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Ship Structure Committee Case Study

This case study has been prepared by the Ship Structure Committee (SSC) as an educational tool to advance the study of ship structures. The SSC is a maritime industry and allied agency partnership that supports, the active pursuit of research and development to identify gaps in knowledge for marine structures. The Committee was formed in 1943 to study Liberty Ship structural failures and now is comprised of 8 Principal Member Agencies. The Committee has established itself as a world recognized leader in marine structures with hundreds of technical reports, a global membership of over 900 volunteer subject matter experts, and a dynamic website to disseminate past, current, and future work of the Committee. We encourage you to review other case studies, reports, and material on ship structures available to the public online at **www.shipistructure.org**.

BULK CARRIERS: Design, Operation, and Maintenance Concerns for Structural Safety of Bulk Carriers

Date:

Summary:

The number and magnitude of bulk carrier accidents in the 1970s and 1980s gave rise to new consciousness, research and regulation of their design and operation. Unfortunately, this has not paid off in terms of either prevention of accidents or mitigation of damage to either life or property.

This case study summarizes common design, operation, and maintenance practices on board bulk carriers that contribute to on-going hazards. Operationally, bulkers are loaded very rapidly, typically in a pattern that emphasizes efficiency over hull strength. When unloading, heavy equipment is used that can be very tough on coatings and plating in the cargo holds. Once the coatings have been compromised, many of the cargoes can be corrosive to the steel beneath. When high strength steel has been utilized to add strength without weight, rapid corrosion degrades structural strength quickly.

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Statistics

A Formal Safety Assessment (FSA) conducted by Japan for the IMO Maritime Safety Committee examined casualty data from 1975 to 1996 (Ref. 1). There were 2916 reported bulk carrier casualties, resulting in the loss of 1890 lives. Between 1978 and August 2000, data from the same source reported 1,126 lives lost in bulker casualties attributable to structure failure or flooding. Figure 1 shows a breakdown of these fatalities.

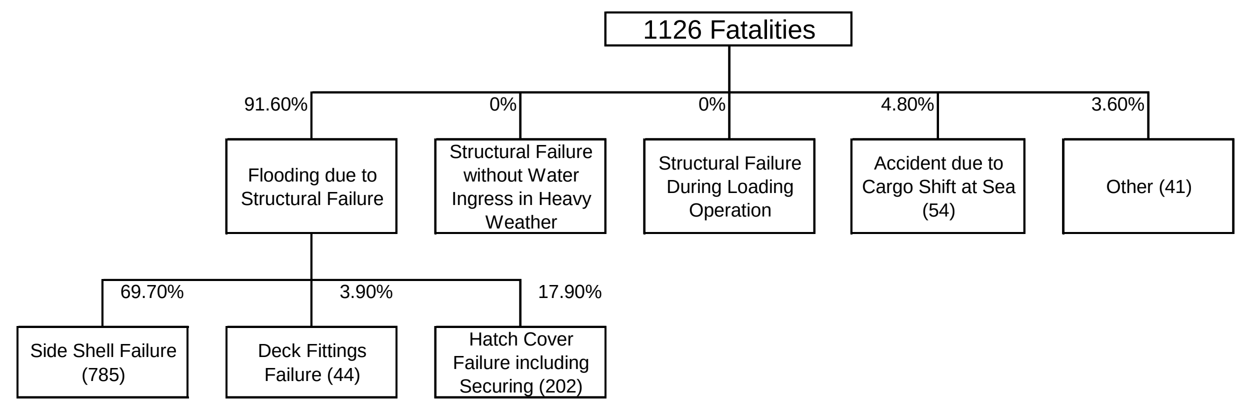

Figure 1. Bulk Carrier Fatalities by Casualty Type, 1978-2000

IMO Flag State Implementation Casualty Statistics and Investigations, list 356 “serious” or “very serious” casualties to bulk carriers in the period from 1998 to 2003 (Ref. 2). “Very Serious” casualties are classified as ”casualties to ships which involve total loss of the ship, loss of life, or severe pollution.” “Serious” casualties are defined as “casualties to ships which do not qualify as "very serious casualties" and which involve a fire, explosion, collision, grounding, contact, heavy weather damage, ice damage, hull cracking, or suspected hull defect, etc., resulting in immobilization of main engines, extensive accommodation damage, severe structural damage, such as penetration of the hull under water, etc., rendering the ship unfit to proceed, or pollution (regardless of quantity); and/or a breakdown necessitating towage or shore assistance.” Table 1 gives a breakdown of the casualties by causality type.

Table 1. Serious/Very Serious Bulker Casualties (1998-2003)

No. of Incidents		*Cause*
Serious	*Very Serious*	
37	15	Collision
92	13	Grounding
17	1	Contact
29	7	Fire/Explosion
24	21	Hull Failure
66	0	Machinery
2	5	List/Capsize
20	10	Other
287	72	Total

Design

Traditional bulk carrier designs are single hull, double bottom arrangements with hoppers at the upper and lower corners similar to the midship section shown in Figure 2. Structure is transversely framed and longitudinally stiffened. Each hold is accessed through a large hatch that is closed watertight with a hatch cover. The size of the hatch is limited by the amount of steel necessary in the deck to resist wracking.

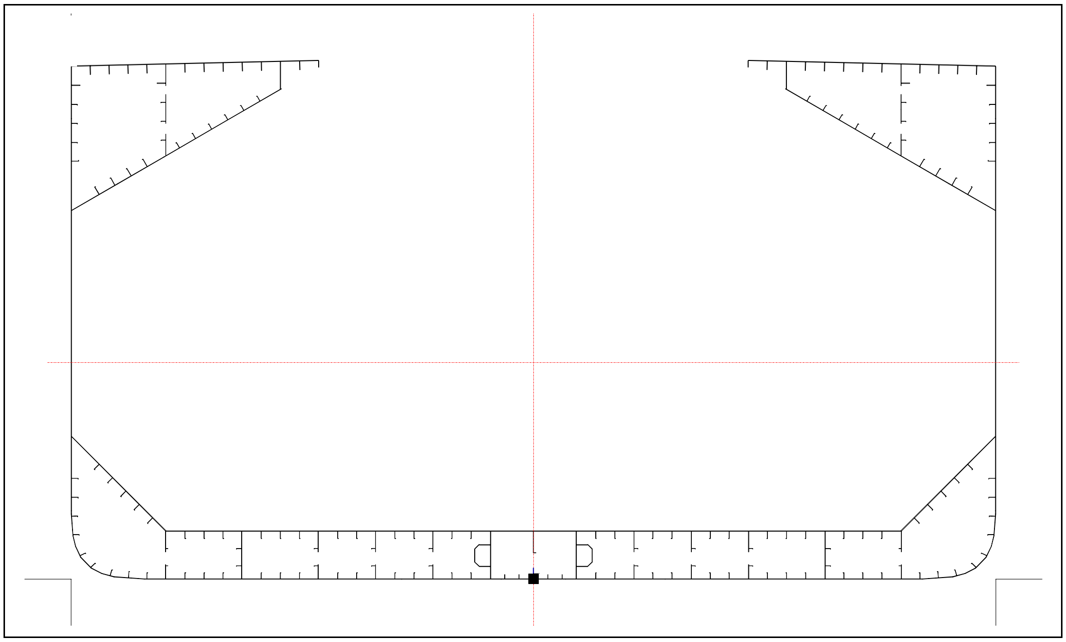

Figure 2. Bulk Carrier Midship Section – Longitudinally Continuous Material

Transverse bulkheads are typically corrugated with upper and lower stools that mimic the hoppers. While the longitudinal structure provides the vessel with its resistance to global bending moment loads, it is the transverse bulkheads that will experience the localized loading of the static weight of cargo or any sloshing loads associated with ballast or accidental flooding.

Operation

Careful planning is required in the loading of bulk carriers. Not only is it critical that the final departure condition be sound, but how the ship is loaded and offloaded is very important for a successful operation.

At sea, the ship is subject to both static and dynamic loading. Static loading from the weight of the vessel and the corresponding buoyancy is well understood. Dynamic loading due to waves – acceleration due to vessel motions in waves, sloshing of fluids in tanks, and bow slamming – are more complicated. Classification societies often define structural requirements as a function of static loading with a margin for dynamics in the form of allowable still water shear force and bending moment. In planning the vessel's operating condition, it is important that the static loading is not such that it does not leave sufficient margin for the dynamic loading in a seaway. In deed, many bulkers are lost in heavy weather, indicating that the vessels were satisfactory to withstand standard operating conditions but without sufficient margin for an increase in sea state.

Loading Patterns

There are three typical loading patterns utilized on bulk carriers: homogeneous, alternate hold, and block loading.

A homogeneous loading pattern as shown in Figure 3 is one in which the same amount of cargo is loaded uniformly in each hold. This is most often done with lighter cargoes like grain or coal. Care must be taken in planning a homogeneous load to mitigate the risk of cargo shifting.

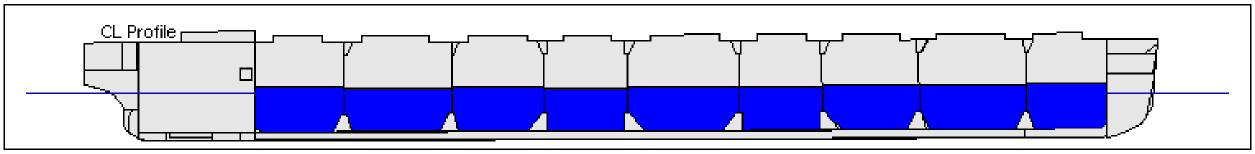

Figure 3. Homogeneous Loading Pattern

Alternate hold loading as shown in Figure 4 is used when high density cargo is being carried to raise the center of gravity. If heavy cargo is loaded homogeneously, snap rolling can result from the low center of gravity. By loading the cargo twice as high in half as many holds, the extreme rolling can be mitigated. Alternate hold loading is something that must be considered in the design phase. Local structure – transverse bulkheads, tank top, and lower hoppers – must be adequately sized to accept the increased weight. In order to save steel weight and not over build all the holds, only those holds that will be loaded in the alternate hold plan are reinforced. In addition to the local structure, this loading can induce high shear forces at the bulkheads where the loading switches from buoyancy dominant to weight dominant.

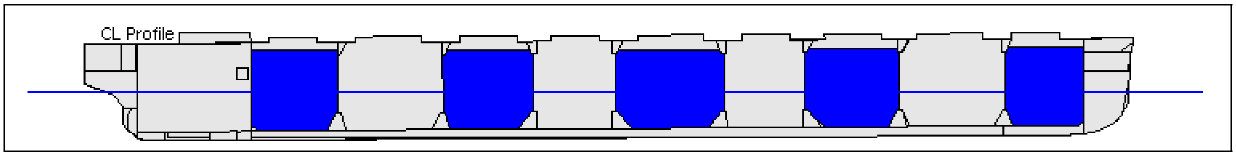

Figure 4. Alternate Hold Loading Pattern

A block loading plan as shown in Figure 5 is similar to the alternate plan except that adjacent holds may be filled in the block plan. (ie. Two pairs of adjacent holds would be filled with one empty hold between them.) This loading scheme is typically used when a vessel is partly loaded. When planning a block load it is very important to be mindful of the weight and buoyancy distribution over the cargo block. Loading manuals will often include charts indicating the amount of cargo that may be carried in a cargo hold at a given local draft.

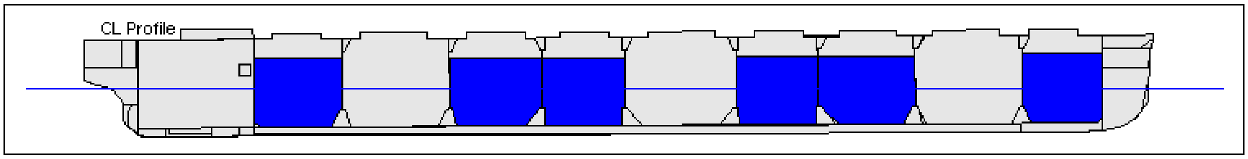

Figure 5. Block Loading Pattern

Figures 6 and 7 compare the shear and bending moment distributions for the various loading patterns. All three patterns carry the same total amount of cargo.

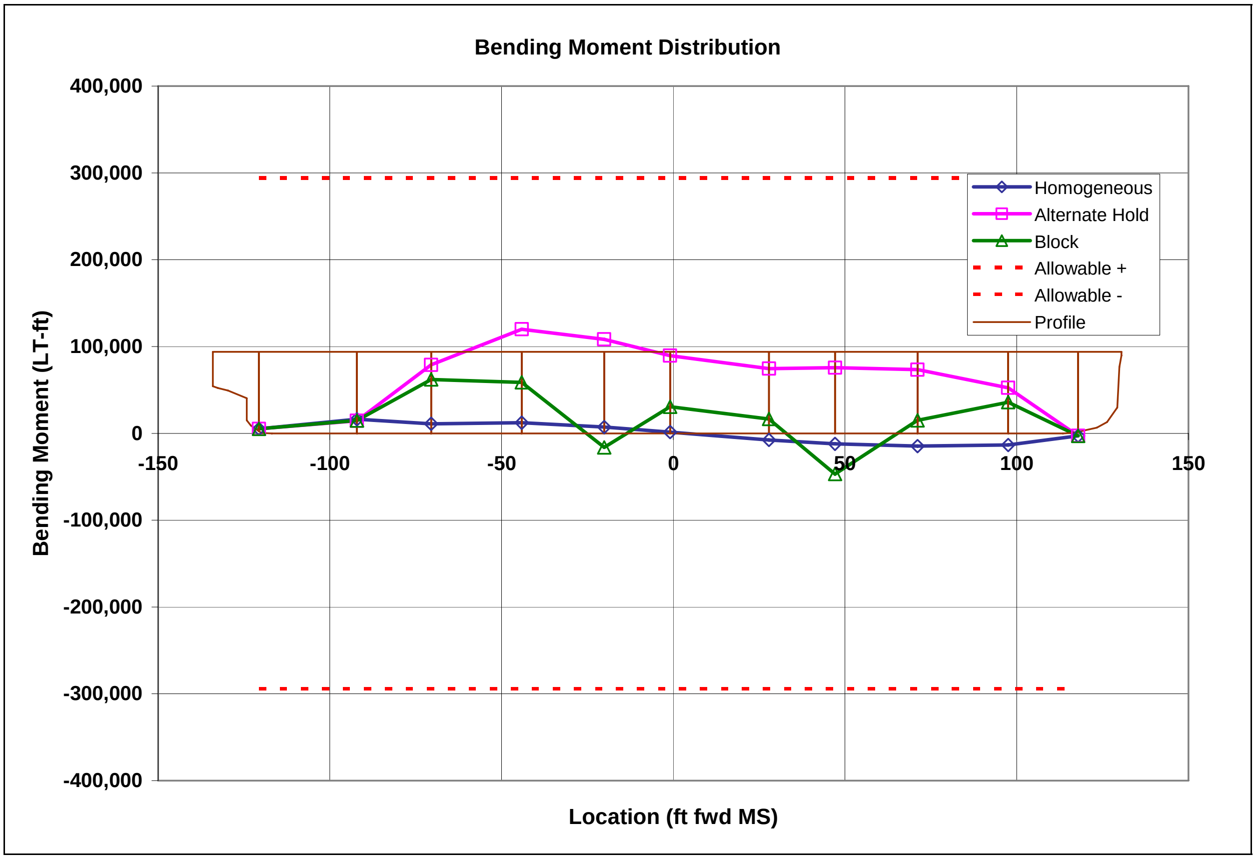

Figure 6. Bending Moment Distribution for Different Loading Patterns

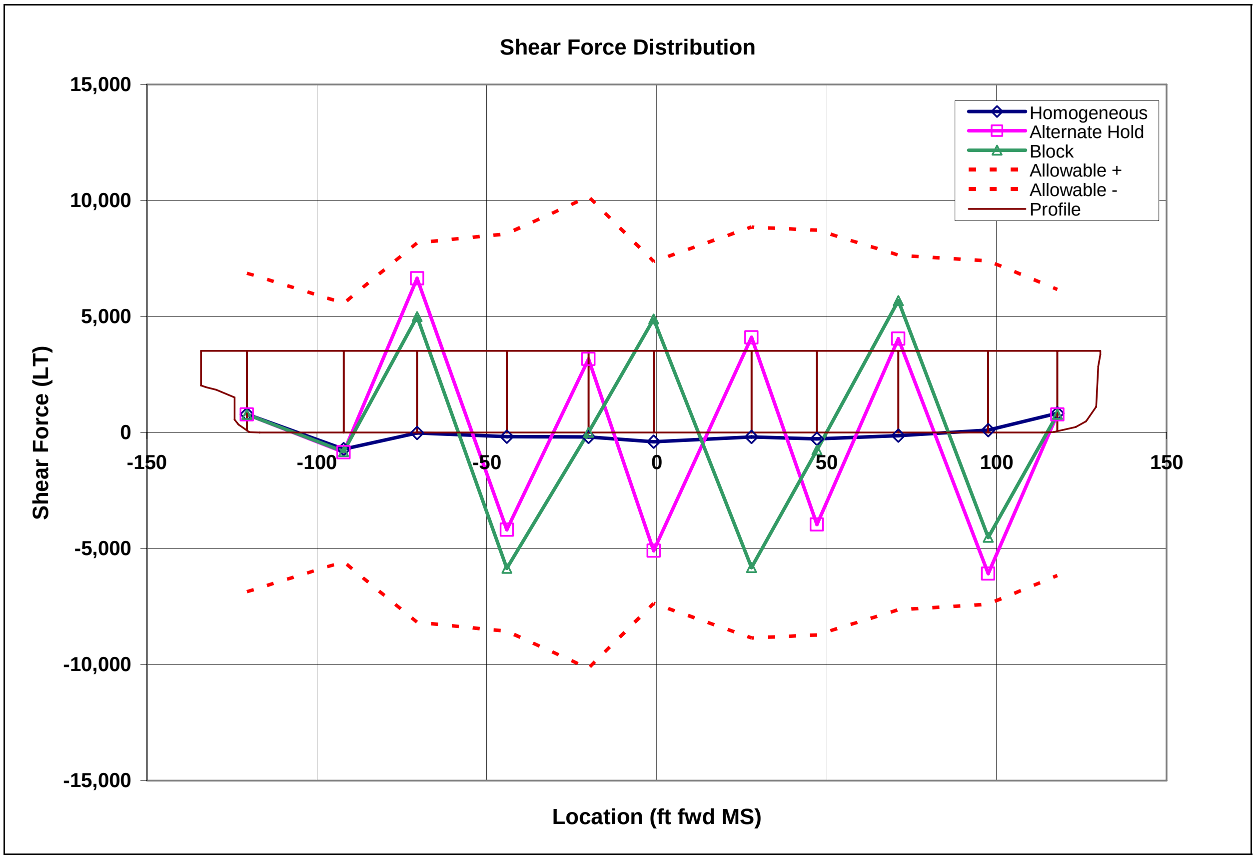

Figure 7. Shear Force Distribution for Different Loading Patterns

Loading and Unloading

In addition to the final loading condition of the vessel, careful planning must go into the sequence in which holds and tanks are loaded and unloaded. Shear and bending moment are to be minimized throughout the loading and unloading process. The ship's crew must work closely with the terminal personnel to plan and monitor the rate of loading, the weight of cargo to be loaded and how it is to be measured, any vessel shifts that will be necessary, draft checks to confirm the weight of cargo loaded and to ensure that intermediate loading still satisfies the limitations based on local draft.

In June 2000, the ALGOWOOD buckled while loading sand and aggregates at Bruce Mines, Ontario, Canada. While a loading sequence had been predetermined, it was modified in the field when the vessel was unable to shift as far aft in the berth as called for. Investigation by Transport Canada found that the bending moment at the time of the failure was 2.3 times the allowable still water bending moment.

During the loading and unloading process heavy equipment is used that can cause heavy wear on the cargo hold structure. Cargo is loaded using conveyor belts and may be dropped from the main deck height to the bottom of the hold. Unloading, clamshell grabs may be used when the ship is not a self-unloader. These grabs can weigh as much as 30tons without their cargo and are dropped and scraped against the tank top. Hydraulic hammers may also be used to dislodge cargo from corners and around framing. All of these practices can lead to rapid degradation of coatings and steel.

Corrosion

Steel corrosion is a chronic problem aboard bulk carriers. They are perhaps more susceptible than other large vessels such as tankers and container ships due to the nature of their construction and operation. Protective coatings are compromised by the use of heavy equipment for loading and discharge. Some cargoes themselves can create a more corrosive environment than water. And the use of high strength steel makes the vessel structure particularly vulnerable to strength degradation due to corrosion.

In September of 2000, EUROBULKER X broke apart while loading cement at Lefkandi Greece. A fifteen month inquiry pointed to a variety of mitigating factors, one of the largest being severe corrosion. Lower deck plating was wasted 30-40 percent and upper ballast tanks ranged from 50 percent to completely wasted in some areas. In addition the loading sequence allowed cargo to be loaded amidships with the fore and aft holds empty.

Coatings

Cargo holds of bulk carriers are typically coated with a complex system of several coats of epoxy. While there are international standards for coatings in ballast tanks and voids, coatings for bulk carriers are highly dependent on the cargo to be carried.
The abrasiveness of the cargo itself and the use of grabs, hammers, and other heavy equipment can rapidly compromise coatings. Once the coating is penetrated, the steel itself is subject to corrosion.

Cargoes

A wide variety of cargoes are carried in bulkers, ranging from grain to coal to iron ore. The physical and chemical properties of the cargo carried can have a substantial impact on the rate of corrosion of a vessel's structure. Sulphur residue in coal cargoes can combine with water to form sulphuric acid. Some cargoes have a residual moisture content that contributes to the humidity in the hold. Some cargoes can cause internal heating within the hold.

High Strength Steel

Many bulk carriers of the 1980s were designed with high tensile steel to improve their structural strength. Although this is an effective way to add to the strength of the new vessel, it can be problematic once corrosion sets in. While high tensile steel can be thinner than mild steel for the same strength, it will corrode at the same rate.

Acknowledgements

Dr. Charles Cushing, PE contributed extensively to this case study.

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