SS EL FARO Stability and Structures Preliminary Report Summary

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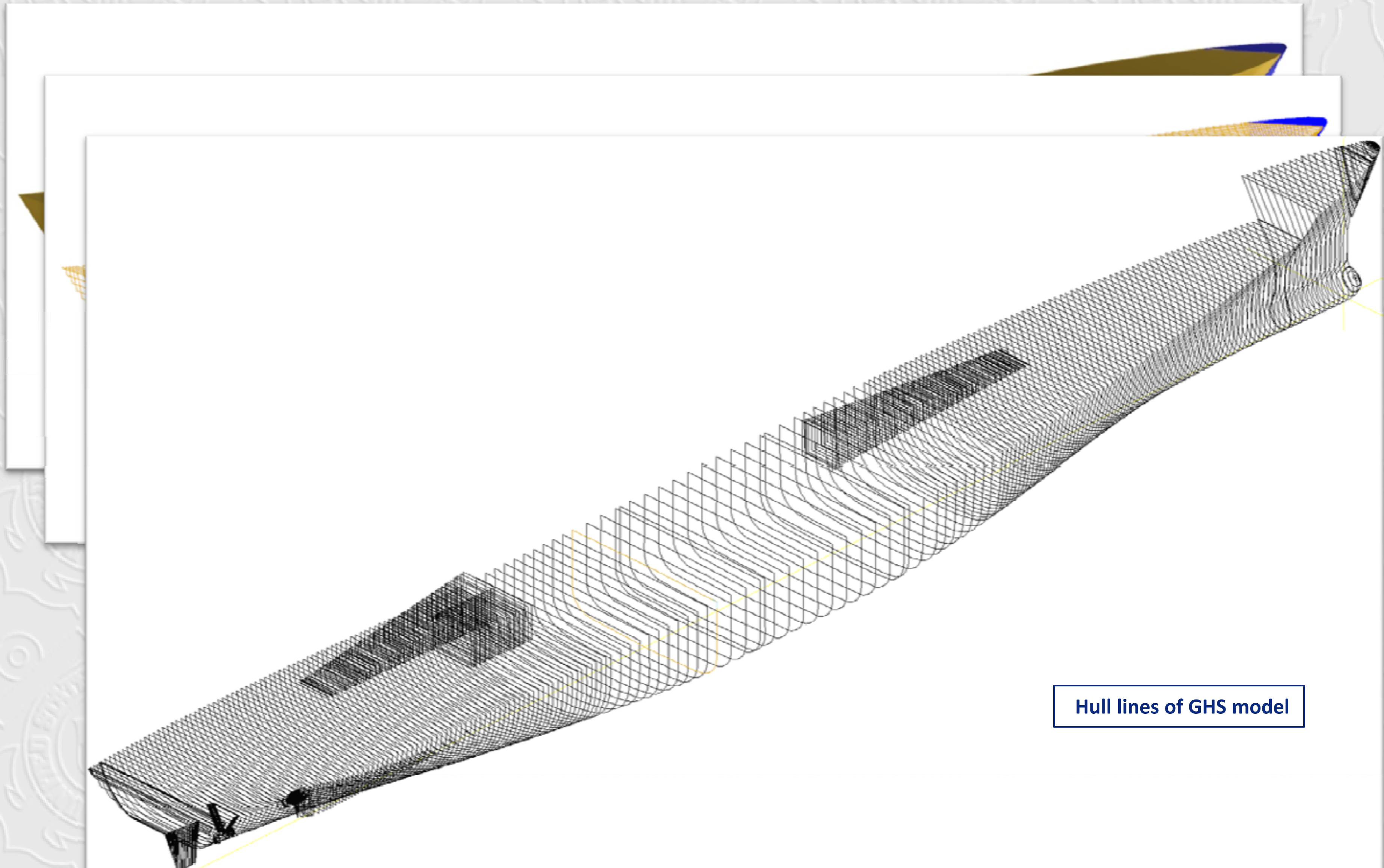
February 6, 2017

Report Outline

- Introduction
- MSC computer model
- Stability test and uncertainty analysis
- Stability booklet and stability software
- Intact and damage stability
- Hydrostatic sinking analyses
- Ship structures
- Conclusions

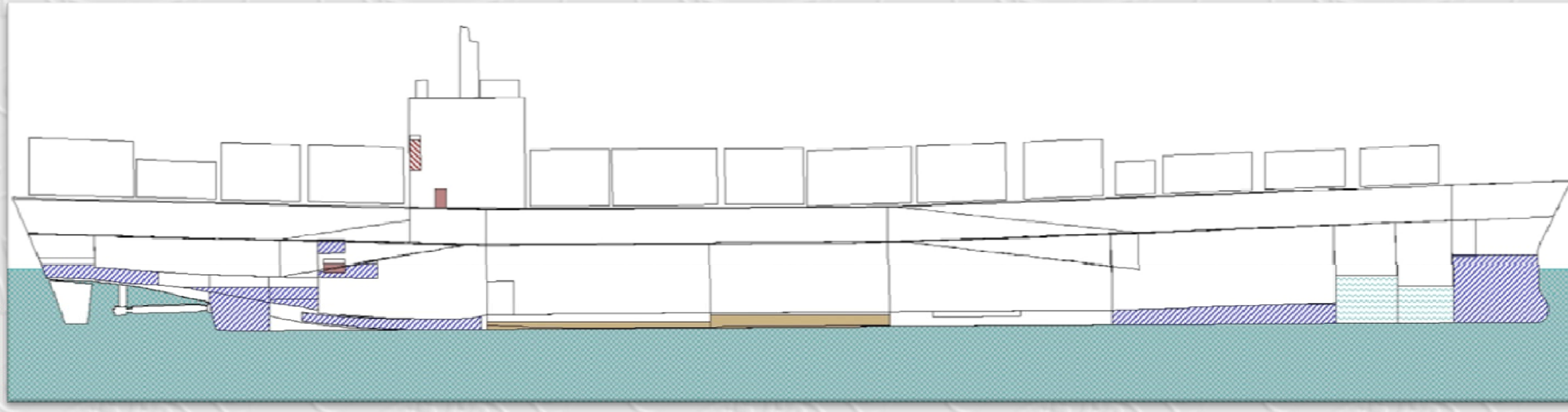
MSC GHS Computer Model



Figures 2-2 to 2-4

MSC GHS Computer Model

Profile view – compartments and tanks



Plan view – compartments and tanks

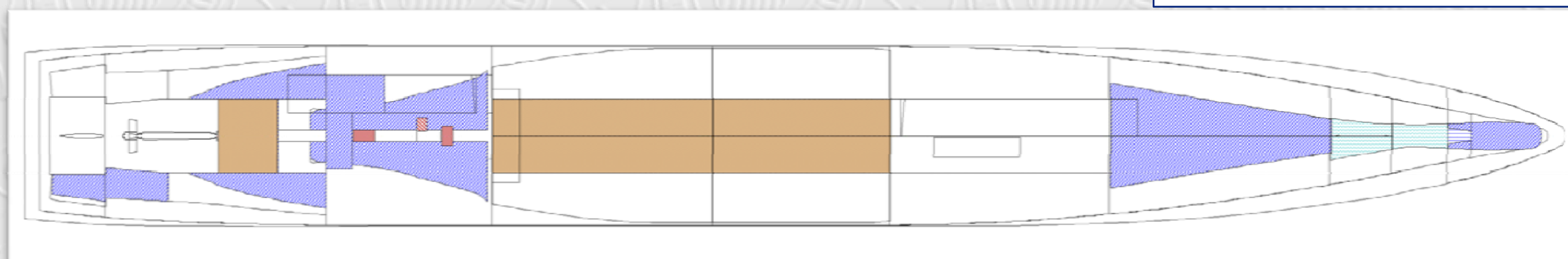


Figure 2-5

Stability Test and Uncertainty Analysis

- Stability test
  - February 12, 2006 (post-conversion)
  - IAW ASTM F1321-92 (2004) guidelines
  - Notes
    - Lightship TCG offset in CargoMax
    - Uncertainty in calculated KG and GM values

- Uncertainty analysis

Revised from Preliminary Report

  - As-inclined → GM = 18.3 ± 0.2 ft, KG = 26.0 ± 0.5 ft
  - Lightship → KG = 27.8 ± 0.7 ft
  - Accident voyage → KG = 37.3 ± 0.6 ft
    GM = 4.3 ± 0.7 ft

With 95% confidence

Stability Booklet and Stability Software

- Trim & Stability (T&S) Booklet
  - 2007, revised from the 1993 Booklet
    - Modified to account for LO/LO cargo, variable tank data
  - Notes
    - Minimum required GM curves – intact stability criteria only

- CargoMax stability and loading software
  - Approved for stability to supplement the T&S Booklet
  - Notes
    - Slack tank requirements in T&S Booklet
    - Approval for loading and ship strength
    - Approval for cargo loading and securing

Ship Structures

- Overall assessment of ship structures
  - Ship structures met regulatory and classification society (ABS) requirements
    - Based on MSC review of documentation available
- CargoMax strength calculations
  - Difference in results vs. MSC analysis
    - Within ABS allowable bending moment
    - Differences in estimated lightship weight distribution
      - Fixed ballast 34% of lightship

Intact and Damage Stability

- Background
  - Righting arms (GZ), righting energy, GM
- Intact stability criteria
  - GM criteria
  - Righting arm (GZ) criteria
- Intact stability assessment of EL FARO
  - GM criteria [applicable]
  - Righting arm (GZ) criteria [if built in 2016]
- Damage stability
  - Damage stability standards
  - Damage stability assessment of EL FARO

Background: Surface Ship Stability

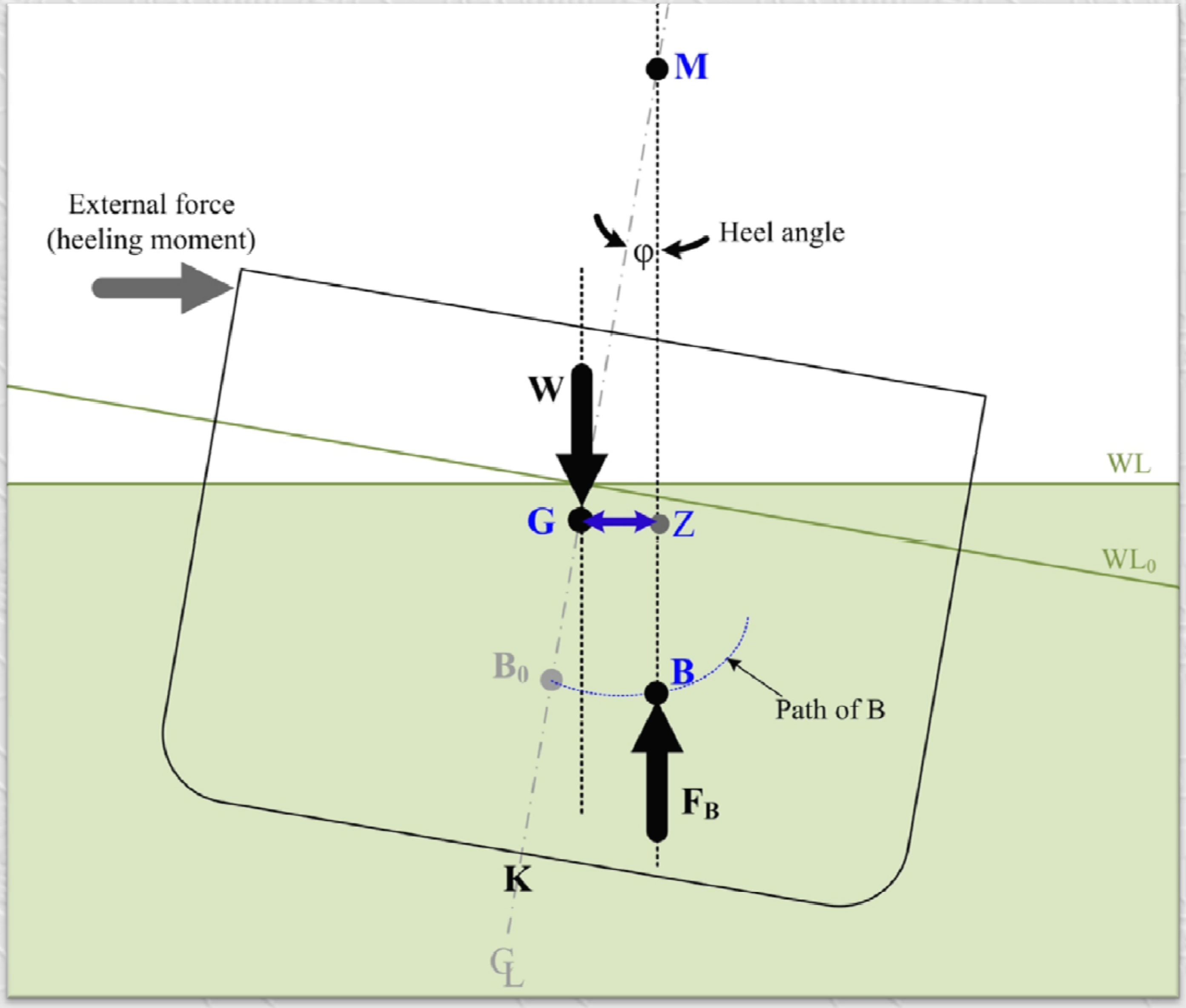


Figure 5-1

Righting Arm (GZ) Curve and GM

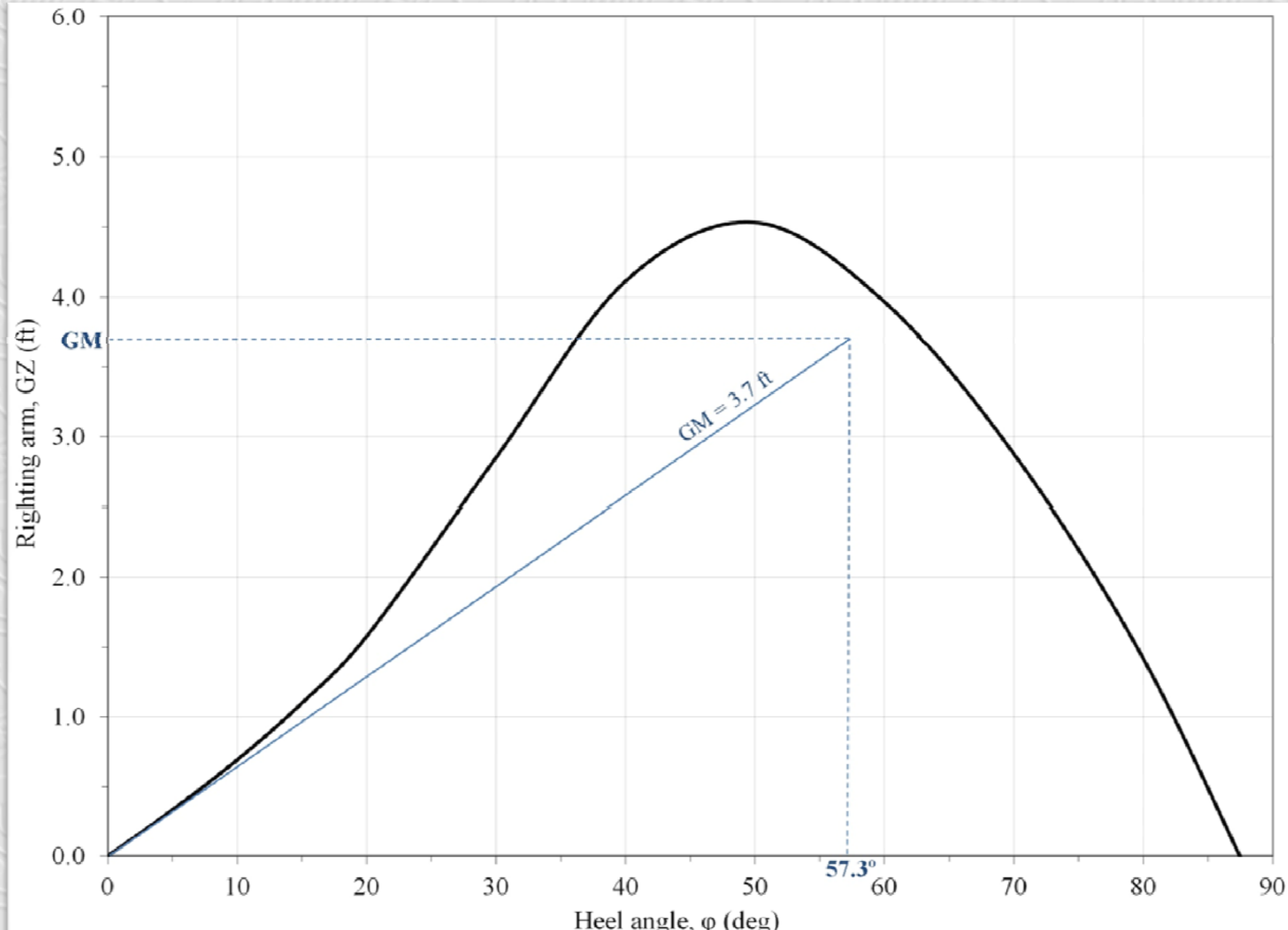


Figure 5-2

Righting Arm (GZ) Curves

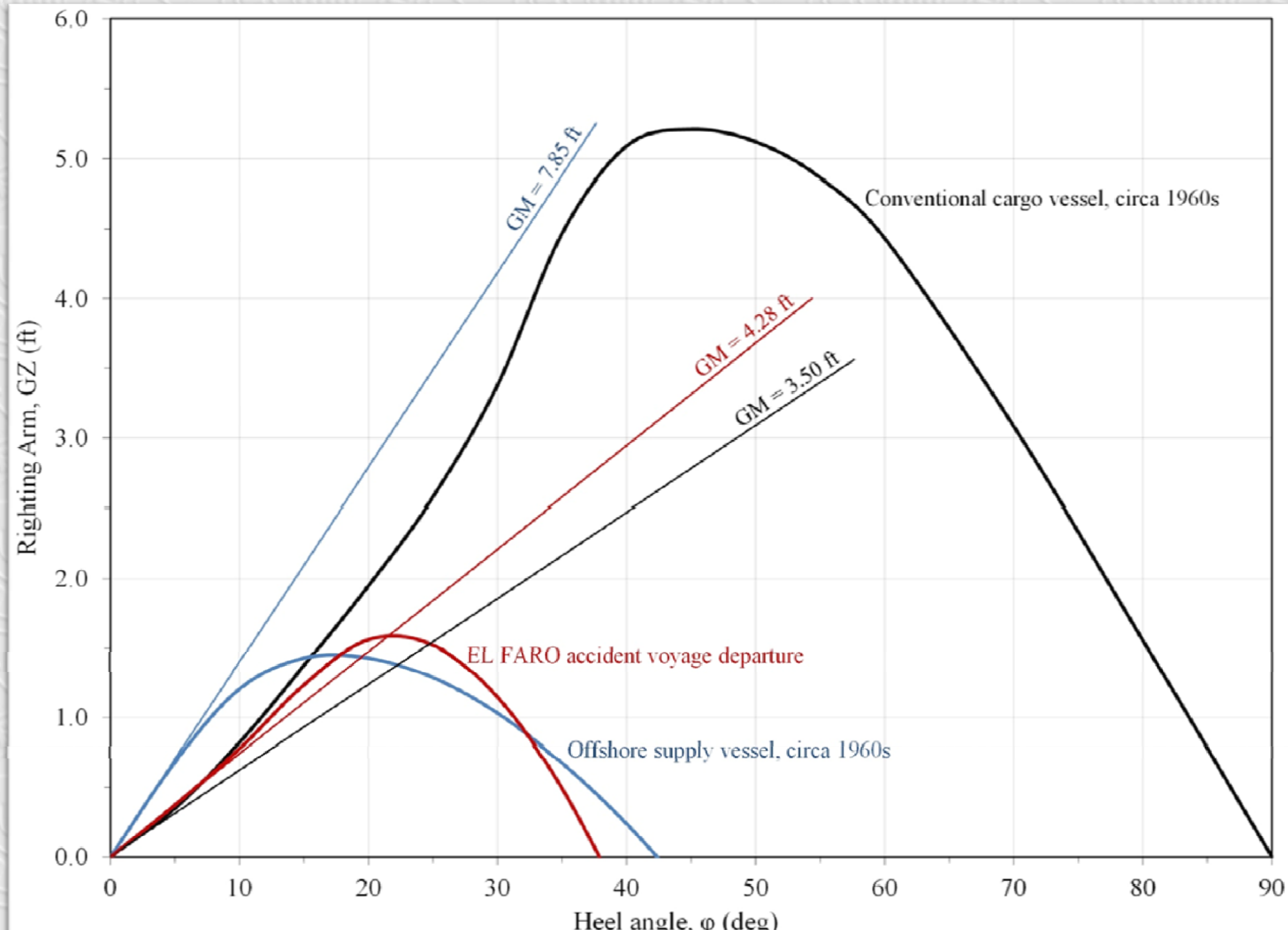


Figure 5-6

EL FARO "Benchmark" Loading Conditions

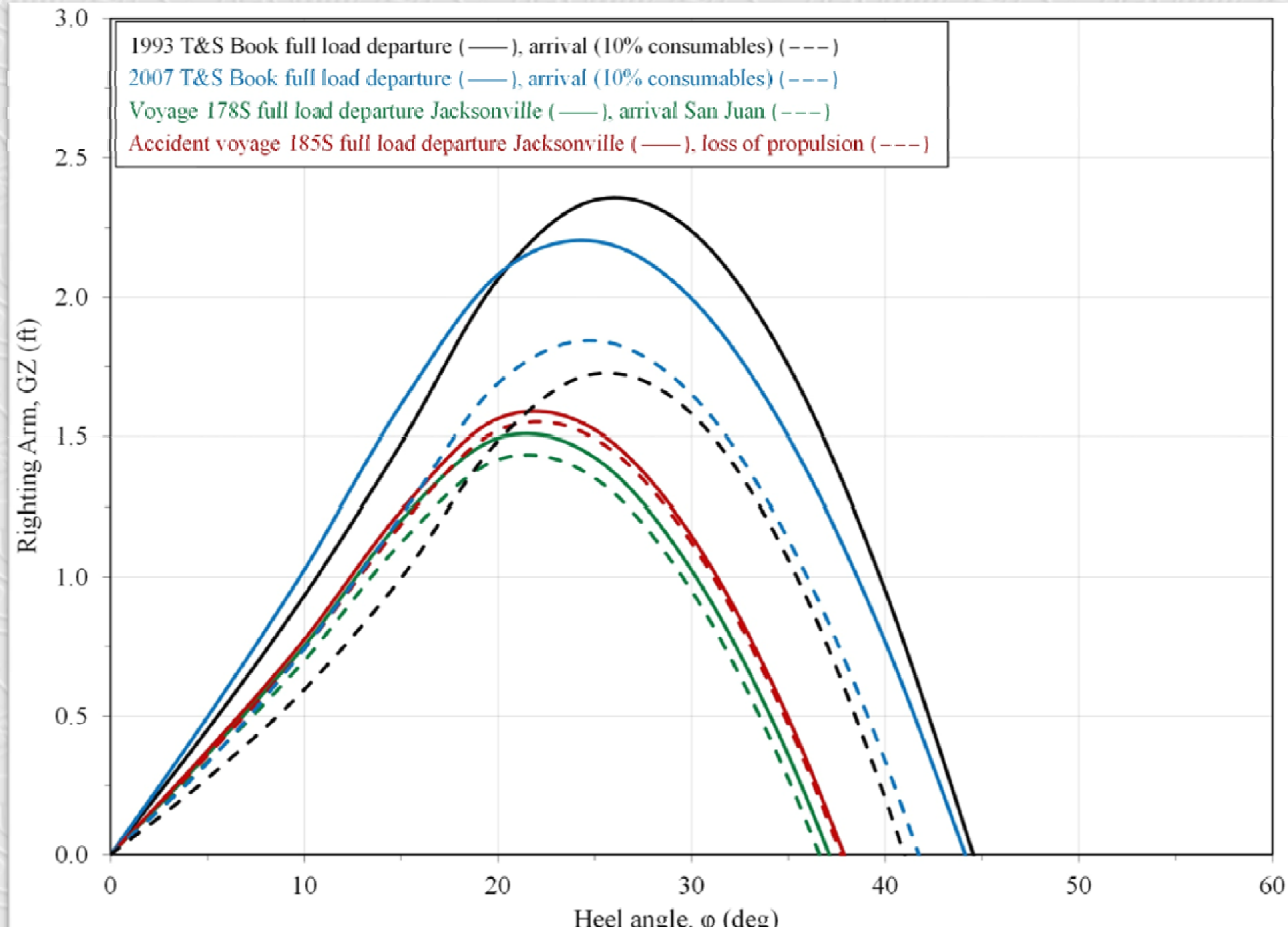
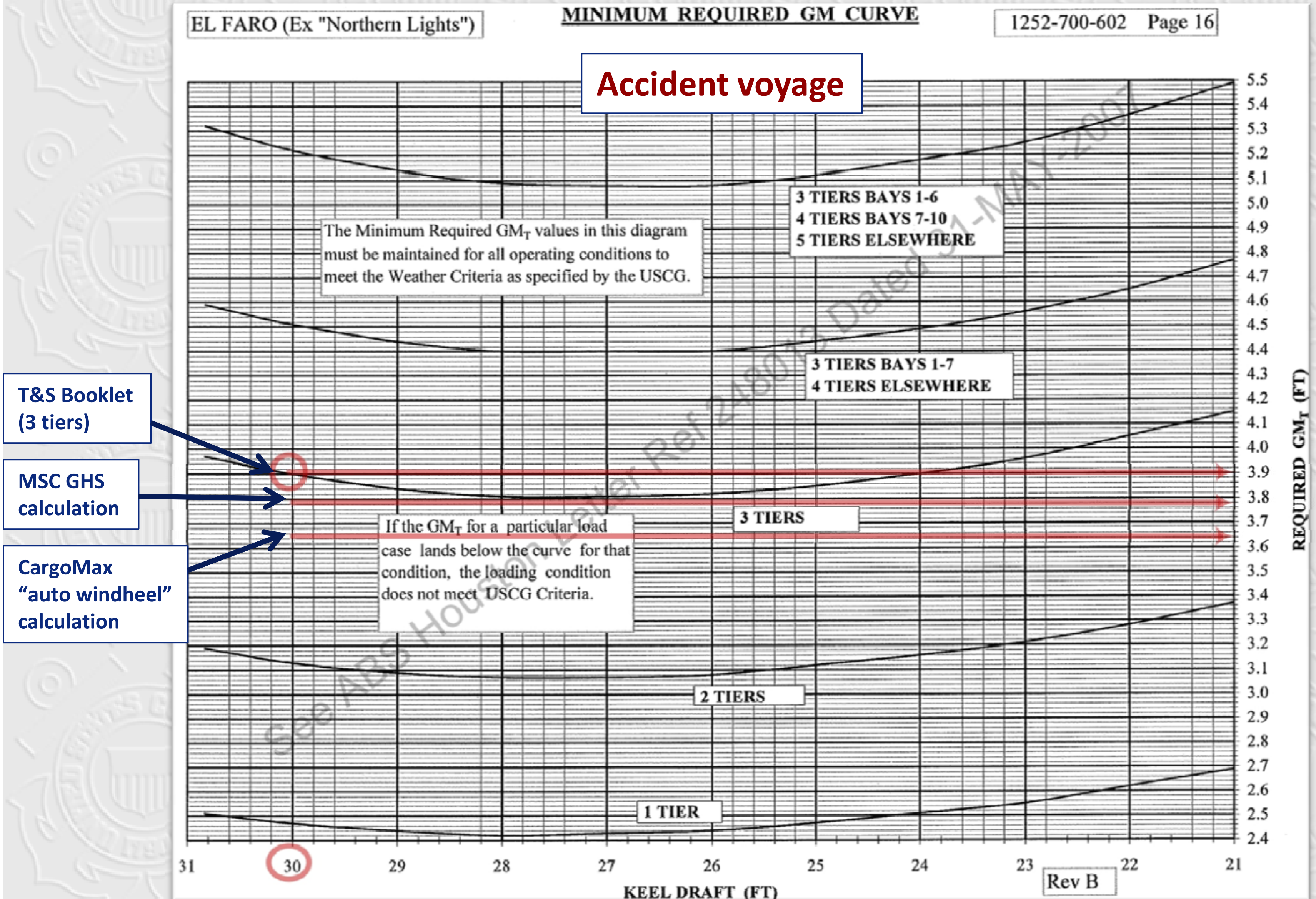


Figure 5-7

Intact Stability: GM Criteria **Applicable**



T&S Booklet

Figure 4-1 (annotated)

Intact Stability: GZ Criteria

If built in 2016

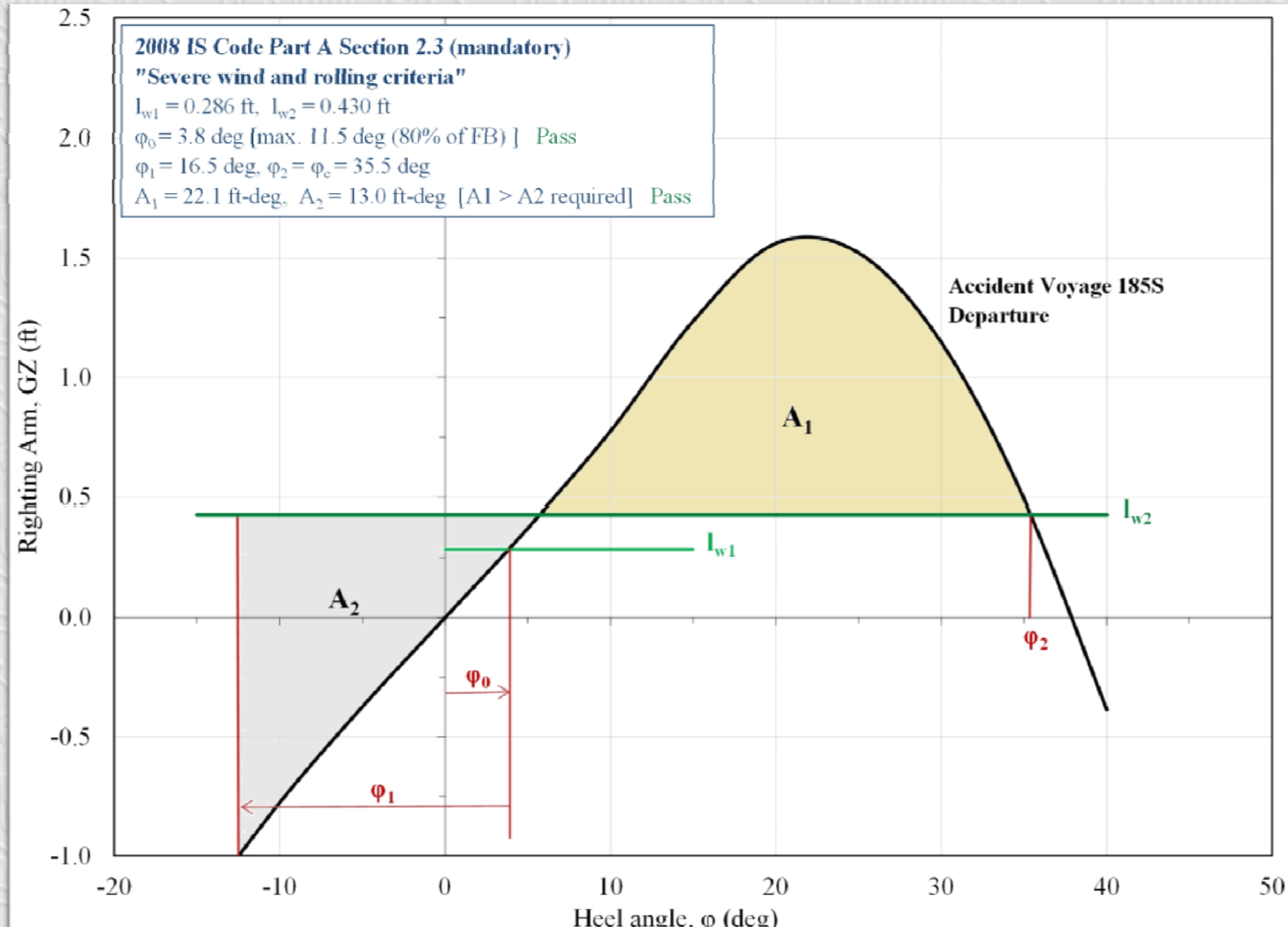


Figure 5-8

Damage Stability

- Damage stability standards
  - SOLAS 1990 (probabilistic)
    - Applicable to EL FARO since 1993 conversion
    - Not completed post-2006 conversion
- MSC analyses
  - SOLAS 1990 [applicable]
  - SOLAS 2009 [if built in 2016*]
- Results:

Analysis	SOLAS Standard	GHS Version	Required index (R)	Required GM (feet)
ABS (Gruber, 2016)	1990	8.30	0.600	2.9
MSC	1990	8.50	0.602	3.1
MSC	1990	15.00	0.602	3.3
MSC	2009*	15.00	0.674	5.8

Table 5-3

Damage Stability

Applicable

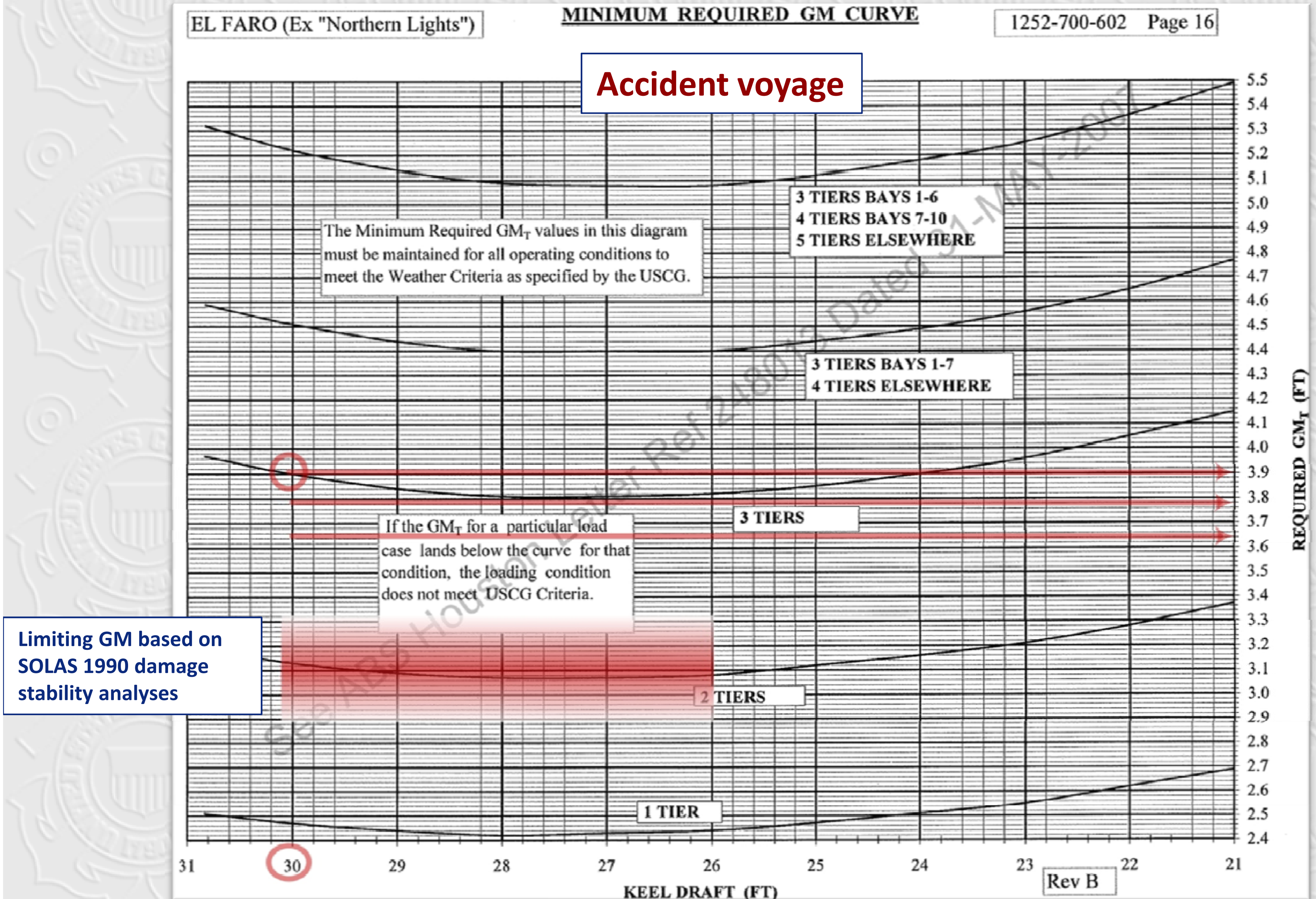


Figure 4-1 (annotated)

Hydrostatic Sinking Analyses

- Environmental conditions
- Potential sources of flooding
- Wind heel effect
- Free surface effect
- Permeability and pocketing effects
- Flooding of Hold 3
- Progressive flooding, downflooding
- Combined effects of wind heel and flooding
- Additional considerations
- Capsizing and sinking

Environmental Conditions

Winds → 70-90 knots (sustained)
Waves → 25-30 feet

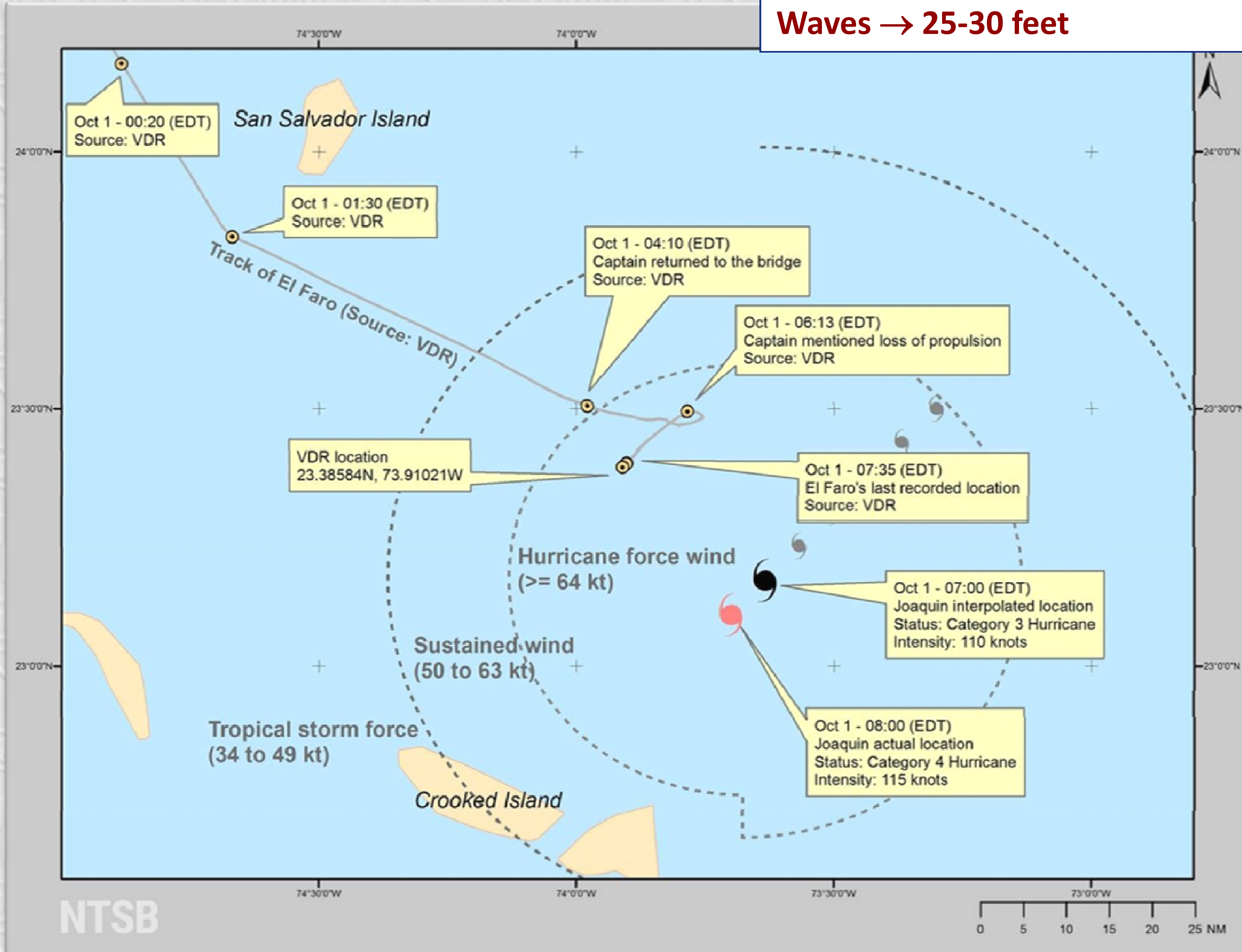


Figure 6-1

Hold 3 Access Scuttle (Starboard)

Figure 6-6

Emergency Fire Pump Piping

Figure 6-7

Cargo Hold Ventilation Openings

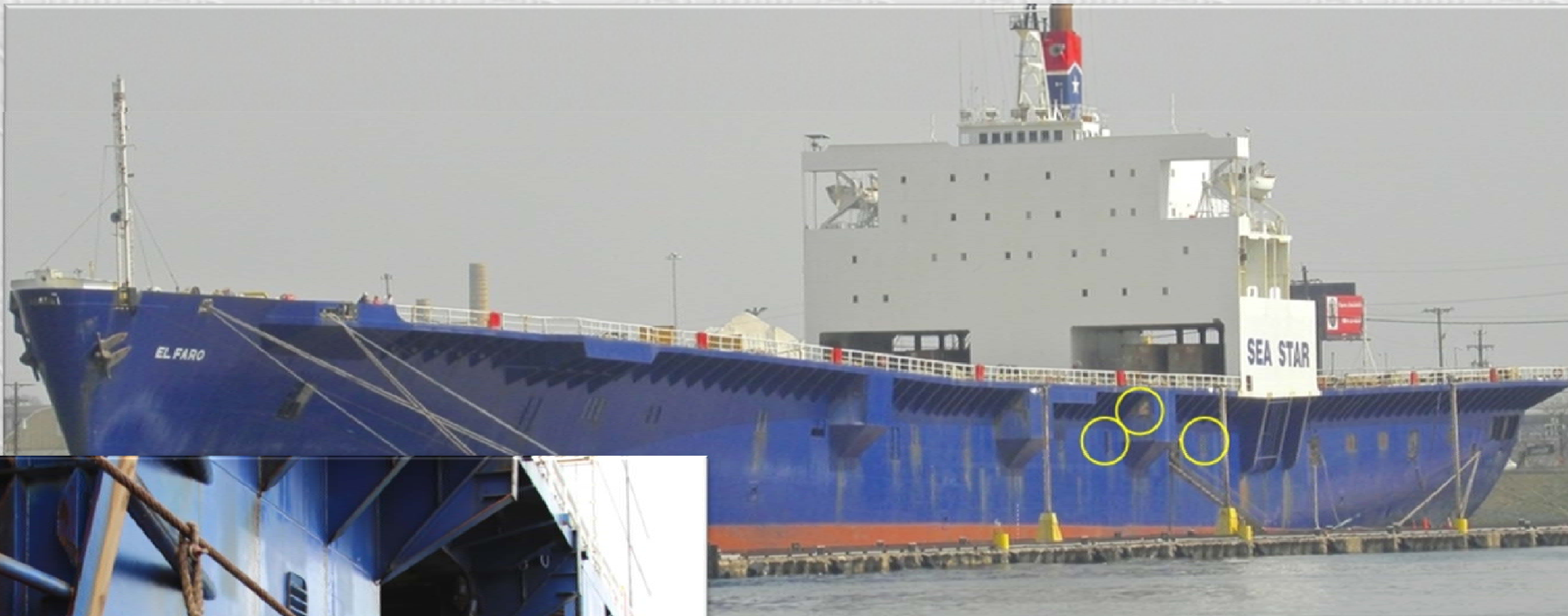


Figure 6-8

Figure 6-10

Cargo Hold Ventilation System

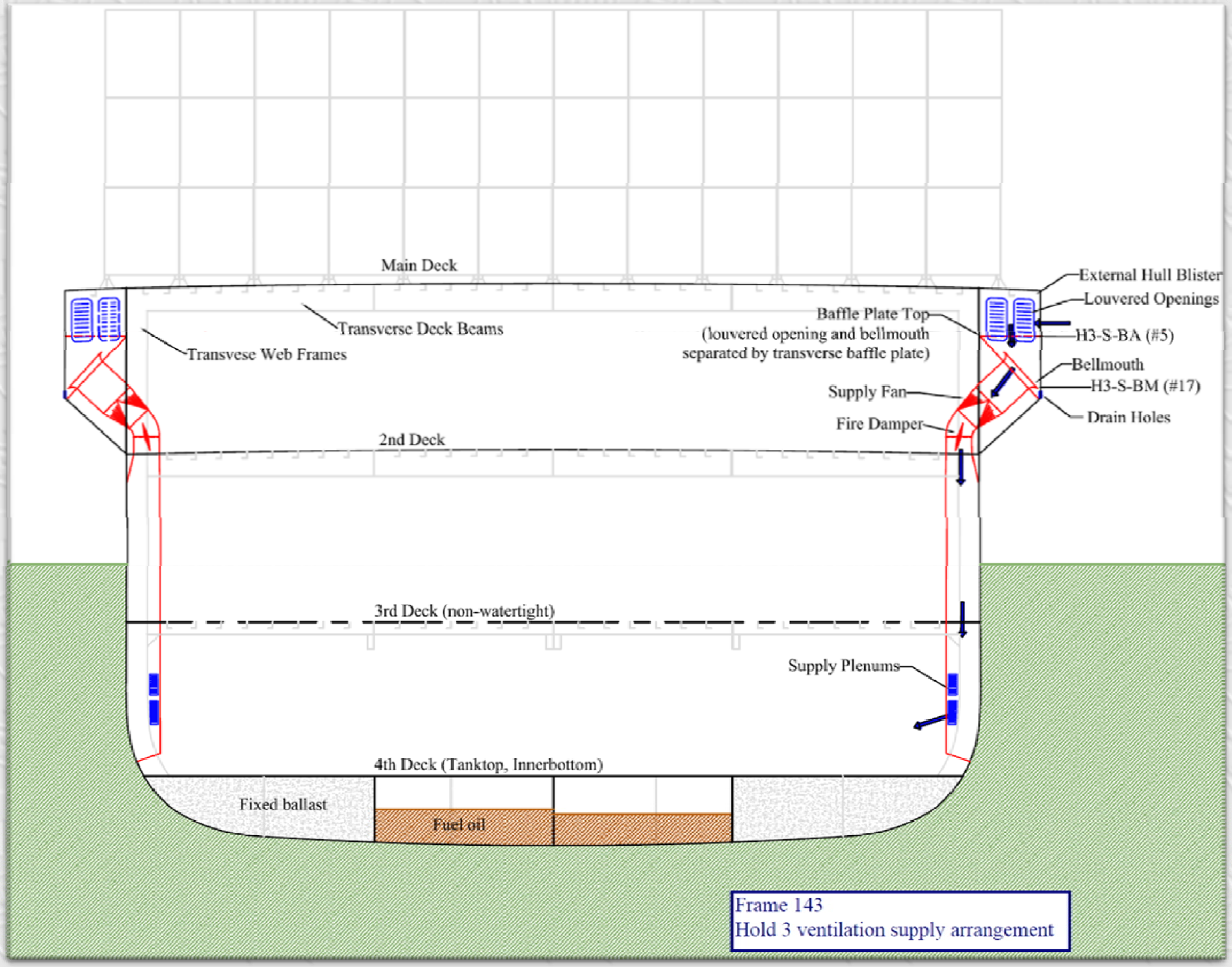
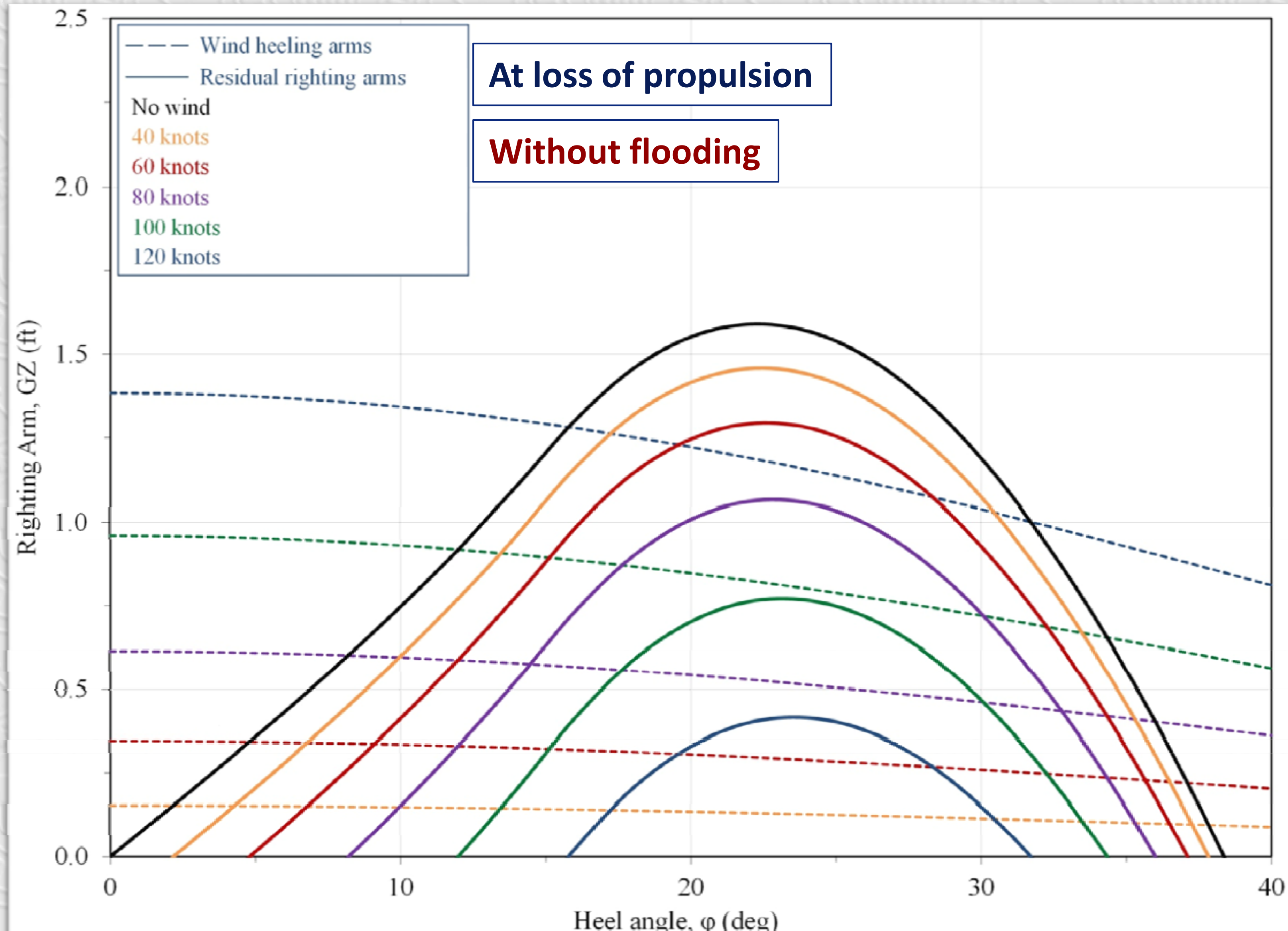


Figure 6-9

Wind Heel Effect



Figures 6-2 and 6-3

Flooding – Free Surface Effect

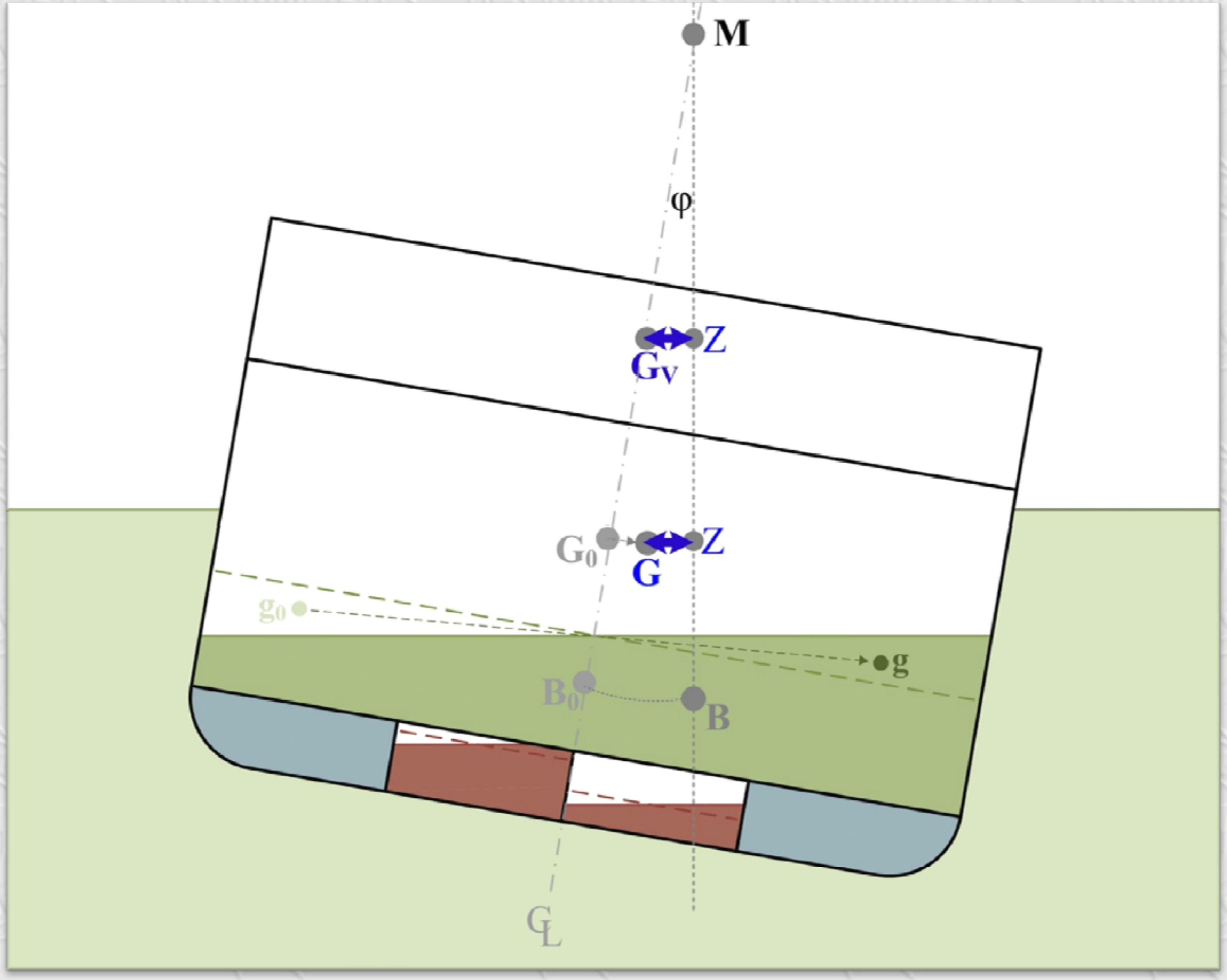


Figure 6-4

Flooding – Permeability and Pocketing

Frame 143
Hold 3 ventilation supply
Hold 3 flooded to 20%
15 degree heel angle

Figure 6-21

Flooding of Hold 3

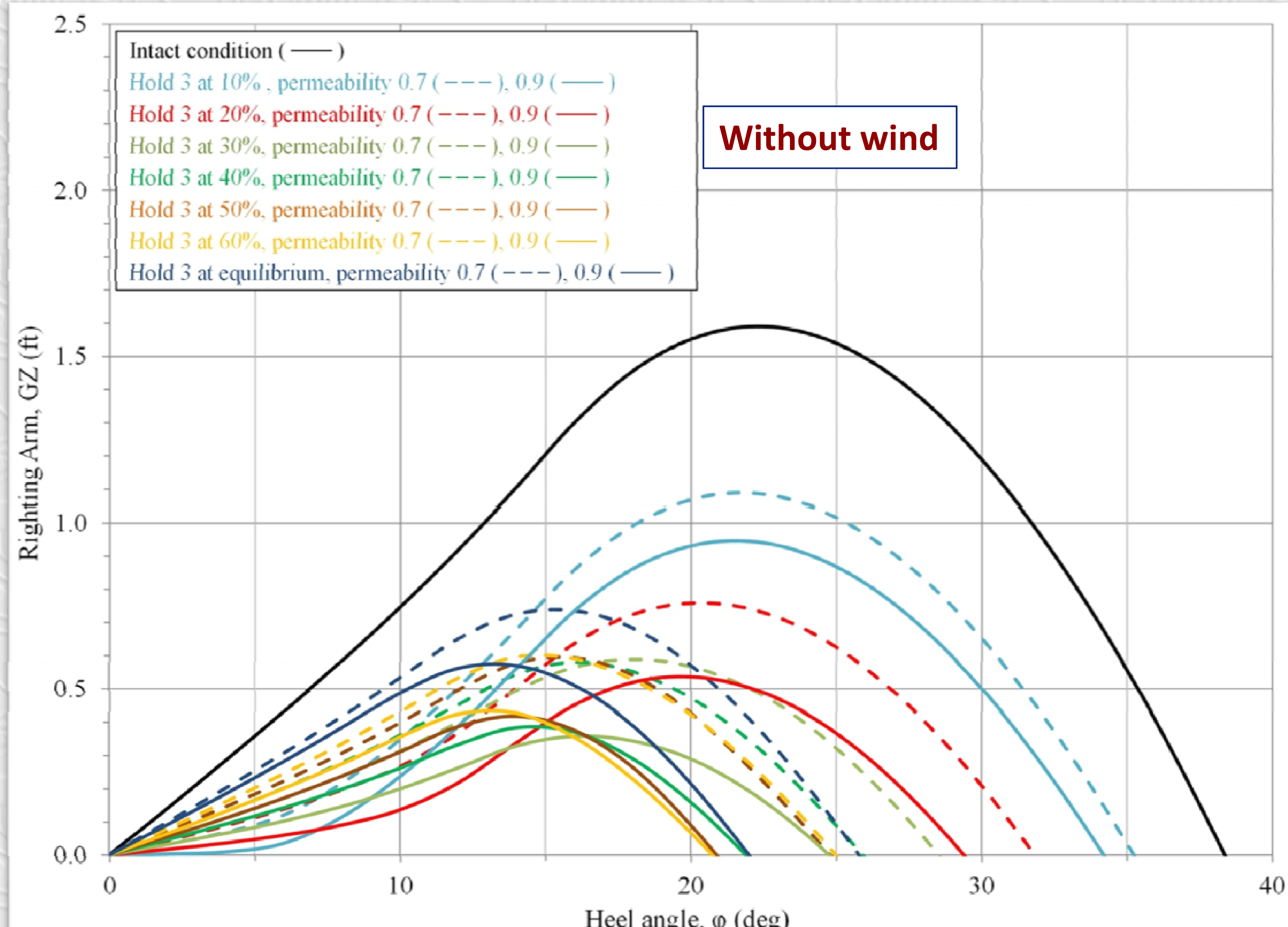


Figure 6-20

Progressive Flooding, Downflooding

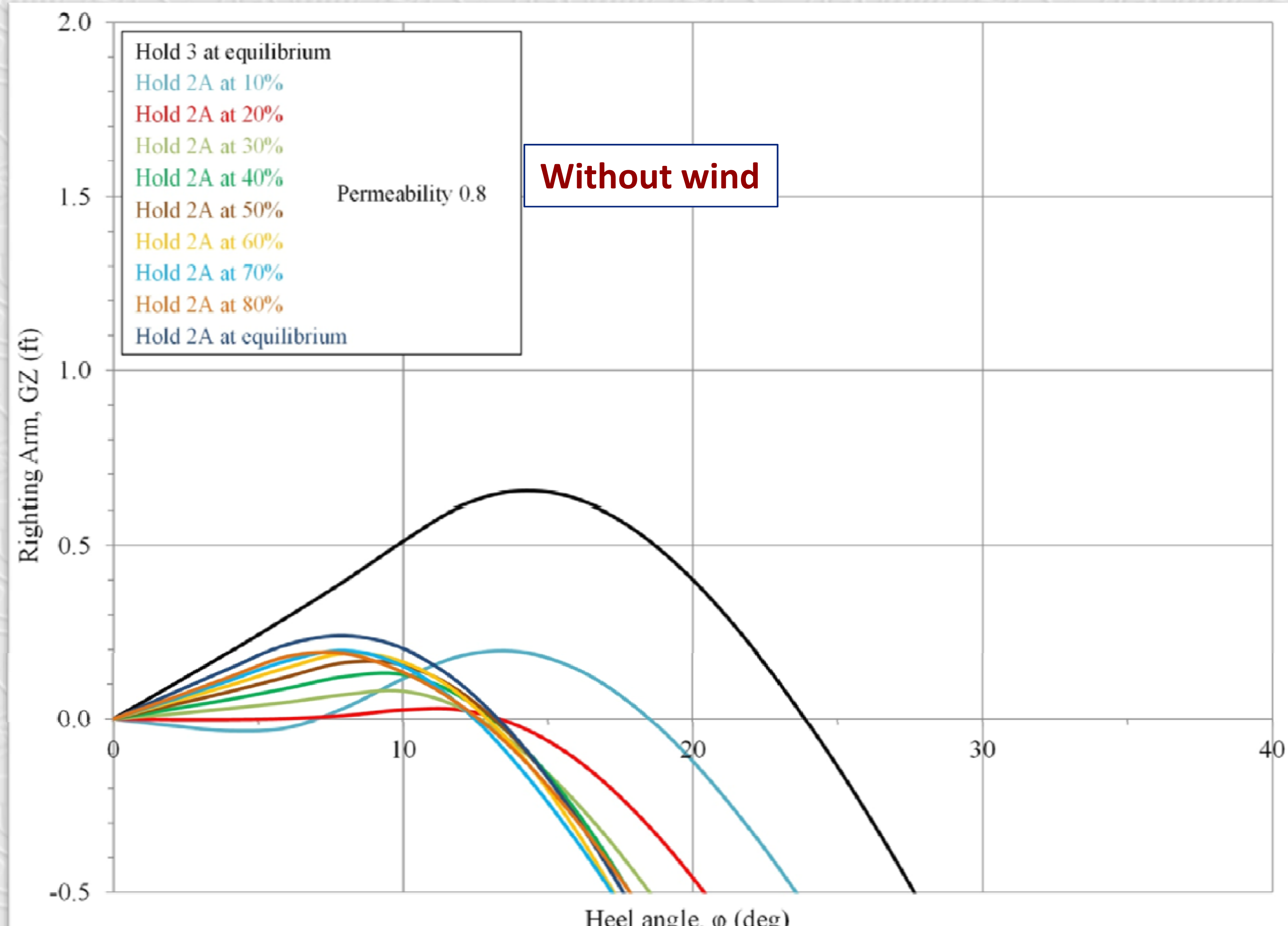


Figure 6-24

Combined Wind Heel and Flooding (Hold 3)

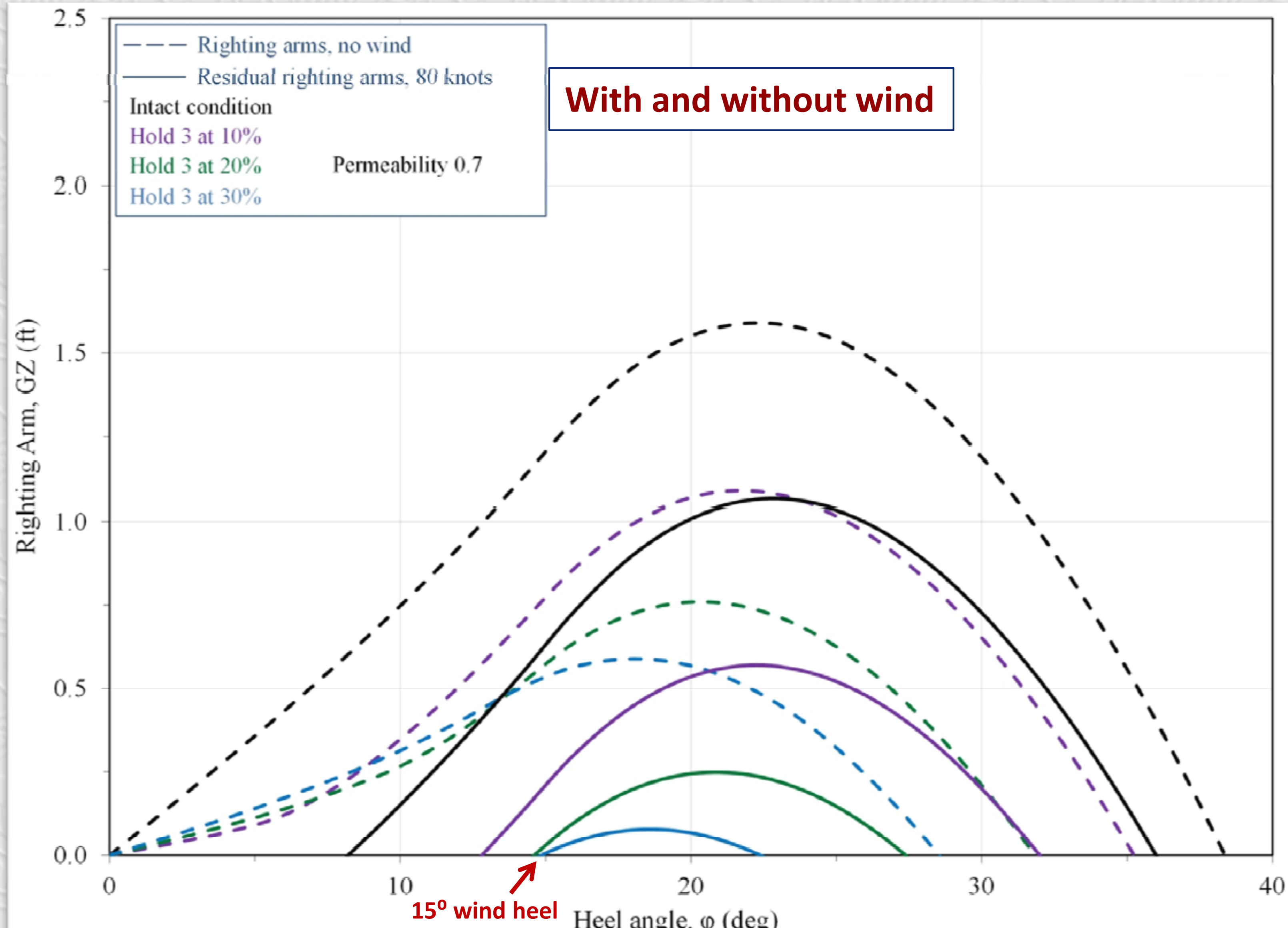


Figure 6-27

Combined Wind Heel and Flooding (Hold 3)

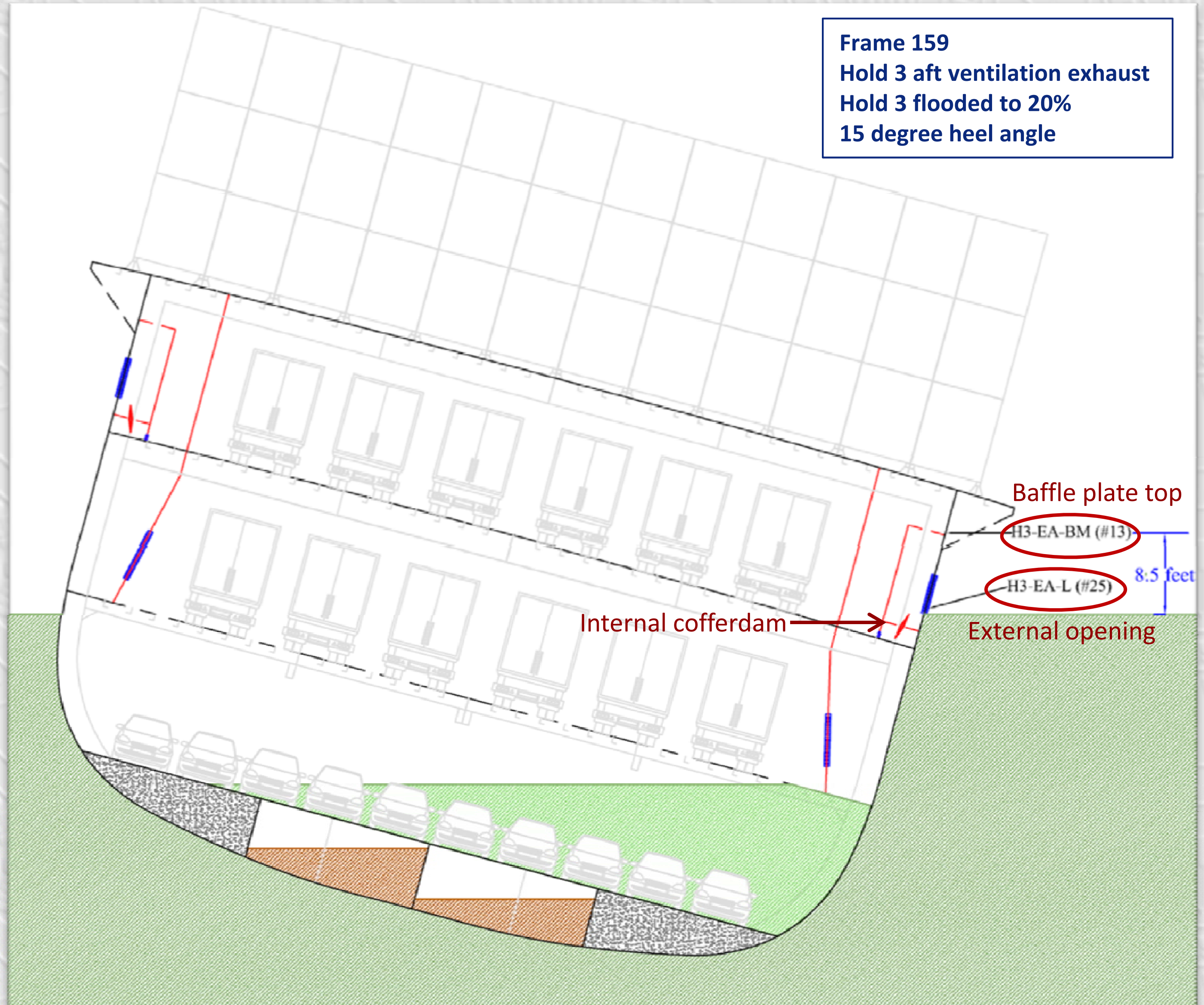


Figure 6-21(A)

Combined Wind Heel and Flooding

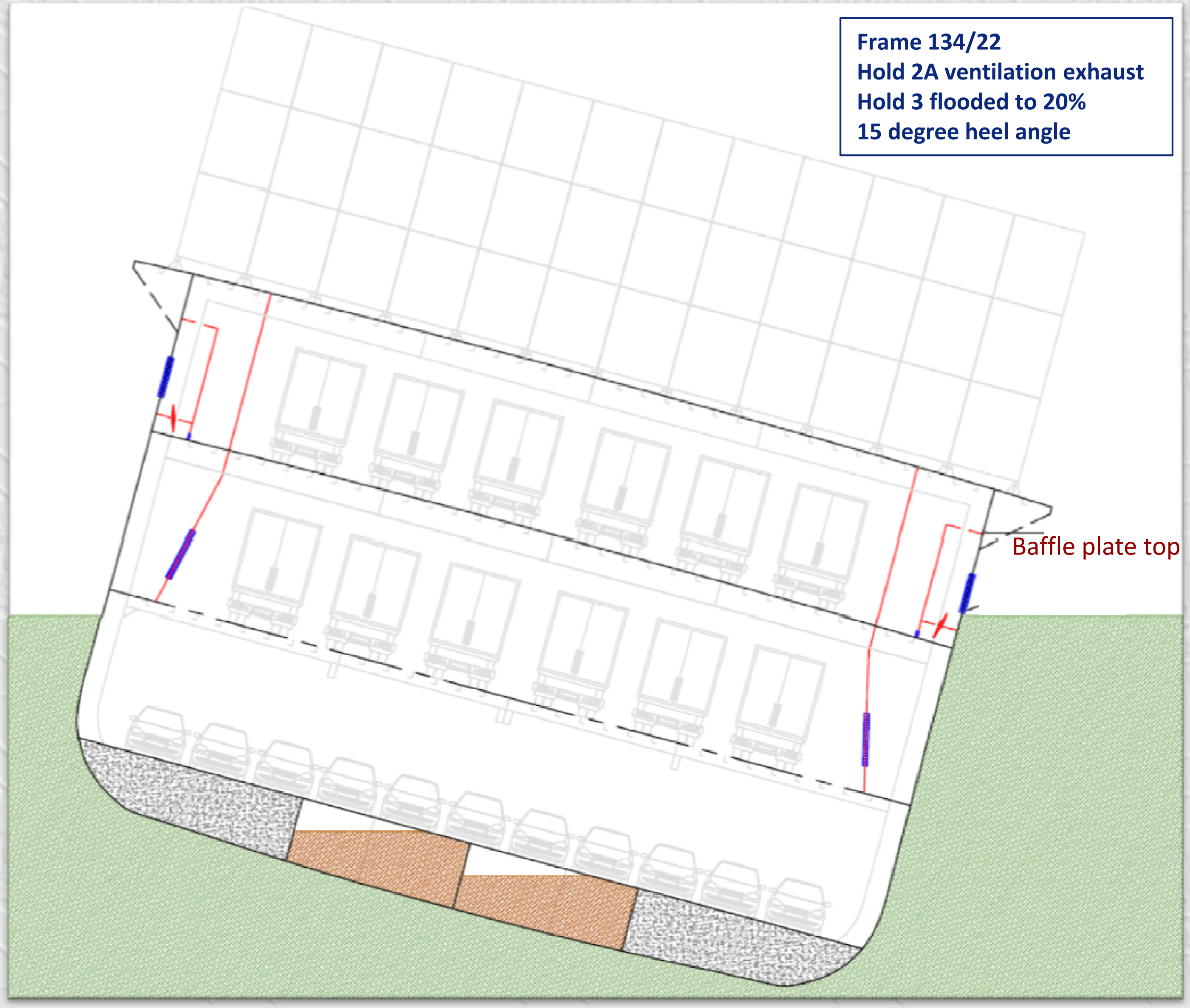


Figure 6-22

Capsizing and Sinking

- Key considerations
  - Large free surface effect (full-beam cargo holds)
  - Large beam wind heel (70-90 knot winds)
  - Large beam waves (25-30 foot seas)
- Plausible sequence
  - Hold 3 floods, wind heel ($\rightarrow$ 15 degrees)
  - Hold 2A floods through vent openings ($\rightarrow$ Holds 2, 1)
  - Loss of stability, partial capsize, port main deck awash
  - Loss of containers on deck (arresting full capsize)
  - Continued flooding through port vent openings
  - Vessel sinks
  - Returns ~upright (fixed ballast)

Key Conclusions

- For accident voyage, met applicable intact and damage stability and strength requirements
  - Operated with minimal stability margin, with limited ballast capacity and available freeboard, leaving little flexibility
- Sinking analyses
  - Results highly sensitive to free surface, permeability, pocketing, wind speed effects
  - Ship vulnerable to progressive flooding through cargo hold ventilation openings
  - Unlikely to survive even single-compartment flooding of Hold 3 with combined 70-90 knot winds and 25-30 foot seas
- If built in 2016
  - As operated, would not meet current intact and damage stability standards

Questions & Answers