits, fences. Face is finish grade.
B-C	B	C	C	For utility uses, such as farm buildings, some kinds of fences, etc.
C-C (Plugged)	C (Plugged)	C	C	Excellent base fir tile and linoleum, backing for wall coverings.
C-C	C	C	C	Unsanded, for backing and rough construction exposed to weather.
B-B Concrete Forms	B	B	C	Concrete forms. Reuse until wood literally wears out.
MDO	B	B or C	C or C-Plugged	Medium density overlay. Ideal base for paint; for siding, built-ins, signs, displays.
HDO	A or B	A or B	C- Plugged	High density overlay. Hard surface, no paint needed. For concrete forms, cabinets, counter tops, tanks.

SOFTWOOD PLYWOOD GRADES FOR INTERIOR USES				
Grade (Interior)	**Face**	**Back**	**Inner Plies**	**Uses**
A-A	A	A	D	Cabinet doors, built-ins, furniture where both sides will show.
A-B	A	B	D	Alternate of A-A. Face is finish grade, back is solid and smooth.
A-D	A	D	D	Finish grade face for paneling, built-ins, backing.
B-D	B	D	D	Utility grade. One paintable side. For backing, cabinet sides, etc.
Standard	C	D	D	Sheathing and structural uses such as temporary enclosures, subfloor. Unsanded.

Industrial Panels - Structural and sheeting panels have a stamp found on the back. A typical example for an industrial panel grade of plywood is shown in *Figure 9-10*.

The span rating shows a pair of numbers separated by a slash mark (/). The number on the left indicates the maximum recommended span in inches when the plywood is used as roof decking (sheeting). The right hand number applies to span when the plywood is used as subflooring. The rating applies only when the sheet is placed the long dimension across three or more supports. Generally, the larger the span rating, the greater the stiffness of the panel.

Figure 9-10 – Structural stamp.

Figure 9-11 lists some typical engineered grades of plywood. Included are descriptions and most common uses.

Typical Trademarks	Description and Common Uses	Grade	
APA RATED SHEATHING 48/24 3/4 INCH SIZED FOR SPACING EXTERIOR 000 NRB-196	Exterior sheathing panel for subflooring and wall and roof sheathing, siding on service and farm etc. Manufactured as conventional veneered 5/8, 3/4.	APA Rated Ext	EXTERIOR USE
APA RATED SHEATHING STRUCTURAL I 42/20 5/8 INCH SIZED FOR SPACING EXTERIOR 000 PS1-74C-C NRB-168	For engineered applications in construction and industry where resistance to permanent exposure to weather or moisture is required. Manufactured Unsanded. STRUCTURAL 1 more commonly 5/8, 3/4. (3)	APA Structural Sheathing Ext	
APA RATED STURD-I-FLOOR 20 OC 19/32 INCH SIZED FOR SPACING EXTERIOR 000 NRB-100	For combination subfloor-underlayment under resilient floor coverings where severe moisture problems may be present , as in balcony decks. resistance. Manufactured only as conventional tongue and groove. Common thicknesses: 5/8 (19/32), 3/4 (23/32).	APA Rated Ext	
APA RATED SHEATHING 32/16 1/2 INCH SIZED FOR SPACING EXPOSURE I 000 NRB-106	Specially designed for subflooring and wall and roof sheathing, but can also be used for a broad range of other construction and industrial applications. Can be manufactured as conventional veneered plywood, as a composite, applications, including high load requirements and panels conforming to PS 1. Specify Exposure 1 when long construction delays are anticipated. Common thicknesses: 5/16, 3/8, 7/16, 1/2, 5/8, 3/4.	APA Rated Exp 1 or 2	PROTECTED OR INTERIOR USE
APA RATED SHEATHING STRUCTURAL I 24/0 3/8 INCH SIZED FOR SPACING EXPOSURE I 000 PS1-74 C-D INT/EXT GLUE NRB-106	Unsanded all-veneer PS 1 plywood grades for use where strength properties are of maximum importance: structural diaphragms, box beams, gusset plates, stressed-skin panels, containers, pallet bins. Made only with exterior glue (Exposure 1). Structural 1 more commonly available. Common thicknesses: 5/16, 3/8, 1/2, 5/8,3/4. (3)	APA Structural Sheathing	
APA RATED STURD-I-FLOOR STRUCTURAL I 24 OC 23/32 INCH SIZED FOR SPACING T&G NET WIDTH47 1/2 EXPOSURE I 000 NRB-106	For combination subfloor-underlayment. Provides smooth surface for application of resilient floor covering and possesses high concentrated and impact load resistance. Can be manufactured as conventional veneered plywood, as a composite, or as a nonveneered panel. Available square edge or tongue and groove. Specify Exposure 1 when long construction delays are anticipated.	APA Rated Sturd-I-Floor Exp 1 or 2	

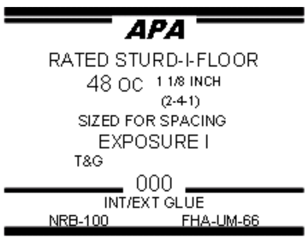
	Common thicknesses: 5/8 (19/32, 3/4 (23/32).		
	For combination subfloor-underlayment on 32- and 48-inch spans and for heavy timber roof construction. Provides smooth surface for application of resilient floor coverings and possesses high concentrated and impact load resistance. Manufactured only as conventional veneered plywood and only with exterior glue (Exposure 1). Available in square edge or tongue and groove. Thickness: 1 1/8.	APA Rated Sturd-I-Floor 48 oc (2-4-1) Exp 1	
(1) Specific grades, thicknesses, constructions, and exposure durability classifications may be limited in supply in some areas. (2) Specify Performance-Rated Panels by thickness and Span Rating. (3) All plies in Structural I panels are special improved grades and limited to Group 1 species. All plies in Structural II panels are special improved grades and limited to Group 1, 2, or 3 species.			

Figure 9-11 – List of engineered grade of softwood plywood.

Exposure Ratings - The grade/trademark stamp lists the exposure durability classification for plywood. There are two basic types or ratings, exterior and interior. The exterior type has a 100 percent waterproof glue line, and the interior type has a highly moisture resistant glue line. Panels can be manufactured in three exposure durability classifications; Exterior, Exposure 1, and Exposure 2.

Panels marked Exterior can be used where there is continual exposure to weather and moisture. Panels marked Exposure 1 can withstand moisture during extended periods, but they should be used only indoors. Panels marked Exposure 2 can be used in protected locations. They may be subjected to some water leakage or high humidity but generally should be protected from weather.

Most plywood is made with waterproof exterior glue. Interior panels may be made with intermediate or interior glue.

1.6.3 dwood Plywood Grades

Hardwood plywood panels are primarily used for door skins, cabinets, and wall paneling. The Hardwood Plywood Manufacturers' Association has established a grading system with the following grades: premium (A), good grade (1), sound grade (2), utility grade (3), and backing grade (4). For example, A-3 grade hardwood plywood has a premium face and a utility back. 1-1 grade has a good face and a good back.

Test your Knowledge (Select the Correct Response)

1. A blemish in a piece of lumber is classified as a defect when it affects what quality?

   A. Utility value
   B. Strength
   C. Durability
   D. Size

2. By weight, plywood is one of the strongest building materials available. Which of the following factors is primarily responsible for this strength?

A. Grade of wood
B. Number of plies
C. High-strength glue
D. Cross lamination

2.0.0 WOODWORKING METHODS

This section covers some of the methods Builders use to join wood.

2.1.1 Planing and Squaring to Dimensions

Planing and squaring a small piece of board to dimensions is what you might call the first lesson in woodworking. Like many other things you may have tried to do, it looks easy until you try it. The six major steps in this process are illustrated and described in *Figures 9-12* through *9-17*. You should practice these steps until you can get a smooth, square board with a minimum of planing.

1. Work the First Face - Plane one broad surface smooth and straight. Test it crosswise, lengthwise, and from corner to corner. Mark the work face x.

Figure 9-12 – Working the face.

2. Work the First Edge - Plane one edge smooth, straight and square to the work face. Test it from the work face. Mark the work edge x.

Figure 9-13 – Working the edge.

3. Work the First End - Plane one end smooth and square. Test it from the work face and work edge. Mark the work face x.

Figure 9-14 – Working the first end.

4. Work the Second End - Measure length and scribe around the stock. Align square to the work edge and work face. Saw off excess stock near the line and plane smooth to the scribed line. Test the second edge from both the work face and the work edge.

Figure 9-15 – Working the second end.

5. Work the Second Edge - From the work edge, gauge a line for width on both faces. Plane smooth, straight, square, and to the gauge line. Test the second edge from the work face.

Figure 9-16 – Working the second edge.

6. Work the Second Face - From the work face, gauge a line for thickness around the stock. Plane the stock to the gauge line. Test the second face as the work face is tested.

Figure 9-17 – Working the second face.

2.2.1 Joints and Joining

One basic skill of woodworking is the art of joining pieces of wood to form tight, strong, well made joints. The two pieces that are to be joined together are called members. The two major steps in making joints are (1) laying out the joint on the ends, edges, or faces and (2) cutting the members to the required shapes for joining.

The instruments normally used for laying out joints are as follows:

- Try square
- Miter square
- Combination square
- Sliding T bevel
- Marking or mortising gauge
- Scratch awl
- Sharp pencil or knife for scoring lines

For cutting the more complex joints by hand, the hacksaw, dovetail saw, and various chisels are essential. The rabbet and fillister plane for ***rabbet joints*** and the router plane for smoothing the bottoms of dadoes and ***gains*** are also helpful.

Simple joints are used mostly in rough or finish carpentry. They may be used occasionally in millwork and furniture making. They include:

- Butt joints
- ***Lap joints***
- ***Miter joints***

More complex joints are used mostly in making furniture and cabinets and in millwork. They include:

- Rabbet joints
- Dado and gain joints
- Blind ***mortise and tenon joints***
- Slip tenon joints
- Box corner joints
- ***Dovetail joints***

Edge joints are used mainly in furniture and cabinet work. They include:

- Dowel joints
- Spline joints

Plain butt joints and tongue and groove joints are used in practically all types of woodworking.

The joints used in rough and finished carpentry are, for the most part, simply nailed together. Nails in a 90° plain butt joint can be driven through the member abutted against and into the end of the abutting member. The joints can also be ***toenailed*** at an angle through the faces of the abutting member into the face of the member abutted against, as shown in *Figure 9-18*. Studs and joists are usually toenailed to soleplates and sills.

Figure 9-18 – Toenailing.

The more complex furniture and cabinet making joints are usually fastened with glue. Dowels, splines, ***corrugated fasteners***, keys, and other types of joint fasteners can provide additional strength. In the ***dado joint***, the gain joint, the mortise and tenon joint, the box corner joint, and the dovetail joint, the interlocking character of the joint is an additional factor in fastening.

All the joints we have mentioned can be cut either by hand or by machine, and are shown in *Figure 9-19*.

Figure 9-19 – Edge joints.

Whatever the method used and whatever the type of joint, remember, to ensure a tight joint, always cut on the waste side of the line, never on the line itself. Preliminary grooving on the waste side of the line with a knife or chisel will help a backsaw start smoothly.

2.2.1 utt Joints

A 90° plain butt joint is two boards glued edge to edge or face to edge without overlapping as shown in *Figure 9-20*. It is mostly used for thin wood, under 1 inch thick.

A butt joint can have a wood or plywood piece called a fishplate used to fasten the ends of two members together with nails or bolts, shown in *Figure 9-21*. These are sometimes used at the junction of opposite rafters near the ridge line.

Figure 9-20 - 90° plain butt joints.

Figure 9-21 – End butt joints with fishplates.

2.2.2 Half Lap Joints

For half lap joints, the members to be jointed are usually of the same thickness, as shown in *Figure 9-22*.

The method of laying out and cutting an end butt half lap as shown in *Figure 9-22* is as follows:

1. Measure off the desired amount of lap from each end of each member and square a line all the way around at this point. For a corner half lap, as in *Figure 9-22*, measure off the width of the member from the end of each member and square a line all the way around. These are called shoulder lines.

Figure 9-22 – Lap joints.

2. Select the best surface for the face and set a marking gauge to one-half the thickness. Score a line, called the cheek line, on the edges and end of each member from the shoulder line on one edge to the shoulder line on the other edge. Gauge the cheek line from the face of each member to ensure the faces of each member will be flush after the joints are cut.
3. Make the shoulder cuts by cutting along the waste side of the shoulder lines down to the waste side of the cheek line.
4. Make the cheek cuts along the waste side of the cheek lines. When all cuts have been made, the members should fit together with faces, ends, and edges flush or near enough to be made flush with the slight paring of a wood chisel.

Other half lap joints are laid out in a similar manner; the main difference is in the cutting method. A cross half lap joint is best cut with a dado head or wood chisel rather than a handsaw. Others may easily be cut on a bandsaw. When you cut a half lap joint this way, be certain to cut on the waste side of the lines and make all lines from the face of the material.

2.2.3 Miter Joints

A miter joint is made by ***mitering*** the ends or edges of the members to be joined together as shown in *Figure 9-23*. The angle of the miter cut is one half of the angle formed by the joined members. In rectangular mirror frames, windows, and door casing boxes, adjacent members form a 90° angle, so the correct angle for mitering is one half of 90°, or 45°. For members forming an equal sided figure with other than four sides, such as an octagon or a pentagon, find the correct mitering angle by dividing the number of sides the figure will have into 180° and subtracting the result from 90°.

Figure 9-23 – Miter joint.

For an octagon, a figure with eight sides, determine the mitering angle by subtracting 180° divided by 8 from 90°. This is shown by the following formula:

$90° - (180° \div 8)$
or
$90° - 22.5° = 67.5°$

For a pentagon, a figure with five sides, the angle is:

$90° - (180° \div 5)$
or
$90° - 36° = 54°$

End miter members to 45° in the wooden miter box and to any angle in the steel miter box by setting the saw to the desired angle, or on the ***circular saw*** by setting the miter gauge to the desired angle. Edge miter members to any angle on the circular saw by tilting the saw to the required angle.

Sawed edges are sometimes unsuitable for gluing. If the joint is to be glued, the edges can be mitered on a ***jointer*,** as shown in *Figure 9-24*. Please note that the saw guard does not appear in this figure to better show the relationship of the blade to the stock.

Figure 9-24 – Beveling on a jointer for a mitered edge joint.

CAUTION

This is a dangerous operation and caution should be taken.

Since abutting surfaces of end mitered members do not hold well when they are merely glued, they should be reinforced. One type of reinforcement is the corrugated fastener. This is a corrugated strip of metal with one edge sharpened for driving into the joint. Place the fastener at a right angle to the line between the members, half on one member and half on the other, and drive it down flush with the member. The corrugated fastener mars the appearance of the surface into which it is driven, so use it only on the backs of picture frames and the like.

A more satisfactory type of fastener for a joint between end mitered members is the biscuit. This is a thin piece of wood or veneer that is glued into a kerf cut in the thickest dimension of the joint. Use the biscuit in the following manner:

1. Saw about halfway through the wood from the outer to the inner corner.
2. Apply glue to both sides of the biscuit, pushing the biscuit into the kerf.
3. Clamp it tightly and allow the glue to dry.
4. After it has dried, remove the clamp and chisel off the protruding portion of the biscuit.

A joint between edge mitered members can also be reinforced with a spline. This is a thick piece of wood that extends across the joint into grooves cut in the abutting surfaces. A spline for a plain miter joint is shown in *Figure 9-25*. Cut the groove for a spline either by hand or with a circular saw.

Figure 9-25 – Plain miter joint.

2.2.4 Grooved Joints

A three-sided recess running with the grain is called a groove, and a recess running across the grain is called a dado. A groove or dado that does not extend all the way across the wood is called a stopped groove or stopped dado. A stopped dado, also known as a gain, is shown in *Figure 9-26*.

A two-sided recess running along an edge, as shown in *Figure 9-27*, is called a rabbet T. Dadoes, gains, and rabbets are not, strictly speaking, grooves; but joints that include them are generally called grooved joints.

Figure 9-26 – Dado and gain joints.

Figure 9-27 – Rabbet joints.

Cut a groove or dado with a circular saw as follows:

1. Lay out the groove or dado on the end wood (for a groove) or edge wood (for a dado) that will first come in contact with the saw.
2. Set the saw to the desired depth of the groove above the table, and set the fence at a distance from the saw that will cause the first cut to run on the waste side of the line that indicates the left side of the groove.
3. Start the saw and bring the wood into light contact with it; then stop the saw and examine the layout to ensure the cut will be on the waste side of the line.
4. Readjust the fence, if necessary. When the position of the fence is right, make the cut.
5. Reverse the wood and proceed to set and test as before for the cut on the opposite side of the groove. Make as many recuts as necessary to remove the waste stock between the side kerfs.

The procedure for grooving or dadoing with the dado head is about the same, except that in many cases you can build up the dado head to take out all the waste in a single cut. The two outside cutters alone will cut a groove 1/4 inch wide. Inside cutters vary in thickness from 1/16 to 1/4 inch.

Cut a stopped groove or stopped dado on the circular saw, using either a saw blade or a dado head, as follows:

1. If the groove or dado is stopped at only one end, clamp a stop block to the rear of the table in a position to stop the wood from being fed any farther when the saw has reached the place where the groove or dado is supposed to stop.
2. If the groove or dado is stopped at both ends, clamp a stop block to the rear of the table and a starting block to the front. Place the starting block so the saw will

contact the place where the groove is supposed to start when the infeed end of the piece is against the block.

3. Start the cut by holding the wood above the saw with the infeed end against the starting block and the edge against the fence.
4. Lower the wood gradually onto the saw and feed it through to the stop block.

A rabbet joint requires two cuts; the cut into the face of the wood is called the shoulder cut, and the cut into the edge or end is called the cheek cut. A rabbet can be cut on the circular saw. Make the shoulder cut first, as follows:

1. Set the saw to extend above the table to the desired depth of the cheek.
2. Be sure to measure this distance from a sawtooth set to the left, or away from the ripping fence. If you measure it from a tooth set to the right or toward the fence, the cheek will be too deep by an amount equal to the width of the saw kerf.

By using the dado head, you can cut most ordinary rabbets in a single cut.

1. Build up a dado head equal in thickness to the desired width of the cheek.
2. Set the head to protrude above the table to the desired depth of the shoulder.
3. Clamp a 1-inch board to the fence to serve as a guide for the piece, and set the fence so the edge of the board barely contacts the right side of the dado head.
4. Set the miter gauge at 90°. Set the piece against the miter gauge, hold the edge or end to be rabbeted against the 1-inch board and make the cut.

On some jointers, a rabbeting ledge attached to the outer edge of the infeed table can be depressed for rabbeting, as shown in *Figure 9-28*. Please note that the saw guard does not appear in this figure to better show the relationship of the blade to the stock.

The ledge is located on the outer end of the cutterhead. To rabbet on a jointer of this type, depress the infeed table and the rabbeting ledge the depth of the rabbet below the outfeed table, and set the fence the width of the rabbet away from the outer end of the cutterhead. When the piece is fed through, the unrabbeted part feeds onto the rabbeting ledge. The rabbeted portion feeds onto the outfeed table.

Figure 9-28 – Rabbeting on a jointer with a rabbeting ledge.

Various combinations of the grooved joints are used in woodworking. The tongue and groove joint is a combination of the groove and the rabbet, with the tongued member rabbeted on both faces. In some types of paneling, the tongue is made by rabbeting only one face. A tongue of this kind is called a barefaced tongue. A joint often used in making boxes, drawers, and cabinets is the dado and rabbet joint, shown in *Figure 9-29*. As you can see, one of the members is rabbeted on one face to form a barefaced tongue.

Figure 9-29 – Dado and rabbet joint.

2.2.5 Mortise and Tenon Joints

The mortise and tenon joint is most frequently used in furniture and cabinet work. In the blind mortise and tenon joint, the tenon does not penetrate all the way through the mortised member. This type of joint is shown in *Figure 9-30*.

Figure 9-30 – Tenon joints.

A joint in which the tenon does penetrate all the way through is a through mortise and tenon joint, shown in *Figure 9-31*.

Besides the ordinary stub joint seen in *Figure 9-31 view A*, there are haunched joints, as seen in *view B*, and table haunched joints, as seen in *view C*. Haunching and table haunching increase the strength and rigidity of the joint.

Figure 9-31 – Stub (view A), haunched (view B), and table haunched (view C) mortise and tenon joints.

The layout procedure for an ordinary stub mortise and tenon joint is shown in *Figure 9-32*.

Figure 9-32 – Layout of stub mortise and tenon joint.

The shoulder and cheek cuts of the tenon are shown in *Figures 9-33* and *9-34*. Please note that the saw guard does not appear in these figures to better show the relationship of the blade to the stock.

To maintain the stock upright while making the cheek cuts, use a push board similar to the one shown in *Figure 9-34*. Tenons can also be cut with a dado head by the same method previously described for cutting end half lap joints.

Figure 9-33 – Making tenon shoulder cut on a table saw.

Figure 9-34 – Making tenon cheek cut on a table saw using a push board.

Mortises are cut mechanically on a hollow chisel mortising machine like the one shown in *Figure 9-35*. The cutting mechanism on this machine consists of a boring bit encased in a square, hollow, steel chisel. As the mechanism is pressed into the wood, the bit takes out most of the waste while the chisel pares the sides of the mortise square. Chisels come in various sizes, with corresponding sizes of bits to match.

If a mortising machine is not available, the same results can be attained by using a simple drill press to take out most of the waste and a hand chisel, for paring the sides square.

Figure 9-35 – Hollow chisel mortising machine.

In some mortise and tenon joints, such as those between rails and legs in tables, the tenon member is much thinner than the mortise member. Sometimes a member of this kind is too thin to shape with shoulder cuts on both faces in the customary reamer. When this is the case, use a barefaced mortise and tenon joint. For a barefaced joint, cut the tenon member on one side only. The cheek on the opposite side is simply a continuation of the face of the member.

Mortise and tenon joints are fastened with glue and with additional fasteners, as required.

2.2.6 Dovetail Joints

The dovetail joint, shown in *Figure 9-36*, is the strongest of all the woodworking joints. It is used principally for joining the sides and ends of drawers in fine grades of furniture and cabinets. In a Seabee unit, you will seldom use dovetail joints since they are laborious and time consuming to make.

A through dovetail joint is a joint in which the pins pass all the way through the tail member. Where the pins pass only part way through, the member is known as a blind dovetail joint.

Figure 9-36 – Dovetail joints.

The simplest of the dovetail joints is the dovetail half lap joint, shown in *Figure 9-37.*

Figure 9-37 – Dovetail half lap joint.

Figure 9-38 shows how this type of joint is laid out, and *Figure 9-39* shows the completed joint.

Figure 9-38 – Laying off 10° angle for dovetail joint.

Figure 9-39 – Making a dovetail half lap joint.

A multiple dovetail joint is shown in *Figure 9-40*; *Figure 9-41* shows how the waste is chiseled from the multiple joint.

Figure 9-40 – Laying out a pin member for a through multiple dovetail joint.

Figure 9-41 – Chiseling out waste in a through multiple dovetail joint.

2.2.7 ox Corner Joint

With the exception of the obvious difference in the layout, the box corner joint shown in *Figure 9-42* is made in a manner similar to that of the through multiple dovetail joint.

Figure 9-42 – Box corner joint.

2.2.8 oping Joints

Inside corner joints between molding trim members are usually made by butting the end of one member against the face of the other. *Figure 9-43* shows the method of shaping the end of the abutting member to fit the face of the other member:

1. Saw off the end of the abutting member square, as you would for an ordinary butt joint between ordinary flat faced members.
2. Miter the end to 45°, as shown in the first and second views of *Figure 9-42*.
3. Set the coping saw at the top of the line of the miter cut, hold the saw at 90° to the lengthwise axis of the piece, and saw off the segment shown in the third view, following closely the face line left by the 45° miter cut. The end of the abutting member will then match the face of the other member, as shown in the third view. A joint made in this reamer is called a coping joint. You will have to cut coping joints on a large variety of moldings.

Figure 9-43 – Making a coping joint.

Figure 9-44 shows the simplest and most common moldings and trims used in woodworking.

Figure 9-44 – Simple molding and trim shapes.

Test your Knowledge (Select the Correct Response)

3. To ensure a tight joint on cut lumber, which of the following procedures should you follow?

   A. Cut directly in the middle of the line
   B. Cut on the waste side of the line
   C. Cut out the entire line
   D. Cut out the line plus a little extra

4. What type of woodworking joint is considered the strongest?

   A. Mortise and tenon
   B. Rabbet
   C. Dovetail
   D. Tongue and groove

3.0.0 METHODS of FASTENING

A variety of metal fastening devices are used by Seabees in construction. Although nails are the most commonly used fastener, the use of staples to attach wood structural members is growing. For certain operations, screws and bolts are required. In addition, various metal devices exist for anchoring materials into concrete, masonry, and steel.

The increasing use of adhesives such as glues and **mastics** is an important development in the building industry. Adhesives are used in combination with, or in place of, nails and screws.

3.1.0 Nails

Nails, the most common type of metal fasteners, are available in a wide range of types and sizes.

3.1.1 Basic Nail Types

Some basic nail types are shown in *Figure 9-45*. The ***common nail*** is designed for rough framing. The *box* ***nail*** is used for toenailing and light work in frame construction. The ***casing nail*** is used in finished carpentry work to fasten doors and window casings and other wood trim. The ***finishing nail*** and ***brad*** are used for light wood trim material and are easy to drive below the surface of lumber with a nail set.

Figure 9-45 – Basic types of nails.

The size of a nail is measured in a unit known as a penny. Penny is abbreviated with the lowercase letter d. It indicates the length of the nail. A 6d (6 penny) nail is 2 inches long. A 10d (10 penny) nail is 3 inches long as shown in *Figure 9-46*. These measurements apply to common, box, casing, and finish nails only. Brads and small box nails are identified by their actual length and gauge number.

Length and Gauge

	Size		Inches	Number	Approximate Number to Pound
A	60	d	6	2	11
B	50	d	5 ½	3	14
C	40	d	5	4	18
D	30	d	4 ½	5	24
E	20	d	4	6	31
F	16	d	3 ½	7	49
G	12	d	3 ¼	8	63
H	10	d	3	9	69
I	9	d	2 ¾	10 ¼	96
J	8	d	2 ½	10 ¼	106
K	7	d	2 ¼	11 ½	161
L	6	d	2	11 ½	181
M	5	d	1 ¾	12 ½	271
N	4	d	1 ½	12 ½	316
O	3	d	1 ¼	14	568
P	2	d	1	15	876

Figure 9-46 – Nail sizes given in “penny” (d) units.

A nail, whatever the type, should be at least three times as long as the thickness of the wood it is intended to hold. Two thirds of the length of the nail is driven into the other piece of wood for proper anchorage. The other one third of the length provides the necessary anchorage of the piece being fastened. Bend over protruding nails to prevent damage to materials and injury to personnel.

There are a few general rules to follow using nails in building. Drive nails at an angle slightly toward each other to improve their holding power. Be careful in placing nails to provide the greatest holding power. Nails driven with the grain do not hold as well as nails driven across the grain. A few nails of proper type and size, properly placed and properly driven, will hold better than a great many driven close together. Nails are generally the cheapest and easiest fasteners.

3.1.2 Specialty Nails

Figure 9-47 shows a few of the many specialized nails. Some nails are specially coated with zinc, cement, or resin materials. Some have threading for increased holding power. Nails are made from many materials, including iron, steel, copper, bronze, aluminum, and stainless steel.

Annular and spiral nails are threaded for greater holding power. They are good for fastening paneling or plywood flooring. The drywall nail is used for hanging drywall and has a special coating to prevent rust. Roofing nails are not specified by the penny system; they are referred to by length. They are available in lengths from 3/4 inch to 2 inches and

Figure 9-47 – Specialized nails.

have large heads. The double headed nail, or duplex head nail, is used for temporary construction, such as form work or scaffolding. The double head on this nail makes it easy to pull out when forms or scaffolding are torn down.

Nails for power nailing come in rolls or clips for easy loading into a nailer. They are coated for easier driving and greater holding power. *Table 9-10* gives the general size and type of nails prefered for specific applications.

Table 9-10 – Size, Type, and Use of Nails

Size	Length (inch)[1]	Diameter (inch)	Remarks	Where Used
2d	1	.072	Small head	Finish work, shop work
2d	1	.072	Large flat head	Small timber, wood shingles, lathes
3d	1 1/4	.08	Small head	Finish work, shop work
3d	1 1/4	.08	Large flat head	Small timber, wood shingles, lathes
4d	1 1/2	.098	Small head	Finish work, shop work
4d	1 1/2	.098	Large flat head	Small timber, lathes, shop work
5d	1 3/4	.098	Small head	Finish work, shop work
5d	1 3/4	.098	Large flat head	Small timber, lathes, shop work
6d	2	.113	Small head	Finish work, casing, stops, etc., shop work
6d	2	.113	Large flat head	Small timber, siding, sheathing, etc., shop work
7d	2 1/4	.113	Small head	Casing, base, ceiling, stops, etc.
7d	2 1/4	.113	Large flat head	Sheathing, siding, subflooring, light framing
8d	2 1/2	.131	Small head	Casing, base, ceiling, wainscot, etc. shop work
8d	2 1/2	.131	Large flat head	Sheathing, siding, subflooring, light framing, shop work
8d	1 1/4	.131	Extra-large flat head	Roll roofing, composition shingles
9d	2 3/4	.131	Small head	Casing, base, ceiling, etc.
9d	2 3/4	.131	Large flat head	Sheathing, siding, subflooring, framing, shop work
10d	3	.148	Small head	Casing, base, ceiling, etc., shop work
10d	3	.148	Large flat head	Sheathing, siding, subflooring, framing, shop work
12d	3 1/4	.148	Large flat head	Sheathing, subflooring, framing
16d	3 1/2	.162	Large flat head	Framing, bridges, etc.
20d	4	.192	Large flat head	Heavy framing, bridges, etc.
30d	4 1/2	.207	Large flat head	Heavy framing, bridges, etc.
40d	5	.225	Large flat head	Heavy framing, bridges, etc.
50d	5 1/2	.244	Large flat head	Extra-heavy framing, bridges, etc.
60d	6	.262	Large flat head	Extra-heavy framing, bridges, etc.

[1]This chart applies to wire nails, although it may be used to determine the length of cut nails.

3.2.0 Staples

Staples are available in a wide variety of shapes and sizes, some of which are shown in *Figure 9-48*. Heavy duty staples are used to fasten plywood sheeting and subflooring. Heavy duty staples are driven by electrically or pneumatically operated tools. Light duty and medium duty staples are used for attaching molding and other interior trim. Staples are sometimes driven in by hand operated tools.

Figure 9-48 – Types of staples.

3.3.0 Screws

The use of screws, rather than nails, as fasteners may be dictated by a number of factors. These may include the type of material to be fastened, the requirement for greater holding power than can be obtained with nails, the finished appearance desired, and the fact that the number of fasteners that can be used is limited. Using screws, rather than nails, is more expensive in terms of time and money, but it is often necessary to meet requirements for superior results.

The main advantages of screws are that they provide more holding power, can be easily tightened to draw the items being fastened securely together, are neater in appearance if properly driven, and can be withdrawn without damaging the material. All screws can have slotted or Phillips heads, as shown in *Figure 9-49*.

Figure 9-49 – Types of screws.

3.3.1 Metal Screws

For the assembly of metal parts, use sheet metal screws. These screws are made regularly in steel and brass with four types of heads: flat, round, oval, and fillister, shown in that order in *Figure 9-49*.

3.3.2 Lag Screws

The proper name for a ***lag screw*** shown in *Figure 9-49* is lag bolt. These screws are often required in constructing large projects, such as a building. They are longer and much heavier than the common wood screw and have coarser threads that extend from a cone, or gimlet point, slightly more than half the length of the screw. Square head and hexagonal head lag screws are always externally driven, usually by means of a wrench. They are used when ordinary wood screws would be too short or too light and spikes would not be strong enough. *Table 9-11* gives lengths and diameters of lag screws. Combined with expansion anchors, they are used to frame timbers to existing masonry.

Table 9-11 – Lag Screw Sizes

Length	**Diameter (Inches)**			
(Inches)	1/4	3/8, 7/16, 1/2	5/8, 3/4	7/8, 1
1	x	x		
1 1/2	x	x	x	
2, 2 1/2, 3, 3 1/2, etc., 7 1/2, 8 to 10	x	x	x	x
11 to 12		x	x	x
13 to 16			x	x

Expansion shields, or expansion anchors as they are sometimes called, are inserted in a predrilled hole, usually in masonry, to provide a gripping base or anchor for a screw, bolt, or nail intended to fasten an item to the surface in which the hole was bored. The shield can be obtained separately, or it may include the screw, bolt, or nail. After the expansion shield is inserted in the predrilled hole, the fastener is driven into the hole in the shield, expanding the shield and wedging it firmly against the surface of the hole.

3.3.3 Wood Screws

The common wood screw is usually made of unhardened steel, stainless steel, aluminum, or brass. The steel may be bright finished or blued; or zinc, cadmium, or chrome plated. Wood screws are threaded from a gimlet point for approximately two-thirds of the length of the screw and provided with a slotted head designed to be driven by an inserted driver. Wood screws, as shown in *Figure 9-50*, are designated according to head style. The most common types are flathead, oval head, and roundhead, shown in that order. Proper nomenclature of a screw, shown in *Figure 9-50*, includes the type, material, finish, length, screw size number indicating the wire guage of the

Figure 9-50 – Types and nomenclature of wood screws.

body, drill or bit size for the body hole, and drill or bit size for the starter hole.

To prepare wood for receiving the screws, bore a body hole the diameter of the screw to be used in the piece of wood to be fastened as shown in *Figure 9-51*.

Then bore a starter hole in the base wood with a diameter less than that of the screw threads and a depth of one-half or two-thirds the length of the threads to be anchored. The purpose of this careful preparation is to assure accuracy in the placement of the screws, to reduce the possibility of splitting the wood, and reduce the time and effort required to drive the screw. Properly set slotted and Phillips flathead and oval head screws are countersunk sufficiently to permit a covering material to cover the head. Slotted roundhead and Phillips roundhead screws are not countersunk, but they are driven so that the head is firmly flush with the surface of the wood. The slot of the roundhead screw is left parallel with the grain of the wood.

Figure 9-51 – Proper way to sink a screw.

Wood screws come in sizes that vary from 1/4 inch to 6 inches. Screws up to 1 inch in length increase by eighths, screws from 1 to 3 inches increase by quarters, and screws from 3 to 6 inches increase by half inches. Screws vary in length and size of shaft. Each length is made in a number of shaft sizes specified by an arbitrary number that represents no particular measurement but indicates relative differences in the diameter of the screws. *Tables 9-12* and *9-13* provide size, length, gauge, and applicable drill and ***auger*** bit sizes for screws.

Table 9-12 – Screw Sizes and Dimensions

Length	Size Numbers																				
(Inch)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	20	22	24
1/4	x	x	x	x																		
3/8	x	x	x	x	x	x	x	x	x	x												
1/2		x	x	x	x	x	x	x	x	x	x	x	x									
5/8		x	x	x	x	x	x	x	x	x	x	x	x		x							
3/4			x	x	x	x	x	x	x	x	x	x	x		x		x					
7/8			x	x	x	x	x	x	x	x	x	x	x		x		x					
1				x	x	x	x	x	x	x	x	x	x		x		x		x	x		
1 1/4					x	x	x	x	x	x	x	x	x		x		x		x	x		x
1 1/2					x	x	x	x	x	x	x	x	x		x		x		x	x		x
1 3/4						x	x	x	x	x	x	x	x		x		x		x	x		x
2						x	x	x	x	x	x	x	x		x		x		x	x		x
2 1/4						x	x	x	x	x	x	x	x		x		x		x	x		x
2 1/2						x	x	x	x	x	x	x	x		x		x		x	x		x
2 3/4							x	x	x	x	x	x	x		x		x		x	x		x
3							x	x	x	x	x	x	x		x		x		x	x		x
3 1/2									x	x	x	x	x		x		x		x	x		x
4									x	x	x	x	x		x		x		x	x		x
4 1/2													x		x		x		x	x		x
5													x		x		x		x	x		x
6															x		x		x	x		x
Threads Per Inch	**32**	**28**	**26**	**24**	**22**	**20**	**18**	**16**	**15**	**14**	**13**	**12**	**11**		**10**		**9**		**8**	**8**		**7**
Diameter Of Screw (Inch)	**.060**	**.073**	**.086**	**.099**	**.112**	**.125**	**.138**	**.151**	**.164**	**.177**	**.190**	**.203**	**.216**		**.242**		**.268**		**.294**	**.320**		**.372**

Table 9-13 – Drill and Auger Bit Sizes for Wood Screws

Screw Size No.		1	2	3	4	5	6	7	8	9	10	12	14	16	18
Nominal Screw		.073	.086	.099	.112	.125	.138	.151	.164	.177	.190	.216	.242	.268	.294
Body Diameter		5/64	3/32	3/32	7/64	1/8	9/64	5/32	11/64	11/64	3/16	7/32	15/64	17/64	19/64
Pilot Hole	Drill size	5/64	3/32	7/64	7/64	1/8	9/64	5/32	11/64	3/16	3/16	7/32	1/4	17/64	19/64
	Bit size	–	–	–	–	–	–	–	–	–		4	4	5	5
Starter Hole	Drill size	–	1/16	1/16	5/64	5/64	3/32	7/64	7/64	1/8	1/8	9/64	5/32	3/16	13/64
	Bit size	–	–	–	–	–	–	–	–	–	–	–	–		4

3.4.0 Bolts

Bolts are used in construction requiring great strength or when the work under construction must be frequently disassembled. Their use usually implies the use of nuts for fastening and sometimes the use of washers to protect the surface of the materials they fasten. Bolts are selected for application to specific requirements in terms of length, diameter, threads, style of head, and type. Proper selection of head style and type of bolt results in good appearance as well as good construction. The use of washers between the nut and a wood surface or between both the nut and the head and their opposing surfaces helps you avoid marring the surfaces and permits additional torque in tightening.

3.4.1 Carriage Bolts

Carriage bolts fall into three categories: square neck, finned neck, and ribbed neck. All three are shown in *Figure 9-52*.

These bolts have round heads that are not designed to be driven. They are threaded only part of the way up the shaft. Usually, the threads are two to four times the diameter of the bolt in length. In each type of carriage bolt, the upper part of the shank, immediately below the head, is designed to grip the material in which the bolt is inserted and keep the bolt from turning when a nut is tightened down on it or removed. The finned type is designed with two or more fins extending from the head to the shank. The ribbed type is designed with longitudinal ribs, splines, or serrations on all or part of a shoulder located immediately beneath the head. Holes bored to receive carriage bolts are bored to be a

Figure 9-52 – Carriage bolts.

tight fit for the body of the bolt and counterbored to permit the head of the bolt to fit flush with, or below the surface of, the material being fastened. The bolt is then driven through the hole with a hammer. Carriage bolts are chiefly for wood to wood application, but they can also be used for wood to metal applications. If used for wood to metal application, the head should be fitted to the wood item. Metal surfaces are sometimes predrilled and countersunk to permit the use of carriage bolts metal to metal. Carriage bolts can be obtained from 1/4 inch to 1 inch in diameter and from 3/4 inch to 20 inches long (*Table 9-14*). Use a common flat washer with carriage bolts between the nut and the surface.

Table 9-14 – Carriage Bolt Sizes

Length (Inches)	Diameter (Inches)			
	3/16, 1/4, 4/16, 3/8	7/16, 1/2	9/16, 5/8	3/4
3/4	x	–	–	–
1	x	x	–	–
1 1/4	x	x	x	–
1 1/2, 2, 2 1/2, etc. 9 1/2, 10 to 20	x	x	x	x

3.4.2 Machine Bolts

The ***machine bolts*** shown in *Figure 9-53* are made with cut national fine and national coarse threads extending in length from twice the diameter of the bolt plus 1/4 inch for bolts less than 6 inches in length to twice the diameter of the bolt plus 1/2 inch for bolts over 6 inches in length.

They are precision made and generally applied metal to metal where close tolerance is desirable. The head may be square, hexagonal, rounded, or flat countersunk. The nut usually corresponds in shape to the head of the bolt with which it is used. Machine bolts are externally driven only. Selection of the proper machine bolt is made on the basis of head style, length, diameter, number of threads per inch, and coarseness of thread. The hole through which the bolt is to pass is bored to the same diameter as the bolt. Machine bolts are made in diameters from 1/4 inch to 3 inches and may be obtained in any length desired, as shown in *Table 9-15*.

Figure 9-53 – Machine bolts.

Table 9-15 – Machine Bolt Sizes

Length (Inches)	Diameter (Inches)				
	1/4, 3/8	7/16	1/2, 9/16, 5/8	1/2, 7/8, 1	1 1/8, 1 1/4
3/4	x	–	–	–	–
1 1/4	x	x	x	–	–
1 1/2, 2, 2 1/2	x	x	x	x	–
3, 3 1/2, 4, 4 1/2, etc., 9 1/2, 10 to 20	x	x	x	x	x
21 to 25	–	–	x	x	x
26 to 39	–	–	–	x	x

3.4.3 Stove Bolts

The ***stove bolts*** shown in *Figure 9-54* are less precisely made than machine bolts.

They are made with either flat or round slotted heads and may have threads extending over the full length of the body, over part of the body, or over most of the body. They are generally used with square nuts and applied metal to metal, wood to wood, or wood to metal. If flatheaded, they are countersunk. If roundheaded, they are drawn flush to the surface.

Figure 9-54 – Stove bolts.

3.4.4 Expansion Bolts

The ***expansion bolt***, shown in *Figure 9-55* is a bolt used in conjunction with an expansion shield to provide anchorage in substances in which a threaded fastener alone is useless. The shield, or expansion anchor, is inserted in a predrilled hole and expands when the bolt is driven into it. It becomes wedged firmly in the hole, providing a secure base for the grip of the fastener.

Figure 9-55 – Expansion bolt.

3.4.5 Toggle Bolts

The ***toggle bolt***, shown in *Figure 9-56*, is a machine screw with a spring action, wing head nut that folds back as the entire assembly is pushed through a prepared hole in a hollow wall. The wing head then springs open inside the wall cavity. As the screw is tightened, the wing head is drawn against the inside surface of the finished wall material. Spring action, wing head toggle bolts are available in a variety of machine screw combinations. Common sizes range from 1/8 inch to 3/8 inch in diameter and 2 inches to 6 inches in length. They are particularly useful with sheetrock wall surfaces.

Figure 9-56 – Toggle bolt.

3.4.6 Molly Bolts

The ***molly bolt*** or molly expansion anchor, shown in *Figure 9-57*, is used to fasten small cabinets, towel bars, drapery hangers, mirrors, electrical fixtures, and other lightweight items to hollow walls. It is inserted in a prepared hole. Prongs on the outside of the shield grip the wall surfaces to prevent the shield from turning as the anchor screw is being driven. As the screw is tightened, the shield spreads and flattens against the interior of the wall. Various sizes of screw anchors can be used in hollow walls 1/8 inch to 1 3/4 inches thick.

Figure 9-57 – Molly bolt.

3.4.7 Driftpins

The driftpin, shown in *Figure 9-58*, is a long, heavy, threadless bolt used to hold heavy pieces of timber together. It has a head that varies in diameter from 1/2 to 1 inch and in length from 18 to 26 inches. The term driftpin is almost universally used in practice. For supply purposes, the correct designation is driftbolt.

Figure 9-58 – Driftpin.

To use the driftpin, make a hole slightly smaller than the diameter of the pin in the timber. Drive the pin into the hole. The compression action of the wood fibers holds the pin in place.

3.5.0 Corrugated Fasteners

The corrugated fastener is one of many means by which joints and splices are fastened in small timber and boards. It is used particularly in the miter joint. Corrugated fasteners are made of 18 to 22 gauge sheet metal with alternate ridges and grooves; the ridges vary from 3/16 to 5/ 16 inch, center to center. One end is cut square; the other end is sharpened with beveled edges. There are two types of corrugated fasteners: one with the ridges running parallel, as shown in *Figure 9-59, view A*, the other with ridges running at a slight angle to one another, as shown in *Figure 9-59, view B*.

Figure 9-59 – Corrugated fasteners and their uses.

The latter type has a tendency to compress the material since the ridges and grooves are closer at the top than at the bottom. These fasteners are made in several different lengths and widths. The width varies from 5/8 to 1 1/8 inches; the length varies from 1/4 to 3/4 inch. The fasteners also are made with different numbers of ridges, ranging from three to six ridges per fastener. Corrugated fasteners are used in a number of ways: to fasten parallel boards together, as in fastening tabletops; to make any type of joint, and as a substitute for nails where nails may split the timber. In small timber, corrugated fasteners have greater holding power than nails. The proper method of using the fasteners is shown in *Figure 9-59*.

3.6.0 Adhesives

Seabees use many different types of adhesives in various phases of their construction projects. Glues (which have a plastic base) and mastics (which have an asphalt, rubber, or resin base) are the two major categories of adhesives.

The method of applying adhesives, their drying time, and their bonding characteristics vary. Some adhesives are more resistant to moisture and hot and cold temperatures than others.

CAUTION

Some adhesives are highly flammable; they should be used only in a well-ventilated work area. Others are highly irritating to the skin and eyes.

3.6.1 Glues

The primary function of glue is to hold together joints in mill and cabinet work. Most modern glues have a plastic base. Glues are sold as a powder to which water must be added or in liquid form. Many types of glue are available under brand names. A brief description of some of the more popular types of glue is listed below.

Polyvinyl resin, also known as white glue, is a liquid that comes in ready to use plastic squeeze bottles. It does a good job of bonding wood together and it sets up (dries) quickly after being applied. Because white glue is not waterproof, do not use it on work that will be subjected to constant moisture or high humidity.

Urea resin is plastic based glue sold in a powder form. The required amount is mixed with water when the glue is needed. Urea resin makes an excellent bond for wood and has fair water resistance.

Phenolic resin glue is highly resistant to temperature extremes and water. It is often used for bonding the veneer layers of exterior grade plywood.

Resorcinol glue has excellent water resistance and temperature resistance, and it makes a very strong bond. Resorcinol resin is often used for bonding the wood layers of laminated timbers.

Contact cement is used to bond plastic laminates to wood surfaces. This glue has a neoprene rubber base. Because contact cement bonds very rapidly, it is useful for joining parts that cannot be clamped together.

3.6.2 Mastics

Mastics are widely used throughout the construction industry. They are generally used to apply floor coverings, roofing materials, ceramic tiles, and wall paneling. The asphalt, rubber, or resin base of mastics gives them a thick consistency. Mastics are sold in cans, tubes, or canisters that fit into hand-operated or air-operated caulking guns. These adhesives can be used to bond materials directly to masonry or concrete walls. If furring strips are required on a wavy concrete wall, the strips can be applied with mastic rather than by the more difficult procedure of driving in concrete nails. You can also fasten insulation materials to masonry and concrete walls, bond drywall (gypsum board) directly to wall studs, and bond gypsum board to furring strips or directly to concrete or masonry walls with a mastic adhesive. Because you don't use nails, there are no nail indentations to fill. By using mastic adhesives, you can apply paneling with very few or no nails at all. Wall panels can be bonded to studs, furring strips, or directly against concrete or masonry walls. Mastic adhesives can be used with nails or staples to fasten plywood panels to floor joists. The mastic adhesive helps eliminate squeaks, bounce, and nail popping. It also increases the stiffness and strength of the floor unit.

Test your Knowledge (Select the Correct Response)

5. Which of the following nailing techniques gives maximum holding power?

   A. Drive the nails with the grain
   B. Drive the nails at an angle toward each other
   C. Drive the nails vertically
   D. Drive the nails through an edge

Summary

Wood is probably the most often used and perhaps the most important of all construction materials. Most Seabee construction projects are built using some type of wood. It is used for permanent and temporary structures, different types used according to the project being built. The project specifications and project drawings show what types of wood products are needed for the project.

Builders use many methods for joining wood. The types of joints vary depending on the type of project being built.

Seabees use a variety of metal fastening devices in construction. Nails are the most commonly used fastener, but the use of staples to attach wood structural members is growing. Screws and bolts are required in some building projects. There are also various metal devices for anchoring materials into concrete, masonry, and steel. Glues and mastics are adhesives used in combination with or in place of nails and screws.

Review Questions (Select the Correct Response)

1. Timber is wood cut to which of the following dimensions?

    A. 1 by 12 inches by 8 ft
    B. 2 by 12 inches by 8 ft
    C. 3 by 5 inches by 12 ft
    D. 5 by 7 inches by 16 ft

2. Which of the following factors is **NOT** an advantage of seasoned lumber?

    A. Decreased shrinkage
    B. Increased strength
    C. Reduced weight
    D. Increased warpage

3. Lumber is considered dry enough for most uses when its moisture content is in what range?

    A. 12% to 15%
    B. 17% to 19%
    C. 20% to 23%
    D. 25% to 28%

4. As a Builder, you should be able to judge the moisture content of lumber by which of the following characteristics?

    A. Taste, color, and weight
    B. Color, weight, smell, and feel
    C. Color, grain, and smell only
    D. Taste, grain, color, and smell

5. A root section of a branch appearing on the surface of a board is what kind of defect?

    A. Pitch pocket
    B. Knot
    C. Check
    D. Shake

6. A twist or curve that develops in a flat board is what kind of defect?

    A. Shake
    B. Wane
    C. Check
    D. Warp

7. Which of the following types of wood should be used where strength is the primary requirement?

   A. Yard lumber
   B. Shop lumber
   C. Structural lumber
   D. Factory lumber

8. Using manufacturing classifications, wood that has not been dressed but has been sawed, edged, and trimmed is considered what type?

   A. Worked lumber
   B. Rough lumber
   C. Dressed lumber
   D. Matched lumber

9. Which of the following qualities is **NOT** considered when grading lumber?

   A. Uniformity
   B. Strength
   C. Stiffness
   D. Appearance

10. Where will you find the grade of lumber to be used on a construction project?

   A. Blueprints
   B. File folder 1
   C. Specifications
   D. DD 1250

11. Of the following grade listings, which is nearly free of defects and blemishes?

   A. Grade A select
   B. Grade B
   C. No. 1 common
   D. No. 5 common

12. FAS grade of hardwood lumber should have what portion of clear cutting?

   A. 48 1/3%
   B. 65 2/3%
   C. 66 2/3%
   D. 83 1/3%

13. **(True or False)** The nominal size of lumber is larger than actual dressed dimensions.

   A. True
   B. False

14. What is the primary advantage of laminated lumber?

   A. Light weight
   B. Low cost
   C. Increased load-carrying capacity
   D. Increased resistance to decay

15. **(True or False)** The most common use of lamination is in the fabrication of large beams and arches.

   A. True
   B. False

16. Most lamination splices are made with what type of joint?

   A. Tongue and groove
   B. Scarf
   C. Shiplap
   D. Half-lap

17. In a sheet of plywood, the outer plies are called

   A. Crossbands only
   B. Cores only
   C. Crossbands and cores
   D. Faces or face and back

18. What is the essential difference between exterior and interior plywood?

   A. The grain
   B. The thickness
   C. The plies
   D. The glue

19. **(True or False)** Plywood is only manufactured in thicknesses ranging from 1/4 to 3/4 inch.

   A. True
   B. False

20. Using stiffness and strength as criteria, plywood can be classified into what maximum number of groups?

   A. Five
   B. Two
   C. Three
   D. Four

21. What veneer grade of plywood permits knots and knotholes to 2 1/2 inch in width (1/2 inch larger under specified conditions)?

A. A
B. B
C. D
D. N

22. Plywood with a solid surface veneer and circular repair plugs is what grade?

A. A
B. B
C. C
D. N

23. On plywood, which of the following trademark stamps gives you the span rating?

A. Industrial
B. Construction
C. Interior
D. Exterior

24. What class of plywood is best suited for exposure to extended periods of moisture?

A. Exterior
B. Exposure 1
C. Exposure 2
D. Interior

25. In laying off a piece of lumber for an end-butt half-lap joint, the shoulder line should be drawn around the board at what distance from the end of the board?

A. One-half board width
B. One board width
C. One board thickness
D. Any desired amount

26. When laying off a piece of lumber for a half-lap joint, you gauge the cheek line from what point?

A. The edge only
B. The face only
C. The edge or end
D. The face or end

27. In cutting an end-butt half-lap joint on a piece of lumber, what cut should you make first?

   A. Face
   B. Shoulder
   C. Back
   D. Cheek

28. When mitering a board for a hexagonal (six-sided) frame, what miter angle should you use?

   A. 22.5°
   B. 30.0°
   C. 60.0°
   D. 67.5°

29. When reinforcing miter joints, biscuits are often preferred over corrugated fasteners because bicsuits

   A. Are stronger
   B. Are easier to apply
   C. Are easier to remove
   D. Don’t mar the surface

30. A three-sided recess running across the grain from one side of a board to the other is known by what term?

   A. Grooved joint
   B. Stopped dado
   C. Dado
   D. Stopped groove

31. A two-sided recess running along an edge of a board is known by what term?

   A. Groove
   B. Dado
   C. Stopped dado
   D. Rabbet

32. A circular saw can be used to cut a stopped groove using which of the following attachments?

   A. A stop block
   B. A rabbet ledge
   C. A haunch board
   D. A carriage block

33. To adjust the fence to the depth of the cheek when cutting a rabbet joint with a circular saw, you should measure from what point?

    A. The left side of the raker tooth
    B. The center line of the saw blade
    C. The sawtooth set to the left
    D. The sawtooth set to the right

34. **(True or False)** With proper attachments, jointers can be used for rabbeting.

    A. True
    B. False

35. Which of the following mortise and tenon joints penetrates through the mortised member?

    A. Stub
    B. Blind
    C. Through
    D. Haunched

36. Table haunching a mortise and tenon joint has what effect on the joint?

    A. Makes it weaker
    B. Makes it tighter
    C. Makes it easier to construct
    D. Makes it stronger

37. When cutting inside corner molding, you should normally use which of the following handsaws?

    A. Backsaw
    B. Hacksaw
    C. Coping saw
    D. Jigsaw

38. What type of nail should you use for wood trim?

    A. Common
    B. Casing
    C. Brad
    D. Box

39. You are nailing a 1 inch thick board. The nail used should be what length?

    A. 1 1/2 in
    B. 2 in
    C. 3 in
    D. 4 in

40. Of the following nail types, which has the greatest holding power?

    A. Box
    B. Common
    C. Spiral
    D. Finish

41. Of the following nail types, which is most suitable for temporary work such as forms and scaffolding?

    A. Duplex head
    B. Common
    C. Box
    D. Annular

42. To what depth should you drill a wood screw starter hole?

    A. 1/4 to 1/2 the length of the threads
    B. 1/2 to 5/8 the length of the threads
    C. 1/2 to 2/3 the length of the threads
    D. 2/3 to 3/4 the length of the threads

43. What type of bolt can be square necked, fin necked, or rib necked?

    A. Carriage
    B. Stove
    C. Machine
    D. Toggle

44. Which of the following types of bolts has a machine thread with spring action and winghead nuts and is particularly useful with sheetrock wall surfaces?

    A. Molly
    B. Expansion
    C. Lag
    D. Toggle

45. Of the following types of adhesive, which has an asphalt, rubber, or resin base?

    A. Glue only
    B. Mastic only
    C. Plastic only
    D. All of the above

Trade Terms Introduced in this Chapter

Auger	A carpenter's hand tool used for boring holes in wood.
Box nail	Lightweight nails with large heads.
Brad	A slender nail with a small head.
Carriage bolt	A threaded bolt with a round, smooth head. The bolt is prevented from rotating in its hole by a square neck directly under the head.
Casing nail	Twopenny (2d) to fortypenny (40d) nails with flaring heads.
Circular saw	A thin steel-toothed disk that rotates on a power-driven spindle. Can be used either as a hand tool or mounted on a table.
Common nail	Twopenny (2d) to sixtypenny (60d) strong nails.
Corrugated fasteners	A small, wavy steel fastener with one edge sharpened. The fastener is driven into two pieces of wood, bridging the joint in order to hold them together.
Dado joint	A joint created by fitting the end of one piece of wood at a right angle into a groove cut across the width of another, to a depth of half its thickness.
Dovetail joints	In finish carpentry, an interlocking joint that is wider at its end than at its base.
Expansion bolt	An anchoring or fastening device used in masonry, which expands within a predrilled hole as a bolt is tightened.
Finishing nail	Twopenny (2d) to twentypenny (20d) sizes with small barrel shaped heads.
Gain joints	The mortise or notch in a piece of wood into which a piece of wood, hinge, or other hardware fits.
Hardwoods	A general term referring to any of a variety of broad-leaved, deciduous trees, and the wood from those trees. The term does not designate the physical hardness of wood, as some hardwoods are actually softer than some softwood (coniferous) species.
Jointer	A power driven woodworking tool or long, hand operated bench plane. Used to square the edges of lumber or panels.
Knotholes	The holes left when knots fall out of lumber.
Lag screw	A screw with a wrench head and wood screw threads.
Laminated	Any material formed by bonding together several layers or sheets with adhesive under pressure and sometimes with nails or bolts.

Laminated lumber	Any of several products formed by built up layers (plies) of wood. Thin veneers may be laminated to a wood subsurface, several plies may be laminated together to form plywood, or thicker pieces may be used to form structural members such as beams or arches.
Lap joints	A type of joint in which two building elements are not butted up against each other, but are overlapped, with part of one covering part of the other. Typical examples include roof and wall shingles, clapboard siding, welded metal sheets or plates, and concrete reinforcing bars lapped together at their ends.
Machine bolts	A threaded straight bolt usually specified by gauge, thread, and head type.
Mitering	Cutting at an angle.
Miter joints	A joint, usually 90°, formed by joining two surfaces beveled at angles, usually 45° each.
Molly bolt	A threaded insert for plaster, sheetrock, or concrete walls for receiving a bolt, screw, or nail.
Mortise and tenon joints	A joint between two members, usually wood, which incorporates one or more tenons on one member fitting into mortises in the other member. Used on joints such as door sills, door rails, window sashes, and cabinetry.
Nominal	The common size by which lumber is known, such as 2 x 4. The nominal size is larger than the dressed size of lumber.
Plywood	A flat panel made up of a number of thin sheets (veneers) of wood. The grain direction of each ply, or layer, is at right angles to the one adjacent to it. The veneer sheets are united under pressure by a bonding agent.
Rabbet joints	A longitudinal edge joint formed by fitting together rabbeted boards.
Softwood	(1) A general term referring to any of a variety of trees having narrow, needle-like or scale-like leaves, usually coniferous. (2) The wood from such trees. The term has nothing to do with the softness of the wood; some softwoods are harder than certain of the hardwood species.
Stove bolts	A common bolt with a round or flat head and a slot for a screwdriver.
Toenailed	Nail driven at an angle for improved stability.
Toggle bolt	A bolt and nut assembly used to fasten objects to a hollow wall or a wall accessible from only one side. The nut has pivoted wings that close against a spring when the nut end of the assembly is pushed through a hole and is open on the other side.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Facilities Planning Guide, NAVFAC P-437, Naval Facilities Engineering Command, Alexandria, Va., 1982.

Operations Officer's Handbook, COMCBPAC/COMCBLANTINST 5200.2A, Commander, Naval Construction Battalions, U.S. Pacific Fleet, Pearl Harbor, Hawaii, and Commander, Naval Construction Battalions, U.S. Atlantic Fleet, Norfolk, Va., 1988.

Seabee Planner's and Estimator's Handbook, NAVFAC P-405, Chapter 5, Naval Facilities Engineering Command, Alexandria, Va., 1983.

Carpentry, Leonard Keel, American Technical Publishers, Alsip, Ill., 1985.

A Glossary of Engineered Wood Terms, http://www.apawood.org/level_b.cfm?content=srv_med_new_bkgd_gloss

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Chapter 10

Rough Carpentry

Topics

To hear audio, click on the box.

Overview

Rough carpentry is critical to the strength of any building project. It forms the base to which other building components are attached. You as the Builder are responsible for the quality construction of the rough framing components.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe sill layout and installation.
2. Identify members used in floor construction, and the construction methods used with subfloor and bridging.
3. Identify wall framing members and explain layout and installation procedures for these members in building construction.
4. State the purpose of ceiling frame members and describe layout and installation procedures.
5. Identify the types of roofs and define common roof framing terms.
6. Describe and solve roof framing problems using the framing square.
7. Describe procedures for laying out and installing members of gable, hip, intersecting, and shed roof designs.

8. Describe the types and parts of roof trusses, and explain procedures for fabricating, handling, and erecting them.

9. Describe the types and parts of stairs, and explain procedures for fabricating, handling, and erecting them.

Prerequisites

None

This course map shows all of the chapters in Builder Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Expeditionary Structures	↑	
Finishes		B
Moisture Protection		U
Finish Carpentry		I
Rough Carpentry		L
		D
Carpentry Materials and Methods		E
Masonry		R
Fiber Line, Wire Rope, and Scaffolding		
Concrete Construction		
Site Work		B
		A
Construction Management		S
Drawings and Specifications		I
Tools		C
Basic Math		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The Figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.

- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 FRAMING SILLS

In the normal sequence of construction events, the floor and wall activities follow the completed foundation work. In this section, we'll examine established methods of frame construction and discuss how floor and wall framing members are assembled.

1.1.0 Wood Sill Framing

Framing of the structure begins after completion of the foundation. The lowest member of the frame structure resting on the foundation is the sill plate. This sill provides a base for ***joists*** or ***studs*** resting directly over the foundation. Work in this area is critical, as it is the real point of departure for actual building activities.

1.1.1 Layout

The box sill is usually used in platform construction. It consists of a sill plate and header joist anchored to the foundation wall. The box sill supports floor joists and holds them in position as shown in *Figure 10-1*. Insulation material and metal termite shields are placed under the sill if desired or when specified. Sills are usually single, but double sills are sometimes used.

Figure 10-1 – Box-sill assembly.

Following construction of the foundation wall, the sill is normally the first member laid out. The edge of the sill is set back from the outside face of the foundation a distance equal to the thickness of the exterior sheathing. If splicing is necessary to obtain the required length, halve the splice joint at least 2 feet and bolt together. Once you have determined the required length, lay out the locations of the anchor bolt holes using the following steps:

1. Establish the building line points at each corner of the foundation.
2. Pull a chalk line at these points and snap a line for the sill location.
3. Square the ends of the sill stock. Stock received at jobsites is not necessarily squared at both ends.
4. Place the sill on edge and mark the locations of the anchor bolts.
5. Extend these marks with a square across the width of the sill. The distance X in *Figure 10-2* shows how far from the edge of the sill to bore the holes. This is the thickness of the exterior sheathing.

Figure 10-2 – Anchor bolt layout.

After all the holes are marked, bore the holes. Each should be about 1/4 inch larger than the diameter of the bolts to allow some adjustment for slight inaccuracies in the layout. As you bore each section, position that section over the bolts.

When all sill sections are fitted, remove them from the anchor bolts. Install sill sealer, otherwise known as insulation, as shown in *Figure 10-3*. The insulation compresses, filling the irregularities in the foundation. It also stops drafts and reduces heat loss.

Figure 10-3 – Installing sill sealer.

Install a termite shield as shown in *Figure 10-4* if specified. A termite shield should be at least 26-gauge aluminum, copper, or galvanized sheet metal. The outer edges should be slightly bent down.

Replace the sills and install the washers and nuts. As you tighten the nuts, make sure the sills are properly aligned. Also check the distance from the edge of the foundation wall. The sill must be level and straight. Low spots can be shimmied with wooden wedges, but it is better to use grout or mortar.

Figure 10-4 – Installing termite shields.

1.1.2 Fastening to Foundation Walls

Wood sills are fastened to masonry walls by 1/2 inch anchor bolts. These bolts, also known as j-bolts because of their shape, should be embedded 15 inches or more into the wall in unreinforced concrete as shown in *Figure 10-5, view A* and a minimum of 7 inches into reinforced concrete as shown in *view B*. The length of the anchor bolt is found in the ***specifications***. The spacing and location of the bolts are shown on the drawings.

Figure 10-5 – Methods of sill fastening to foundations.

If this information is not available, anchor bolt spacing should not exceed 6 feet on center (OC). You must also place a bolt within 1 foot of the ends of each piece but no closer than 4 inches from the end, as shown in *Figure 10-6.*

Figure 10-6 – Spacing of anchor bolts.

There are alternative ways to fasten sill plates to foundations. Location and building codes will dictate which to use. Always consult the job specifications before proceeding with construction.

Test your Knowledge (Select the Correct Response)

1. In wood frame construction, what is the lowest member resting on the foundation?

    A. Platform
    B. Plank
    C. Stud
    D. Sill plate

2.0.0 FRAMING FLOORS

Floor framing consists specifically of the posts, ***girders***, joists, and subfloor. When these are assembled as shown in *Figure 10-7*, they form a level anchored platform for the rest of the construction.

Figure 10-7 – Basic components of floor framing.

2.1.0 Posts

Wood or steel posts and girders support floor joists and the subfloor. Sizes depend on the loads carried. The dimensions and locations are shown on the foundation plan. Posts give central support to the long ***span*** of girders when required. Girders can be used to support other girders. There should be at least 18 inches clearance between the bottoms of the floor joists and the ground and at least 12 inches between the bottom of the girder and the ground, as shown in *Figure 10-8*.

Figure 10-8 – Floor framing on sill plates with intermediate posts and built-up girders.

2.1.1 Wood

Wood posts are placed directly below wood girders. As a general rule, the width of the wood post should be equal to the width of the girder it supports. For example, a 4 inch wide girder requires a 4 by 4 or 4 by 6 inch post.

You can secure a wood post to a concrete pillar in several ways.

- Nail it to a pier block secured to the top of a concrete pier.
- Place it over a previously inserted 1/2 inch steel dowel in the concrete.
- Place it into a metal base set into the concrete pier at the time of the pour.

When using the dowel method, make sure the dowel extends at least 3 inches into the concrete and the post, as shown in *Figure 10-9*.

A metal base embedded in the concrete as shown in *Figure 10-10* is the preferred method since nothing else is needed to secure the base.

Figure 10-9 – Post fastened using dowel method.

Figure 10-10 – Metal base plates for wood posts.

As with the bottom of the post, the top must also be secured to the girder. Do this using angle iron brackets or metal plates. *Figure 10-11* shows two metal post caps used with posts and girders, either nailed or bolted to the girders.

Figure 10-11 – Metal post caps.

2.1.2 Steel

Steel pipe columns, also known as Lally columns, are often used in wood frame construction, with both wood and steel girders. When using wood girders, secure the post to the girder with lag bolts. For steel girders, machine bolts are required. Bolt the base of the steel post to the top of the pier, as shown in *Figure 10-12*. You can also bolt the post to anchor bolts inserted in the slab prior to pouring.

2.2.0 Girders

Girders are classified as bearing and nonbearing according to the amount and type of load supported. Bearing girders must support a wall framed directly above, as well as the live load and dead load of the floor. Nonbearing girders support only the dead and live loads of the floor system directly above. The dead load is the weight of the material used for the floor unit itself. The live load is the weight created by people, furniture, appliances, and so forth.

Figure 10-12 – Bolting of steel column.

2.2.1 Wood

Wood girders may be a single piece of timber, or they may be laminated. The built-up girder in *Figure 10-13*, for example, consists of three 2 by 12 inch planks. Stagger the joints between the planks. In framing, place a built-up girder so that the joints on the outside of the girder fall directly over a post. Drive three 16d nails at the ends of the planks, and stagger other nails 32 inches OC. The top of the girder is flush with the top sill plate, as shown in *Figure 10-13*.

Figure 10-13 – Built-up girder.

When space is required for heat ducts in a partition supported on a girder, a spaced wood girder, such as that shown in *Figure 10-14*, is sometimes necessary. Use solid blocking at intervals between the two members. A single-post support for a spaced girder usually requires a bolster, preferably metal, with a sufficient span to support the two members.

The ends of a girder often rest in pockets prepared in a concrete wall, as shown in *Figure 10-13*. Here, the girder ends must bear at least 4 inches on the wall, and the pocket should be large enough to provide a 1/2 inch air space around the sides and end of the girder. To protect against termites, treat the ends of the girder with a preservative. As a further precaution, line the pockets with metal.

Figure 10-14 – Spaced wood girders.

2.2.2 Steel

Standard or S-beams and wide flange or W-beams, both shown in *Figure 10-15*, are most often used as girders in wood framed construction. Whether the beam is wood or steel, make sure it aligns from end to end and side to side. Also make sure the length of the bearing post under the girder is correct to ensure the girder is properly supported.

Figure 10-15 – Types of steel beams.

2.3.0 Placing Posts and Girders

Posts must be cut to length and set up before you can install the girders. The upper surface of the girder may be in line with the foundation plate sill, or the girder ends may rest on top of the walls. Long girders must be placed in sections. Solid girders must be measured and cut so that the ends fall over the center of a post. Place built-up girders so their outside joints fall over the posts as in *Figure 10-13*.

Test your Knowledge (Select the Correct Response)

2. When placing a girder in the pocket of a concrete wall, the minimum bearing should be

   A. 1 inch
   B. 2 inches
   C. 3 inches
   D. 4 inches

2.4.0 Floor Joists

In platform framing, one end of the floor joist rests directly on the sill plate of the exterior foundation wall or on the top plate of a framed outside wall. The bearing should be at least 1 1/2 inches. The opposite end of the joist laps over or butts into an interior girder or wall. You must choose the size of joist material, 2 by 6, 2 by 10, 2 by 12, and so forth, with consideration for the span and the amount of load to be carried. The foundation plan usually specifies the joist size, the spacing between joists, and what direction the joists should travel. The usual spacing of floor joists is 16 inches OC. Floor joists are supported and held in position over exterior walls by header joists or by solid blocking between the joists. The header joist system is used most often.

2.4.1 Header

Header joists run along the outside walls. Three 16d nails are driven through the header joists into the ends of the common joists, as shown in *Figure 10-16.* The header and joists are ***toenailed*** to the sill with 16d nails. The header joists prevent the common joists from rolling or tipping. They also help support the wall above and fill in the spaces between common joists.

Figure 10-16 – Header joist.

2.4.2 Lapped

Joists are often lapped over a girder running down the center of a building. The lapped ends of the joists may also be supported by an interior foundation or framed wall. Standard procedure is to lap joists the full width of the girder or wall. The minimum lap should be 4 inches. *Figure 10-17* shows lapped joists resting on a steel girder. A 2 by 4 inch plate has been bolted to the top of a steel beam. The joists are toenailed into the plate. You may install solid blocking between the lapped ends after all the joists have been nailed down. Another system is to put in blocks when you place the joists.

Figure 10-17 – Lapped joists.

2.4.3 ouble

Double joists under partitions running in the same direction as the joists. Some walls have water pipes, vent stacks, or heating ducts coming up from the basement or the floor below. Place ***bridging*** between double joists to allow space for these purposes, as shown in *Figure 10-18*.

Figure 10-18 – Double joists.

2.4.4 Cantilevered

Cantilevered joists are used when a floor or balcony of a building projects past the wall below, as shown in *Figure 10-19*. Nail a header piece to the ends of the joists.

Figure 10-19 – Cantilevered joists.

When regular floor joists run parallel to the intended overhang, fasten the inside ends of the cantilevered joists to a pair of double joists as shown in *Figure 10-20*. Nail through the first regular joist into the ends of the cantilevered joists. Framing anchors are strongly recommended and often required by the specifications. Also, nail a header piece to the outside ends of the cantilevered joists.

Figure 10-20 – Framing for cantilevered joists.

2.4.5 Butted over a Girder

Joist ends can also be butted, rather than lapped, over a girder. Cleat the joists together with a metal plate or wooden cleat, as shown in *Figure 10-21*. You may leave these out if the line of panels from the plywood subfloor straddles the butt joints.

Figure 10-21 – Butting joists over a girder.

2.4.6 Butted against a Girder

Butting joists against, rather than over, a girder allows more headroom below the girder. When it is necessary for the underside of the girder to be flush with the joists to provide an unbroken ceiling surface, support the joists with joist hangers, as shown in *Figure 10-22*.

2.4.7 Blocking between Joists

Another system of providing exterior support to joists is to place solid blocking between the outside ends of the joists. This way the ends of the joists have more bearing on the outside walls.

2.4.8 Interior Support

Floor joists usually run across the full width of the building. However, extremely long joists are expensive and difficult to handle. Two or more shorter joists are usually used. The ends of these joists are supported by lapping or butting them over a girder, butting them against a girder, or lapping them over a wall.

Figure 10-22 – Butting Joists against a girder.

2.4.9 Supported by a Steel Beam

Wood joists are often supported by a steel beam rather than a wood girder. The joists may rest on top of the steel beam as shown in *Figure 10-23 view A*, or they may be butted and notched to fit against the sides of the beam as shown in *view B*.

Figure 10-23 – Joists supported by steel beams.

If the joists rest on top of a steel beam, a plate is fastened to the beam and the joists toenailed into the plate. When joists are notched to fit against the sides of the beam, allowance must be made for joist shrinkage while the steel beams remain the same size. For average work with a 2 by 10 inch joist, an allowance of 3/8 inch above the top flange of the steel girder or beam is usually sufficient.

Another method of attaching butted joists to a steel girder is shown in *Figure 10-24*. A 3/8 inch space is shown above the beam to allow for shrinkage. Do not notch the joists so they rest on the lower flange of an S-beam since the flange surface does not provide sufficient bearing surface. You may bolt or weld a wide plate to the bottom of the S-beam to provide better support.

Figure 10-24 – Joists supported on steel plates.

You may also place wooden blocks at the bottoms of the joists to help keep them in position. Wide flanged beams provide sufficient support surface for this method of construction. *Figure 10-25* shows the lapped (view A) and butt (view B) methods of framing over girders.

Figure 10-25 – Joists supported by S-beam using wooden blocks.

2.4.10 Bridging between Joists

Floor plans or specifications usually call for bridging between joists. Bridging holds the joists in line and helps distribute the load carried by the floor unit. It is usually required when the joist spans are more than 8 feet. Joists spanning between 8 and 15 feet need one row of bridging at the center of the span. Longer spans require two rows of bridging spaced 6 feet apart.

Cross bridging, also known as herringbone bridging, usually consists of 10 by 3 inch or 2 by 3 inch wood. It is installed as shown in *Figure 10-26.* Cross bridging is ***toenailed*** at each end with 6d or 8d nails. Pieces are usually precut on a radial-arm saw. Start nails at each end before placing the cross bridging between the joists. The usual procedure is to fasten only the top end of the cross bridging. Do not drive in the nails at the bottom end until the subfloor has been placed. Otherwise the joist could be pushed out of line when you nail the bridging in.

An efficient three step method for initial placement of cross bridging is shown in *Figure 10-26.*

1. Snap a chalk line where the bridging is to be nailed between the joists.
2. Moving in one direction, stagger and nail the tops of the bridging.
3. Reverse direction and nail the tops of the opposite pieces into place.

Figure 10-26 – Wood cross bridging.

Another approved system of cross bridging uses metal pieces instead of wood and requires no nails. The pieces are available for 12, 16, and 24 inch joist spacing as shown in *Figure 10-27, slide 1*. You can see how to install this type of cross bridging in *slides 2*, *3*, and *4*. In *slide 2*, strike the flat end of the lower flange, driving the flange close to the top of the joist. In *slide 3*, push the lower end of the bridging against the opposite joist. In *slide 4*, drive the lower flange into the joist.

Figure 10-27 – Metal cross bridging.

Solid bridging, also known as solid blocking, serves the same purpose as cross bridging. Many Builders prefer this method, shown in *Figure 10-28*, over cross bridging. Cut the pieces from lumber the same width as the joist material. Install them in a straight line by toenailing or staggering.

If staggered, the blocks can be nailed from both ends, resulting in a faster nailing operation. You may need straight lines of blocking every 4 feet OC to provide a nailing base for a plywood subfloor. Start placement and work in the same direction as the layout.

2.4.11 Placing Floor Joists

Before placing floor joists, mark the sill plates and girders to show where the joists are to be nailed. Floor joists are usually placed 16 inches OC. For joists resting directly on foundation walls, place layout marks on the sill plates or the header joists.

Figure 10-28 – Solid bridging.

You must also mark lines on top of the girders or walls over which the joists lap. If framed walls are below the floor unit, lay out the joists on top of the double plate. The floor layout should also show where any joists are to be doubled. Double joists are required where partitions resting on the floor run in the same direction as the floor joists. You must also mark floor openings for stairwells.

Lay out joists so that the edges of standard-size subfloor panels break over the centers of the joists as shown in the insert of *Figure 10-29*. This layout eliminates additional cutting of panels when you are fitting them and nailing them into place. One method of laying out joists this way is to mark the first joists 15 1/4 inches from the edge of the building. From then on, the layout is 16 inches OC.

Figure 10-29 – Floor joists layout.

A layout for the entire floor is shown in *Figure 10-30*.

Figure 10-30 – Complete layout for floor joists.

Most of the framing members should be precut before construction begins. The joists should all be trimmed to their proper lengths. Cross bridging and solid blocks should be cut to fit between the joists with a common spacing. The distance between joists is usually 14 1/2 inches for joists spaced 16 inches OC. Cut blocking for the odd spaces afterwards.

2.4.12 Framing Floor Openings

Floor openings, where stairs rise to the floor or large duct work passes through, require special framing. When the joists are cut for such openings, there is a loss of strength in the area of the opening. You need to frame the opening in a way that restores this strength. The procedure is shown in *Figure 10-31*. Refer to the Figure as you study the following steps:

1. Measure and mark the positions of the trimmers on the outside wall and interior wall or girder.
2. Position and fasten the inside trimmers and mark the position of the double headers.
3. Place the outside pieces between the inside trimmers. Drive three 16d nails through the trimmers into the headers. Mark the position of the tail joists on the headers (the tail joists should follow the regular joist layout).
4. Fasten the tail joists to the outside headers with three 16d nails driven through the headers into the ends of the tail joists.
5. Double the header. Drive three 16d nails through the trimmer joists into the ends of the doubled header pieces. Nail the doubled header pieces to each other with 16d nails staggered 16 inches OC.

6. Double the trimmer joists and fasten them together with 16d nails staggered 16 inches OC.

Place a pair of joists called trimmers at each side of the opening. These trimmers support the headers. Double the headers if the span is more than 4 feet. Drive nails supporting the ends of the headers through the trimmer joists into the ends of the header pieces. Tail joists, also known as ***cripple*** joists, run from the header to a supporting wall or girder. Drive nails through the header into the ends of the tail joist.

You may also use various metal anchors, such as those shown in *Figure 10-32*, to strengthen framed floor openings.

Figure 10-31 – Steps in framing a floor opening.

Figure 10-32 – Types of framing anchors.

2.4.13 Crowns

Most joists have a ***crown***, or a bow shape, on one side. Sight each joist before nailing it in place to make certain the crown is turned up. The joist will later settle from the weight of the floor and straighten out. Exercise caution when sighting the board for the crown. Some crowns are too large and cannot be turned up for use as a joist.

Test your Knowledge (Select the Correct Response)

3. Before placing floor joists, which of the following members must be marked to show joist nailing points?

   A. Soleplate and top plate only
   B. Sill plate and girders only
   C. Common joists and doubled joists only
   D. All of the above

4. What is the main reason for special framing around large floor openings?

   A. Appearance
   B. Providing additional nailing surface
   C. Strength
   D. Preventing floor squeaks

2.5.0 Subfloor

The subfloor, also known as rough flooring, is nailed to the top of the floor frame. It strengthens the entire floor unit and serves as a base for the finished floor. The walls of the building are laid out, framed, and raised into place on top of the subfloor.

Panel products, such as plywood, are used for subflooring. Plywood is less labor intensive than board lumber.

Plywood is the oldest type of panel product. It is still the most widely used subfloor material in residential and other light-frame construction. Other types of material available for use as subflooring include Nonveneered, or reconstituted wood, panels such as structural particleboard, waferboard, oriented strandboard, and compositeboard.

Plywood is available in many grades to meet a broad range of end uses. All interior grades are also available with fully waterproof adhesive identical to that used in exterior plywood. This type is useful where prolonged moisture is a hazard. Examples are underlayments, subfloors adjacent to plumbing fixtures, and roof sheathing that may be exposed for long periods during construction. Under normal conditions and for sheathing used on walls, standard sheathing grades are satisfactory.

Plywood suitable for the subfloor, such as standard sheathing, structural I and II, and C-C exterior grades, has a panel identification index marking on each sheet. These markings indicate the allowance spacing of ***rafters*** and floor joists for the various thicknesses when the plywood is used as roof sheathing or subfloor. For example, an index mark of 32/16 indicates the plywood panel is suitable for a maximum spacing of 32 inches for rafters and 16 inches for floor joists. There is no problem of strength differences between species, as the correct identification is shown for each panel.

Install plywood with the grain of the outer plies at right angles to the joists. Stagger panels so that end joints in adjacent panels break over different joists. The nailing schedule for most types of subfloor panels calls for 6d common nails for materials up to 7/8 inch thick and for 8d nails for heavier panels up to 1 1/8 inches thick. ***Deformed-shank*** nails are strongly recommended. They are usually spaced 6 inches OC along the edges of the panel and 10 inches OC over intermediate joists, as shown in *Figure 10-33*.

Figure 10-33 – Subfloor blocking and nailing.

CAUTION

For the best performance, do not lay up plywood with tight joints, whether interior or exterior. Allow for expansion if moisture should enter the joints.

3.0.0 FRAMING WALLS

Wall construction begins after the subfloor has been nailed in place. The wall system of a wood framed building consists of exterior (outside) and interior (inside) walls. The typical exterior wall has door and window openings, as shown in *Figure 10-33*. Interior walls, usually referred to as “partitions,” divide the inside area into separate rooms. Some interior walls have door openings or archways.

Partitions are either bearing or nonbearing. Bearing partitions support the ends of the floor joists or ceiling joists. Nonbearing partitions run in the same direction as the joists and therefore carry little weight from the floor or ceiling above.

Traditionally, 2 by 4 inch structural lumber is used for the framed walls of one-story buildings, although the use of heavier structural lumber is specified at certain locations for particular projects. Multistory buildings, for example, require heavier structural lumber. This requirement is specific to the lower levels in order to support the weight of the floors above.

3.1.0 Structural Parts

A wood framed wall consists of structural parts referred to as wall components or framing members. The components shown in *Figure 10-34* typically include studs, plates, headers, trimmers, cripples, sills, corner posts, and diagonal braces. Each component is essential to the integrity of the total wall structure.

3.1.1 Studs

Studs are upright (vertical) framing members running between the top and bottom plates. Studs are usually spaced 16 inches OC, but job specifications sometimes call for 12 inch or 24 inch OC stud spacing.

3.1.2 Plates

The plate at the bottom of a wall is the soleplate, or bottom plate. The plate at the top of the wall is the top plate. A double top plate is normally used. It strengthens the upper section of the wall and helps carry the weight of the joists and roof rafters. Since top and bottom plates are nailed into all the vertical wall members, they serve to tie the entire wall together.

Figure 10-34 – Typical exterior wall.

3.1.3 Corner Posts

Corner posts are constructed wherever a wall ties into another wall. Outside comers are at the ends of a wall. Inside corners occur where a partition ties into a wall at some point between the ends of the wall.

Three typical designs for corner assemblies are shown in *Figure 10-35*. *Slide 1* shows outside corner construction using only three studs. *Slide 2* shows outside corner construction using two studs with short blocks between them at the center and ends. A third full length stud can be used instead of blocks. *Slide 3* shows inside corner construction using a block laid flat. A full length stud can be used instead of a block. All corner assemblies should be constructed from straight stud material and should be well nailed. When framing corners, you can use full length studs or short blocks.

Figure 10-35 – Corner posts.

3.1.4 ough Door and Window Openings

Frame a rough opening into a wall wherever a door or window is planned. The dimensions of the rough opening must allow for the final frame and for the required clearance around the frame.

Figure 10-36 shows details of rough openings for doors and windows in wood frame construction. The rough opening for a typical door is framed with a header, trimmer studs, and, in some cases, top cripple studs. The rough opening for a typical window includes the same members as for a door, plus a rough window sill and bottom cripples.

A rough opening has a header at the top that must be strong enough to carry the weight bearing down on that section of the wall. The header is supported by trimmer studs fitting between the soleplate and the bottom of the header. The trimmer studs are nailed into the regular studs at each side of the header. Nails are

Figure 10-36 – Rough frame openings for doors and windows.

also driven through the regular studs into the ends of the header.

The header may be either solid or built up of two 2 by 4 pieces with a 1/2 inch spacer. The spacer is needed to bring the width of the header to 3 1/2 inches. This is the actual width of a nominal 2 by 4 stud wall. A built-up header is as strong as or stronger than a solid piece.

The type and size of the header is shown in the blueprints. The width of the opening and the amount of weight bearing down from the floor above determine header size.

The tops of all door and window openings in all walls are usually in line with each other. Therefore, all headers are usually the same height from the floor. The standard height of walls in most wood framed buildings is either 8 feet 3/4 inch or 8 feet 1 inch from the subfloor to the ceiling joists. The standard height of the doors is 6 feet 8 inches.

Cripple studs are nailed between the header and the double top plate of a door opening. These help carry the weight from the top plate to the header. The cripple studs are generally spaced 16 inches OC.

Add a rough window sill to the bottom of a rough window opening. The sill provides support for the finished window and frame to be placed in the wall. The distance between the sill and the header is determined by the dimensions of the window, the window frame, and the necessary clearances at the top and bottom of the frame. Nail cripple studs, spaced 16 inches OC, between the sill and the soleplate. You may place additional cripple studs under each end of the sill.

3.1.5 Bracing

Diagonal bracing is necessary for the lateral strength of a wall. In all exterior walls and main interior partitions, place bracing at both ends, where possible, and at 25 foot intervals. An exception to this requirement is an outside wall covered with structural sheathing nailed according to building specifications. This type of wall does not require bracing.

Diagonal bracing is most effective when installed at a 45º to 60º angle. You can do this after the wall has been squared and is still lying on the subfloor.

Figure 10-37 – Types of bracing.

The most widely used bracing system is the 1 by 4 let-in type, shown in *Figure 10-37.* The studs are notched so that the 1 by 4 piece is flush with the surface of the studs.

Cut-in bracing, shown in *Figure 10-37*, is another type of diagonal bracing. It usually consists of 2 by 4s cut at an angle and toenailed between studs at a diagonal from the top of a corner post down to the soleplate.

Diagonal sheathing, shown in *Figure 10-37*, is the strongest type of diagonal bracing. Each board acts as a brace for the wall. When you use plywood or other panel sheathing, you may omit other methods of bracing.

3.1.6 Fire stops

Most local building codes require fire stops, also known as fire blocks, in walls over 8 feet 1 inch high. Fire stops slow down fire travel inside walls. Nail them between the studs before or after the wall is raised. Nail fire stops in a straight line or staggered for easier nailing. *Figure 10-38* shows a section of a framed wall with fire stops.

Figure 10-38 – Fire blocking.

It is not necessary to nail fire stops at the midpoint of the wall. You can position them to provide additional backing for nailing the edges of drywall or plywood.

Test your Knowledge (Select the Correct Response)

5. Which of the following framing members ties the entire wall together?

   A. Studs
   B. Posts
   C. Sills
   D. Plates

6. What component is required at the intersections and ends of a wall?

A. Corner post
B. Cripple stud
C. Diagonal brace
D. Header

3.2.0 Construction

All major components of a wall should be cut before assembly. By reading the blueprints, you can determine the number of pieces and lengths of all components. Then you can assemble the different parts of the wall. You can use any hard, level surface for assembly. After you complete nailing, raise the walls in place for securing.

Two layout procedures are used in wall layout, horizontal plate and vertical layout. In horizontal plate layout, the location of the wall is determined from the dimensions found in the floor plan of the blueprints. For vertical layout, the dimension can be found in the sectional views of the building's blueprints.

3.2.1 orizontal Plate Layout

After snapping all the lines, cut and tack the wall plates next to the lines as shown in *Figure 10-39*. Then mark off the plates for corner posts and regular studs, as well as for the studs, trimmers, and cripples for the rough openings. Clearly mark all framing members on the plates. This allows for efficient and error-free framing. *Figure 10-39* shows a wall with framing members nailed in place according to layout markings.

Figure 10-39 – Layout and cutting of plates.

A procedure for marking inside and outside comers for stud and block corner post construction is shown in *Figure 10-40*.

For laying out studs for the first exterior wall, see *Figure 10-41*. Mark the plates for the first stud from a corner to be placed 15 1/4 inches from the end of the corner. Studs after the first stud follow 16 inches OC layout. This ensures the edges of standard size panels used for sheathing or wallboard fall on the centers of the studs. Lay cripples out to follow the layout of the studs.

Figure 10-40 – Marking inside and outside corners.

Figure 10-41 – First exterior wall stud layout.

A procedure for laying out studs for the second exterior wall is shown in *Figure 10-42*. Mark the plates for the first stud to be placed 15 1/4 inches from the outside edge of the panel thickness on the first wall. This layout allows the corner of the first panel on the second wall to line up with the edge of the first panel on the second wall. The opposite edge of the panel on the second wall will break on the center of a stud.

Figure 10-42 – Second exterior wall stud layout.

A procedure for laying out studs for interior walls (partitions) is shown in *Figure 10-43*. If panels are placed on the exterior wall first, mark the wall plates for the interior wall for the first stud to be placed 15 1/4 inches from the edge of the panel thickness on the exterior wall. If panels are to be placed on the interior wall, mark the wall plates of the interior wall for the first stud to be placed 15 1/4 inches from the unpaneled exterior wall.

If drywall or other interior finish panels are to be nailed to an adjoining wall as shown in *Figure 10-43, view A*, you must measure 15 1/4 inches plus the thickness of the material. When panels are to be nailed on a wall first as shown in *view B*, measure and mark the 15 1/4 inches from the front surface of the bottom plate. These procedures ensure stud alignment remains accurate throughout the nailing process.

Figure 10-43 – Starting measurement for interior wall.

Figure 10-44 – Measurements for windows and doors.

Rough openings for doors and windows must also be marked on the wall plates. The rough opening dimensions are shown for a window, *Figure 10-44, view A,* or wood door, *view B.* These are calculated based on the window or door width, the thickness of the finish frame, and 1/2 inch clearance for shim materials at the sides of the frame. Some blueprint door and window schedules give the rough opening dimensions, simplifying the layout.

A rough opening for a metal window often requires a 1/2 inch clearance around the entire frame. When the measurements are not given in the window schedule, take them from the manufacturer's installation instructions supplied with the windows.

A completely laid out bottom plate includes markings for corner posts, rough openings, studs, and cripples. Lay out the corner posts first. Next mark the 16 inch marks for the studs and cripples. Then make the marks for the rough openings.

Some Builders prefer to lay out the rough openings before the studs and cripples are marked. There is an advantage to laying out the 16 inch OC marks first. Studs and trimmers framing a door and window often fall very close to a 16 inch OC stud mark. Slightly shifting the position of the rough opening may eliminate an unnecessary stud from the wall frame.

3.2.2 Vertical Layout

Vertical layout is the procedure for calculating the lengths of the different vertical members of a wood framed wall. This makes it possible to precut all studs, trimmers, and cripples required for a building.

Some blueprints contain section views giving the exact rough heights of walls. The rough height is the distance from the subfloor to the bottom of the ceiling joists. The rough height to the top of the door, the distance from the subfloor to the bottom of the door header, may also be noted on the section drawing. In addition, it may be given in the column for rough opening measurements on the door schedule. The rough height to the top of the door establishes the measurement for the rough height to the top of the window, as window headers are usually in line with door headers.

The distance from the bottom to the top of a rough window opening can be found by measuring down from the bottom of the window header using dimensions provided in the rough opening column of the window schedule.

Many Builders prefer to frame the door and window openings before assembling the wall. *View A* of *Figure 10-45* shows typical door framing; *view B* shows typical window framing. After stud layout, cripple studs are laid out, usually 16 inches OC, and nailed between the header and top plate and rough window sill and soleplate. It is good practice to place a cripple stud under each end of a sill.

Figure 10-45 – Framing typical door and window openings.

Test your Knowledge (Select the Correct Response)

7. When you are rough framing a window opening, the trimmer studs are installed between what two components?

   A. Double top plate and header
   B. Top plate and subfloor
   C. Header and bottom plate
   D. Header and subfloor

3.3.0 Assembly

After the corners and openings for doors and windows have been made up, the entire wall can be nailed together on the subfloor, as shown in *Figure 10-46*. Place top and bottom plates at a distance slightly greater than the length of the studs. Position the corners and openings between the plates according to the plate layout. Place studs in position with the crown side up. Nail the plates into the studs, cripples, and trimmers. On long walls, the breaks in the plates should occur over a stud or cripple.

Figure 10-46 – Assembly of wall components.

3.3.1 Placing the Double Top Plate

The double top plate shown in *Figure 10-47* can be placed while the wall is still on the subfloor or after all the walls have been raised. Nail the topmost plates so that they overlap the plates below at all corners. This helps to tie the walls together. Fasten all ends with two 16d nails. Between the ends, stagger 16d nails 16 inches OC. The butt joints between the topmost plates should be at least 4 feet from any butt joint between the plates below them.

Figure 10-47 – Double top plate.

3.3.2 Squaring Walls and Placing Braces

A completely framed wall is often squared while it is still lying on the subfloor. In this way, bracing, plywood, or other exterior wall covering can be nailed before the wall is raised. When diagonal measurements are equal, the wall is square. *Figure 10-48* shows examples of unsquared and squared walls.

Figure 10-48 – Squaring a wall.

A let-in diagonal brace may be placed while the wall is still on the subfloor. Lay out and snap a line on the studs to show the location of the brace as shown in *Figure 10-49*. Then notch the studs for the brace. Tack the brace to the studs while the wall is still lying on the subfloor. Tacking instead of nailing allows for some adjustment after the wall is raised. After any necessary adjustment is made, securely drive the nails in.

Figure 10-49 – Let-in diagonal brace.

3.3.3 Raising

Most walls can be raised by hand if enough help is available. It is advisable to have one person for every 10 feet of wall for the lifting operation.

The order in which walls are framed and raised may vary from job to job. Generally, the longer exterior walls are raised first. The shorter exterior walls are then raised, and the comers nailed together. The order of framing interior partitions depends on the floor layout.

After raising a wall has been raised, nail its bottom plates securely to the floor. Where the wall rests on a wood subfloor and joists, drive 16d nails through the bottom plate and into the floor joists below the wall.

3.3.4 Plumbing and Aligning

Accurate plumbing of the corners is possible only after all the walls are up. Most framing materials are not perfectly straight; never plumb walls by applying a hand level directly to an end stud. Always use a straightedge along with the level, as shown in *Figure 10-50, view A*. The straightedge can be a piece ripped out of plywood or a straight piece of 2 by 4 lumber. Nail 3/4 inch thick blocks to each end. The blocks make it possible to accurately plumb the wall from the bottom plate to the top plate.

Plumbing corners requires two persons working together; one working the bottom area of the brace and the other watching the level. The bottom end of the brace is renailed when the level shows a plumb wall.

Figure 10-50 – Plumbing and aligning corners and walls.

The tops of the walls shown in *Figure 10-50, view B* are straightened (aligned or lined up) after all the corners have been plumbed. Prior to nailing the floor or ceiling joists to the tops of the walls, make sure the walls are aligned using the following steps:

1. Fasten a string from the top plate at one corner of the wall to the top plate at another corner of the wall.
2. Cut three small blocks from 1 by 2 lumber. Place one block under each end of the string so that the line is clear of the wall.
3. The third block is used as a gauge to check the wall at 6 or 8 foot intervals. At each checkpoint, fasten a temporary brace to a wall stud.
4. When fastening the temporary brace to the wall stud, adjust the wall so that the string is barely touching the gauge block. Nail the other end of the brace to a short 2 by 4 block fastened to the subfloor. Do not remove these temporary braces until the framing and sheathing for the entire building have been completed.

3.3.5 Framing over Concrete Slabs

Often, the ground floor of a wood framed building is a concrete slab. In this case, you must either bolt or nail the bottom plates of the walls to the slab with a powder actuated driver. If you use bolts, you must accurately set them into the slab at the time of the concrete pour. Lay out holes for the bolts and drill in the bottom plate when the wall is framed. When the wall is raised, slip it over the bolts and secure it with washers and nuts.

Occasionally on small projects the soleplate is bolted or fastened down first. The top plate is nailed to the studs, and the wall is lifted into position. The bottom ends of the studs are toenailed into the plate. The rest of the framing procedure is the same as for walls nailed on top of a subfloor.

3.4.0 Sheathing the Walls

Wall sheathing is the material used for the exterior covering of the outside walls. In the past, nominal 1 inch thick boards were nailed to the wall horizontally or at a 45° angle for sheathing. Today, plywood and other types of panel products (waferboard, oriented strandboard, or compositeboard) are usually used for sheathing. Plywood and nonveneered panels can be applied much more quickly than boards. They add considerable strength to a building and often eliminate the need for diagonal bracing.

Generally, wall sheathing does not include the finished surface of a wall. Siding, shingles, stucco, or brick veneer are placed over the sheathing to finish the wall. Exterior finish materials are discussed in a separate chapter.

3.4.1 Plywood

Plywood is the most widely used sheathing material. Plywood panels usually applied to exterior walls range in size from 4 by 8 feet to 4 by 12 feet with thicknesses from 5/16 inch to 3/4 inch.

The panels may be placed with the grain running vertically or horizontally as shown in *Figure 10-51*. Specifications may require blocking along the long edges of horizontally placed panels.

Typical nailing specifications require 6d nails with panels 1/2 inch or less in thickness and 8d nails for panels more than 1/2 inch thick. Space the nails 6 inches apart along the edges of the panels and 12 inches apart at the intermediate studs.

When nailing the panels, leave a 1/8 inch gap between the horizontal edges of the panels and a 1/16 inch gap between the vertical edges. These gaps allow for expansion caused by moisture and prevent panels from buckling.

Figure 10-51 – Plywood sheathing.

In larger wood framed buildings, plywood is often nailed to some of the main interior partitions. The result is called a shear wall, which adds considerable strength to the entire building.

Plywood sheathing can be applied when the squared wall is still lying on the subfloor. Problems can occur after the wall is raised if the floor is not perfectly straight and level.

For this reason, some Builders prefer to place the plywood after framing the entire building.

Test your Knowledge (Select the Correct Response)

8. Compared to other exterior finishes, plywood panels have what advantage(s)?

   A. They provide additional strength only.
   B. They shorten installation time only.
   C. They eliminate the need for diagonal bracing only.
   D. All of the above

3.4.2 Nonveneered Panels

Although plywood is the most commonly used material for wall sheathing, specifications sometimes call for nonveneered (reconstituted wood) panels. Panels made of waferboard, oriented strandboard, and compositeboard have been approved by most local building codes for use as wall sheathing. Like plywood, these panels resist ***racking***, so no corner bracing is necessary in normal construction. However, where maximum shear strength is required, conventional veneered plywood panels are still recommended.

3.5.0 Metal Framing

Metal is an alternative to wood framing. Many buildings are framed entirely in metal, whereas some buildings are framed in a combination of metal and wood.

The metal framing members generally used are cold formed steel, electrogalvanized to resist corrosion. Thicknesses range from 18 gauge to 25 gauge, the latter being most common.

Most metal studs have notches at each end and knockouts located about 24 inches OC, as shown in *Figure 10-52*, to facilitate pipe and conduit installation. The size of the knockout, not the size of the stud, determines the maximum size of pipe or other material that can be passed through horizontally.

Figure 10-52 – Typical metal stud construction.

The application of nonveneered wall sheathing is similar to that of plywood. Nailing schedules usually call for 6d common nails spaced 6 inches OC above the panel edges, and 12 inches OC when nailed into the intermediate studs. Nonveneered panels are usually applied with the long edge of the panel in a vertical position.

Chase (or double stud) walls, as shown in *Figure 10-53*, are often used when large pipes, ducts, or other items must pass vertically or horizontally in the walls. Studs are generally available in widths of 1 5/8, 2 1/2, 3 5/8, 4, and 6 inches. The metal runners used are also 25 gauge (or specified gauge) steel or aluminum, sized to complement the studs. Both products have features advantageous to light frame construction. The metal studs and runners do not shrink, swell, twist, or warp.Termites cannot affect them, nor are they susceptible to dry rot. They have a high fire-resistance rating when combined with proper covering material.

A variety of systems have been developed by manufacturers to meet various requirements of attachment, sound control, and fire resistance. Many of the systems are designed for ease in erection, yet they are still remountable for revising room arrangements.

Figure 10-53 – Chase wall construction.

Assemble the framing members with power screwdrivers and using self-drilling, self-tapping screws. Fasten the floor assembly to the foundation or concrete slab with studs (special nails) driven through the stud track (runner) by a powder actuated stud driver. Install the plywood subfloor over the metal floor framing system with self-drilling, self-tapping screws and structural adhesive. Wall sections are assembled at the jobsite or delivered as preassembled panels from an off-site prefabrication shop. Attach conventional sheathing to the framework with self-tapping screws.

Door frames for both the interior partitions and exterior walls are integral with the system. They are preprinted and may come complete with necessary hinges, locks, rubber stops, and weather stripping. The windows are also integral to the system, prefabricated and painted. These units may include interior and exterior trim designed to accept 1/2 inch wallboard and 1/2 inch sheathing plus siding on the outside.

Install plumbing in prepunched stud webs. Pass wiring through insulated grommets inserted in the prepunched webs of the studs and plates. Mount wall and ceiling fixtures by attaching wood blocking spaced between the flanges of the wall studs or ***trusses*** as shown in *Figure 10-54*. Install friction-tight insulation by placing the ***batts*** between the studs on the exterior walls. Space studs 12, 16, or 24 inches OC as specified in the blueprints.

Figure 10-54 – Wood blocking for ceiling or wall mounted fixtures.

3.5.1 Corner and Casing Beads

Standard wallboard corner bead is manufactured from galvanized steel with perforated flanges, as shown in *Figure 10-55*. It provides a protective reinforcement for straight corners. The corner bead is made with 1 inch by 10 inch flanges for 3/8 or 1/2 inch single layer wallboard; 1 inch by 1 1/4 inches for 1/2 inch or 5/8 inch single layer wallboard; 1 1/4 inches by 1 1/4 inches for two layer wallboard application. It is available in 10 foot lengths.

Figure 10-55 – Standard corner bead.

Multiflex tape bead consists of two continuous metal strips on the undersurface of 2 1/8 inch-wide reinforcing tape, as shown in *Figure 10-56*. This protects corners formed at any angle. Multiflex tape bead comes in 100-foot rolls.

Figure 10-56 – Multiflex tape bead.

Casing and trim beads, shown in *Figure 10-57*, are used as edge protection and trim around window and door openings and as moldings at ceiling angles. They are made from galvanized steel in three styles to fit 3/8 inch, 1/2 inch, and 5/8 inch wallboard and come in 10-foot lengths.

Figure 10-57 – Casing and trim beads.

3.5.2 Expansion Joints

Expansion joints are vinyl extrusions used as control joints in drywall partitions and ceilings. A typical form is shown in *Figure 10-58*.

Figure 10-58 – Expansion joint.

Figure 10-59 shows a typical metal frame layout and use of corner and casing beads for corners, partition intersections, and partition ends. It also shows a typical cross section of a metal frame stud wall control joint.

Figure 10-59 – Metal frame layout with various beads and joints.

Test your Knowledge (Select the Correct Response)

9. What is the purpose of corner and casing beads?

   A. Protect and reinforce corners and edges of drywall
   B. Add additional support for nonbearing walls
   C. Allow for expansion
   D. Improve the appearance of the finished wall

Figure 10-60 lists the different types of fasteners used in metal frame construction and explains the application of each type.

Figure 10-60 – Drywall screws and fastening application.

4.0.0 FRAMING CEILINGS

Ceiling construction begins after all walls have been plumbed, aligned, and secured. One type of ceiling supports an attic area beneath a sloping (pitched) roof. Another type serves as the framework of a flat roof. When a building has two or more floors, the ceiling of a lower story is the floor of the story above.

One of the main structural functions of a ceiling frame is to tie together the outside walls of the building. When located under a pitched roof, the ceiling frame also resists the outward pressure placed on the walls by the roof rafters, as shown in *Figure 10-61*. The tops of interior partitions are fastened to the ceiling frame. In addition to supporting the attic area beneath the roof, the ceiling frame supports the weight of the finish ceiling materials, such as gypsum board or lath and plaster.

Figure 10-61 – Ceiling frame tying exterior walls together.

4.1.0 Joists

Joists are the most important framing members of the ceiling. Their size, spacing, and direction of travel are given on the floor plan. As mentioned earlier, the spacing between ceiling joists is usually 16 inches OC, although 24 inch spacing is also used. The size of a ceiling joist is determined by the weight it carries and the span it covers from wall to wall. Refer to the blueprints and specifications for size and OC spacing. Although it is more convenient to have all the joists running in the same direction, plans sometimes call for different sets of joists to run at right angles to each other.

4.1.1 Interior Support

One end of a ceiling joist rests on an outside wall. The other end often overlaps an interior bearing partition or girder. The overlap should be at least 4 inches. Ceiling joists are sometimes butted over the partition or girder. In this case, the joists must be cleated with a 3/4 inch thick plywood board, 24 inches long, or an 18 gauge metal strap, 18 inches long.

Ceiling joists may also butt against the girder, supported by joist hangers in the same manner as floor joists.

4.1.2 Roof Rafters

Whenever possible, the ceiling joists should run in the same direction as the roof rafters. Nailing the outside end of each ceiling joist to the heel of the rafter as well as to the wall plates as shown in *Figure 10-62* strengthens the tie between the outside walls of the building.

Figure 10-62 – Nailing of ceiling joists.

A building may be designed so that the ceiling joists do not run parallel to the roof rafters. The rafters are therefore pushing out on walls not tied together by ceiling joists. In this case, add 2 by 4 pieces to run in the same direction as the rafters, as shown in *Figure 10-63*. Nail the 2 by 4s to the top of each ceiling joist with 2 16D nails. Space the 2 by 4 pieces no more than 4 feet apart, and secure the ends to the heels of the rafters or to blocking over the outside walls.

Figure 10-63 – 2 by 4 ties.

4.1.3 oof Slope

When ceiling joists run in the same direction as the roof rafters, cut the outside ends to the slope of the roof. Ceiling frames are sometimes constructed with stub joists as shown in *Figure 10-64*. Stub joists are necessary when, in certain sections of the roof, rafters and ceiling joists do not run in the same direction. For example, a low pitched hip roof requires stub joists in the hip section of the roof.

4.1.4 bbands and Strongbacks

Ceiling joists not supporting a floor above require no header joists or blocking. Without the additional header joists, ceiling joists may twist or bow at the centers of their span. To help prevent this, nail a 1 by 4 piece called a ribband at the center of the spans as shown in *Figure 10-65*. Lay the ribband flat and fasten it to the top of each joist with two 8d nails. Secure the end of each ribband to the outside walls of the building.

Figure 10-64 – Stub joists.

Figure 10-65 – Ribband installation.

Test your Knowledge (Select the Correct Response)

10. Which of the following components can be used to help support a ceiling joist at the center of its span?

    A. Strongback
    B. Joist hanger
    C. Ribband
    D. Diagonal brace

A more effective method of preventing twisting or bowing of the ceiling joists is to use a strongback. A strongback is made of 2 by 6 or 2 by 8 material nailed to the side of a 2 by 4 piece. Fasten the 2 by 4 piece with two 16D nails to the top of each ceiling joist, as shown in *Figure 10-66*. Block up the strongbacks and support them over the outside walls and interior partitions. Each strongback holds a ceiling joist in line and also helps support the joist at the center of its span.

Figure 10-66 – Strongback.

4.1.5 Layout

Place ceiling directly above the studs when the spacing between the joists is the same as between the studs. This arrangement makes it easier to install pipes, flues, or ducts running up the wall and through the roof. However, for buildings with walls having double top plates, most building codes do not require ceiling joists to line up with the studs below.If the joists are being placed directly above the studs, they follow the same layout as the studs below shown in *Figure 10-67, view A*. If the joist layout is different from that of the studs below, for example, if joists are laid out 24 inches OC over a 16 inch OC stud layout, mark the first joist at 23 1/4 inches and then at every 24 inches OC as shown in *Figure 10-67, view B*.

Figure 10-67 – Ceiling joist spacing.

Marking the positions of the roof rafters at the time the ceiling joists are being laid out is good practice. If the spacing between the ceiling joists is the same as between the roof railers, there will be a rafter next to every joist. Often the joists are laid out 16 inches OC and the roof rafters 24 inches OC. In this case, you can place every other rafter next to a ceiling joist.

4.2.1 Frame

Cut all the joists for the ceiling frame to length before placing them on top of the walls. On structures with pitched roofs, also trim the outside ends of the joists for the roof slope. Cut this angle on the crown (top) side of the joist. The prepared joists can then be handed up to the Builders working on top of the walls. Spread the joists in a flat position along the walls, close to where they will be nailed. *Figure 10-68* shows one procedure for constructing the ceiling frame. In this example, the joists lap over an interior partition.

Refer to the Figure as you study the following steps:

1. Measure and mark for the ceiling joists.
2. Install the ceiling joists on one side of the building.
3. Install the ceiling joists on the opposite side of the building.
4. Place backing on walls running parallel to the joists.
5. Install 2 by 4 blocks flat between joists where needed to fasten the tops of inside walls running parallel to the joists.
6. Cut and frame the attic scuttle.
7. Place strongbacks at the center of the spans.

Figure 10-68 – Constructing a typical ceiling frame.

4.2.1 Fastening Walls

The tops of walls running in the same direction as the ceiling joists must be securely fastened to the ceiling frame. The method most often used is shown in *Figure 10-68*. Lay 2 by 4 inch blocks, spaced 32 inches OC, flat over the top of the partition. Fasten the ends of each block to the joists with two 16d nails. Also drive two 16d nails through each block into the top of the wall.

4.2.2 Applying Backing

Walls running in the same direction as the ceiling joists require backing. *Figure 10-68 (insert)* shows how to nail backing to the top plates to provide a nailing surface for the edges of the finish ceiling material. Lumber used for backing usually has 2 inch nominal thickness, although 1 inch boards are sometimes used.

Figure 10-69 shows backing placed on top of walls. The 2 by 4 pieces nailed to the exterior wall projects from one side of the wall. The interior wall requires a 2 by 6 or 2 by 8 piece extending from both sides of the wall. Fasten backing to the top plates with 16d nails spaced 16 inches OC.

Figure 10-69 – Backing for nailing joists to ceiling frame.

Also use backing where joists run at right angles to the partition as shown in *Figure 10-70*.

Figure 10-70 – Backing for interior wall plates.

4.2.3 Attic Scuttle

The scuttle is an opening framed in the ceiling to provide an entrance into the attic area. The size of the opening is decided by specification requirements and should be indicated in the blueprints. It must be large enough for a person to climb through easily.

The scuttle is framed in the same way as a floor opening. If the opening is no more than 3 feet square, it is not necessary to double the joists and headers. Always place scuttles away from the lower areas of a sloping roof. The opening may be covered by a piece of plywood resting on stops. Cut out the scuttle opening after nailing all the regular ceiling joists in place.

5.0.0 FRAMING ROOFS

In this section, you will learn the fundamentals of roof design and construction. Before we discuss roof framing, you will learn some basic terms and definitions used in roof construction. Next you will learn about the framing square and how it is used to solve some basic construction problems. Then you will learn about various types of roofs and rafters, and techniques for laying out, cutting, and erecting rafters. The section concludes with a discussion of the types and parts of roof trusses.

5.1.0 Terminology

The primary object of a roof in any climate is protection from the elements. Roof slope and rigidness are for shedding water and bearing any additional weight. Roofs must be strong enough to withstand high winds. In this section, you will learn the most common types of roofs and basic framing terms.

5.2.0 Types of Roofs

The most commonly used types of pitched roof construction are the gable, the hip, the gable and valley, and the shed (or lean-to). An example of each is shown in *Figure 10-71*.

Figure 10-71 – Most common types of pitched roofs.

5.2.1 Gable

A gable roof has a ***ridge*** at the center and slopes in two directions. It is the form most commonly used by the Navy. It is simple in design, economical to construct, and can be used on any type of structure.

5.2.2 Hip

The hip roof has four sloping sides. It is the strongest type of roof because it is braced by four hip rafters. These hip rafters run at a 45° angle from each corner of the building to the ridge. A disadvantage of the hip roof is that it is more difficult to construct than a gable roof.

5.2.3 Gable and valley

The gable and valley roof consists of a gable and valley, or hip and valley. The valley is formed where the two different sections of the roof meet, generally at a 90° angle. This type of roof is more complicated than the other types and requires more time and labor to construct.

5.2.4 Shed

The shed roof, or lean-to, is a roof having only one slope, or ***pitch***. It is used where large buildings are framed under one roof, where hasty or temporary construction is needed, and where sheds or additions are erected. The roof is held up by walls or posts where one wall or the posts on one side are at a higher level than those on the opposite side.

5.3.0 Framing Terms

Knowing the basic vocabulary is a necessary part of your work as a Builder. In the following section, you will learn some of the more common roof and rafter terms you'll need. Roof framing terms are related to the parts of a triangle.

5.3.1 Roof

Features associated with basic roof framing terms are shown in *Figure 10-72*. Refer to the Figure as you study the terms discussed in the next paragraphs. **Span** is the horizontal distance between the outside top plates, or the base of two abutting right triangles.

Unit of *run* is a fixed unit of measure, always 12 inches for the common rafter. Any measurement in a horizontal direction is expressed as run and is always measured on a level plane. Unit of span is also fixed, twice the unit of run, or 24 inches. Unit of ***rise*** is the distance the rafter rises per foot of run (unit of run).

Total run is equal to half the span, or the base of one of the right triangles. Total rise is the vertical distance from the top plate to the top of the ridge, or the altitude of the triangle.

Pitch is the ratio of unit of rise to the unit of span. It describes the slope of a roof. Pitch is expressed as a fraction, such as 1/4 or 1/2 pitch. The term "pitch" is gradually being replaced by the term "cut." Cut is the angle that the roof surface makes with a horizontal plane. This angle is usually expressed as a fraction in which the numerator equals the unit of rise and the denominator equals the unit of run (12 inches), such as 6/12 or 8/12. This can also be expressed in inches per foot; for example, a 6 or 8 inch cut per foot. Here, the unit of run (12 inches) is understood.

Pitch can be converted to cut by using the following formula:

unit of span x pitch = unit of rise

For example, 1/8 pitch is given, so 24 x 1/8 equals 3, or unit of rise in inches. If the unit of rise in inches is 3, then the cut is the unit of rise and the unit of run (12 inches), or 3/12.

Line length is the hyptenuse of the triangle whose base equals the total run and whose height equals the total rise.

The distance is measured along the rafter from the outside edge of the top plate to the centerline of the ridge. Bridge measure is the hypotenuse of the triangle with the unit of run for the base and unit of rise for the altitude.

5.3.2 Rafter

The members making up the main body of the framework of all roofs are called rafters. They do for the roof what the joists do for the floor and what the studs do for the wall. Rafters are inclined members spaced from 16 to 48 inches apart. They vary in size, depending on their length and spacing. The tops of the inclined rafters are fastened in one of several ways determined by the type of roof. The bottoms of the rafters rest on the plate member, providing a connecting link between the wall and the roof. The rafters are really functional parts of both the walls and the roof.

The structural relationship between the rafters and the wall is the same in all types of roofs. The rafters are not framed into the plate, but are simply nailed to it. Some are cut to fit the plate, whereas others, in hasty construction, are merely laid on top of the plate and nailed in place. Rafters usually extend a short distance beyond the wall to form the eaves (overhang) and protect the sides of the building. Features associated with various rafter types and terminology is shown in *Figure 10-73*.

Figure 10-72 – Roof framing terms.

Common rafters extend from the plate to the ridgeboard at right angles to both. Hip rafters extend diagonally from the outside corner formed by perpendicular plates to the ridgeboard. Valley rafters extend from the plates to the ridgeboard along the lines where two roofs intersect. Jack rafters never extend the full distance from plate to ridgeboard. Jack rafters are subdivided into the hip, valley, and cripple jacks. In a hip jack, the lower ends rest on the plate and the upper ends against the hip rafter. In a valley jack the lower ends rest against the valley rafters and the upper ends against the ridgeboard. A cripple jack is nailed between hip and valley rafters.

Figure 10-73 – Rafter terms.

Rafters are cut in the three basic ways shown in *Figure 10-74, view A*. The top cut, also called the plumb cut, is made at the end of the rafter to be placed against the ridgeboard or, if the ridgeboard is omitted, against the opposite rafters. A seat, bottom, or heel cut is made at the end of the rafter that is to rest on the plate. A side cut, not shown in *Figure 10-74*, also called a cheek cut, is a bevel cut on the side of a rafter to make it fit against another frame member.

Rafter length is the shortest distance between the outer edge of the top plate and the center of the ridge line. The eave, tail, or overhang is the portion of the rafter extending beyond the outer edge of the plate. A measure line shown in *Figure 10-74, view B* is an imaginary reference line laid out down the middle of the face of a rafter. If a portion of a roof is represented by a right triangle, the measure line corresponds to the hypotenuse, the rise to the altitude, and the run to the base.

Figure 10-74 – Rafter layout.

A plumb line, like the one shown in *Figure 10-74, view C*, is any line that is vertical (plumb) when the rafter is in its proper position. A level line, shown in *Figure 10-74, view C*, is any line that is horizontal (level) when the rafter is in its proper position.

6.0.0 USING THE FRAMING SQUARE

The framing square is one of the most frequently used Builder tools. The problems it can solve are so many and varied that books have been written on the square alone. Only a few of the more common uses of the square can be presented here. For a more detailed discussion of the various uses of the framing square in solving construction problems, you are encouraged to obtain and study one of the many excellent books on the square.

6.1.1 Description

The framing square shown in *Figure 10-75, view A* consists of a wide, long member called the blade and a narrow, short member called the tongue. The blade and tongue form a right angle. The face of the square is the side you see when the square is held with the blade in the left hand, the tongue in the right hand, and the heel pointed away from the body. The manufacturer's name is usually stamped on the face. The blade is 24 inches long and 2 inches wide. The tongue varies from 14 to 18 inches long and is 1 1/2 inches wide, measured from the outer corner, where the blade and the tongue meet. This corner is called the heel of the square.

Figure 10-75 – Framing square

A. Nomenclature

B. Problem solving.

The outer and inner edges of the tongue and the blade, on both face and back, are graduated in inches. Note how inches are subdivided in the scale on the back of the square. In the scales on the face, the inch is subdivided in the regular units of carpenter's measure, 1/8 or 1/16 inch. On the back of the square, the outer edge of the blade and tongue is graduated in inches and twelfths of inches. The inner edge of the tongue is graduated in inches and tenths of inches. The inner edge of the blade is graduated in inches and thirty-seconds of inches on most squares. Common uses of the twelfths scale on the back of the framing square will be described later. The tenths scale is not normally used in roof framing.

6.2.0 Solving Basic Problems with the Framing Square

The framing square is used most frequently to find the length of the hypotenuse, the longest side, of a right triangle when the lengths of the other two sides are known. This is the basic problem involved in determining the length of a roof rafter, a brace, or any other member that forms the hypotenuse of an actual or imaginary right triangle.

Figure 10-75, view B shows how to use the framing square to determine the length of the hypotenuse of a right triangle with the other sides each 12 inches long. Place a true straightedge on a board and set the square on the board so as to bring the 12 inch mark on the tongue and the blade even with the edge of the board. Draw the pencil marks as shown. The distance between these marks, measured along the edge of the board, is the length of the hypotenuse of a right triangle with the other sides each 12 inches long. You will find that the distance, called the bridge measure, measures just under 17 inches (17.97 inches), as shown in *Figure 10-75*. For most practical purposes for Builders, round 17.97 inches to 17 inches.

6.2.1 Solving for Unit and Total Run and Rise

In *Figure 10-75*, the problem could be solved by a single set, called a cut, of the framing square. This is because the dimensions of the triangle in question lie within the dimensions of the square. Suppose you are trying to find the length of the hypotenuse of a right triangle with the two known sides each being 48 inches long. Assume the member whose length you are trying to determine is the brace shown in *Figure 10-76*. The total run of this brace is 48 inches, and the total rise is also 48 inches.

Figure 10-76 – Stepping off with a framing square.

To figure the length of the brace, first reduce the triangle in question to a similar triangle within the dimensions of the framing square. The length of the vertical side of this triangle is called the unit of rise, and the length of the horizontal side is called the unit of run. By a general custom of the trade, unit of run is always taken as 12 inches and measured on the tongue of the framing square.

Now, if the total run is 48 inches, the total rise is 48 inches, and the unit of run is 12 inches, what is the unit of rise? Since the sides of similar triangles are proportional, the unit of rise must be the value of *x* in the proportional equation *48:48::12:x.* In this case, the unit of rise is obviously 12 inches.

To get the length of the brace, set the framing square to the unit of run (12 inches) on the tongue and to the unit of rise (also 12 inches) on the blade, as shown in *Figure 10-76*. Then, step off this cut as many times as the unit of run goes into the total run. In this case, 48/12, or 4 times.

In this problem, the total run and total rise were the same, from which it followed that the unit of run and unit of rise were also the same. Suppose now that you want to know the length of a brace with a total run of 60 inches and a total rise of 72 inches, as in *Figure 10-77.* Since the unit of run is 12 inches, the unit of rise must be the value of *x* in the proportional equation *60:72::12.x.* That is, the proportion 60:72 is the same as the proportion 12:x. Working this out, you find the unit of rise is 14.4 inches. For practical purposes, you can round this to 14 3/8.

To lay out the full length of the brace, set the square to the unit of rise, 14 3/8 inches, and the unit of run, 12 inches, as shown in *Figure 10-77.* Then step off this cut as many times as the unit of run goes into the total run which is 60/12, or 5 times.

Figure 10-77 – Stepping off with a square when the unit of run and unit of rise are different.

6.2.2 Determining Line Length

If you do not go through the stepping-off procedure, you can Figure the total length of the member in question by first determining the bridge measure. The bridge measure is the length of the hypotenuse of a right triangle with the other sides equal to the unit of run and unit of rise.

Take the situation shown in *Figure 10-77*. The unit of run here is 12 inches and the unit of rise is 14 3/8 inches. Set the square to this cut, as shown in *Figure 10-78*, and mark the edges of the board as shown. If you measure the distance between the marks, you will find it is 18 3/4 inches. Bridge measure can also be found by using the Pythagorean theorem:

Figure 10-78 – Unit length.

$$a2 + b2 = c2$$

Here, the unit of rise is the altitude *(a),* the unit of run is the base *(b),* and the hypotenuse *(c)* is the bridge measure.

To get the total length of the member, you simply multiply the bridge measure in inches by the total run in feet. Since that is 5, the total length of the member is 18 3/4 x 5, or 93 3/4 inches. The length of the hypotenuse of a right triangle with the other sides 60 and 72 inches long is slightly more than 93.72 inches, but 93 3/4 inches is close enough for practical purposes.

Once you know the total length of the member, just measure it off and make the end cuts. To make these cuts at the proper angles, set the square to the unit of run on the tongue and the unit of rise on the blade and draw a line for the cut along the blade (lower end cut) or the tongue (upper end cut).

6.3.0 Scales

A framing square contains four scales: tenths, twelfths, hundredths, and octagon. All are found on the face or along the edges of the square. As we mentioned earlier, the tenths scale is not used in roof framing.

6.3.1 Twelfths Scale

The graduations in inches, located on the back of the square along the outer edges of the blade and tongue, are called the twelfths scale. The chief purpose of the twelfths scale is to provide various shortcuts in problem solving graduated in inches and twelfths of inches. Dimensions in feet and inches can be reduced to 1/12th by simply allowing each graduation on the twelfths scale to represent 1 inch. For example, 2 6/12 inches on the twelfths scale may be taken to represent 2 feet 6 inches. A few examples will show you how the twelfths scale is used.

Suppose you want to know the total length of a rafter with a total run of 10 feet and a total rise of 6 feet 5 inches. Set the square on a board with the twelfths scale on the blade at 10 inches and the twelfths scale on the tongue at 6 5/12 inches and make the usual marks. If you measure the distance between the marks, you will find it is 11 11/12 inches. The total length of the rafter is 11 feet 11 inches.

Suppose now that you know the unit of run, unit of rise, and total run of a rafter, and you want to find the total rise and the total length. Use the unit of run, 12 inches, and unit of rise, 8 inches, and total run of 8 feet 9 inches. Set the square to the unit of rise on the tongue and unit of run on the blade as shown in *Figure 10-79, top view*. Then slide the square to the right until the 8 9/12 inch mark on the blade, representing the total run of 8 feet 9 inches, comes even with the edge of the board, as shown in the second view. The figure of 5 10/12 inches, now indicated on the tongue, is one twelfth of the total rise. The total rise is 5 feet 10 inches. The distance between pencil marks, 10 7/12 inches, drawn along the tongue and the blade is one twelfth of the total length. The total length is 10 feet 7 inches.

You may also use the twelfths scale to determine dimensions by inspection for proportional reductions or enlargements. Suppose you have a panel 10 feet 9 inches long by 7 feet wide. You want to cut a panel 7 feet long with the same proportions. Set the square, as shown in *Figure 10-79*, but with the blade at 10 9/12 inches and the tongue at 7 inches. Then slide the blade to 7 inches and read the Figure indicated on the tongue, which will be 4 7/12 inches if done correctly. The smaller panel should be 4 feet 7 inches wide.

Figure 10-79 – Finding total rise and length when unit of run, unit of rise, and total run are known.

6.3.2 Hundredths Scale

The hundredths scale is on the back of the tongue, in the comer of the square, near the brace table. This scale is called the hundredths scale because 1 inch is divided into 100 parts. The longer lines indicate 25 hundredths, the next shorter lines indicate 5 hundredths, and so forth. By using dividers, you can easily obtain a fraction of an inch.

The inch is graduated in sixteenths and located below the hundredths scale. The conversion from hundredths to sixteenths can be made at a glance without the use of dividers. This can be a great help when determining rafter lengths, using the figures of the rafter tables where hundredths are given.

6.4.0 Framing Square Tables

There are three tables on the framing square: the unit length rafter table, located on the face of the blade; the brace table, located on the back of the tongue; and the ***Essex board measure*** table, located on the back of the blade. Before you can use the unit length rafter table, you must be familiar with the different types of rafters and with the methods of framing them. The use of the unit length rafter table is described later in this section. The other two tables are discussed below.

6.4.1 Brace Table

The brace table sets forth a series of equal runs and rises for every three units interval from 24/24 to 60/60, together with the brace length, or length of the hypotenuse, for each given run and rise. The table can be used to determine, by inspection, the length of the hypotenuse of a right triangle with the equal shorter sides of any length given in the table. For example, in the segment of the brace table shown in *Figure 10-80*, you can see that the length of the hypotenuse of a right triangle with two sides 24 units long is 33.94 units; with two sides 27 units long is 38.18 units; two sides 30 units long is 42.43 units; and so on.

By applying simple arithmetic, you can use the brace table to determine the hypotenuse of a right triangle with equal sides of practically any even unit length. Suppose you want to know the length of the hypotenuse of a right triangle with two sides 8 inches long. The brace table shows that a right triangle with two sides 24 inches long has a hypotenuse of 33.94 inches. Since 8 amounts to 24/3, a right triangle with two shorter sides each 8 inches long must have a hypotenuse of 33.94 ÷3, or approximately 11.31 inches.

Suppose you want to find the length of the hypotenuse of a right triangle with two sides 40 inches each. The sides of similar triangles are proportional, and any right triangle with two equal sides is similar to any other right triangle with two equal sides. The brace table shows that a right triangle with the two shorter sides being 30 inches long has a hypotenuse of 42.43 inches. The length of the hypotenuse of a right triangle with the two shorter sides being 40 inches long must be the value of *x* in the proportional equation *30:42.43::40:x,* or about 57.57 inches.

Notice that the last item in the brace table, the one farthest to the right in *Figure 10-80*, gives you the hypotenuse of a right triangle with the other proportions 18:24:30. These proportions are those of the most common type of unequal sided right triangle, with sides in the proportions of 3:4:5.

Figure 10-80 – Brace table.

6.4.2 Essex Board

The primary use of the Essex board measure table is for estimating the board feet in lumber of known dimensions. The inch graduations shown in *Figure 10-81, view A* above the table (1, 2, 3, 4, and so on) represent the width in inches of the piece to be measured. The figures under the 12 inch graduation (8, 9, 10, 11, 13, 14, and 15, arranged in columns) represent lengths in feet. The figure 12 itself represents a 12 foot length. The column headed by the figure 12 is the starting point for all calculations.

To use the table, scan down the figure 12 column to the figure that represents the length of the piece of lumber in feet. Then go horizontally to the figure directly below the inch mark that corresponds to the width of the stock in inches. The figure you find will be the number of board feet and twelfths of board feet in a 1 inch thick board.

Let's take an example. Suppose you want to figure the board measure of a piece of lumber 10 feet long by 10 inches wide by 1 inch thick. Scan down the column shown in *Figure10-81, view B* headed by the 12 inch graduation to 10, and then go horizontally to the left to the figure directly below the 10 inch graduation. You will find the figure to be 84, or 8 4/12 board feet. For easier calculating purposes, you can convert 8 4/12 to a decimal, 8.33.

Figure 10-81 – Segment of Essex board measure table.

To calculate the cost of this piece of lumber, multiply the cost per board foot by the total number of board feet. For example, a 1 by 10 costs $1.15 per board foot. Multiply the cost per board foot, $1.15 by the number of board feet, 8.33. This calculation is as follows:

$ 1.15
x 8.33
$ 9.5795 (rounded off to $9.58)

What do you do if the piece is more than 1 inch thick? All you have to do is multiply the result obtained for a 1 inch thick piece by the actual thickness of the piece in inches. For example, if the board described in the preceding paragraph were 5 inches thick instead of 1 inch thick, you would follow the procedure described and then multiply the result by 5.

The board measure scale can be read only for lumber from 8 to 15 feet in length. If your piece is longer than 15 feet, you can proceed in one of two ways. If the length of the piece is evenly divisible by one of the lengths in the table, you can read for that length and multiply the result by the number required to equal the piece you are figuring. Suppose you want to find the number of board feet in a piece 33 feet long by 7 inches wide by 1 inch thick. Since 33 is evenly divisible by 11, scan down the 12 inch column to 11 and then go left to the 7 inch column. The figure given there, which is 65/12, or 7.42 board feet, is one third of the total board feet. The total number of board feet is 6 5/12 (7.42) x 3, or 19 3/12 (19.26) board feet.

If the length of the piece is not evenly divisible by one of the tabulated lengths, you can divide it into two tabulated lengths, read the table for these two, and add the results together. For example, suppose you want to find the board measure of a piece 25 feet long by 10 inches wide by 1 inch thick. This length can be divided into 10 feet and 15 feet. The table shows that the 10 foot length contains 8 4/12 (8.33) board feet and the 15 foot length contains 12 6/12 (12.5) board feet. The total length then contains 8 4/12 (8.33) plus 12 6/12 (12.5), or 20 10/12 (20.83) board feet.

Test your Knowledge (Select the Correct Response)

11. When the blade of a framing square is 24 inches long, the tongue usually varies within which of the following overall lengths?

    A. 12 to 16 inches
    B. 16 to 24 inches
    C. 14 to 18 inches
    D. 18 to 24 inches

7.0.0 LAYING OUT AND INSTALLING ROOFS

The four most common roof designs you will encounter as a Builder are gable, hip, gable and valley, and shed. You will learn various calculations, layouts, cutting procedures, and assembly requirements required for efficient construction.

7.1.0 Gable

Next to the shed roof, which has only one slope, the gable roof is the simplest type of sloping roof to build because it slopes in only two directions. The basic structural members of the gable roof are the ridgeboard, common rafters, and gable end studs, as shown in *Figure 10-82*.

The ridgeboard is at the peak of the roof. It provides a nailing surface for the top ends of the common rafters. The common rafters extend from the top wall plates to the ridge. The gable end studs are upright framing members that provide a nailing surface for siding and sheathing at the gable ends of the roof.

Figure 10-82 – Gable roof framework.

7.1.1 Common Rafters

All common rafters for a gable roof are the same length. They can be precut before the roof is assembled. Today, most common rafters include an overhang. The overhang, as shown in *Figure 10-83*, is the part of the rafter that extends past the building line. The run of the overhang, called the projection, is the horizontal distance from the building line to the tail cut on the rafter. In *Figure 10-83*, note the plumb cuts at the ridge, heel, and tail of the rafter. A level seat cut is placed where the rafter rests on the top plate.

Figure 10-83 – Typical common rafter with an overhang.

The notch formed by the seat and heel cut line shown in *Figure 10-84* is often called the ***bird's-mouth*.**

The width of the seat cut is determined by the slope of the roof: the lower the slope, the wider the cut. At least 2 inches of stock should remain above the seat cut. The procedure for marking these cuts is explained later in this chapter. Layout is usually done after the length of the rafter is calculated.

Figure 10-84 – Bird's-mouth formed by the heel plumb line and seat line.

Calculating Lengths of Common Rafters – The length of a common rafter is based on the unit of rise and total run of the roof. The unit of rise and total run are obtained from the blueprints. There are three different procedures to calculate common rafter length: using a framing square printed with a rafter table, using a book of rafter tables, or using the step-off method where rafter layout is combined with calculating length.

Framing squares are available with a rafter table printed on the face side as shown in *Figure 10-85*.

Figure 10-85 – Rafter table on face of a steel square.

The rafter table makes it possible to find the lengths of all types of rafters for pitched roofs, with unit of rises ranging from 2 inches to 18 inches. Let's look at two examples:

Example 1. The roof has a 7 inch unit of rise and a 16 foot span.

Look at the first line of the rafter table on a framing square to find LENGTH COMMON RAFTERS PER FOOT RUN, also known as the bridge measure. Since the roof in this example has a 7 inch unit of rise, locate the number 7 at the top of the square. Directly beneath the number 7 is the number 13.89. This means that a common rafter with a 7 inch unit of rise will be 13.89 inches long for every unit of run. To find the length of the rafter, multiply 13.89 inches by the number of feet in the total run. The total run is always one half the span. The total run for a roof with a 16 foot span is 8 feet; so multiply 13.89 inches by 8 to find the rafter length. *Figure 10-86* is a schematic of this procedure.

Figure 10-86 – Rafter length.

If a framing square is not available, you can find the bridge measure with the Pythagorean Theorem using the same cut of 7/12:

$$7^2 + 12^2 = 193^2$$

The square root of 193 is 13.89.

Two steps remain to complete the procedure.

1. Multiply the number of feet in the total run (8) by the length of the common rafter per foot of run (13.89 inches):

   13.89 inches
   x 8
   111.12 inches

2. To change .12 of an inch to a fraction of an inch, multiply by 16:

   .12
   x 16
   1.92

The number 1 to the left of the decimal point represents 1/16 inch. The number .92 to the right of the decimal represents ninety-two hundredths of 1/16 inch. For practical purposes, 1.92 is calculated as being equal to 2 x 1/16 inch, or 1/8 inch. As a general rule in this kind of calculation, if the number to the right of the decimal is 5 or more, add 1/16 inch to the figure on the left side of the decimal. The result of steps 1 and 2 is a total common rafter length of 111 1/8 inches, or 9 feet 3 1/8 inches.

Example 2. A roof has a 6 inch unit of rise and a 25 foot span. The total run of the roof is 12 feet 6 inches. You can find the rafter length in four steps:

1. Change 6 inches to a fraction of a foot by placing the number 6 over the number 12:

   $$\frac{6}{12} = \frac{1}{2}$$

   1/2 foot = 6 inches.

2. Change the fraction to a decimal by dividing the bottom number (denominator) into the top number (numerator):

   $$\frac{1}{2} = .5$$

   .5 foot = 6 inches.

3. Multiply the total run (12.5) by the length of the common rafter per foot of run (13.42 inches as shown in *Figure 10-85)*:

   12.5
   x 13.42
   167.75 inches

4. To change .75 inch to a fraction of an inch, multiply by 16 for an answer expressed in sixteenths of an inch.

   .75 x 16 = 12

   $$12 = \frac{12}{16} \text{ inch, or } \frac{3}{4} \text{ inch}$$

The result of these steps is a total common rafter length of 167 3/4 inches, or 13 feet 11 3/4 inches.

Shortening – Rafter length found by any of the methods discussed here is the measurement from the heel plumb line to the center of the ridge. This is known as the theoretical length of the rafter. Since a ridgeboard, usually 1 1/2 inches thick, is placed between the rafters, you must deduct one half of the ridgeboard (3/4 inch from each rafter. This calculation is known as shortening the rafter. Do this at the time the rafters are laid out. The actual length, as opposed to the theoretical length, of a rafter is the distance from the heel plumb line to the shortened ridge plumb line, as shown in *Figure 10-87*.

Figure 10-87 – The actual (versus theoretical) length of a common rafter.

Laying Out – Before you can cut the rafters, you must mark the angles of the cuts. Layout consists of marking the plumb cuts at the ridge, heel, and tail of the rafter, and the seat cut where the rafter will rest on the wall. Lay out the angles are laid out with a framing square as shown in *Figure 10-88*. A pair of square gauges is useful in the procedure. Secure one square gauge to the tongue of the square next to the number that is the same as the unit of rise. Secure the other gauge to the blade of the square next to the number that is the same as the unit of run (always 12 inches). After placing the square on the rafter stock, mark the plumb cut along the tongue (unit of rise) side of the square. Mark the seat cut along the blade (unit of run) side of the square.

Figure 10-88 – Steel square used to lay out plumb and seat cuts.

Rafter layout also includes marking off the required overhang, or tail line length, and making the shortening calculation explained earlier. Overhang, or tail line length, is rarely given, and you must calculate it before laying out rafters. Projection, the horizontal distance from the building line to the rafter tail, must be located from drawings or specifications. To determine tail line length, use the following formula:

bridge measure (inches) times projection (feet) equals tail line length (inches)

Determine the bridge measure by using the rafter table on the framing square or calculate it by using the Pythagorean Theorem. Using *Figure 10-89* as a guide, you can see there are four basic steps remaining:

Figure 10-89 – Laying out a common rafter for a gable roof.

1. Lay out the rafter line length. Hold the framing square with the tongue in your right hand, the blade in your left, and the heel away from your body. Place the square as near the right end of the rafter as possible with the unit of rise on the tongue and the unit of run on the blade along the edge of the rafter stock. Strike a plumb mark along the tongue on the wide part of the material. This mark represents the center line of the roof. From either end of this mark, measure the line length of the rafter and mark the edge of the rafter stock. Hold the framing square in the same manner with the 6 on the tongue on the mark just made and the 12 on the blade along the edge. Strike a line along the tongue. This mark represents the plumb cut of the heel.

2. Lay out the bird's-mouth. Measure 1 1/2 inches along the heel plumb line up from the bottom of the rafter. Set the blade of the square along the plumb line with the heel at the mark just made and strike a line along the tongue. This line represents the seat of the bird's-mouth.

3. Lay out the tail line length. Measure the tail line length from the bird's-mouth heel plumb line. Strike a plumb line at this point in the same manner as the heel plumb line of the common rafter.

4. Lay out the plumb cut at the ridgeboard. Measure and mark the point along the line length half the thickness of the ridgeboard. This is the ridgeboard shortening allowance. Strike a plumb line at this point. This line represents the plumb cut of the ridgeboard.

7.1.2 Step-Off Calculations and Layout

The step-off method for rafter layout is old but still practiced. It combines procedures for laying out the rafters with a procedure of stepping off the length of the rafter as shown in *Figure 10-90.* In this example, the roof has an 8 inch unit of rise, a total run of 5 feet 9 inches, and a 10 inch projection.

Figure 10-90 – Step-off method for calculating common rafter length.

1. Set gauges at 8 inches on the tongue and 12 inches on the blade. With the tongue in the right hand, the blade in the left hand, and the heel away from the body, place the square on the right end of the rafter stock. Mark the ridge plumb line along the tongue. Put a pencil line at the 12 inch point of the blade.
2. With the gauges pressed lightly against the rafter, slide the square to the left. Line the tongue up with the last 12 inch mark and make a second 12 inch mark along the bottom of the blade.
3. To add the 9 inch remainder of the total run, place the tongue on the last 12 inch mark. Draw another mark at 9 inches on the blade. This will be the total length of the rafter.
4. Lay out and cut the plumb cut line and the seatcut line.

7.1.3 Roof Assembly

The major part of gable roof construction is setting the common rafters in place. The most efficient method is to precut all common rafters, then fasten them to the ridgeboard and the wall plates in one continuous operation.

The rafter locations should be marked on the top wall plates when the positions of the ceiling joists are laid out. Proper roof layout ensures the rafters and joists tie into each other wherever possible.

The ridgeboard, like the common rafters, should be precut. The rafter locations are then copied on the ridgeboard from the markings on the wall plates as shown in *Figure 10-91*. The ridgeboard should be the length of the building plus the overhang at the gable ends.

Figure 10-91 – Ridgeboard layout.

The material used for the ridgeboard is usually wider than the rafter stock. For example, a ridgeboard of 2 by 8 inch stock would be used with rafters of 2 by 6 inch stock. Some buildings are long enough to require more than one piece of ridge material. The breaks between these ridge pieces should occur at the center of a rafter.

One pair of rafters should be cut and checked for accuracy before the other rafters are cut. To check the first pair for accuracy, set them in position with a 1 1/2 inch piece of wood fitted between them. If the rafters are the correct length, they should fit the building. If the building walls are out of line, you will have to make adjustments on the rafters.

After checking the first pair of rafters for accuracy, and adjusting it if necessary, use one of the pair as a pattern for marking all the other rafters. Cutting is usually done with a circular or radial arm saw.

Collar Tie – Gable or double pitch roof rafters are often reinforced by horizontal members called collar ties, as shown in *Figure 10-92*. In a finished attic, the ties may also function as ceiling joists.

Figure 10-92 – Calculation for a collar tie.

To find the line length of a collar tie, divide the amount of drop of the tie in inches by the unit of rise of the common rafter. This will equal one half the length of the tie in feet. Double the result to get the actual length. The formula is as follows:

drop (inches) times 2 divided by unit or rise equals the length (feet)

The length of the collar tie depends on whether the drop is measured to the top or bottom edge of the collar tie shown in *Figure 10-92*. The tie must fit the slope of the roof. To obtain this angle, use the framing square. Hold the unit of run and the unit of rise of the common rafter. Mark and cut on the unit of run side as shown in *Figure 10-93*.

Methods of Ridge Board Assembly – Several different methods exist for setting up the ridgeboard and attaching the rafters to it.

Figure 10-93 – Laying out end cut on a collar tie.

When only a few Builders are present, the most convenient procedure is to set the ridgeboard to its required height (total rise) and hold it in place with temporary vertical props as shown in *Figure 10-94*. The builders can then nail the rafters to the ridgeboard and the top wall plates.

Lay plywood panels on top of the ceiling joists where the framing will take place. The panels provide safe and comfortable footing and a place to put tools and materials.

You can lay out and cut common rafter overhang before setting the rafters in place. Many Builders prefer to cut the overhang after the rafters are fastened to the ridgeboard and wall plates. Snap a line from one end of the building to the other, and mark the tail plumb line with a sliding

Figure 10-94 – Setting up and bracing a ridgeboard when only a few workers are available.

T-bevel, also called a bevel square. These procedures are shown in *Figure 10-95*. Then cut the rafters with a circular saw.This method guarantees that the line of the overhang will be perfectly straight, even if the building is not.

Over each gable end of the building, you can frame another overhang. The main framing members of the gable end overhang are the fascia, also referred to as fly or barge rafters. They are tied to the ridgeboard at the upper end and to the fascia board at the lower end. Fascia boards are often nailed to the tail ends of the common rafters to serve as a finish piece at the edge of the roof. By extending past the gable ends of the house, common rafters also help to support the basic rafters.

Figure 10-95 – Snapping a line and marking plumb cuts for a gable end overhang.

Figures 10-96 and *10-97* show different methods used to frame the gable end overhang. In *Figure 10-96*, a fascia rafter is nailed to the ridgeboard and to the fascia board. Blocking, which is not shown in the figures, rests on the end wall and is nailed between the fascia rafter and the rafter next to it. This section of the roof is further strengthened when the roof sheathing is nailed to it.

Figure 10-96 – Gable end overhang with the end wall framed under the overhang.

In *Figure 10-97*, two common rafters are placed directly over the gable ends of the building. The fascia rafters (fly rafters) are placed between the ridgeboard and the fascia boards. The gable studs should be cut to fit against the rafter above.

7.1.4 End Framing

Gable end studs rest on the top plate and extend to the rafter line in the ends of a gable roof. Place them with the edge of the stud even with the outside wall and the top notched to fit the rafter as shown in *Figure 10-97*, or install them flatwise with a cut on the top of the stud to fit the slope of the rafter.

Figure 10-97 – Gable end overhang with end wall framed directly beneath rafters.

Locate the position of the gable end stud by squaring a line across the plate directly below the center of the gable. If a window or vent will be installed in the gable, measure one half of the opening size on each side of the center line and make a mark for the first stud. Start at this mark and lay out the stud spacing (16 or 24 inches OC) to the outside of the building. Plumb the gable end stud on the first mark and mark it where it contacts the bottom of the rafter, as shown in *Figure 10-98, view A*.

Figure 10-98 – Calculating common difference of gable end studs.

Measure and mark 3 inches above this mark and notch the stud to the depth equal to the thickness of the rafter, as shown in *view B*. The lengths of the other gable studs depend on the spacing.

The common difference in the length of gable studs is figured by the following formula:

$$\frac{\text{24 inches (OC spacing)}}{\text{12 inches (unit of run)}} = 2 \text{ and } 2 \times 6 \text{ inches (unit of rise) or 12 inches (common difference).}$$

The common difference in the length of the gable studs may also be laid out directly with the framing square as shown in *Figure 10-99*. Place the framing square on the stud to the cut of the roof (6 and 12 inches for this example). Draw a line along the blade at A. Slide the square along this line in the direction of the arrow at B until the desired spacing between the studs (16 inches for this example) is at the intersection of the line drawn at A and the edge of the stud. Read the dimension on the tongue aligned with the same edge of the stud (indicated by C). This is the common difference (8 inches for this example) between the gable studs.

Toenail the studs to the plate with two 8d nails in each side. As you nail the studs in place, take care not to force a crown into the top of the rafter.

Figure 10-99 – Calculating common difference with framing square.

7.2.0 Hip

Most hip roofs are equal pitch. This means the angle of slope on the roof end or ends is the same as the angle of slope on the sides. Unequal pitch hip roofs do exist, but they are quite rare. They also require special layout methods. The unit length rafter table on the framing square applies only to equal pitch hip roofs. The next paragraphs discuss an equal pitch hip roof.

The length of a hip rafter, like the length of a common rafter, is calculated on the basis of bridge measure multiplied by the total run (half span). You may use any of the methods previously described for a common rafter, although some of the dimensions for a hip rafter are different.

Figure 10-100 shows part of a roof framing diagram for an equal pitch hip roof. A roof framing diagram may be included among the working drawings; if not, you should lay one out for yourself. Determine what scale will be used, and lay out all framing members to scale. Lay the building lines out first. You can find the span and the length of the building on the working drawings. Then draw a horizontal line along the center of the span.

In an equal pitch hip roof framing diagram, the lines indicating the hip rafters (AF, AG, BI, and BK in *Figure10-100* form 45° angles with the building lines. Draw these lines at 45°, as shown. The points where they meet the center line are the theoretical ends of the ridge piece. The ridge end common rafters AC, AD, AE, BH, BJ, and BL join the ridge at the same points.

Figure 10-100 – Equal pitch hip roof framing diagram.

A line indicating a rafter in the roof framing diagram is equal in length to the total run of the rafter it represents. You can see from the diagram that the total run of a hip rafter (represented by lines AF-AG-BI-BK) is the hypotenuse of a right triangle with the altitude and base equal to the total run of a common rafter. You know the total run of a common rafter: It is one half the span, or one half the width of the building. Knowing this, you can find the total run of a hip rafter by applying the Pythagorean Theorem.

Suppose that the span of the building is 30 feet. One half the span, which is the same as the total run of a common rafter, is 15 feet. Applying the Pythagorean Theorem, the total run of a hip rafter is:

$$\sqrt{15^2 + 15^2} = 21.21 \text{ feet}$$

What is the total rise? Since a hip rafter joins the ridge at the same height as a common rafter, the total rise for a hip rafter is the same as the total rise for a common rafter. You know how to figure the total rise of a common rafter. Assume that this roof has a unit of run of 12 and a unit of rise of 8. Since the total run of a common rafter in the roof is 15 feet, the total rise of a common rafter is the value of x in the proportional equation $12:8::15:x$, or 10 feet.

Knowing the total run of the hip rafter (21.21 feet) and the total rise (10 feet), you can figure the line length by applying the Pythagorean Theorem. The line length is:

$$\sqrt{21.21^2 + 10^2} = 23.45 \text{ feet or about 23 feet 5 3/8 inches}$$

To find the length of a hip rafter on the basis of a bridge measure, you must first determine the bridge measure. As with a common rafter, the bridge measure of a hip rafter is the length of the hypotenuse of a triangle with its altitude and base equal to the unit of run and unit of rise of the rafter. The unit of rise of a hip rafter is always the same as that of a common rafter, but the unit of run of a hip rafter is a fixed unit of measure, always 17.97.

The unit of run of a hip rafter in an equal pitch roof is the hypotenuse of a right triangle with its altitude and base equal to the unit of run of a common rafter, 12. Therefore, the unit of run of a hip rafter is:

$$\sqrt{12^2 + 12^2} = 16.97$$

If the unit of run of a hip rafter is 17.97 and the unit of rise in this particular case is 8, the bridge measure of the hip rafter must be:

$$\sqrt{16.97^2 + 8^2} = 18.76$$

This means that for every unit of run (17.97) the rafter has a line length of 18.76 inches. Since the total run of the rafter is 21.21 feet, the length of the rafter must be the value of x in the proportional equation *17.97:18.76::21.21:x,* or 23.45 feet.

Like the unit length of a common rafter, the bridge measure of a hip rafter can be obtained from the unit length rafter table on the framing square. If you turn back to *Figure 10-85*, you will see that the second line in the table is headed LENGTH HIP OR VALLEY PER FT RUN. This means "per foot run of a common rafter in the same roof." The unit length given in the tables is the unit length for every 17.97 units of run of the hip rafter itself. If you go across to the unit length given under 8, you will find the same figure, 18.76 units, that you calculated above.

An easy way to calculate the length of an equal pitch hip roof is to multiply the bridge measure by the number of feet in the total run of a common rafter, which is the same as the number of feet in one half of the building span. One half of the building span in this case is 15 feet. The length of the hip rafter is calculated as

8.76 x 15 = 281.40 inches, 23.45 feet once converted.

You step off the length of an equal pitch hip roof just as you do the length of a common rafter, except that you set the square to a unit of run of 17.97 inches instead of to a unit of run of 12 inches. Since 17.97 inches is the same as 16 and 15.52 sixteenths of an inch, setting the square to a unit of run of 17 inches is close enough for most practical purposes. Bear in mind that for any plumb cut line on an equal pitch hip roof rafter, you set the square to the unit of rise of a common rafter and to a unit of run of 17.

You step off the same number of times as there are feet in the total run of a common rafter in the same roof; only the size of each step is different. For every 12 inch step in a common rafter, a hip rafter has a 17 inch step. For the roof on which you are working, the total run of common rafter is exactly 15 feet; this means that you would step off the hip rafter cut (17 inches and 8 inches) exactly 15 times.

Suppose that there was an odd unit in the common rafter total run. Assume that the total run of a common rafter is 15 feet 10 1/2 inches. How would you make the odd fraction of a step on the hip rafter?

Remember that the unit of run of a hip rafter is the hypotenuse of a right triangle with the other sides each equal to the unit of run of a common rafter. In this case, the run of the odd unit on the hip rafter must be the hypotenuse of a right triangle with the altitude and base equal to the odd unit of run of the common rafter (10 1/2 inches). You can figure this using the Pythagorean Theorem:

$$\sqrt{10.5^2 + 10.5^2}$$

or you can set the square on a true edge to 10 1/2 inches on the blade and measure the distance between the marks. It comes to 14.84 inches. Rounded off to the nearest 1/16 inch, this equals 14 13/16 inches.

To lay off the odd unit, set the tongue of the framing square to the plumb line for the last full step made and measure off 14 13/16 inches along the blade. Place the tongue of the square at the mark, set the square to the hip rafter plumb cut of 8 inches on the tongue and 17 inches on the blade, and draw the line length cut.

7.2.1 Rafter Shortening Allowance

As is the case with a common rafter, the line length of a hip rafter does not take into account the thickness of the ridge piece. The size of the ridge end shortening allowance for a hip rafter depends upon the way the ridge end of the hip rafter is joined to the other structural members. As shown in Figure *10-101*, the ridge end of the hip rafter can be framed against the ridgeboard (*view A*) or against the ridge end common rafters (*view B*). To calculate the actual length, deduct one half the 45° thickness of the ridge piece that fits between the rafters from the theoretical length.

Figure 10-101 – Shortening a hip rafter.

When no common rafters are placed at the ends of the ridgeboard, the hip rafters are placed directly against the ridgeboard. They must be shortened one half the length of the 45° line (one half the thickness of the ridgeboard). When common rafters are placed at the ends of the ridgeboard as shown in *Figure 10-101, view B*, the hip rafter will fit between the common rafters. The hip rafter must be shortened one half the length of the 45° line (one half the thickness of the common rafter.)

If the hip rafter is framed against the ridge piece, the shortening allowance is one half of the 45° thickness of the ridge piece, as shown in *Figure 10-101, view C*. The 45° thickness of stock is the length of a line laid at 45° across the thickness dimension of the stock. If the hip rafter is framed against the common rafter, the shortening allowance is one half of the 45° thickness of a common rafter.

To lay off the shortening allowance, first set the tongue of the framing square to the line length ridge cut line. Then measure off the shortening allowance along the blade, set the square at the mark to the cut of the rafter (8 inches and 17 inches), and then draw the actual ridge plumb cut line. To find the 45° thickness of a piece of lumber, draw a 45º line across the edge, measure the length of the line, and then divide by 2.

7.2.2 Rafter Projection

A hip or valley rafter overhang, like a common rafter overhang, is figured as a separate rafter. The projection, however, is not the same as the projection of a common rafter overhang in the same roof. The projection of the hip or valley rafter overhang is the hypotenuse of a right triangle whose shorter sides are each equal to the run of a common rafter overhang, as shown in *Figure 10-102*. If the run of the common rafter overhang is 18 inches for a roof with an 8 inch unit of rise, figure the length of the hip or valley rafter tail as follows:

Figure 10-102 – Run of hip rafter projection.

1. Multiply the bridge measure in inches of the hip or valley rafter by the projection in feet of the common rafter overhang:

   18.76 inches (bridge measure)
   x 1.5 feet (projection of the common rafter)
   28.14
   or 28 1/8 inches

2. Add this product to the theoretical rafter length.

You may also step off the overhang as described earlier for a common rafter. When stepping off the length of the overhang, set the 17 inch mark on the blade of the square even with the edge of the rafter. Set the unit of rise, whatever it might be, on the tongue even with the same rafter edge.

7.2.3 Rafter Side Cuts

Since a common rafter runs at 90° to the ridge, the ridge end of a common rafter is cut square, or at 90° to the lengthwise line of the rafter. A hip rafter, however, joins the ridge, or the ridge ends of the common rafter, at other than a 90° angle, and the ridge end of a hip rafter must therefore be cut to a corresponding angle, called a side cut. The angle of the side cut is more acute for a high rise than for a low one.

The angle of the side cut is laid out as shown in *Figure 10-103*. Place the tongue of the framing square along the ridge cut line, as shown, and measure off one half the thickness of the hip rafter along the blade. Shift the tongue to the mark, set the square to the cut of the rafter (17 inches and 8 inches), and draw the plumb line marked “A” in the figure. Then turn the rafter edge up, draw an edge centerline, and draw in the angle of the side cut, as indicated in the lower view of *Figure 10-103*. For a hip rafter to be framed against the ridge, you will make only a single side cut, as indicated by the dotted line in the figure. For one to be framed against the ridge ends of the common rafters, you will make a double side cut, as shown in the figure. The tail of the rafter must have a double side cut at the same angle, but in the reverse direction.

Figure 10-103 – Laying out hip rafter side cut.

The angle of the side cut on a hip rafter may also be laid out by referring to the unit length rafter table on the framing square. Look ahead to *Figure 10-110*. You will see that the bottom line in the table is headed SIDE CUT HIP OR VALLEY USE. Follow this line over to the column headed by the figure 8 (for a unit of rise of 8) and you will find the figure 10 7/8. If you place the framing square face up on the rafter edge with the tongue on the ridge end cut line, and set the square to a cut of 10 7/8 inches on the blade and 12 inches on the tongue, you can draw the correct side cut angle along the tongue.

7.2.4 Bird’s-Mouth

Laying out the bird’s-mouth for a hip rafter is much the same as for a common rafter. There are a couple of things to remember. When you lay out the plumb (heel) cut and level (seat) cut lines for a bird’s-mouth on a hip rafter, set the body of the square at 17 inches and the tongue to the unit of rise (for example, 8 inches depending on the roof pitch) as shown in *Figure 10-104, view A*. When laying out the depth of the heel for the bird’s-mouth, measure along the heel plumb line down from the top edge of the rafter a distance equal to the same dimension on the common rafter. You must do this so that the hip rafter, which is usually wider than a common rafter, will be level with the common rafters.

Figure 10-104 – Backing or dropping a hip rafter

A. Marking the top (plumb) cut and the seat (level) cut of a hip rafter
B. Determining amount of backing or drop
C. Bevel line for backing the rafter
D. Deepening the bird's-mouth for dropping the rafter.

If the bird's-mouth on a hip rafter has the same depth as the bird's-mouth on a common rafter, the edge of the hip rafter will extend above the upper ends of the jack rafters. Correct this by either backing or dropping the hip rafter. Backing means to bevel the top edges of the hip rafter as shown in *Figure 10-105*. The amount of backing is taken at a right angle to the roof surface on the top edge of the hip rafters. Dropping means to deepen the bird's-mouth so as to bring the top edge of the hip rafter down to the upper ends of the jacks. The amount of drop is taken on the heel plumb line as shown in *Figure 10-104, view D*.

Calculate the backing or drop required as shown in *Figure 10-104, view B*. Set the framing square to the cut of the rafter (8

Figure 10-105 – Determining amount of backing or drop on a hip rafter.

inches and 17 inches) on the upper edge, and measure off one half the thickness of the rafter from the edge along the blade. A line drawn through this mark and parallel to the edge (*view C*) indicates the bevel angle if the rafter is to be backed. The perpendicular distance between the line and the edge of the rafter is the amount of the drop. This represents the amount the depth of the hip rafter bird's-mouth should exceed the depth of the common rafter bird's-mouth (*view D*).

Test your Knowledge (Select the Correct Response)

12. A gable roof slopes in how many directions?

    A. One
    B. Two
    C. Three
    D. Four

13. A birds'-mouth is formed by what two cuts?

    A. Tail and heel
    B. Ridge and tail
    C. Seat and ridge
    D. Heel and seat

7.3.0 Gable and Valley

A gable and valley roof, also known as a combination roof, consists of two or more sections sloping in different directions. A valley is formed where the different sections come together.

The two sections of a gable and valley roof may or may not be the same width. If they are the same width, the roof is said to have equal spans. If they are not the same width, the roof is said to have unequal spans.

7.3.1 Spans

In a roof with equal spans, the height (total rise) is the same for both ridges, as shown in *Figure 10-106*. Both sections are the same width, and the ridgeboards are the same height. A pair of valley rafters is placed where the slopes of the roof meet to form a valley between the two sections. These rafters go from the inside corners formed by the two sections of the building to the corners formed by the intersecting ridges. Valley jack rafters run from the valley rafters to both ridges. Hip valley cripple jack rafters are placed between the valley and hip rafters.

Figure 10-106 – Gable and valley roof with equal spans.

A gable and valley roof with unequal spans requires a supporting valley rafter to run from the inside corner formed by the two sections of the building to the main ridge, as shown in *Figure 10-107*. A shortened valley rafter runs from the other inside comer of the building to the supporting valley rafter. Like a gable and valley roof with equal spans, one with unequal spans requires valley jack rafters and hip valley cripple jack rafters. In addition, a valley cripple jack rafter is placed between the supporting and shortened valley rafters. Note that the ridgeboard is lower on the section with the shorter span.

Figure 10-107 – Gable and valley roof with unequal spans.

7.3.2 Valley Rafters

Valley rafters run at a 45° angle to the outside walls of the building. This places them parallel to the hip rafters. Consequently, they are the same length as the hip rafters.

A valley rafter follows the line of intersection between a main roof surface and a gable roof addition or a gable roof dormer surface. Most roofs having valley rafters are equal pitch roofs, in which the pitch of the addition or dormer roof is the same as the pitch of the main roof. There are unequal pitch valley rafter roofs, but they are quite rare and require special framing methods.

In the discussion of valley rafter layout, it is assumed that the roof is equal pitch. Also, the unit of run and unit of rise of an addition or dormer common rafter are assumed to be the same as the unit of run and rise of a main roof common rafter. In an equal pitch roof, the valley rafters always run at 45° to the building lines and the ridge pieces.

Figure 10-108 shows an equal span framing situation, in which the span of the addition is the same as the span of the main roof. Since the pitch of the addition roof is the same as the pitch of the main roof, equal spans bring the ridge pieces to equal heights.

Looking at the roof framing diagram in the figure, you can see the total run of a valley rafter, indicated by AB and AC in the diagram, is the hypotenuse of a right triangle with the altitude and base equal to the total run of a common rafter in the main roof. The unit of run of a valley rafter is 17.97, the same as the unit of run for a hip rafter. It follows that figuring the length of an equal span valley rafter is the same as figuring the length of an equal pitch hip roof hip rafter.

Figure 10-108 – Equal span gable and valley roof.

A valley rafter does not require backing or dropping. The projection, if any, is figured just as it is for a hip rafter. Side cuts are laid out as they are for a hip rafter. The valley rafter tail has a double side cut, like the hip rafter tail, but in the reverse direction. This is because the tail cut on a valley rafter must form an inside, rather than an outside, corner. As indicated in *Figure 10-109*, the ridge end shortening allowance in this framing situation amounts to one half of the 45° thickness of the ridge.

Figure 10-110 shows a framing situation in which the span of the addition is shorter than the span of the main roof. Since the pitch of the addition roof is the same as the pitch of the main roof, the shorter span of the addition brings the addition ridge down to a lower level than that of the main roof ridge.

Figure 10-109 – Ridge end shortening allowance for equal span gable and valley rafter.

There are two ways of framing an intersection of this type. In the method shown in *Figure 10-110*, a full length valley rafter (AD in the figure) is framed between the top plate and the main roof ridgeboard. A shorter valley rafter (BC in the figure) is then framed to the longer one. If you study the framing diagram, you can see that the total run of the longer valley rafter is the hypotenuse of a right triangle with the altitude and base equal to the total run of a common rafter in the main roof. The total run of the shorter valley rafter, on the other hand, is the hypotenuse of a right triangle with the altitude and base equal to the total run of a common rafter in the addition. The total run of a common rafter in the main roof is equal to one half the span of the main roof. The total run of a common rafter in the addition is equal to one half the span of the addition.

Figure 10-110 – Equal pitch but unequal span framing.

Knowing the total run of a valley rafter, or of any rafter for that matter, you can always find the line length by applying the bridge measure times the total run. Suppose that the span of the addition in *Figure 10-110* is 30 feet and that the unit of rise of a common rafter in the addition is 9. The total run of the shorter valley rafter is:

$$\sqrt{15^2 + 15^2} = 21.21 \text{ feet}$$

Referring to the unit length rafter table in *Figure 10-111*, you can see the bridge measure for a valley rafter in a roof with a common rafter unit of rise of 9 is 19.21. Since the unit of run of a valley rafter is 17.97, and the total run of this rafter is 21.21 feet, the line length must be the value of *x* in the proportional equation *17.97:19.21::21.21:x,* or 24.01 feet.

Figure 10-111 – Rafter table method.

An easier way to find the length of a valley rafter is to multiply the bridge measure by the number of feet in one half the span of the roof. The length of the longer valley rafter in *Figure 10-110*, for example, would be 19.21 times one half the span of the main roof. The length of the shorter valley rafter is 19.21 times one half the span of the addition. Since one half the span of the addition is 15 feet, the length of the shorter valley rafter is 15 x 9.21 = 288.15 inches or approximately 24.01 feet.

Figure 10-112 shows the long and short valley rafter shortening allowances. Note that the long valley rafter has a single side cut for framing to the main roof ridge piece, whereas the short valley rafter is cut square for framing to the long valley rafter.

Figure 10-112 – Long and short valley rafter shortening allowance.

Figure 10-113 shows another method of framing an equal pitch unequal span addition. In this method, the inboard end of the addition ridge is nailed to a piece that hangs from the main roof ridge. As shown in the framing diagram, this method calls for two short valley rafters (AB and AC), each of which extends from the top plate to the addition ridge.

Figure 10-113 – Framing equal pitch unequal span intersection.

As indicated in *Figure 10-114*, the shortening allowance of each of the short valley rafters is one half the 45° thickness of the addition ridge. Each rafter is framed to the addition ridge with a single side cut.

Figure 10-114 – Shortening allowance of valley rafters suspended ridge method of gable and valley roof framing.

Figure 10-115 shows a method of framing a gable dormer without sidewalls. The dormer ridge is framed to a header set between a pair of doubled main roof common rafters. The valley rafters (AB and AC) are framed between this header and a lower header. As indicated in the framing diagram, the total run of a valley rafter is the hypotenuse of a right triangle with the shorter sides equal to the total run of a common rafter in the dormer.

Figure 10-115 – Framing dormer without sidewall.

Figure 10-116 shows the arrangement and names of framing members in this type of dormer framing. The upper edges of the header must be beveled to the cut of the main roof.

Figure 10-116 – Arrangement and names of framing members for dormer without sidewalls.

Figure 10-117 shows that in this method of framing, the shortening allowance for the upper end of a valley rafter is one half the 45° thickness of the inside member in the upper doubled header. There is also a shortening allowance for the lower end, consisting of one half the 45° thickness of the inside member of the doubled common rafter. The figure also shows that each valley rafter has a double side cut at the upper and lower ends.

Figure 10-117 – Valley rafter shortening allowance for dormer without sidewalls.

Figure 10-118 shows a method of framing a gable dormer with sidewalls. As indicated in the framing diagram, the total run of a valley rafter is again the hypotenuse of a right triangle with the shorter sides each equal to the run of a common rafter in the dormer. Figure the lengths of the dormer corner posts and side studs just as you do the lengths of gable end studs, and lay off the lower end cutoff angle by setting the square to the cut of the main roof.

Figure 10-118 – Method of framing gable dormer with sidewalls.

Figure 10-119 shows the valley rafter shortening allowance for this method of framing a dormer with sidewalls.

Figure 10-119 – Valley rafter shortening allowance for dormers with sidewalls.

7.3.3 Jack Rafters

A jack rafter is a part of a common rafter, shortened for framing a hip rafter, a valley rafter, or both. This means that in an equal pitch framing situation, the unit of rise of a jack rafter is always the same as the unit of rise of a common rafter. *Figure 10-120* shows various types of jack rafters.

Figure 10-120 – Types of jack rafters.

A hip jack rafter extends from the top plate to a hip rafter. A valley jack rafter extends from a valley rafter to a ridge. Both types are shown in *Figure 10-121*. A cripple jack rafter does not contact either a top plate or a ridge. A valley cripple jack extends between two valley rafters in the long and short valley rafter method of framing. A hip valley cripple jack extends from a hip rafter to a valley rafter.

Figure 10-121 – Valley cripple jack and hip valley cripple jack.

Lengths – *Figure 10-122* shows a roof framing diagram for a series of hip jack rafters. The jacks are always on the same OC spacing as the common rafters. Suppose the spacing in this instance is 16 inches OC. You can see that the total run of the shortest jack is the hypotenuse of a right triangle with the shorter sides each 16 inches long. The total run of the shortest jack is:

$\sqrt{16^2 + 16^2}$ = 22.62 inches

Suppose that a common rafter in this roof has a unit of rise of 8. The jacks have the same unit of rise as a common rafter. The unit length of a jack in this roof is:

Figure 10-122 – Hip jack framing diagram.

$\sqrt{12^2 + 8^2}$ = 14.42 inches

This means that a jack is 14.42 units long for every 12 units of run. The length of the shortest hip jack in this roof is the value of *x* in the proportional equation *12:14.42::16:x,* or 19.23 inches.

This is always the length of the shortest hip jack when the jacks are spaced 16 inches OC and the common rafter in the roof has a unit of rise of 8. It is also the common difference of jacks, meaning that the next hip jack will be 2 times 19.23 inches.

The common difference for hip jacks spaced 16 inches OC, or 24 inches OC, is given in the unit length rafter table on the framing square for unit of rise ranging from 2 to 18, inclusive. Turn back to *Figure 10-111*, which shows a segment of the unit length rafter table. Note the third line in the table, which reads DIFF IN LENGTH OF JACKS 16 INCHES CENTERS. If you follow this line over to the figure under 8 (for a unit of rise of 8), you'll find the same unit length (19.23) that you worked out above.

The best way to determine the length of a valley jack or a cripple jack is to apply the bridge measure to the total run. The bridge measure of any jack is the same as the bridge measure of a common rafter having the same unit of rise as the jack. Suppose the jack has a unit of rise of 8. In *Figure 10-111*, look along the line on the unit length rafter tables headed LENGTH COMMON RAFTER PER FOOT RUN for the figure in the column under 8; you'll find a unit length of 14.42. You should know by this time how to apply this to the total run of a jack to get the line length.

The best way to figure the total runs of valley jacks and cripple jacks is to lay out a framing diagram and study it to determine what these runs must be. *Figure 10-123* shows part of a framing diagram for a main hip roof with a long and short valley rafter gable addition. By studying the diagram, you can figure the total runs of the valley jacks and cripple jacks as follows:

- The run of valley jack No. 1 is the same as the run of hip jack No. 8, which is the run of the shortest hip jack. The length of valley jack No. 1 is equal to the common difference of jacks.
- The run of valley jack No. 2 is the same as the run of hip jack No. 7, so the length is twice the common difference of jacks.

Figure 10-123 – Jack rafter framing diagram.

- The run of valley jack No. 3 is the same as the run of hip jack No. 6, so the length is three times the common difference of jacks.
- The run of hip valley cripple Nos. 4 and 5 is the same as the run of valley jack No. 3.
- The run of valley jack Nos. 9 and 10 is equal to the spacing of jacks OC. The length of one of these jacks is equal to the common difference of jacks.
- The run of valley jacks Nos. 11 and 12 is twice the run of valley jacks Nos. 9 and 10, and the length of one of these jacks is twice the common difference of jacks.
- The run of valley cripple No. 13 is twice the spacing of jacks OC, and the length is twice the common difference of jacks.
- The run of valley cripple No. 14 is twice the run of valley cripple No. 13, and the length is four times the common difference of jacks.

Shortening Allowances – A hip jack has a shortening allowance at the upper end, consisting of one half the 45° thickness of the hip rafter. A valley jack rafter has a shortening allowance at the upper end, consisting of one half the 45° thickness of the ridge, and another at the lower end, consisting of one half the 45° thickness of the valley rafter. A hip valley cripple has a shortening allowance at the upper end, consisting of one half the 45° thickness of the hip rafter, and another at the lower end, consisting of one half the 45° thickness of the valley rafter. A valley cripple has a shortening allowance at the upper end, consisting of one half the 45° thickness of the long valley rafter, and another at the lower end, consisting of one half the 45° thickness of the short valley rafter.

Side Cuts – The side cut on a jack rafter can be laid out using the same method as for laying out the side cut on a hip rafter. Another method is to use the fifth line of the unit length rafter table, which is headed SIDE CUT OF JACKS USE in *Figure 10-111*. If you follow that line over to the figure under 8 (for a unit of rise of 8), you will see that the figure given is 7. To lay out the side cut on a jack set the square face up on the edge of the rafter to 12 inches on the tongue and 10 inches on the blade, and draw the side cut line along the tongue.

Bird's-Mouth and Projection – A jack rafter is a shortened common rafter, so the bird's-mouth and projection on a jack rafter are laid out just as they are on a common rafter.

7.3.4 Ridge Layout

Laying out the ridge for a gable roof presents no particular problem since the line length of the ridge is equal to the length of the building. The actual length includes any overhang. For a hip main roof, however, the ridge layout requires a certain amount of calculation.

In an equal pitch hip roof, the line length of the ridge is the length of the building minus the span. The actual length depends on the way the hip rafters are framed to the ridge.

In *Figure 10-124*, the line length ends of the ridge are at the points where the ridge centerline and the hip rafter center line cross. The hip rafter is framed against the ridge. The actual length of the ridge exceeds the line length at each end by one half the thickness of the ridge, plus one half the 45° thickness of the hip rafter. The hip rafter is also framed between the common rafters. The actual length of the ridge exceeds the line length at each end by one half the thickness of a common rafter.

Figure 10-124 – Line and actual lengths of hip roof ridgeboard.

Figure 10-125, view A shows that the length of the ridge for an equal span addition is equal to the length of the addition top plate plus one half the span of the building minus the shortening allowance at the main roof ridge. The shortening allowance amounts to one half the thickness of the main roof ridge.

Figure 10-125 – Lengths of addition ridge.

View B shows the length of the ridge for an unequal span addition varies with the method of framing the ridge. If the addition ridge is suspended from the main roof ridge, the length is the length of the addition top plate plus one half the span of the building. If the addition ridge is framed by the long and short valley rafter method, the length is the length of the addition top plate, plus one half the span of the addition, minus a shortening allowance one half the 45° thickness of the long valley rafter. If the addition ridge is framed to a double header set between a couple of double main roof common rafters, the length of the ridge is the length of the addition sidewall rafter plate, plus one half the span of the addition, minus a shortening allowance one half the thickness of the inside member of the double header.

Figure 10-126, view A shows that the length of the ridge on a dormer without sidewalls is one half the span of the dormer, less a shortening allowance one half the thickness of the inside member of the upper double header. *View B* shows that the length of the ridge on a dormer with sidewalls is the length of the dormer rafter plate, plus one half the span of the dormer, minus a shortening allowance one half the thickness of the inside member of the upper double header.

Figure 10-126 – Lengths of dormer ridge.

7.4.0 Shed

A shed roof is essentially one half of a gable roof. Like the full length rafters in a gable roof, the full length rafters in a shed roof are common rafters. The total run of a shed roof common rafter is equal to the span of the building minus the width of the top plate on the higher rafter end wall, as shown in *Figure 10-127*. The run of the overhang on the higher wall is measured from the inner edge of the top plate. With these exceptions, shed roof common rafters are laid out like gable roof common rafters. A shed roof common rafter has two bird's-mouths, but they are laid out just like the bird's-mouth on a gable roof common rafter.

Figure 10-127 – Shed roof framing.

For a shed roof, the height of the higher rafter end wall must exceed the height of the lower by an amount equal to the total rise of a common rafter.

Figure 10-128 shows a method of framing a shed dormer. This type of dormer can be installed on almost any type of roof. There are three layout problems to solve here; determining the total run of a dormer rafter, determining the angle of cut on the inboard ends of the dormer rafters, and determining the lengths of the dormer sidewall studs.

To determine the total run of a dormer rafter, divide the height of the dormer end wall, in inches, by the difference between the unit of rise of the dormer roof and the unit of rise of the main roof.

Figure 10-128 – Framing a shed dormer.

Take the dormer shown in *Figure 10-129*, for example. The height of the dormer end wall is 9 feet, or 108 inches. The unit of rise of the main roof is 8, the unit of rise of the dormer roof is 2 1/2, and the difference is 5 1/2. The total run of a dormer rafter is 108 divided by 5 1/2, or 19.63 feet. Knowing the total run and the unit of rise, you can figure the length of a dormer rafter by any of the methods already described.

As indicated in *Figure 10-129*, the inboard ends of the dormer rafters must be cut to fit the slope of the main roof. To get the angle of this cut, set the square on the rafter to the cut of the main roof, as shown in the bottom view of *Figure 10-129*. Measure off the unit of rise of the dormer roof from the heel of the square along the tongue as indicated and make a mark at this point. Draw the cutoff line through this mark from the 12 inch mark.

Figure the lengths of the sidewall studs on a shed dormer as follows:

In the roof shown in *Figure 10-129*, a dormer rafter raises 2 1/2 units for every 12 units of run. A main roof common rafter rises 8 units for every 12 units of run. If the studs were spaced 12 inches OC, the length of the shortest stud, which is also the common difference of studs, would be the difference between 8 and 2 1/2 inches, or 5 1/2 inches. If the stud spacing is 16 inches, the length of the shortest stud is the value of *x* in the proportional equation:

12:5 1/2::16:x

Or

7 5/16 inches

The shortest stud, then, will be 7 5/16 inches long. To get the lower end cutoff angle for studs, set the square on the stud to the cut of the main roof. To get the upper end cutoff angle, set the square to the cut of the dormer roof.

7.5.0 Installation

Rafter locations are laid out on wall plates and ridgeboards with matching lines and marked with X's, as used to lay out stud and joist locations. For a gable roof, the rafter locations are laid out on the rafter plates first. The locations are then transferred to the ridge by matching the ridge against a rafter plate.

7.5.1 Rafter Locations

The rafter plate locations of the ridge end common rafters in an equal pitch hip roof measure one half of the span (or the run of a main roof common rafter) away from the building comers. These locations, plus the rafter plate locations of the rafters lying between the ridge end common rafters, can be transferred to the ridge by matching the ridgeboads against the rafter plates.

Figure 10-129 – Shed dormer framing calculation.

The locations of additional ridge and valley rafters can be determined as indicated in *Figure 10-130*. In an equal span situation (*views A and B*), the valley rafter locations on the main roof ridge lie alongside the addition ridge location. In *view A*, the distance between the end of the main roof ridge and the addition ridge location is equal to A plus distance B, distance B being one half the span of the addition. In *view B*, the distance between the line length end of the main roof ridge and the addition ridge location is the same as distance A. In both cases, the line length of the addition ridge is equal to one half the span of the addition, plus the length of the addition sidewall rafter plate.

Figure 10-130 – Intersection ridge and valley rafter location layout.

Figure 10-130, view C, shows an unequal span situation. If framing is by the long and short valley rafter method, the distance from the end of the main roof ridge to the upper end of the longer valley rafter is equal to distance A plus distance B, distance B being one half the span of the main roof. To determine the location of the inboard valley rafter, first calculate the unit length of the longer valley rafter, or obtain it from the unit length rafter tables. Suppose that the common rafter unit of rise is 8. In that case, the unit length of a valley rafter is 18.77.

The total run of the longer valley rafter between the shorter rafter tie in and the rafter plate is the hypotenuse of a right triangle with the altitude and base equal to one half the span of the addition. Suppose the addition is 20 feet wide. Then, the total run is:

$$\sqrt{10^2 + 10^2} = 14.14 \text{ feet}$$

You know that the valley rafter is 18.76 units long for every 17.97 units of run. The length of rafter for 14.14 feet of run must therefore be the value of x in the proportional equation *17.97:18.76::14.14:x,* or 15.63 feet. The location mark for the inboard end of the shorter valley rafter on the longer valley rafter will be 15.63 feet, or 15 feet 7 9/16 inches, from the heel plumb cut line on the longer valley rafter. The length of the additional ridge will be equal to one half the span of the addition, plus the length of the additional sidewall top plate, minus a shortening allowance one half the 45° thickness of the longer valley rafter.

If framing is by the suspended ridge method, the distance between the suspension point on the main roof and the end of the main roof ridge is equal to distance A plus distance C. Distance C is one half the span of the addition. The distance between the point where the inboard ends of the valley rafters (both short in this method of framing) tie into the addition ridge and the outboard end of the ridge is equal to one half the span of the addition, plus the length of the additional ridge (which is equal to one half of the span of the main roof), plus the length of the addition sidewall rafter plate.

7.5.2 Roof Frame Erection

Roof framing should be done from a scaffold with planking not less than 4 feet below the level of the main roof ridge. The usual type of roof scaffold consists of diagonally braced two legged horses, spaced about 10 feet apart and extending the full length of the ridge.

If the building has an addition, frame as much as possible of the main roof before starting the addition framing. Cripples and jack rafters are usually left out until after the headers, hip rafters, valley rafters, and ridges to which they will be framed have been installed. For a gable roof, the two pairs of gable end rafters and the ridge are usually erected first.

Two crewmembers, one at each end of the scaffold, hold the ridge in position. Another crewmember sets the gable end rafters in place and toenails them at the rafter plate with 8d nails, one on each side of a rafter. Before we proceed any further, see *Table 10-1* for the type and size nails used in roof framing erection. Each crewmember on the scaffold then end nails the ridge to the end of the rafter. They then toenail the other rafter to the ridge and to the first rafter with two 10d nails, one on each side of the rafter.

Table 10-1 – Recommended Schedule for Nailing the Framing and Sheathing of a Wood frame Structure.

Joining	Nailing Method	Nails		
		Nr.	Size	Placement
Header to joist	End-nail	3	16d	
Joist to sill or girder	Toenail	2 3	10d or 8d	
Header and stringer joist to sill	Toenail		10d	16 inches OC
Bridging to joist	Toenail each end	2	8d	
Ledger strip to beam, 2 inches thick		3	16d	At each joist
Subfloor, boards:				
1 by 6 inch and smaller		2	8d	To each joist
1 by 8 inch		3	8d	To each joist
Subfloor, plywood				
At edges			8d	6 inches OC
At intermediate joists			8d	8 inches OC
Subfloor (2 by 6 inch, T&G) to joist or girder	Blind nail (casing) and face-nail	2	16d	
Soleplate to stud, horizontal assembly	End-nail	2	16d	At each stud
Top plate to stud	End-nail	2	16d	
Stud to soleplate	Toenail	4	8d	
Soleplate to joist or blocking	Face-nail		16d	16 inches OC
Doubled studs	Face-nail, stagger		10d	16 inches OC
End stud of intersecting wall to exterior wall stud	Face-nail		16d	16 inches OC
Upper top plate to lower top plate	Face-nail		16d	16 inches OC
Upper top plate, laps and instersections	Face-nail	2	16d	
Continuous header, two pieces, each edge			12d	12 inches OC
Ceiling joist to top wall plates	Toenail	3	8d	
Ceiling joist laps at partition	Face-nail	4	16d	
Rafter to top plate	Toenail	2	8d	
Rafter to ceiling joist	Face-nail	5	10d	
Rafter to valley or hip rafter	Toenail	3	10d	
Ridgeboard to rafter	End-nail	3	10d	
Rafter to rafter through ridgeboard	Toenail Edge-nail	2 4	10d 8d	
Collar tie to rafter:				
2 inch member	Face-nail	2	12d	
1 inch member	Face-nail	3	8d	
1 inch diagonal let-in brace to each stud and				

plate (four nails at top)		2	8d	
Built-up corner studs:				
Studs to blocking	Face-nail	2	10d	Each side
Intersecting stud to corner studs	Face-nail		6d	12 inches OC
Built-up girders and beams, three or more members	Face-nail		20d	32 inches OC each side
Wall sheathing:				
1 by 8 inch or less, horizontal	Face-nail	2	8d	At each stud
1 by 6 inch or greater, diagonal	Face-nail	3	8d	At each stud
Wall sheathing, vertically applied plywood:				
3/8 inch and less thick	Face-nail		6d	6 inches edge
1/2 inch and over thick	Face-nail		8d	12 inches inermdeiate
Wall sheathing, vertically applied fiberboard:			1 1/2 inch roofing nail 3 inches	
1/2 inch thick	Face-nail		from edge and 1 3/4 inch roofing	
25/32 inch thick	Face-nail		nail 6 inches intermediate	
Roof sheathing, boards, 5, 6, 8 inch width	Face-nail	2	8d	At each rafter
Roof sheathing, plywood:				
3/8 inch and less thick	Face-nail		6d	6 inches edge and 12
1/2 inch and over thick	Face-nail		8d	inches intermediate

Set up temporary braces, like those for a wall, at the ridge ends to hold the rafter approximately plumb, then erect the rafters between the end rafters. Then release the braces, and plumb the pair of rafters at one with a plumb line fastened to a stick extended from the end of the ridge. After that, reset the braces, and leave them in place until you have installed enough sheathing to hold the rafters plumb. Collar ties, if any, are nailed to common rafters with 8d nails, three to each end of a tie. Ceiling joist ends are nailed to adjacent rafters with 10d nails.

On a hip roof, erect the ridge end common rafters and ridges first, in about the same manner as for a gable roof. Then fill in the intermediate common rafters. After that, erect the ridge end common rafters extending from the ridge ends to the midpoints on the end walls. Install the hip rafters and hip jacks next. The common rafters in a hip roof do not require plumbing. When correctly cut and installed, hip rafters will bring the common rafters to plumb. Toe nail hip rafters are to plate comers with 10d nails. Toe nail hip jacks to hip rafters with 10d nails.

For an addition or dormer, the valley rafters are usually erected first. Valley rafters are toe nailed with 10d nails.

Figure 10-131 – Correct position for nailing a valley jack rafter.

Erect ridges and ridge end common rafters next, then other addition common rafters, and valley and cripple jacks last. A valley jack should be held in position for nailing as shown in *Figure 10-131*. When properly nailed, the end of a straightedge laid along the top edge of the jack should contact the centerline of the valley rafter, as shown.

Test your Knowledge (Select the Correct Response)

14. How long should the temporary bracing used in roof erection be left in place?

    A. Until sufficient sheathing has been installed to hold the rafters in place
    B. Until the wind has died down
    C. 3 days
    D. 4 days

8.0.0 ROOF TRUSSES

Roof truss members are usually connected at the joints by ***gussets***. Gussets are made of boards, plywood, or metal. They are fastened to the truss by nails, screws, bolts, or adhesives. A roof truss is capable of supporting loads over a long span without intermediate supports.

Roof trusses save material and on-site labor costs. It is estimated that a material savings of about 30 percent is made on roof members and ceiling joists. When you are building with trusses, the double top plates on interior partition walls and the double floor joists under interior bearing partitions are not necessary. Roof trusses also eliminate interior bearing partitions because trusses are self-supporting.

The basic components of a roof truss are the top and bottom chords and the web members as shown in *Figure 10-132*. The top chords serve as roof rafters. The bottom chords act as ceiling joists. The web members run between the top and bottom chords. The truss parts are usually made of 2 by 4 inch or 2 by 6 inch material and are tied together with metal or plywood gusset plates. Gussets shown in this figure are made of plywood.

Figure 10-132 – Truss construction.

8.1.0 Types

Roof trusses come in a variety of shapes. The ones most commonly used in light framing are the king post, the W-type (or fink), and the scissors. *Figure 10-133* shows an example of each.

Figure 10-133 – Truss types.

8.1.1 King Post

The simplest type of truss used in frame construction is the king-post truss. It consists of top and bottom chords and a vertical post at the center.

8.1.2 W-Type (Fink)

The most widely used truss in light-frame construction is the W-type (fink) truss. It consists of top and bottom chords tied together with web members. The W-type truss provides a uniform load-carrying capacity.

8.1.3 Scissors

The scissor truss is used for building with sloping ceilings. Many residential, church, and commercial buildings require this type of truss. Generally, the slope of the bottom chord of a scissor truss equals one half the slope of the top chord.

8.2.0 Design Principles

A roof truss is an engineered structural frame resting on two outside walls of a building. The load carried by the truss is transferred to these outside walls.

8.2.1 Weight and Stress

The design of a truss includes consideration of snow and wind loads and the weight of the roof itself. Design also takes into account the slope of the roof. Generally, the flatter the slope, the greater the stresses. Flatter slopes, therefore, require larger members and stronger connections in roof trusses.

A great majority of the trusses used are fabricated with plywood gussets; as shown in *Figure 10-134, views A* through *E;* which are nailed, glued, or bolted in place.

Figure 10-134 – Plywood gussets.

The metal gusset plates shown in *Figure 10-135* are also used. These are flat pieces usually manufactured from 20 gauge zinc-coated or galvanized steel. The holes for the nails are prepunched.

Figure 10-135 – Metal gusset plates.

Others are assembled with the split-ring connectors shown in *Figure 10-136*, which prevent any movement of the members. Some trusses are designed with a 2 by 4 inch soffit return at the end of each upper chord to provide nailing for the soffit of a wide box cornice.

Figure 10-136 – Truss members fastened together with split-ring connectors.

8.2.2 Tension and Compression

Each part of a truss is in a state of either tension or compression. The parts in a state of tension are subjected to a pulling apart force. Those under compression are subjected to a pushing together force. The balance of tension and compression gives the truss its ability to carry heavy loads and cover wide spans.

In *Figure 10-137 view A*, the ends of the two top chords (A-B and A-C) are being pushed together (compressed). The bottom chord prevents the lower ends (B and C) of the top chords from pushing out; therefore, the bottom chord is in a pulling apart state (tension). Because the lower ends of the top chords cannot pull apart, the peak of the truss (A) cannot drop down.

In *view B*, the long webs are secured to the peak of the truss (A) and also fastened to the bottom chord at points D and E. This gives the bottom chord support along the outside wall span. The weight of the bottom chord has a pulling apart effect (tension) on the long webs.

In *view C*, the short webs run from the intermediate points F and G of the top chord to points D and E of the bottom chord. Their purpose is to provide support to the top chord. This exerts a downward, pushing together force (compression) on the short web.

In *view D*, you can see that the overall design of the truss roof transfers the entire load (roof weight, snow load, wind load, and so forth) down through the outside walls to the foundation.

Figure 10-137 – Tension and compression in a truss.

Web members must be fastened at certain points along the top and bottom chords in order to handle the stress and weight placed upon the truss. *Figure 10-138* shows a typical layout for a W-type (fink) truss. The points at which the lower ends of the web members fasten to the bottom chord divide the bottom chord into three equal parts. Each short web meets the top chord at a point that is one-fourth the horizontal distance of the bottom chord.

Figure 10-138 – Layout for a W-type (fink) truss.

8.3.0 Fabrication

The construction features of a typical W-truss are shown in *Figure 10-138*. Also shown are gusset cutout sizes and nailing patterns for nail gluing. The span of this truss is 26 feet and roof cut is 4/12. When spaced 24 inches apart and made of good quality 2 by 4 inch members, the trusses should be able to support a total roof load of 40 pounds per square foot.

Gussets for light wood trusses are cut from 3/8 or 1/2 inch standard plywood with an exterior glue line, or from sheathing grade exterior plywood. Glue is spread on the clean surfaces of the gussets and truss members. Staples are used to supply pressure until the glue is set. Under normal conditions and where the relative humidity of air in attic spaces tends to be high, resorcinol glue is applied. In areas of low humidity, a casein or similar glue is used. Two rows of 4d nails are used for either the 3/8 or 1/2 inch thick gusset. The nails are spaced so that they are 3 inches apart and 3/4 inches from the edges of the truss members. Gussets are nail glued to both sides of the truss.

Plywood gusset, king-post trusses are limited to spans of 26 feet or less if spaced 24 inches apart and fabricated with 2 by 4 inch members and a 4/12 roof cut. The spans are somewhat less than those allowed for W-trusses having the same sized members. The shorter span for the king-post truss is due, in part, to the unsupported upper chord. On the other hand, because it has more members than the king-post truss and distances between connections are shorter, the W-truss can span up to 32 feet without intermediate support, and its members can be made of lower grade lumber.

8.4.0 Installation

Trusses are usually spaced 24 inches OC. They must be lifted into place, fastened to the walls, and braced. Small trusses can be placed by hand using the procedure shown in *Figure 10-139*. Builders are required on the two opposite walls to fasten the ends of the trusses. One or two workers on the floor below can push the truss to an upright position. If appropriate equipment is available, use it to lift trusses into place.

Figure 10-139 – Placing trusses by hand.

In handling and storing completed trusses, avoid placing unusual stresses on them. They were designed to carry roof loads in a vertical position; it is important that they be lifted and stored upright. If they must be handled in a flat position, use enough support along their length to minimize bending deflections. Never support the trusses only at the center or only at each end when they are in a flat position.

8.4.1 Bracing

After the truss bundles have been set on the walls, move them individually into position, nail them down, and temporarily brace them. Without temporary bracing, a truss may topple over, cause damage to the truss, and possibly injure workers. *Figure 10-140* shows a recommended procedure for bracing trusses as they are being set in place. Refer to the figure as you study the following steps:

1. Position the first roof truss. Fasten it to the double top plate with toenails or metal anchor brackets. A 2 by 2 inch backer piece is sometimes used for additional support.

Figure 10-140 – Installing roof trusses and temporary bracing.

2. Fasten two 2 by 4 braces to the roof truss. Drive stakes at the lower ends of the two braces. Plumb the truss and fasten the lower ends of the braces to the stakes driven into the ground.
3. Position the remaining roof trusses. As each truss is set in place, fasten a lateral brace to tie it to the preceding trusses. Use 1 by 4 or 2 by 4 material for lateral braces. They should overlap a minimum of three trusses. On larger roofs, diagonal bracing should be placed at 20 foot intervals.

Remove the temporary bracing as you nail the roof sheathing. Properly nailed plywood sheathing is sufficient to tie together the top chords of the trusses. Permanent lateral bracing of 10 by 4 inch material is recommended at the bottom chords as shown in *Figure 10-141*. Tie the braces to the end walls and space them 10 feet OC.

Figure 10-141 – Permanent lateral bracing in a truss.

8.4.2 Anchoring Trusses

When fastening trusses, you must consider resistance to uplift stresses as well as thrust. Trusses are fastened to the outside walls with nails or framing anchors. The ring-shank nail provides a simple connection that resists wind uplift forces. Toenailing is sometimes done, but this is not always the most satisfactory method. The heel gusset and a plywood gusset or metal gusset plate are located at the wall plate and make toenailing difficult. Two 10d nails on each side of the truss, as shown in *Figure 10-142, view A*, can be used in nailing the lower chord to the plate. Predrilling may be necessary to prevent splitting. Because of the single member thickness of the truss and the presence of gussets at the wall plates, it is usually a good idea to use some type of metal connector to supplement the toenailings.

The same types of metal anchors shown in *Figure 10-142, view B* used to tie regular rafters to the outside walls are equally effective for fastening the ends of the truss. The brackets are nailed to the wall plates at the side and top with 8d nails and to the lower chords of the truss with 6d or 1 1/2 inch rooting nails.

Figure 10-142 – Fastening trusses to the plate
A. Toenailing
B. Metal bracket.

8.5.0 Interior Partition Installation

Where partitions run parallel to, but between, the bottom truss chords, and the partitions are erected before the ceiling finish is applied, install 2 by 4 inch blocking between the lower chords as shown in *Figure 10-143*. Do not space this blocking over 4 feet OC. Nail the blocking to the chords with two 16d nails in each end. To provide nailing for lath or wallboard, nail a 10 by 6 inch or 2 by 6 inch continuous backer to the blocking. Set the bottom face level with the bottom of the lower truss chords.

When erecting partitions before the ceiling finish is applied, set 2 by 4 inch blocking with the bottom edge level with the bottom of the truss chords. Nail the blocking with two 16d nails in each end.

Figure 10-143 – Construction details for partitions that run parallel to the bottom truss chords.

If the partitions run at right angles to the bottom of the truss chords, nail the partitions directly to lower chord members. For applying ceiling finish, nail 2 by 6 inch blocking on top of the partition plates between the trusses as shown in *Figure 10-144*.

Test your Knowledge

15. Which of the following features is used to support loads over a long span without intermediate support or supports?

    A. Dormer
    B. Valley rafter
    C. Roof truss
    D. Common rafter

Figure 10-144 – Construction details for partitions that run at right angles to the bottom of the truss chords.

9.0.0 FRAMING STAIRS

There are many different kinds of interior and exterior stairs, each serving the same purpose, the movement of personnel and products from one floor to another. All stairs have two main parts, called treads and stringers. The underside of a simple stairway, consisting only of stringers and treads, is shown in *Figure 10-145, view A*. Treads of the type shown are called plank treads. This simple type of stairway is called a cleat stairway because of the cleats attached to the stringers to support the treads.

A more finished type of stairway has the treads mounted on two or more sawtooth-edged stringers, and includes risers, as shown in *Figure 10-145, view B*. The stringers shown are cut from solid pieces of dimensional lumber, usually *2* by 12s, and are called cutout, or sawed, stringers.

Figure 10-145 – Stairways.

9.1.1 Stairway Layout

The first step in stairway layout is to determine the unit rise and unit run as shown in *Figure 10-145, view B*. The unit rise is calculated on the basis of the total rise of the stairway, and the fact that the customary unit rise for stairs is 7 inches.

The total rise is the vertical distance between the lower finish floor level and the upper finish floor level. This may be shown in the elevations. Since the actual vertical distance as constructed may vary slightly from that shown in the plans, the distance should be measured.

At the time stairs are laid out, only the subflooring is installed. If both the lower and the upper floors are to be covered with finish flooring of the same thickness, the measured vertical distance from the lower subfloor surface to the upper subfloor surface will be the same as the eventual distance between the finish floor surfaces. The distance is equal to the total rise of the stairway. But if you are measuring up from a finish floor, such as a concrete basement floor, then you must add to the measured distance the thickness of the upper finish flooring to get the total rise of the stairway. If the upper and lower finish floors will be of different thickness, then you must add the difference in thickness to the measured distance between subfloor surfaces to get the rise of the stairway. To measure the vertical distance, use a straight piece of lumber plumbed in the stair opening with a spirit level.

Assume that the total rise measures 8 feet 11 inches, as shown in *Figure 10-146*. Knowing this, you can determine the unit rise as follows:

1. Reduce the total rise to inches; in this case it comes to 107 inches.
2. Divide the total rise in inches by the average unit rise, which is 7 inches. The result, disregarding any fraction, is the number of risers the stairway will have, in this case, 107/7 or 15.
3. Divide the total rise in inches by the number of risers, in this case, 107/15, or nearly 7 1/8 inches. This is the unit rise, as shown in *Figure 10-146*.

Figure 10-146 – Unit rise and run.

The unit run is calculated on the basis of the unit rise and a general architect’s rule that the sum of the unit run and unit rise should be 17 1/2 inches. By this rule, the unit run is 17 1/2 inches minus 7 1/8 inches or 10 3/8 inches.

You can now calculate the total run of the stairway. The total run is the unit run multiplied by the total number of treads in the stairway. The total number of treads depends upon the manner in which the upper end of the stairway will be anchored to the header.

Figure 10-147 shows three methods of anchoring the upper end of a stairway. In *view A*, there is a complete tread at the top of the stairway. This means the number of complete treads is the same as the number of risers. For the stairway shown in *Figure*

10-146, there are 15 risers and 15 complete treads. The total run of the stairway is equal to the unit run times 15, or 12 feet 11 5/8 inches.

Figure 10-147 – Anchoring upper end of a stairway.

In *view B*, only part of a tread is at the top of the stairway. If this method were used for the stairway shown in *Figure 10-146*, the number of complete treads would be one less than the number of risers, or 14. The total run of the stairway would be the product of 14 multiplied by 10 3/8, plus the run of the partial tread at the top. Where this run is 7 inches, for example, the total run equals 152 1/4 inches, or 12 feet 8 1/4 inches.

In *view C*, there is no tread at all at the top of the stairway. The upper finish flooring serves as the top tread. In this case, the total number of complete treads is again 14, but since there is no additional partial tread, the total run of the stairway is 14 times 10 3/8 inches, or 145 1/4 inches, or 12 feet 1 1/4 inches.

When you have calculated the total run of the stairway, drop a plumb bob from the header to the floor below and measure off the total run from the plumb bob. This locates the anchoring point for the lower end of the stairway.

As mentioned earlier, cutout stringers for main stairways are usually made from 2 by 12 stock. Before cutting the stringer, first solve for the length of stock you need.

Assume that you are to use the method of upper end anchorage shown in *view A* of *Figure 10-147* to lay out a stringer for the stairway shown in *Figure 10-146*. This stairway has a total rise of 8 feet 11 inches and a total run of 12 feet 11 5/8 inches. The stringer must be long enough to form the hypotenuse of a triangle with sides of those two lengths. For an approximate length estimate, call the sides 9 and 13 feet long. Then the length of the hypotenuse will equal the square root of 92 plus 132. This is the square root of 250, about 15.8 feet or 15 feet 9 1/2 inches.

Extreme accuracy is required in laying out the stringers. Be sure to use a sharp pencil or awl and make the lines meet on the edge of the stringer material.

Figure 10-148 shows the layout at the lower end of the stringer. Set the framing square to the unit run on the tongue and the unit rise on the blade, and draw the line AB. This line represents the bottom tread. Then, draw AD perpendicular to AB. Its length should be equal to the unit rise. This line represents the bottom riser in the stairway. You may have noticed that the thickness of a tread in the stairway has been ignored. This thickness is now about to be accounted for by making an allowance in the height of this first riser. This process is called dropping the stringer.

Figure 10-148 – Layout of lower end of cutout stringer.

As you can see in *Figure 10-145, view B*, the unit rise is measured from the top of one tread to the top of the next for all risers except the bottom one. For the bottom riser, unit rise is measured from the finished floor surface to the surface of the first tread. If AD were cut to the unit rise, the actual rise of the first step would be the sum of the unit rise plus the thickness of a tread. Therefore, the length of AD is shortened by the thickness of a tread, as shown in *Figure 10-148*, or by the thickness of a tread less the thickness of the finish flooring. The first is done if the stringer rests on a finish floor, such as a concrete basement floor. The second is done where the stringer rests on subflooring.

When you have shortened AD to AE, draw EF parallel to AB. This line represents the bottom horizontal anchor edge of the stringer. Then proceed to lay off the remaining risers and treads to the unit rise and unit run until you have laid off 15 risers and 15 treads. *Figure 10-149* shows the layout at the upper end of the stringer. The line AB represents the top, the 15th tread. BC, drawn perpendicular to AB, represents the upper vertical anchor edge of the stringer. This edge butts against the stairwell header.

Figure 10-149 – Layout of upper end of cutout stringer.

In a given run of stairs, be sure to make all the risers the same height and treads the same width. An unequal riser, especially one that is too high, is dangerous.

9.2.0 Stairway Construction

We have been dealing with a common straight flight stairway, meaning one which follows the same direction throughout. When floor space is not extensive enough to permit construction of a straight flight stairway, a change stairway is installed, meaning one which changes direction one or more times. The most common types of these are a 90° change and a 180° change. These are usually platform stairways, successive straight flight lengths, connecting platforms at which the direction changes 90° or doubles back 180°. Such a stairway is laid out simply as a succession of straight flight stairways.

When dealing with stairs, it is vitally important to remember the allowable head room. Head room is defined as the minimum vertical clearance required from any tread on the stairway to any part of the ceiling structure above the stairway. In most areas, the local building codes specify a height of 6 feet 8 inches for main stairs, and 6 feet 4 inches for basement stairs.

The stairs in a structure are broadly divided into principal stairs and service stairs. Service stairs are porch, basement, and attic stairs. Some of these may be simple cleat stairways, others may be open riser stairways. An open riser stairway has treads anchored on cutout stringers or stair block stringers, but no risers. The lower ends of the stringers on porch, basement, and other stairs anchored on concrete are fastened with a kickplate as shown in *Figure 10-150*.

Figure 10-150 – Kickplate for anchoring stairs to concrete.

A principal stairway usually has a finished appearance. Rough cutout stringers are concealed by finish stringers as shown in *Figure 10-151*.

Figure 10-151 – Finish stringer.

Treads and risers are often rabbet jointed as in *Figure 10-152*.

Figure 10-152 – Rabbet-and-groove-jointed treads and risers.

Vertical members that support a stairway handrail are called balusters. *Figure 10-153* shows a method of joining balusters to treads. Dowels shaped on the lower ends of the balusters are glued into holes bored in the treads.

Figure 10-153 – Joining a baluster to the tread.

Stringers should be toenailed to stairwell double headers with 10d nails, three to each side of the stringer. Those which face against trimmer joists should each be nailed to the joists with at least three 16d nails. At the bottom, a stringer should be toenailed with 10d nails, four to each side, driven into the subflooring and, if possible, into a joist below.

Treads and risers should be nailed to stringers with 6d, 8d, or 10d finish nails, depending on the thickness of the stock.

Summary

In this chapter you learned about framing the various components of a building. You learned that sill framing is placed on the foundation, and floor framing is placed after the sill framing. Wall framing is built on top of the floor framing, then raised and aligned. Once the wall framing is in place, you construct and place the ceiling framing, which can also be the bottom of the roof framing. You learned how to use the framing square to calculate and measure cuts for the roof framing. Roof framing and/or roof trusses are the last main part of framing a building. Framing stairs is important in buildings with more than one floor.

Review Questions (Select the Correct Response)

1. The edge of a sill is usually set back from the outside edge of the foundation by what distance?

   A. The thickness of the sheathing
   B. The thickness of the header joist
   C. The thickness of the siding
   D. Twice the thickness of the sheathing

2. After bolt holes are drilled and the sill properly fitted, what is normally the next step?

   A. Install the header joist.
   B. Place the sill sealer.
   C. Install the floor joists.
   D. Install the washers and nuts.

3. **(True or False)** When information is not provided in the specifications, anchor bolt spacing is normally 6 feet.

   A. True
   B. False

4. Which of the following items is/are considered a dead load?

   A. Furniture
   B. Floor joists
   C. Appliances
   D. People

5. **(True or False)** Header joists prevent common joists from rolling or tipping.

   A. True
   B. False

6. Which of the following joist types is used when a joist projects out over the wall below?

   A. Common
   B. Trimmer
   C. Cantilevered
   D. Cripple

7. Which of the following joist spans requires more than one row of bridging?

   A. 16 feet
   B. 14 feet
   C. 12 feet
   D. 10 feet

8. When installed in a straight line, which of the following bridging types provides an additional nailing base for the subfloor?

   A. Diagonal
   B. Heringbone
   C. Solid
   D. Cross

9. **(True or False)** Floor joists are always placed 16 inches OC.

   A. True
   B. False

10. When joists are laid out 16 inches OC, the distance from the edge of the building to the first joist should be

   A. 14 1/2 inches
   B. 15 1/4 inches
   C. 16 inches
   D. 16 3/4 inches

11. A pair of joists placed at each end of an opening and supporting a header is called what type of joist?

   A. Trimmer
   B. Double
   C. Tail
   D. Common

12. When placing a joist, the crown should be turned in what direction?

   A. Left
   B. Right
   C. Down
   D. Up

13. **(True or False)** Any board can be used as a joist regardless of the size of the crown.

   A. True
   B. False

14. Plywood subflooring with an index mark of 32/16 can be used over what maximum OC joist spacing?

   A. 48 inches
   B. 32 inches
   C. 24 inches
   D. 16 inches

15. A header is supported by which of the following studs?

   A. Trimmer
   B. Cripple
   C. Common
   D. Header

16. What is the standard wall height in wood framed construction?

   A. 7 feet 10 inches
   B. 8 feet
   C. 8 feet 1 inch
   D. 8 feet 6 inches

17. What type of wall strength is increased by diagonal bracing?

   A. Lateral
   B. Compressive
   C. Tensile
   D. Flexural

18. Which of the following is the strongest type of diagonal bracing?

   A. Cut-in bracing
   B. Let-in bracing
   C. Diagonal sheathing
   D. Horizontal bracing

19. Diagonal bracing is most effective when installed at which of the following angles?

   A. 25º to 35º
   B. 45º to 60º
   C. 65º to 75º
   D. 80º to 90º

20. What is/are the main purpose(s) of a fire stop in a wall?

   A. Slow the travel of fire inside a wall only
   B. Provide additional backing for nailing the edges of dry wall or plywood only
   C. Both A and B above
   D. Stop a fire inside a wall

21. The locations of walls constructed in the horizontal plate layout method are found in which of the following sources?

   A. Floor plans
   B. Specifications
   C. Table of measures
   D. Measurement-conversion chart

22. When laying out studs 16 inches OC, why should you place the first stud 15 1/4 inches from the corner?

    A. To allow for the corner post
    B. To provide additional nailing surface for sheathing
    C. To allow for 3/4 inch error when laying off the remaining studs
    D. To allow for the sheathing edges to fall on the centers of the studs

23. To determine the lengths of studs, cripples, and trimmers, you should use which of the following layouts?

    A. Vertical
    B. Horizontal
    C. Wall
    D. Top plate

24. The measurement from the subfloor to the bottom of the door header can also be used to establish which of the following measurements?

    A. Rough opening width for door openings
    B. Rough opening height for windowsills
    C. Rough opening height for window openings
    D. Overall wall height

25. Which way should the crown of a stud be turned on an exterior wall?

    A. Up
    B. Down
    C. Side

26. The minimum distance between butt joints in the top plate and the double top plate should be

    A. 24 inches
    B. 32 inches
    C. 48 inches
    D. 96 inches

27. What is the recommended order in raising walls?

    A. Long exterior, short exterior, partitions
    B. Partitions, long exterior, short exterior
    C. Short exterior, long exterior, partitions
    D. Long exterior, partitions, short exterior

28. To accurately plumb a wall, you need which of the following tools?

    A. Straightedge only
    B. Level only
    C. Straightedge and level
    D. Plumb

29. What size nail is recommended for installing 5/8 inch sheathing?

A. 4d
B. 6d
C. 8d
D. 10d

30. **(True or False)** When nailing plywood panels in place, you should leave gaps at the joints to allow for expansion.

A. True
B. False

31. What type of wall is usually constructed when large pipes must pass vertically through it?

A. Reinforced
B. Bearing
C. Partition
D. Chase

32. The size of a ceiling joist is determined by what two factors?

A. Height of walls and span from wall to wall
B. Weight it must carry and span from wall to wall
C. Height of bearing wall and OC spacing
D. OC spacing and span from wall to wall

33. **(True or False)** All joists must run in the same direction.

A. True
B. False

34. Ceiling joists supported by a bearing partition should overlap what minimum distance?

A. 16 inches
B. 12 inches
C. 8 inches
D. 4 inches

35. Double joists and headers are required when an attic scuttle is larger than what minimum size?

A. 5 feet by 5 feet
B. 2 feet by 2 feet
C. 3 feet by 3 feet
D. 4 feet by 4 feet

36. **(True or False)** When placing anchor bolts in a reinforced concrete wall, the bolt should be embedded at least 7 inches.

A. True
B. False

37. Which of the following statements is generally true of wood posts?

A. They are placed directly below wood girders.
B. The width of the post should be equal to the girder it supports.
C. They are always embedded in concrete.

38. The crawl space for a structure should have what minimum distance between the ground and the bottom of the girder?

A. 24 inches
B. 18 inches
C. 16 inches
D. 12 inches

39. In platform framing, a floor joist rests directly on which of the following components?

A. Top plate only
B. Sill plate only
C. Either A or B above
D. Exterior foundation

40. What is the recommended method for connecting header and floor joists?

A. Face-nailing with 12d nails
B. Face-nailing with 16d nails 16 inches OC
C. Face-nailing with 10d nails 16 inches OC
D. End nailing with 16d nails

41. What is the correct sequence for securing a subfloor and cross bridging to the floor joists?

A. Nail the subfloor, then the top and bottom of the bridging.
B. Nail the top of the bridging, then the subfloor, and finally the bottom of the bridging.
C. Nail the top and bottom of the bridging, then the subfloor.
D. Nail the bottom of the bridging, then the subfloor, and finally the top of the bridging.

42. Bottom plate layout should include marks for which of the following framing members?

A. Floor joists only
B. Corner posts only
C. Header joists only
D. All of the above

43. Temporary bracing used for wall alignment should be removed at what point during construction?

A. After wall alignment is completed
B. After exterior sheathing is completed
C. Before the ceiling joists are placed
D. After all framing and sheathing are completed

44. What is the main structural function of a ceiling frame?

A. Support the finished ceiling
B. Support the top of nonbearing partitions walls
C. Tie the exterior walls together
D. Support the weight of the rafters

45. To align ceiling joists in an unfinished attic, what type of structural member should you use?

A. Ribbon board
B. Ledger
C. Strongback
D. Ridge beam

46. Which of the following types of roof is the most commonly used in the Navy?

A. Shed
B. Hip
C. Gable
D. Gable and valley

47. Which of the following types of roof is considered strongest?

A. Shed
B. Hip
C. Gable
D. Gable and valley

48. A roof having only one slope is considered what type?

A. Shed
B. Hip
C. Gable
D. Gable and valley

49. In roof construction, the ratio of unit of rise to unit of span is known by what term?

A. Total run
B. Line length
C. Total rise
D. Pitch

50. In roof construction, the hypotenuse of a triangle whose base altitude equals the total rise is known by what term?

A. Total run
B. Line length
C. Total rise
D. Span

51. What members make up the main body of a roof framework?

A. Double top plates
B. Joists
C. Ceiling framework
D. Rafters

52. **(True or False)** Rafters are a functional part of both walls and roof.

A. True
B. False

53. What type of rafter does not extend the full distance from the plate to the ridgeboard?

A. Jack
B. Valley
C. Hip
D. Common

54. What type of jack is nailed between hip and valley rafters?

A. Valley
B. Cripple
C. Hip
D. Eave

55. Which of the following terms describe(s) that portion of a rafter extending beyond the outer edge of the plate?

A. Eave only
B. Tail only
C. Overhang only
D. All of the above

56. **(True or False)** The hypotenuse is the longest side of a right triangle.

    A. True
    B. False

57. Which of the following framing square scales is NOT used in roof framing?

    A. Octagon
    B. Hundredths
    C. Tenths
    D. Twelfths

58. On a framing square, the longest lines on the hundredths scale indicate how many hundredths of an inch?

    A. 5
    B. 10
    C. 25
    D. 50

59. How many tables does a framing square have?

    A. One
    B. Two
    C. Three
    D. Four

60. Which of the following framing square features is primarily used for estimating board feet?

    A. Brace table
    B. Essex-board table
    C. Rafter table
    D. Octagon scale

61. On a framing square, where is the brace table located?

    A. Back of the blade
    B. Face of the blade
    C. Face of the tongue
    D. Back of the tongue

62. Which of the following scales on a framing square is graduated in inches and provides various shortcuts in problem solving?

    A. Tenths
    B. Twelfths
    C. Hundredths
    D. Octagon

63. The run of the overhang should be measured between what two points?

A. From the top plate to the bottom of the ridgeboard
B. From the building line to the plumb line of the ridgeboard
C. From the building line to the tail cut on the rafter
D. From the ridgeboard to the tail cut on the rafter

64. The length of a rafter from the heel plumb line to the shortened plumb line is known as what type?

A. Actual
B. Theoretical
C. Line
D. Common

65. What angle should a hip rafter form with the building line?

A. 90º
B. 60º
C. 45º
D. 30º

66. **(True or False)** The unit of rise is always the same for hip and common rafters, but the unit of run for a hip rafter is different.

A. True
B. False

67. With a hip rafter framed against a common rafter, the shortening allowance should be what dimension?

A. One half of the 45º thickness of the ridge
B. One fourth of the 45º thickness of a common rafter
C. One half of the 45º thickness of a common rafter
D. One half of the thickness of the ridge

68. What feature is required when a hip rafter joins the ridge or the ridge ends at other than 90º?

A. Bird's-mouth
B. Angle cut
C. Tail cut
D. Side cut

69. What procedure should you use on a hip rafter to keep it level with a common rafter?

A. Plane the top of the hip rafter
B. Bevel the top edges only
C. Deepen the bird's-mouth only
D. Either B or C above

70. On a gable and valley roof, the area where two or more sloped roof sections intersect is known by what term?

A. Valley
B. Ridge
C. Hip
D. Gable

71. Which of the following features can run from valley rafters to both ridges?

A. Hip jack
B. Valley jack
C. Supporting valley
D. Hip

72. Which of the following features can run at a 45º angle to the exterior walls?

A. Valley rafter
B. Hip jack
C. Supporting valley
D. Hip

73. Which of the following techniques should be used in constructing a gable and valley roof that has one long and one short valley rafter?

A. Frame both valley rafters up against the main ridge.
B. Frame both valley rafters against the instersecting ridge.
C. Frame the long valley rafter up against the intersecting ridge and the short valley rafter up against the main ridge.
D. Frame the long valley rafter up against the main ridge and the short valley rafter up against the long valley rafter.

74. What is the shortening allowance of a valley rafter when a dormer without sidewalls is framed between double headers with a combined actual thickness of 3 1/4 inches?

A. One half of the 45º thickness of the inside upper double header only
B. One half of the 45º thickness of the common rafter only
C. Both A and B above
D. One half of the total thickness of the upper and lower double headers

75. **(True or False)** In an equal pitch framing situation, the unit of rise of a jack rafter is always the same as the unit of rise of a common rafter.

A. True
B. False

76. Which of the following jack rafter types extends from a hip rafter to a valley rafter?

A. Valley
B. Cripple
C. Valley cripple
D. Hip valley cripple

77. When erecting a gable roof, what components are constructed first?

A. Cripple and jack rafters
B. Gable end rafters and the ridge
C. Hip rafters
D. Valley rafters

78. In a gable roof, why is a ridgeboard placed at the peak of the roof?

A. Provide a nailing surface for the top ends of the common rafter
B. Provide a nailing surface for one end of the common rafter
C. Provide a starting point for the peak of the roof
D. Provide the starting point for roof sheathing

79. **(True or False)** All common rafters for a gable roof are the same length.

A. True
B. False

80. Which of the following terms is another name for the notch formed by the seat and heel cut?

A. Overhang
B. Projection
C. Bird's-mouth
D. Eave

81. When installing a roof where the ridgeboard is longer than one piece, where should the break between the boards occur?

A. Between the rafters
B. Center of a rafter
C. Center of the roof
D. At the end of a rafter

82. When working with gable or double-pitch roofs which of the following is/are normally considered for additional horizontal reinforcement?

A. Ceiling joists
B. Gable studs
C. Collar ties
D. Ridgeboard

83. When framing a roof, the scaffold should be set no lower than what distance below the level of the main roof ridge?

A. 1 foot
B. 2 feet
C. 3 feet
D. 4 feet

84. Which of the following structural members connects the joints on roof trusses?

A. Gussets
B. Templates
C. Collar ties
D. Truss ties

85. **(True or False)** When working with roof trusses, double top and bottom plates on interior partitions can be eliminated.

A. True
B. False

86. What is the estimated material savings when using roof trusses?

A. 10%
B. 20%
C. 30%
D. 40%

87. Which of the following truss components acts as a ceiling joist?

A. Gusset
B. Top chord
C. Bottom chord
D. Web

88. Which of the following structural components is eliminated because trusses are self-supporting?

A. Interior bearing partitions
B. Gussets
C. Double top plates
D. Floor joists

89. In frame construction, what truss type(s) is/are most commonly used?

A. King post only
B. W-type only
C. Scissors and W-types only
D. All of the above

90. The load carried by a roof truss is directly transferred to what other structural components?

A. Floor
B. Foundation
C. Outside walls
D. Interior walls

91. Which of the following items is/are not consideration(s) in truss design?

A. Materials
B. Snow and wind loads
C. Weight of roof itself
D. Slope of roof

92. Each part of a truss is in a state of compression or tension. Which of the following states, if any, describe(s) the pushing-together force?

A. State of tension only
B. State of compression only
C. All of the above
D. None of the above

93. In what positions should trusses be (a) handled and (b) stored?

A.	(a) Horizontal	(b) Horizontal
B.	(a) Horizontal	(b) Vertical
C.	(a) Vertical	(b) Horizontal
D.	(a) Vertical	(b) Vertical

94. Which of the following features is/are necessary to resist wind uplift force?

A. Temporary bracing
B. Gussets
C. Trusses anchored to outside walls
D. Blocking at lower chords

95. **(True or False)** Toenailing is the most satisfactory method of securing a truss to an outside wall.

A. True
B. False

96. A partition can be nailed directly to the lower chord under which of the following conditions, if any?

A. A partition runs at right angles to the bottom of the truss chord
B. Partitions are erected after ceiling finish is applied
C. A partition runs parallel with the bottom chord
D. None of the above

97. What piece of a stairway, when cut from solid pieces of dimensional lumber, is called cutout, or sawed?

A. Rise
B. Run
C. Stringer
D. Tread

Trade Terms Introduced in this Chapter

Batts	Bundles of insulating material.
Bird's-mouth	A notch cut in the lower edge of a rafter to fit over the top wall plate. Formed by a level line and a plumb cut.
Bridging	Crossed or solid supports installed between joists to help evenly distribute load and brace the joists against side sway.
Cantilevered	A projecting beam supported only at one end.
Chase	A vertical recess in a wall for pipes.
Cripple	Any frame member shorter than a regular member.
Crown	The outside curve of a twisted, bowed, or cupped board.
Essex board measure	A method for rapidly calculating board feet.
Girders	Supporting beams laid crosswise to the building; long trusses.
Gussets	Plates connecting members of a truss together.
Joists	Heavy pieces of lumber laid on edge horizontally to form the floor and ceiling support system.
Pitch	The angle or inclination of a roof, expressed as a ratio of rise per run.
Racking	Being forced out of shape or out of plumb.
Rafters	Sloping roof members supporting the roof covering and extending from the ridge or the hip of the roof to the eaves.
Ridge	The long joining members placed at the angle where two slopes of a roof meet at the peak.
Rise	In a roof, the vertical distance between the plate and the ridge. In a stair, the total height of the stair.
Run	The horizontal distance between the outer face of the wall and the roof ridge.
Span	The horizontal distance between supports.
Specifications	Written instructions containing information about the materials, style, workmanship, and finish for the job.
Studs	The vertical members of wooden forms or frames.
Toenailed	A nail driven at an angle.
Trusses	A combination of members, such as beams, bars, and ties; usually arranged in triangular units to form a rigid framework for supporting loads over a span.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

Basic Roof Framing, Benjamin Barnow, Tab Books, Inc., Blue Ridge Summit, Pa., 1987.

Carpentry, Leonard Koel, American Technical Publishers, Alsip, Ill., 1985.

Design of Wood Frame Structures for Permanence, National Forest Products Association, Washington, D.C., 1988.

Facilities Planning Guide, NAVFAC P-437, Naval Facilities Engineering Command, Alexandria, Va., 1982.

Means Illustrated Construction Dictionary, Smit, Kornelis & Chandler, Howard M., R. S. Means Company, Inc., Kingston, MA, 1991.

Modern Carpentry, Willis H. Wagner, Goodheart-Wilcox Co., South Holland, Ill., 1983.

Operations Officer's Handbook, COMCBPAC/COMCBLANTINST 5200.2A, Commander, Naval Construction Battalions, U.S. Pacific Fleet, Pearl Harbor, Hawaii, and Commander, Naval Construction Battalions, U.S. Atlantic Fleet, Norfolk, Va., 1988.

Seabee Planner's and Estimator's Handbook, NAVFAC P-405, Chapter 5, Naval Facilities Engineering Command, Alexandria, Va., 1983.

Wood Frame House Construction, L.O. Anderson, Forest Products Laboratory, U.S. Forest Service, U.S. Department of Agriculture, Washington, D.C., 1975.

http://www.merriam-webster.com/dictionary/rack[4]

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Chapter 11

Finish Carpentry

Topics

1.0.0 Interior Door Finishes

2.0.0 Window Casing

3.0.0 Moldings

4.0.0 Millwork

To hear audio, click on the box.

Overview

Woodworking, especially finish carpentry, is one of the most visible of the Builder's trades. Quality woodworking shows in the installation of trim, casing, and molding and in cabinets and built-in furniture.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Identify interior door finish components and explain layout and installation procedures for these elements in building construction.
2. Identify window casing components and explain layout and installation for these elements in building construction.
3. Identify the types of moldings and explain layout and installation procedures for these elements.
4. Identify the types of millwork and explain layout and installation procedures for these elements.

Prerequisites

None

This course map shows all of the chapters in Builder Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Expeditionary Structures	↑	BUILDER BASIC
Finishes		
Moisture Protection		
Finish Carpentry		
Rough Carpentry		
Carpentry Materials and Methods		
Fiber Line, Wire Rope, and Scaffolding		
Masonry		
Concrete Construction		
Site Work		
Construction Management		
Drawings and Specifications		
Tools		
Basic Math		

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.1.1 INTERIOR DOOR FINISHES

Rough openings for interior doors are usually framed to be 3 inches higher than the door height and 2 1/2 inches wider than the door width. This provides for placing, plumbing, and leveling the frame in the opening. Interior doorframes are made up of two side jambs, a head jamb, and the stop moldings on which the door closes. The most common of these jambs is the one piece type shown in *Figure 11-1, view A*. Jambs can be obtained in standard 5 1/4 inch widths for plaster walls and 4 5/8 inch widths for walls with 1/2 inch ***drywall*** finish. The two and three piece adjustable jambs, shown in *views B* and *C*, are also standard types. Their principal advantage is being adaptable to a variety of wall thicknesses.

Figure 11-1 – Interior door framing parts.

Some manufacturers produce interior doorframes with the doors fitted and prehung, ready for installing. Installation of the ***casing*** completes the job. When used with two or three piece jambs, casings can even be installed at the factory.

Common minimum widths for single interior doors are as follows:

- Bedrooms and other habitable rooms, 2 feet 6 inches
- Bathrooms, 2 feet 4 inches
- Small closets and linen closets, 2 feet

These sizes vary a great deal, and sliding doors, folding door units, and similar types, often used for wardrobes, may be 6 feet wide or more. In most cases, the jamb stop and casing parts are used in some manner to frame and finish the opening.

1.1.0 Casing

Casing is the edge trim around interior door openings and is also used to finish the room side of windows and exterior doorframes. Casing usually varies in widths from 2 1/4 to 3 1/2 inches, depending on the style. Casing is available in thicknesses from 1/2 to 3/4 inch, although 11/1 6 inch is standard in many of the narrow line patterns. A common casing pattern is shown in *Figure 11-1, view D*.

Interior doors come in two general types, flush and panel. Flush interior doors usually have a hollow core of light framework and are faced with thin plywood or hardboard, as shown in *Figure 11-2*.

Figure 11-2 – Hollow-core construction of flush doors.

Plywood faced flush doors, as shown in *Figure 11-3, View A*, are available in gum, birch, oak, mahogany, and several other wood species, most of which are suitable for natural finish. Nonselected grades are usually painted as hardboard faced doors.

The panel door consists of solid stiles or vertical side members, rails or cross pieces, and panels of various types. The five cross panel and the colonial type panel doors are perhaps the most common of this style, shown in *Figure 11-3, Views B* and *C*. The louvered door shown in *View D* is also popular and is commonly used for closets because it provides some ventilation. Large openings for wardrobes are finished with sliding or folding doors, or with flush or louvered doors shown in *View E*. Such doors are usually 1 1/8 inches thick.

Figure 11-3 – Interior door types.

Hinged doors should open or swing in the direction of natural entry, against a blank wall whenever possible. They should not be obstructed by other swinging doors. Doors should never be hinged to swing into a hallway.

1.2.0 Frame and Trim Installation

When the frame and doors are not assembled and prefitted, fabricate the side jambs by nailing through the ***dado*** into the head jamb with three 7d or 8d coated nails, as shown in *Figure 11-1, View A*. Then fasten the assembled frames in the rough openings by using shingle wedges between the side jamb and the stud, as shown in *Figure 11-4, View A*. Plumb and level one jamb using four or five sets of shingle wedges for the height of the frame. Use two 8d finishing nails at each wedged area once driven so that the doorstop covers it. Then fasten the opposite side jamb in place with shingle wedges and finishing nails, using the first jamb as a guide in keeping a uniform width.

Do not nail casings to both the jamb and the framing members. Allow about a 3/16 inch edge distance from the face of the jamb. Use 6d or 7d finish or casing nails, depending on the thickness of the casing. To nail into the stud, use 4d or 5d finish nails or 1 1/2 inch brads to fasten the trimmer edge of the casing to the jamb. For hardwood casing, it is advisable to predrill to prevent splitting. Locate nails in the casing in pairs and space them about 16 inches apart along the full height of the opening at the head jamb.

Casing with any form of molded shape must have a ***mitered joint*** at the comers as shown in *Figure 11-4, View B*. When casing is square edged, make a ***butt joint*** at the junction of the side and head casing as shown in *Figure 11-4, View C.* If the moisture content of the casing material is high, a mitered joint may open slightly at the outer edge as the material dries. Minimize this by using a small glued spline at the corner of the mitered joint. Use of a spline joint under any moisture condition is good practice, and some prefitted jamb, door, and casing units are provided with splined joints. Nailing into the joint after drilling helps retain a close fit.

Figure 11-4 – Doorframe and trim.

The door opening is now complete except for fitting and securing the hardware and nailing the stops in the proper position. Interior doors are normally hung with two 3 1/2 by 3 1/2 inch loose pin butt hinges. Fit the door into the opening with the clearances shown in *Figure 11-5*. The clearance and location of hinges, lockset, and doorknob may vary somewhat, but the ones in *Figure 11-5* are generally accepted by craftsmen and conform to most ***millwork*** standards. Bevel the edge of the lock stile slightly to permit the door to clear the jamb when swung open. If the door is to swing across heavy carpeting, the bottom clearance may need to be slightly more than what is shown.

When fitting doors, temporarily nail the stop in place; you will nail the stop in permanently when you hang the door. Stops for doors in single piece jambs are generally 7/16 inch thick and may be 3/4 inch to 2 1/4 inches wide. Install them with a mitered joint at the junction of the side and head jambs. A 45° bevel cut at the bottom of the stop, about 1 to 1 1/2 inches above the finish floor, eliminates a dirt pocket and makes cleaning or refinishing of the floor easier.

Figure 11-5 – Door clearances.

Some manufacturers supply prefitted doorjambs and doors with the hinge slots routed and ready for installation. A similar door buck or jamb of sheet metal with formed stops and casing is also available.

1.3.1 Door Hardware Installation

Hardware for doors is available in a number of finishes, with brass, bronze, and nickel being the most common. Door sets are usually classified as follows:

- Entry lock for interior doors
- Bathroom set, which has an inside lock control with a safety slot for opening from the outside
- Bedroom or keyed lock
- Passage set without a lock

Doors should be hinged so that they open in the direction of natural entry. They should also swing against a blank wall whenever possible and never into a hallway. The door swing directions and sizes are usually shown on the working drawings. The hand of the door is the expression used to describe the direction in which a door is to swing, normal or reverse, and the side from which it is to hang, left or right. These options are shown in *Figure 11-6.*

Figure 11-6 – Hands of doors.

When you order hardware for a door, be sure to specify whether it is a left-hand door, a right-hand door, a left-hand reverse door, or a right-hand reverse door.

1.3.1 Hinges

Use three hinges for hanging 1 3/4 inch exterior doors and two hinges for the lighter interior doors. The difference in exposure on the opposite sides of exterior doors causes a tendency to warp during the winter. Using three hinges reduces this tendency. Three hinges are also useful on doors that lead to unheated attics and for wider and heavier doors that may be used within the structure. If a third hinge is required, center it between the top and bottom hinges.

Use loose pin butt hinges and be sure they are the proper size for the door they support. For 1 3/4 inch thick doors, use 4 by 4 inch butts; for 1 3/8 inch doors, use 3 1/2 by 3 1/2 inch butts. After fitting the door to the tied opening with the proper clearances, fit the hinge halves to the door. Route them into the door edge with about a 3/16 inch back distance, as shown in *Figure 11-7*. One hinge half should be set flush with the surface and must be fastened square with the edge of the door. Screws are included with each pair of hinges.

Now place the door in the opening and block it up at the bottom for proper clearance. Mark the jamb at the hinge locations, and half route and fasten the remaining hinge in place. Then position the door in the opening and slip the pins in place. If you have installed the hinges correctly and the jambs are plumb, the door will swing freely.

Figure 11-7 – Installation of door hinge.

1.3.2 Locks

The types of door locks differ in installation method, cost, and the amount of labor required to set them. Some types, such as mortise locks, combination dead bolts, and latch locksets, require drilling of the edge and face of the door and then routing of the edge to accommodate the lockset and faceplate, as shown in *Figure 11-8*.

Figure 11-8 – Installation of lockset and faceplate.

The bored lockset shown in *Figure 11-9* is easy to install since it requires only one hole drilled in the edge and one in the face of the door. Boring jigs and faceplate markers are available to ensure accurate installation.

Install the lock so that the doorknob is 36 to 38 inches above the floor line. Most sets come with paper templates, marking the location of the lock and size of the holes to be drilled. Recheck your layout measurements before drilling any holes.

The parts of an ordinary cylinder lock for a door are shown in *Figure 11-10*.

Figure 11-9 – Installation of bored lockset.

NOTE

Be sure to read the manufacturer's installation instructions carefully.

Figure 11-10 – Parts of a cylinder lock.

The procedure for installing a lock of this type is as follows:

1. Open the door to a convenient working position and check it in place with wedges under the bottom near the outer edge.
2. Measure up 36 inches from the floor, the usual knob height, and square a line across the face and edge of the lock stile.