

BALLAST WATER FLOW-THROUGH EXCHANGE BEST PRACTICES REVIEW

PREPARED FOR: Department of Fish and Wildlife Olympia, Washington		BY: Kevin J. Reynolds, PE SENIOR ASSOCIATE	
THE GLOSTEN ASSOCIATES 1201 Western Avenue, Suite 200, Seattle, Washington 98101-2921 TEL 206.624.7850 FAX 206.682.9117 www.glosten.com		CHECKED: Dirk H. Kristensen, PE PRINCIPAL	
DOC:		APPROVED: Dirk H. Kristensen, PE PRINCIPAL-IN-CHARGE	
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References

1. Guidelines for the Control and Management of Ships' Ballast Water to Minimize the Transfer of Harmful Aquatic Organisms and Pathogens, Resolution A.868(20), International Maritime Organization (IMO), 27 November 1997.
2. International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004, International Maritime Organization, 16 February 2004.
3. Guidelines for Ballast Water Exchange (G6), Resolution MEPC.124(53), International Maritime Organization, 22 July 2005.
4. Code of Federal Regulations, Title 33, Part 151, Subpart D - Ballast Water Management for Control of Nonindigenous Species in Waters of the United States.
5. Washington Administrative Code, Chapter 220-77-090, Ballast Water Management and Control — Reporting and Sampling Requirements.

Executive Summary

This short report was prepared for the Washington State Department of Fish and Wildlife (WDFW) to support the state's regulation of ballast water. Preparation of the report included an analysis of flow-through ballast water exchange operating procedures and equipment on board a typical tank vessel. Further efforts included considerations relevant to flow-through exchange on all marine vessels. The report delivers the following:

- Review of the flow-through a ballast water exchange system for the example tank vessel. This includes suggested changes for operating procedures and installed equipment that would increase exchange efficiency.
- Proposed general best practices and best systems that could serve as a guide for efficient ballast water exchange on other ships.
- Recommendations for further research that could lead to improved ballast water exchange.

Introduction

Ballast water exchange has been promoted or required by numerous regulatory bodies as a method to minimize the spread of harmful aquatic organisms and pathogens by means of ships' ballast water. The International Maritime Organization (IMO) identifies three acceptable methods of ballast water exchange:

- Sequential, where tanks are emptied and then refilled.
- Flow-through, where tanks are overfilled by a prescribed amount.
- Dilution, where a tank is filled on top while it is being discharged from the bottom. These exchange events are conducted in deep oceanic waters.

This report reviews only the flow-through method of ballast water exchange.

The 2004 IMO Ballast Water Convention established a timetable for phasing out ballast water exchange and requiring installations of treatment systems over the next decade. In the interim, ballast water exchange remains the standard method for reducing the spread of aquatic nuisance organisms. Further improvement upon current ballast water exchange practices should, therefore, focus on simple and practical modifications.

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- Review of the flow-through ballast water exchange system for the example tank vessel; this includes suggested changes for operating procedures and installed equipment that would increase exchange efficiency.
- Proposed general best practices and best systems that could serve as a guide for efficient ballast water exchange on other ships.
- Recommendations for further research that could lead to improved ballast water exchange.

The scope of the analysis and best practices included in this report are limited to volumetric efficiency and pipe fouling. For more information regarding vessel stability, propeller submergence, bridge visibility, and other operational concerns, a vessel's trim and stability book should be reviewed. For details concerning general ballast management practices, such as suitable locations for ballast exchange, a vessel's ballast management manual, IMO Resolution A.868(20), or the IMO G6 Guidelines (References 1 and 3) should be reviewed.

It is relevant to this report that volumetric efficiency and organism efficacy are distinctly different. Volumetric efficiency considers the physical amount of water which is displaced by the exchange event, while organism efficacy considers the ability to remove or inactivate organisms by the exchange event. This report focuses on volumetric efficiency.

Review Methodology

This report is a third party review of ballast water exchange practices, both aboard the example tank vessel and as generally applicable to all ships. The process used to generate this report included:

- A shipcheck of the example vessel. This consisted of a review of crew practices and procedures, as well as a survey of mechanical equipment and two ballast tank internals.

- An engineering review of the example vessel. This included calculations to determine the throughput to each tank from the ballast pump and a review of ballast tank configuration for estimating flow directions internal to the ballast tanks.
- Development of proposed best practices applicable to all vessels based on the results of the example vessel survey and engineering review, as well as prior understanding and knowledge of ballast water exchange.

Example Vessel

The challenges associated with ballast water exchange are generally applicable to all marine vessels. A tank vessel was selected for survey and review as its ballast water exchange practices and equipment would well represent the challenges faced by all marine vessels. The tank vessel, newly delivered, is well maintained and fully operational. The crew was versed in the details of the regulatory requirements for ballast water management and recordkeeping.

Vessel Particulars

Delivery Date	2006
DWT	~25,000 Tonnes
Cargo Capacity (100%)	~30,000 Tonnes
Number Cargo Tanks	14
Ballast Capacity (100%)	~12,000 Tonnes
Number of Ballast Tanks	15

Example Vessel Ballast System Overview

The example tank vessel provides a reasonable study platform for ballast exchange efficiency that can be applied to marine vessels in general. The following review considers key features as they relate to exchange efficiency. More detailed information concerning ballast water exchange aboard the example vessel, including photos of key components and structure, is provided in Appendix A.

Ballast Tank Arrangement and Structure

Figure 1, below, shows a section of one ballast tank which identifies the wing wall, outboard and inboard double bottom sections. Each section is partitioned by plates which have accesses cut just large enough for a person to squeeze through.

This section (11 meters in breadth and 12 meters in height) is only about 2 meters in length. A typical ballast tank on this vessel is comprised of eight of these sections, with a total length of 16 meters. In this way, a single ballast tank is really twenty-four (24) steel boxes welded together with lightening holes just big enough to allow fluid and personnel access between them. These tanks are longitudinally framed, meaning that smaller structure running from forward to aft is provided about every 750 millimeters.

The location of the ballast water fill and the overflow location superimposed on the below figure. The blue “paint” portrays the likely path through which ballast water will be flushed from the fill to the overflow. An improved ballast water “recommended inboard inlet” location is shown.

The following aspects of the current system are likely to promote exchange efficiency:

- The fill and exchange dedicated overboard are widely separated vertically in the wing wall section, as shown.
- The fill and overboard are widely separated longitudinally in the wing wall section. Note, the fill is in the aft most section of the tank and the overflow is actually six tank frames forward.

The following aspects of the current system are likely to hamper exchange efficiency:

- The fill and overboard location are far removed from the inboard and outboard double bottom sections of the tank, isolating them from the likely flow of the ballast water exchange (painted blue section). These areas are labeled below as a ‘Likely Dead Zone.’
- The longitudinal structure between the wing wall section and the outboard double bottom will significantly reduce any mixing or exchange of ballast in the outboard double bottom. Similar structure between the inboard and outboard double bottom will further isolate the inboard double bottom significantly limiting exchange in this area.

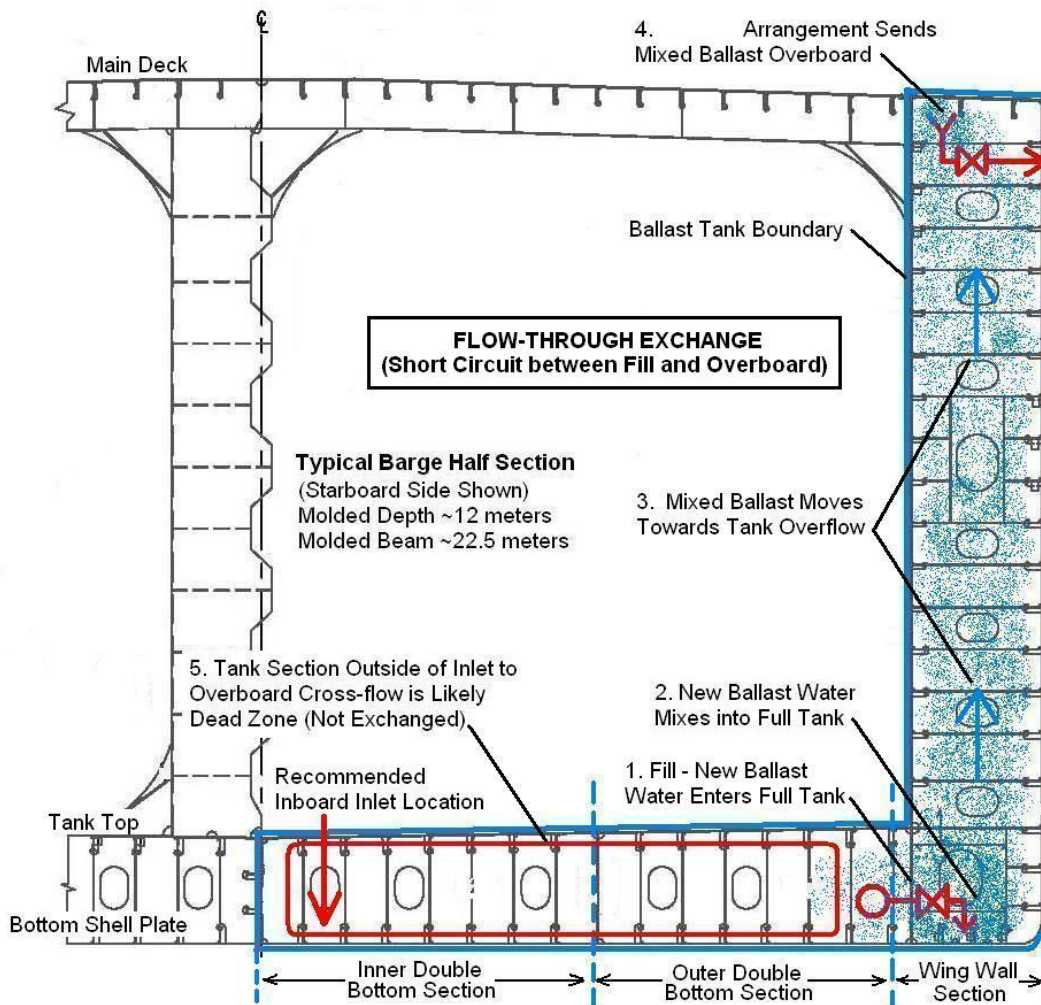


Figure 1 – Tank section with ballast water flow-through exchange path highlighted.

It is relevant that the “effectiveness” of ballast water exchange is frequently determined by pulling plankton nets through the vertical water column from the main deck. The access for these nets is typically from the main deck, and in the example case directly overlap with the volume of the ballast tank which would most likely be well exchanged. The dead zone identified in the below figure would be outside the range of the plankton net. In such a case, the “effectiveness” of the exchange would likely be over-reported in comparison to both exchange volumetric efficiency and organism efficacy. Appendix B provides additional review.

Ballast Piping System

Figure 2, below, shows schematic arrangements of the example vessel ballast piping system. There are port and starboard ballast mains each fit with a single deepwell ballast pump. These mains are fitted with cross-overs which permit pumping of ballast from any pump to any tank. A special overboard (top left in figure) is provided at each tank to facilitate flow-through exchange while keeping overflowing ballast water off the barge’s decks.

The following aspects of the current system are likely to promote exchange efficiency:

- Because the special overboards are positioned at the top of the tanks, complete mixing is encouraged throughout the full vertical height of the ballast tank.
- Bondstrand, a plastic piping material, is widely used in the tank piping. This inert material does not encourage marine growth internally.
- The port and starboard piping header arrangement with a large cross-over permits the use of any pump when exchanging any ballast tank. This allows optimizing the flow rate to any one ballast tank. A high ballast flow rate increases turbulence inside a tank and encourages mixing.

The following aspect of the current system is likely to hamper exchange efficiency:

- There are sections of steel piping at the sea chest, main deck piping, and at the pump. The sections in way of the seachest are of particular concern, as low flow rates that are normal in the area will encourage piping and seachest fouling.

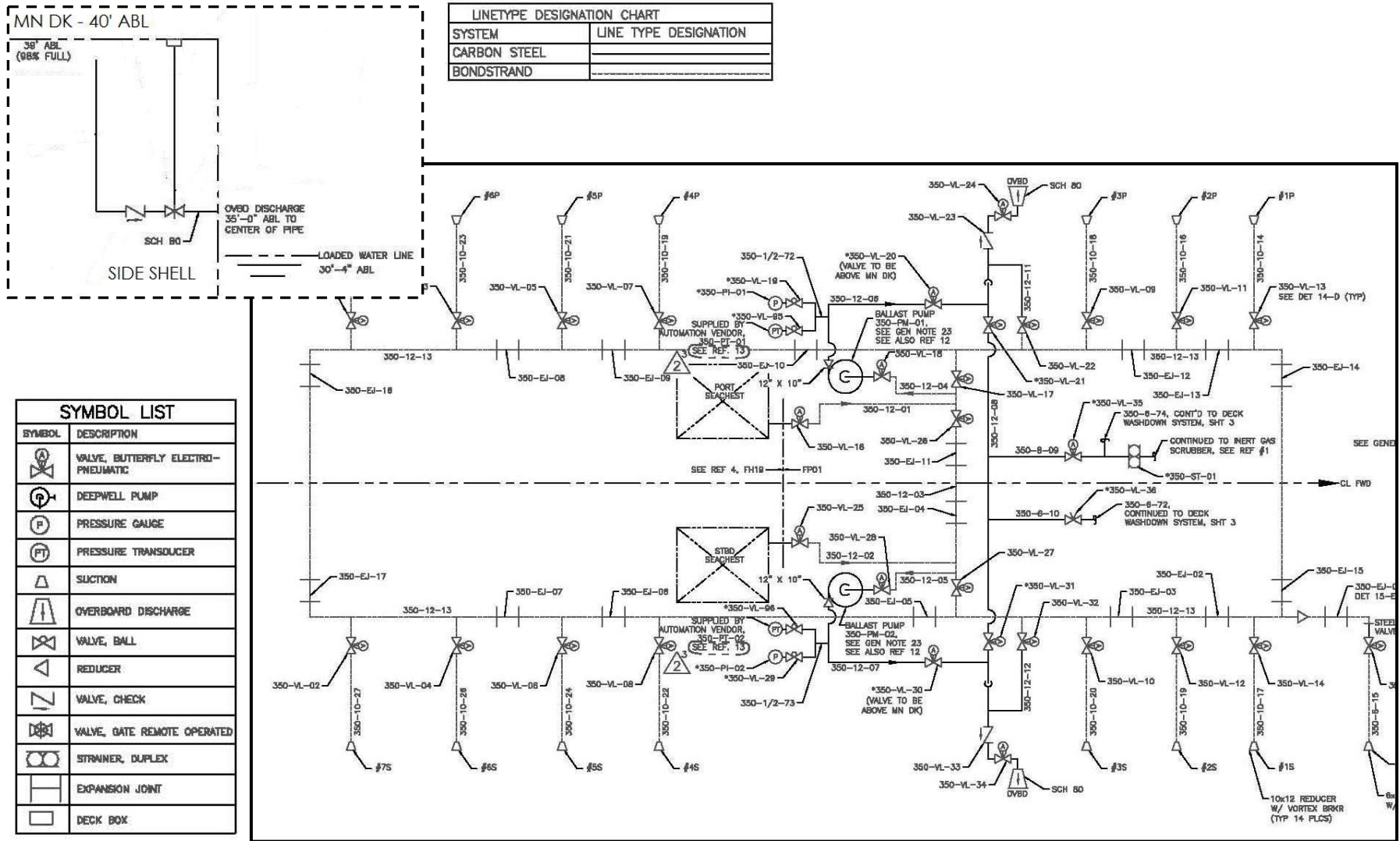


Figure 2 - Schematic arrangements of the example vessel ballast piping system.

Proposed Best Practices and System for Flow-Through Ballast Water Exchange

Listed below in *italic* are the proposed best practices and system design considerations that may maximize the volumetric efficiency of flow-through ballast water exchange and minimize the negative effects of piping or seachest fouling. These proposed considerations are based on the vessel survey and engineering review of the example vessel, as well as previous work by The Glostén Associates regarding ballast water exchange efficiency. Explanations of these best practices and systems are included where deemed necessary.

Best Practices

- *The ballast pump(s) should be run at the highest possible capacity to as few ballast tanks at a single time as possible; e.g., pumping with two pumps through a single pair of ballast tanks at one time.* Efficiency of exchange depends, in part, on inducing turbulence within a ballast tank. Increasing the flow rate to individual ballast tanks encourages this turbulence.
- *Ballast tanks should be kept as clean as possible, and chemicals used to prevent the buildup of sediments.* Sediment, in addition to providing habitat for certain organisms, creates a boundary layer within the ballast tank. This boundary layer minimizes the mixing of these habitats with the exchanged ballast water, therefore increasing organism viability within ballast tanks. Chemicals, such as flocculants, can suspend sediments in the ballast water to prevent their accumulation.
- *Machinery should be well maintained such that pumps operate efficiently, valves can be fully opened, and piping clean so as to minimize internal flow resistance.* A properly maintained system will ensure that flow rates to tanks are kept as high as possible to maintain the highest system turbulence rates and associated mixing.

Best System

- *Internal tank structure should be as smooth as possible to minimize local dead zones; e.g., using bulb structure rather than angles or flanged plates, maximizing the size and number of lightening and limber holes, etc.* An open and smooth structure can reduce localized dead zones and minimize trapped sediment.
- *Ballast water inlet and overflow locations should be separated as far as possible, vertically, transversely, and longitudinally.* Water is most effectively exchanged between the cross-flow of the inlet and overflow. Separating these locations as far as possible will increase the volume of water that is flushed by this cross-flow.
- *Ballast pump(s) should be of the highest practical capacity, given electrical plant and piping limitations.* Increasing the flow rate will encourage turbulence and improve the efficiency of mixing.
- *Ballast piping should be constructed of material that is toxic to marine growth or at least inert; e.g., copper nickel piping, regulatory approved plastic piping.*
- *Sea chests should be fitted with antifouling devices; e.g. zinc or impressed current copper anodes, ozone/chlorine systems.*

Analysis of Example Vessel

The following worksheet outlines the recommendations for improved flow-through exchange efficiency for the example vessel. These are based on the comparison of the above “Best Practices and Systems” criteria to the example vessel systems and operations.

Item	Vessel Status	Recommendation
Best Practices		
Follow applicable guidance and requirements for vessel safety and recommended practices to minimize uptake of organisms.	Typical. Ballast Management Plan is kept on board, and includes recommended and required guidance.	None.
The ballast pump(s) should be run at the highest possible capacity to as few ballast tanks at a single time as possible.	Typical. Two ballast pumps are used to exchange at most two tanks. The resulting velocity of 15 feet per second is high, promoting best possible ballast exchange.	None.
Ballast tanks should be kept as clean as possible.	Exceeds Typical. The inspected ballast tanks were relatively free of sediment.	None.
Machinery should be well maintained such that pumps operate efficiently, valves can be fully opened and clean piping minimizes internal flow resistance.	Exceeds Typical. Machinery and piping was maintained in excellent condition.	None.
Best System		
Internal tank structure should minimize local dead zones by being as smooth as possible.	Typical. Vessel meets industry standard with typical use of angles and flanged plate. However, industry standard does result in tank dead zones.	None. Rework of structure is impractical following vessel design and delivery.
Ballast water inlet and overflow locations should be as far separated as possible both transversely and longitudinally.	Exceeds Typical. A single overboard per tank, dedicated to exchange, is fitted. Fill location however is outboard to facilitate reach rod location.	Significant Cost. The ballast water fill/discharge line could be extended to the vessel centerline while leaving the valve arrangement in its current location.
Ballast pump(s) should be of the highest capacity practical given electrical plant and piping limitations.	Exceeds Typical. It is estimated that each of the two pumps provide 4500 gpm when conducting flow-through exchange. The resulting velocities in the mains are close to piping limits.	None.
Ballast piping which is toxic to marine growth or at least inert is preferred.	Exceeds Typical. Bondstrand 7000M piping is an inert plastic piping used in most locations. Steel piping, which is subject to fouling, use is limited.	None.
Sea chests should be fitted with antifouling devices.	Sea chest is fitted with aluminum anodes	None.

Figure 3. Best Practices and Systems Work Sheet

Recommendations for Further Exploration

There are multiple opportunities for improving ballast water exchange that require further exploration to determine the full extent of their effectiveness and practical applications. Recommendations are included below. It is recognized that with a pending phase-out of ballast water exchange, only relatively simple improvements could be considered practical.

Before reading the following section, a key distinction must be made between the definitions of volumetric efficiency and efficacy. Volumetric efficiency considers the physical amount of water that is displaced by the exchange event. A volumetric efficiency of 95% means that only 5% of the original water remains in the tank following ballast exchange. Efficacy considers the ability to remove or inactivate organisms by the exchange event. An efficacy of 70% means that 30% of the organisms in the tank are from the original location and are still viable (alive and reproducing).

Field Testing Suggested to Better Understand Ballast Exchange Operations

- **Biological sampling by plankton net and in tank sample in double bottom portion:** A previous section of this report proposes that plankton net sampling from the main deck of a vessel likely over-estimates the efficacy of ballast water exchange. It is recommended that a test protocol be developed and executed that performs both plankton net sampling and takes samples from the double bottom areas of the tank. While a single data set will not be statistically convincing, it would provide a better understanding of how to consider plankton net data collected to date.
- **Biological sampling by plankton net and end-of-pipe continuous sample at ballast system overboard:** Similar to the proposed above effort, this would provide a comparison of plankton net sampling to what is actually discharged from the tank.
- **Dye testing to determine the magnitude of the effect of varying the ballast water flow rate during ballast water exchange:** It would compare a flow rate of approximately 2200 gallons per minute during exchange to a flow rate of approximately 3000 gallons per minute. The results would determine if efforts to maximize flow rate are worth while.

Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) offers the opportunity to understand the relative difference between two activities without having to construct physical components. A computer runs through complex simulations yielding theoretical results. Promising results can then be evaluated for construction and physical testing.

A model would be built of one of the example vessel ballast tanks. Various typical exchange scenarios would be performed to develop baseline efficiency. The model could then be calibrated against actual field tests using dye. From this calibrated model, one can then determine the relative effects of the following:

- **Multiple variations in flow rate:** This would provide an indication of how much a change in flow will affect volumetric efficiency (how much water is actually removed, with no consideration of biology). This would help indicate if “maximizing” flow per tank is worth the effort.

- **Relocation of ballast fill/discharge pipe:** It is likely that locating the inlet for exchange water inboard will offer significant improvement in volumetric efficiency as well as efficacy. The analysis would consider several locations to gauge the optimal position.
- **Multiple overflow and/or fill locations:** It is possible that having two or more overflow locations would increase the volumetric efficiency. It is also possible that a manifold arrangement on the inlet, offering the opportunity to adding exchange water at multiple locations, would increase volumetric efficiency. The analysis would consider these combinations, including varying the flow pattern during the exchange event.
- **Use of mixers:** It is possible that a mixer, imparting energy in the tank's likely dead zones, would increase volumetric efficiency. These could be powered by a slip stream from the ballast fill line, or separately. The analysis would determine the effect of various amounts of energy and positions in the tank.
- **Changes in tank structure:** It is likely that changes in the tank structure would increase volumetric efficiency of ballast exchange. The model would be varied to consider both large structural changes to the shape, size, and pattern of location of the lightening holes (perhaps staggered). The model would be varied to provide transition pieces in way of both small structure and large structural members, to encourage smooth flow and limit dead zones.

Conclusions

Ballast water exchange systems and operations on board the example vessel surveyed exceeds regulatory requirements. The crew is professional and the systems well maintained. However, the conducted review indicates that even regulatory compliance and above average performance cannot overcome the physical and operational limitations of ballast water exchange. Operational efforts on board the vessel are excellent, with no practical recommended changes to improve ballast water exchange efficiency. Extending the fill/suction piping inboard is suggested; however, the significant funds required for this modification would likely be better spent on installing an effective ballast water treatment system.

While ballast water treatment systems are being phased in over the next two to ten years, ballast water exchange (although imperfect) remains an effective tool in combating the spread of harmful aquatic organisms and pathogens by means of ships' ballast water. The "Best Practices and Systems" offered in the report provide practical considerations during design, construction, and operation for any marine vessel in order to maximize the effectiveness of this tool.

Appendix A. Example Vessel Ballast System Particulars

This appendix provides additional details in regard to the example vessel ballast system.

The challenges associated with ballast water exchange are generally applicable to all marine vessels. A tank vessel was selected for survey and review as its ballast water exchange practices and equipment would well represent the challenges faced by all marine vessels. The tank vessel, newly delivered, is well maintained and fully operational. The crew was versed in the details of the regulatory requirements for ballast water management and record keeping.

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Ballast System Overview



Figure A-1. Cargo pump impeller.

The cargo pump impeller shown here is of similar construction as the ballast pumps. These are deep well pumps, which submerge the impeller in the fluid to be pumped. The long pipe seen serves to both support the assembly in its almost 40 foot length, as well as a pipe for transporting the pumped fluid.



Figure A-2. Deck Side

This photo shows the deck side of the deep well ballast pump and connected piping. A remote valve actuator can also be seen.



Figure A-3. Ballast tank vent.

A typical ballast tank vent is seen here. To limit wear and tear on this equipment, and to facilitate flow-through exchange without flooding the barge decks, dedicated overflow ballast lines have been installed.



Figure A-4. Overfill line.

This picture shows one of the overfill lines which are located in each ballast tank. The top of the pipe is open, allowing water to enter and be directed overboard. The overboard connection can not be seen, but is to the bottom left in this picture.

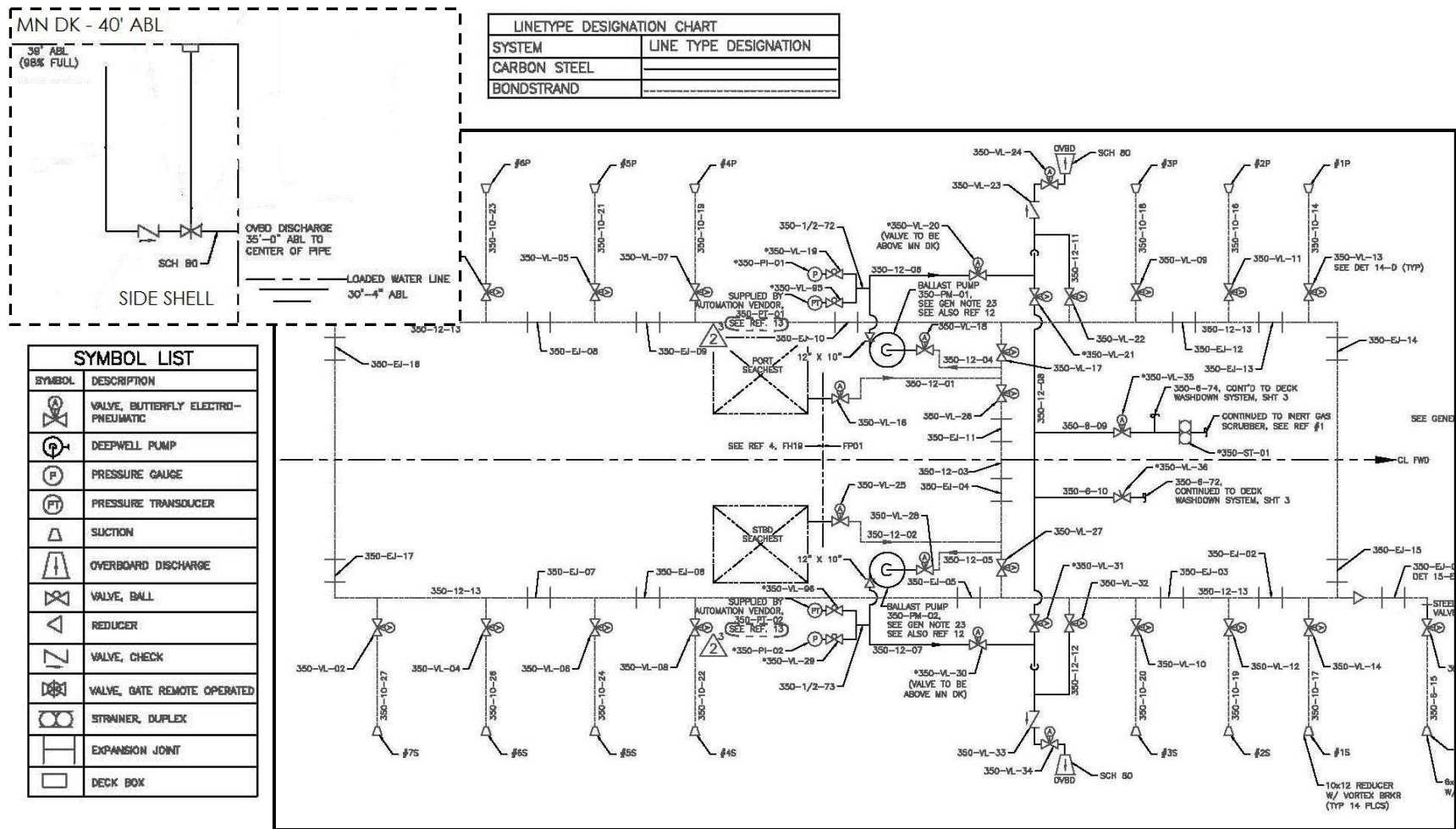


Figure A-5. Ballast piping system schematic.

The above figures show schematic arrangements of the ballast piping system. There are port and starboard ballast mains each fit with a single deepwell ballast pump. These mains are fitted with cross-overs which permit pumping of ballast from any pump to any tank. A special overboard (top left figure) is provided at each tank to facilitate flow-through exchange while keeping overflowing ballast water off the barge's decks.

Ballast Tank Structure

The figure below shows a section of one ballast tank which identifies the wing wall, outboard and inboard double bottom sections. Each section is partitioned by plates which have accesses cut just large enough for a person to squeeze through.

This section (11 meters in breadth and 12 meters in height) is only about 2 meters in length. A typical ballast tank on this vessel is comprised of eight of these sections, with a total length of 16 meters. In this way, a single ballast tank is really twenty-four (24) steel boxes welded together with lightening holes just big enough to allow fluid and personnel access between them. These tanks are longitudinally framed, meaning that smaller structures running from forward to aft are provided about every 750 millimeters.

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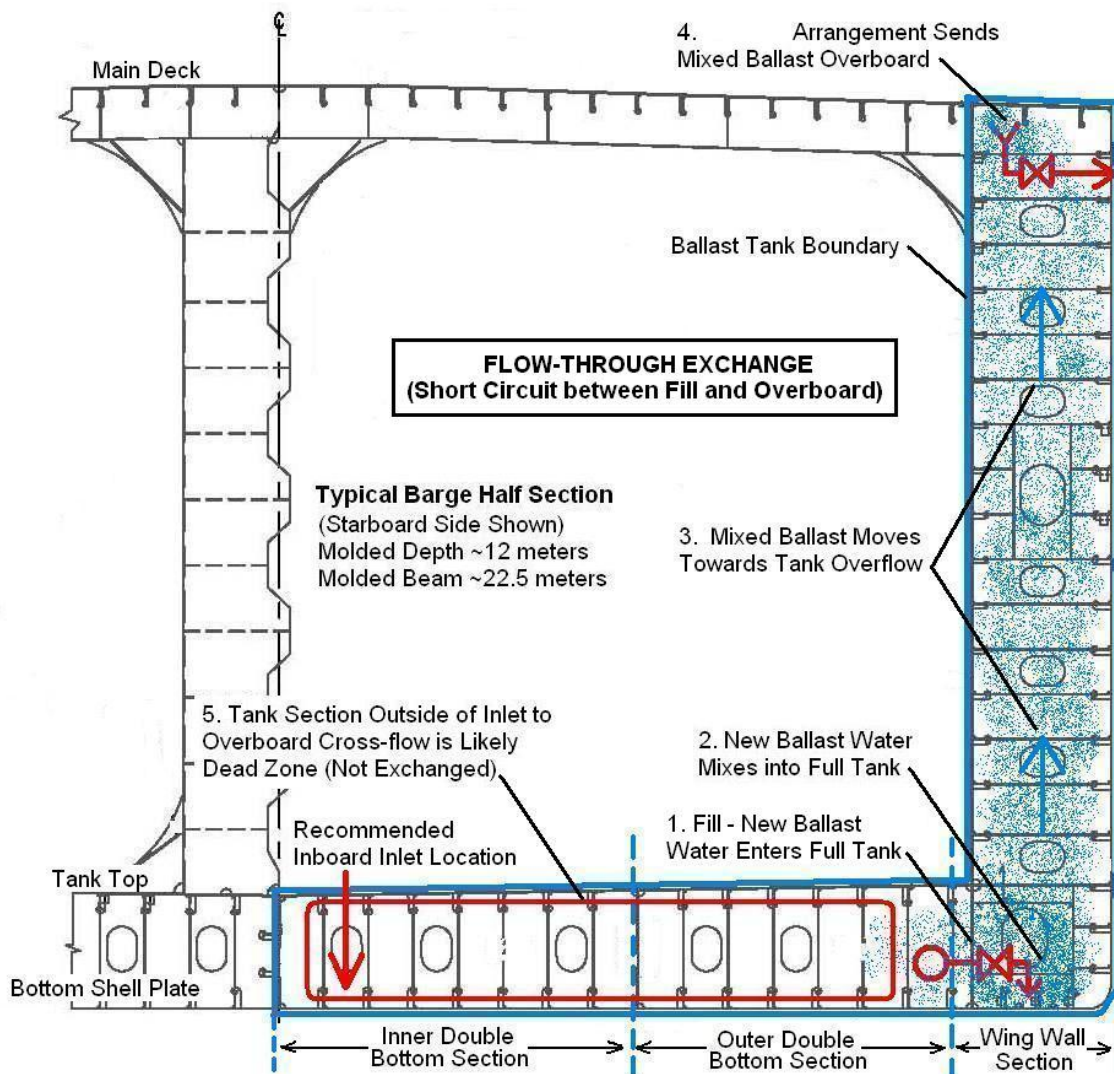


Figure A-6. Ballast tank structure.



Figure A-7. Lightening hole.

A Glosten engineer is shown here getting ready to squeeze through a lightening hole to pass from the inboard double bottom section to the outboard double bottom section. He is standing on the smaller longitudinal structure. It should be noted that the approximate 700 millimeters of standing water in the tank is typical and expected when a vessel must maintain an even trim for operational reasons (constant draft from bow to stern).



Figure A-8. Exchange water inlet location.

The port engineer examines the exchange water inlet location (ballast water fill/discharge valve and end bell). This is located in the bottom of the wing wall section. The lightening hole to his left is one of ten through which the next tank section can be accessed.



Figure A-9. Wing wall section.

This view looks down the wing wall section from the main deck. This is a very clean tank, with the sediment on the bulkheads and structures being considered minor.



Figure A-10. Double bottom sections.

This view looks forward from one double bottom section towards several others. The other sections can be seen through the lightening hole in the center of the picture.



Figure A-11. Net sample access.

This picture looks down into a hatch that might be used for gaining a plankton net sample of a tank's ballast water. This view only affords access to the wing wall portion of the tank.



Figure A-12. Inboard, double bottom portion.

This picture looks inboard in the double bottom portion of the ballast tank. This portion is not accessible to plankton nets dropped from the main deck.

Appendix B. Considerations of Accuracy of Plankton Net Sampling Methods for Ballast Water Exchange

The main body of the report implies that biological sampling of shipboard ballast tanks using plankton nets may over report the “effectiveness” of ballast water exchange. This is relevant because these results impact policy when comparing the efficacy of ballast water exchange to that of ballast water treatment. This appendix provides a few additional details on this topic.

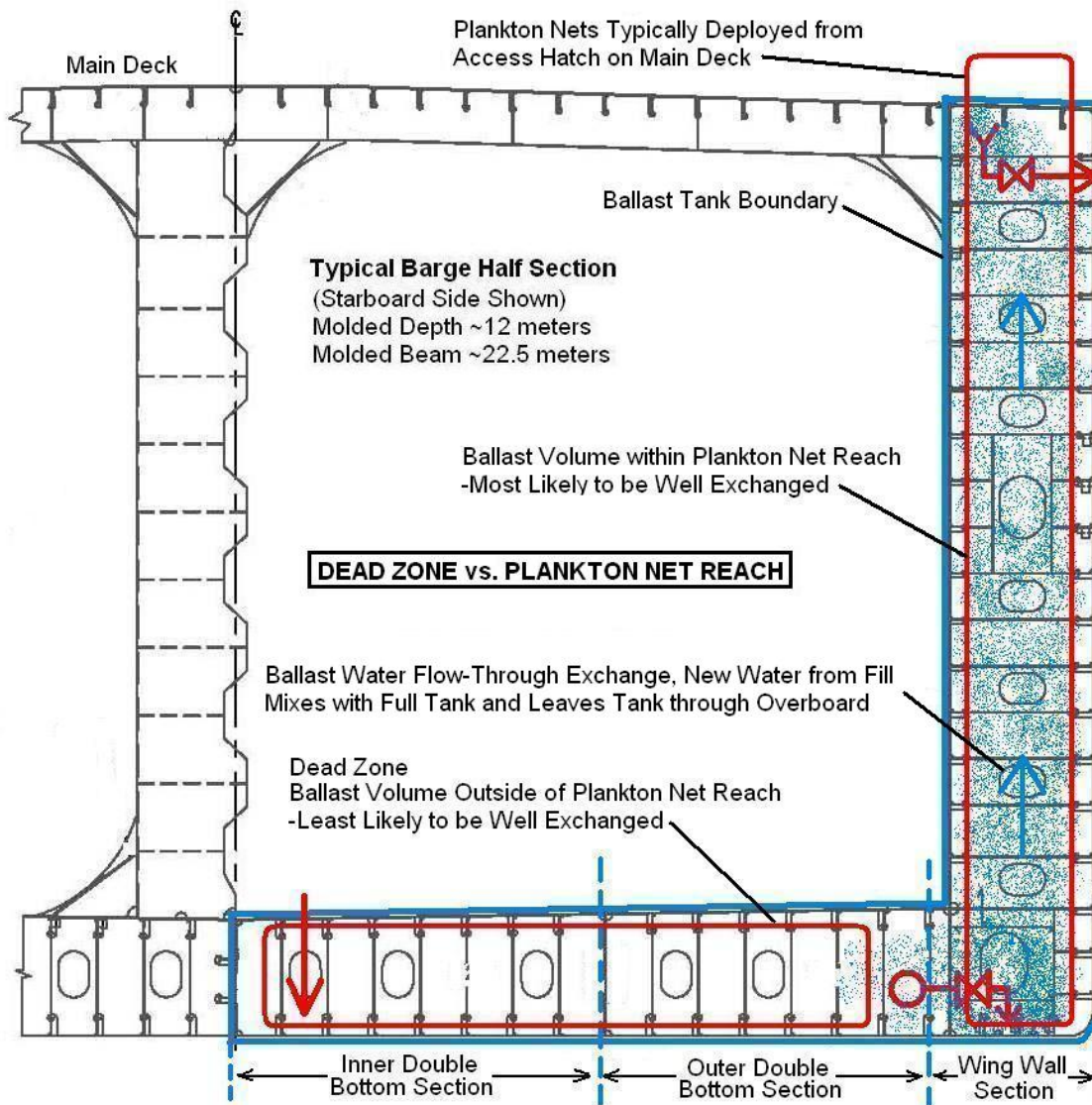


Figure B-1. Dead zone vs. plankton net reach in the example vessel ballast water tanks.

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The “effectiveness” of ballast water exchange is frequently determined by pulling plankton nets through the vertical water column from the main deck. The access for these nets is typically from the main deck and in the above example case this directly overlaps with the volume of the ballast tank which would most likely be well exchanged. The blue “paint” portrays the likely path through which ballast water will be flushed from the fill to the overflow. The dead zone identified in the above figure would be outside the range of the plankton net. In such a case, the “effectiveness” of the exchange would likely be over-reported in comparison to both exchange volumetric efficiency and organism efficacy.



Figure B-2. Hatch for plankton net sampling.

Looking down into a hatch which might be used for gaining a plankton net sample of a tank’s ballast water. This view only affords access to the wing wall portion of the tank.



Figure B-3. Double bottom portion of the ballast tank.

The above figure looks inboard in the double bottom portion of the ballast tank. This portion is not accessible to plankton nets dropped from the main deck. This is the same section of the piping which is most likely to be a dead zone and not be flushed during ballast water exchange.

The main report outlines several studies which might quantify the difference between the implied “effectiveness” of ballast exchange from plankton net sampling methods, and the actual biological efficacy of ballast water exchange.