Engineers at Liftech designed the structure of the first container crane and have designed and reviewed thousands of container cranes since.

Liftech is the structural review engineer of record for most of the cranes at the Port of Oakland.

Voyage Forces

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As you know, voyage loss and damage is common.

Offload Mistake

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Many things can go wrong

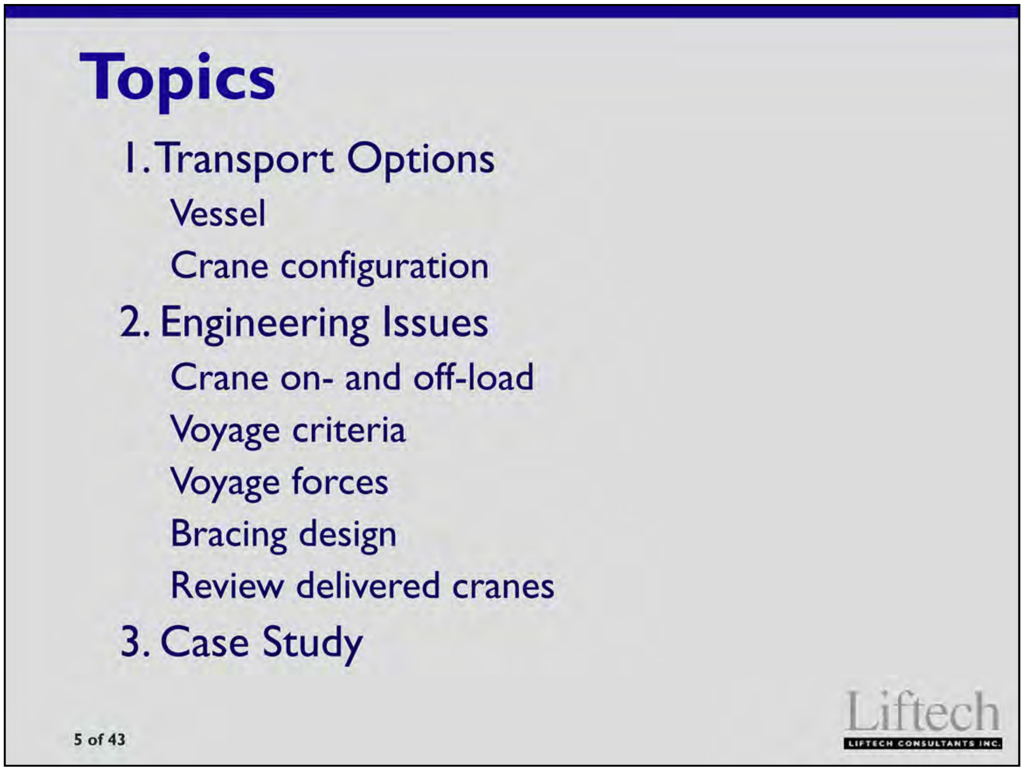
Just prior to delivery, the Captain decided to begin moving the crane without installing the “hold back” lines.

The ship pitched and the crane rolled off the ship.

Even short voyages have risk.

These two cranes were lost in China after the barge encountered sudden strong gusts of wind.

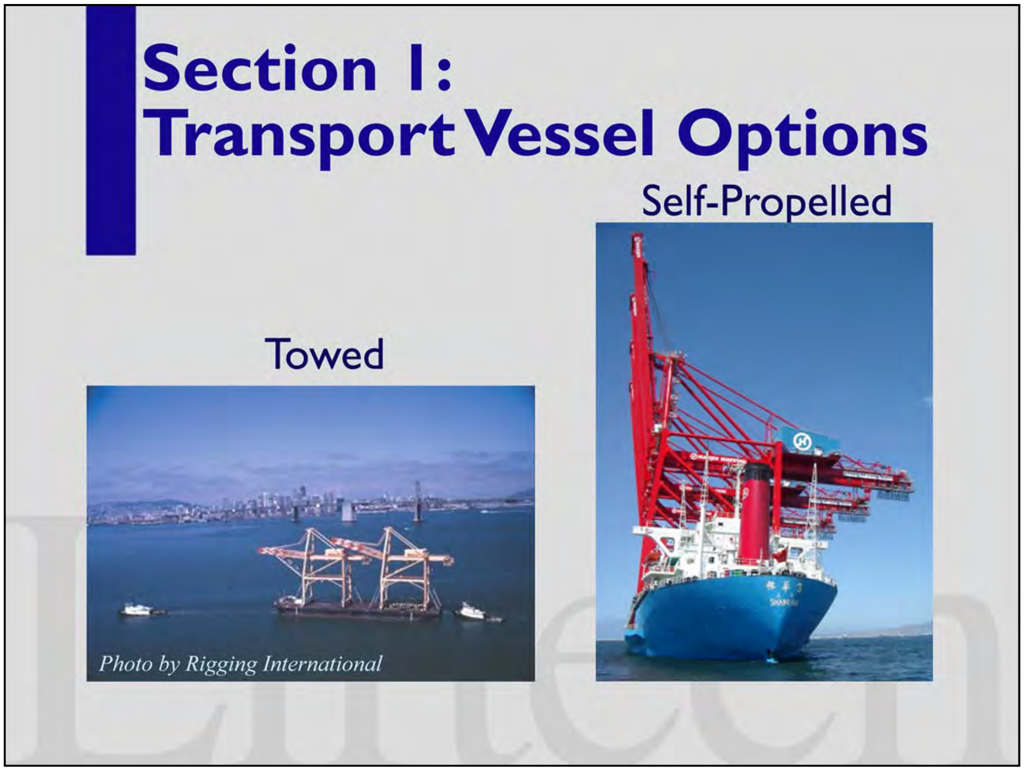
The “after” photo shows the collapsed cranes on the barge.



Today I will discuss the transport options and engineering involved in transporting container cranes.

Transport options include Type of vessel, orientation of crane on vessel, boom raised or lowered, assembly state.

Engineering issues include loading and offloading the crane, checking the wharf structure, the voyage forces and bracing, and reviewing the delivered cranes for damage and to ensure proper bracing removal.



The design of container crane transport begins, and is most affected by the mode of transport and crane transport configuration. Cranes are transported using self-propelled vessels or towed vessels. Common crane configurations include orienting the cranes transversely or longitudinally on the vessel and with the boom raised or lowered, or with the cranes partially assembled.

Cranes are now shipped assembled unless there are shipping interferences such as bridges.

Towed

- Longer voyage times
- Larger design accelerations
- Cost depends on vessel availability

Reference: "Container Crane Transport Options: Self-Propelled Ship versus Towed Barge" by Frank van Hoorn (www.argonautics.com)

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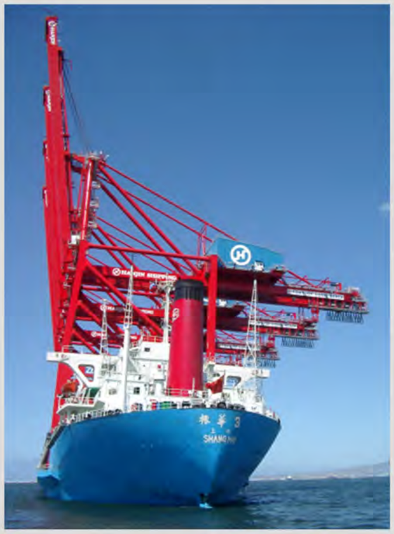
Towed vessels are used more frequently than ships for short voyages, voyages between US ports, and voyages with fewer cranes. Typically only one or two cranes. Some benefit if there are longer on and offloads times.

Many cranes are relocated within the US by barge due to the Jones act which requires that goods shipped between US ports be transported on US ships with a US crew.

For a more detailed discussion, refer to the reference provided at the bottom of the slide.

Self-Propelled



- Faster
- Better at avoiding rough seas
- Can control wave heading
- Lower voyage accelerations
- Less bracing required
- At-sea inspections and repairs

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Self-propelled transport has many advantages over towed. Most new cranes are transported by self-propelled ships. Many cranes can be transported quickly over large distances.

The vessel crew can inspect the cranes and bracing daily and make repairs if necessary. Cranes towed by barges are inspected using binoculars. Repairs cannot be made at sea.

Crane Configuration

Photo by Argonautics Marine Engineers

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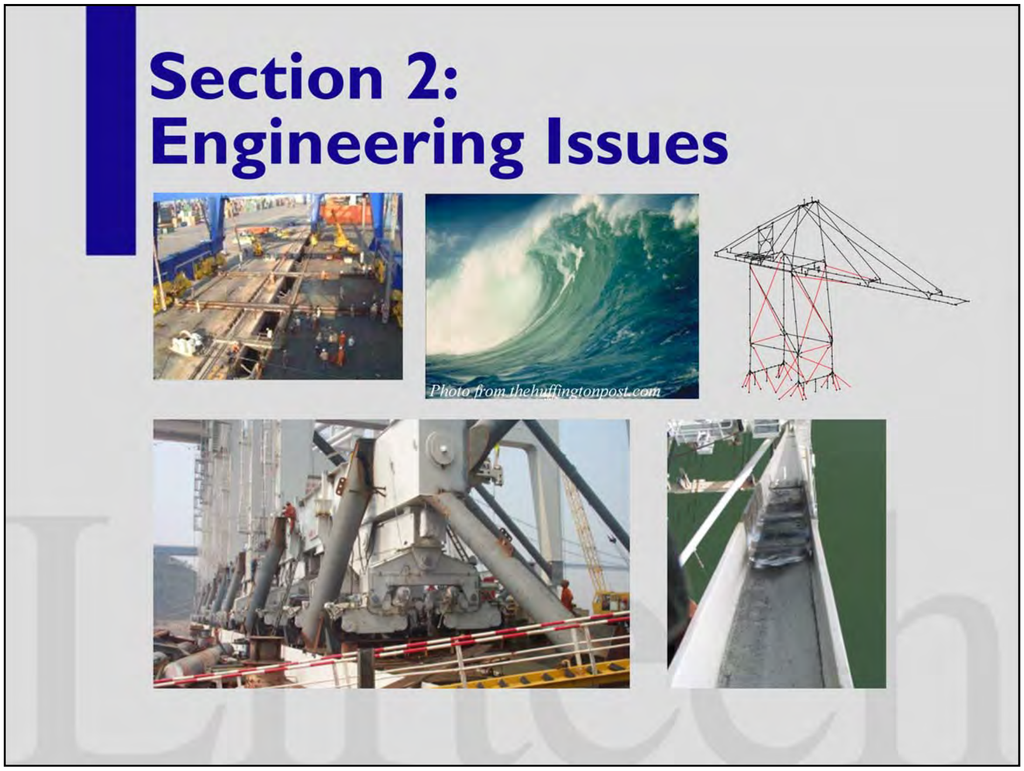
Cranes are now typically delivered assembled. Some are delivered partially assembled, typically due to clearance requirements such as bridges.

Shipping with the crane structure closer to the vessel deck will result in lower design forces.



Engineering issues in crane transport include:

1. Designing the on and offload procedures which includes checking the wharf, vessel, and strength of the move hardware
2. Determining the voyage design criteria
3. Calculating the voyage forces
4. Checking the strength of the crane and bracing structures
5. Checking the strength of the vessel structure
6. Review the installed seafastening
7. Survey the delivered crane to check for damage and to confirm the bracing is removed acceptably.
8. Developing repair procedures if necessary

Voyage forces are typically provided by a Marine Engineer, alsoreferred to as a Naval Architect who may also perform the other engineering tasks.

This photo is of a skid system used to load and offload cranes. The wharf is on the left and the ship is on the right. The crane is lifted using jacks that are mounted on skids, one per corner.

This particular skid system uses only two skid beams resulting in very large concentrated loads. With such a system, the beams typically must be aligned with the wharf piling and may need to be strong enough to span between piles.

Proper ballasting of the ship is important regardless of what system is used to move the crane. If the ship has ballasting problems the crane may get stuck between the wharf and ship.

Typically twice the required ballasting capacity is provided for redundancy.

This photo is of a bogie system. Two bogies are used per corner. The bogies each have hydraulic jacks to lift the crane. The bogies roll on temporary rails. The ship's winch is used with the reeving shown to move the crane laterally.

With the large bogie loads, bridge beams are commonly used to span from the ship to the wharf's waterside crane girder.

The wharf waterside of the waterside girder is typically not strong enough to support the large truck loads.

This is a photo of a crane being moved using a rubber tired dolly system. The ship is on the left and the wharf on the right. The crane load is distributed between many wheels over a large distance.

With more lightly loaded dollies, the gap between the wharf and ship can be spanned with thick or lightly stiffened plates.

The loading on the wharf typically does not require special structures or alignment.

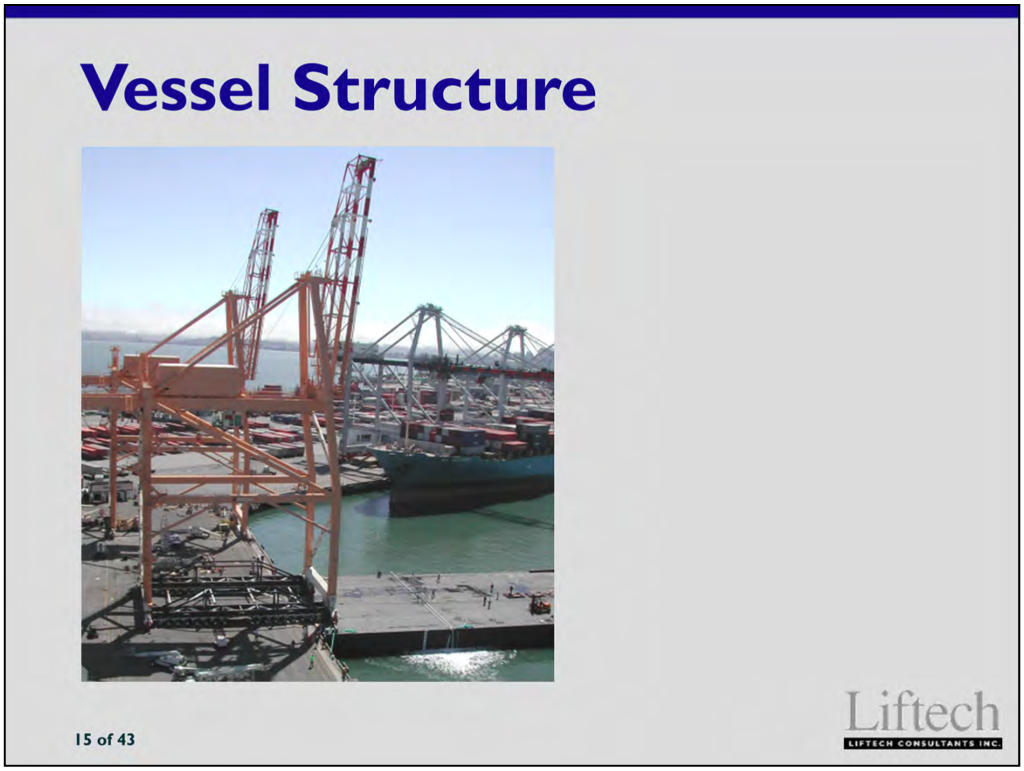
This photo shows one of the most recently delivered Portsmouth Marine Terminal cranes positioned over the crane rails and raised on jacks. The temporary offload bogies have been removed from the temporary rails. The entire crane is supported on four jacking pedestals.

This loading is typically distributed through eight wheels over a distance of 35’ to 40’.

The strength of the crane girder must be checked for this large point loading.

For most new wharves, the crane loading does not need special distribution onto the wharf structure.

For older wharves, special offload procedures or load distribution structures may be required.

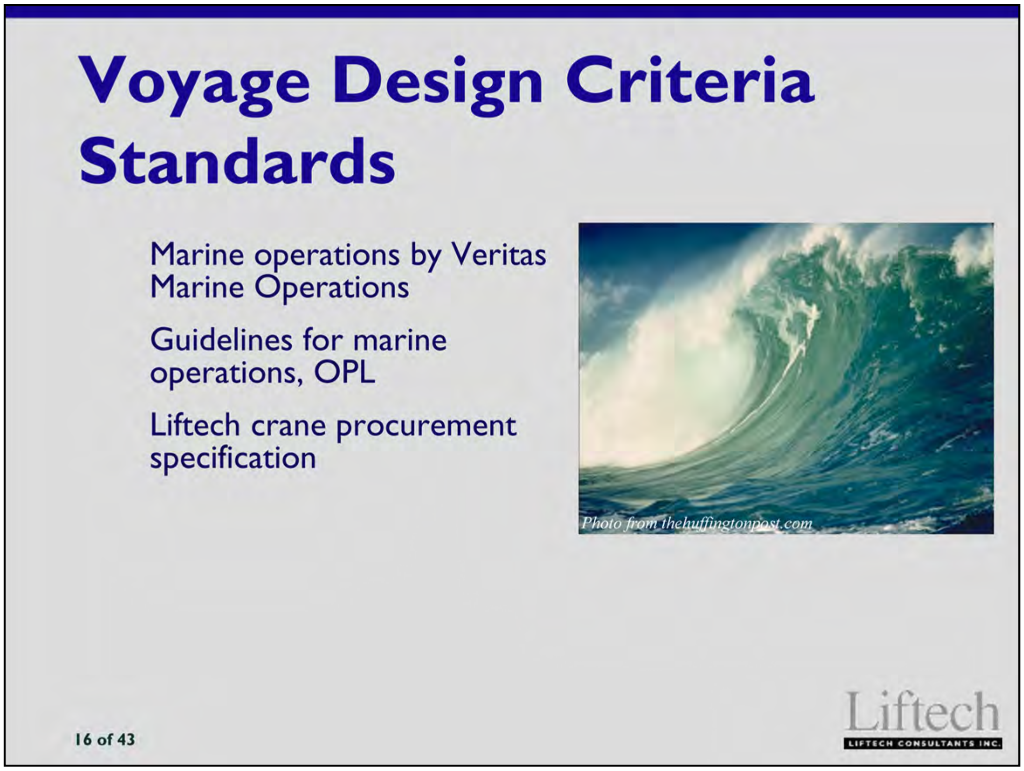


This photo shows a crane at the Port of Oakland being loaded onto a barge using a dolly system.

The loading on the vessel structure must be considered.

Although not required for a dolly system, some systems requires strict alignment with the stiffeners under the barge deck plate.

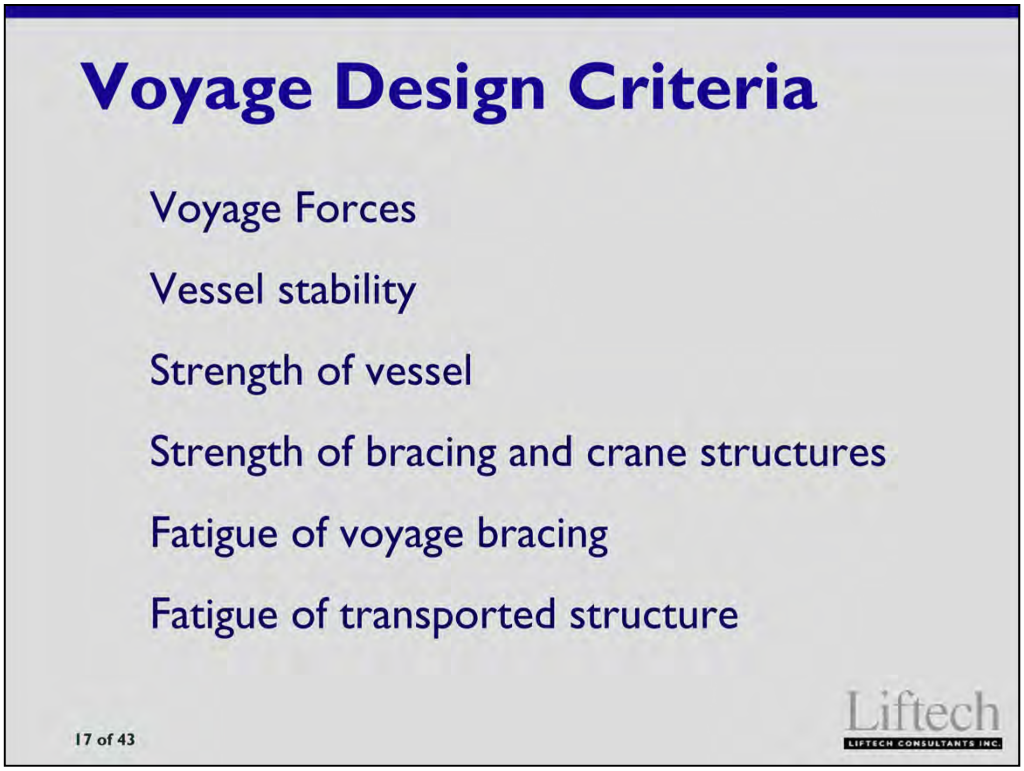
Although rare, sometimes strengthening of the barge deck structure is required.



There are many standards for voyage design criteria.

Most standards have similar requirements.

Standards are evolving over time as available wind and wave data increases.

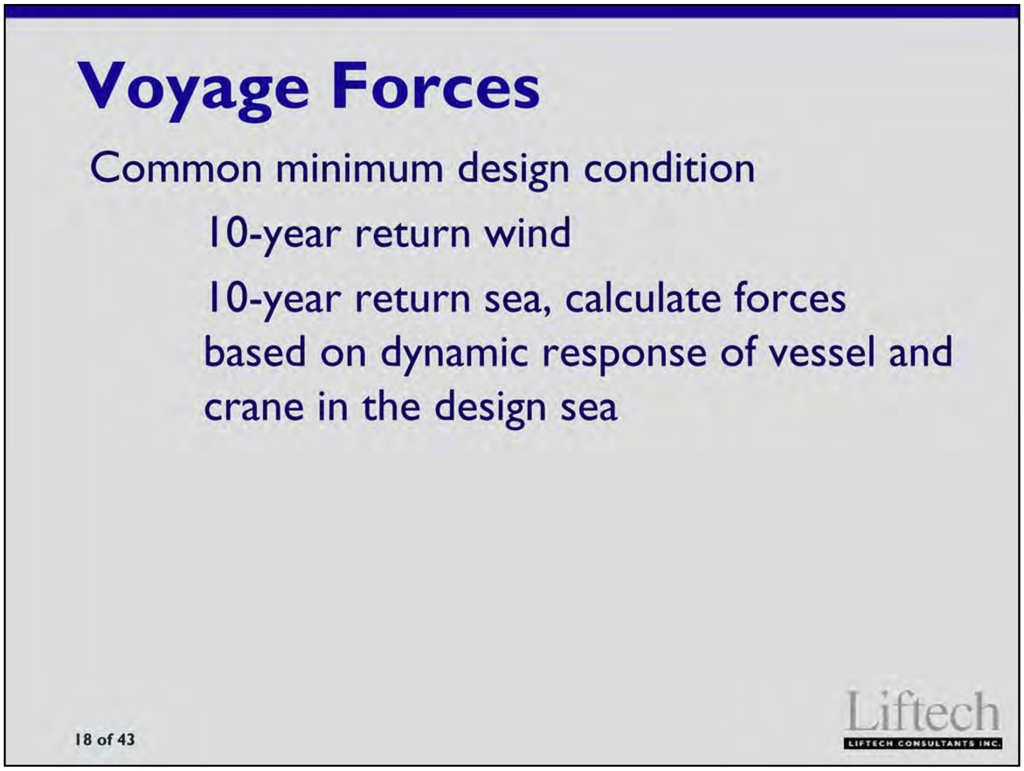


For the voyage design criteria, stability and strength criterion are common.

Fatigue strength for the voyage bracing and transported structure are less common.

Stability concerns ship overturning.

Strength concerns overstressing the bracing and container crane structures.



Voyage forces are controlled by wave and wind loadings.

The design sea state and wind loads are those that based on current data are expected to occur, on average, once every 10 years.

Design forces are based on the response of the vessel and cargo in the design sea state.

Note:

Probability of 10-yr event happening in 10 years = 65%

Probability of 10-yr event happening in 1 year = 10%

Probability of 10-yr event happening in 14 days = 0.4%

Strength Design Criteria

Load combinations vary, wind and wave loading usually applied concurrently

Allowable design stress: 1.33 x AISC basic allowable

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Load combinations vary. Typically apply accelerations from vessel movements and wind forces concurrently.

For extreme and unlikely events, most structural design codes permit designing to 133% of the design stresses allowed for more extreme, more frequent events.

Fatigue Criteria

Design cycles: 200,000 of design loading*

Fatigue:

Voyage + operating < 1.25 (operating allowable)

NDT inspection of crane at delivery if rough seas encountered or if damage suspected

**Note: Varies—200,000 is typical for a trans-Pacific voyage*

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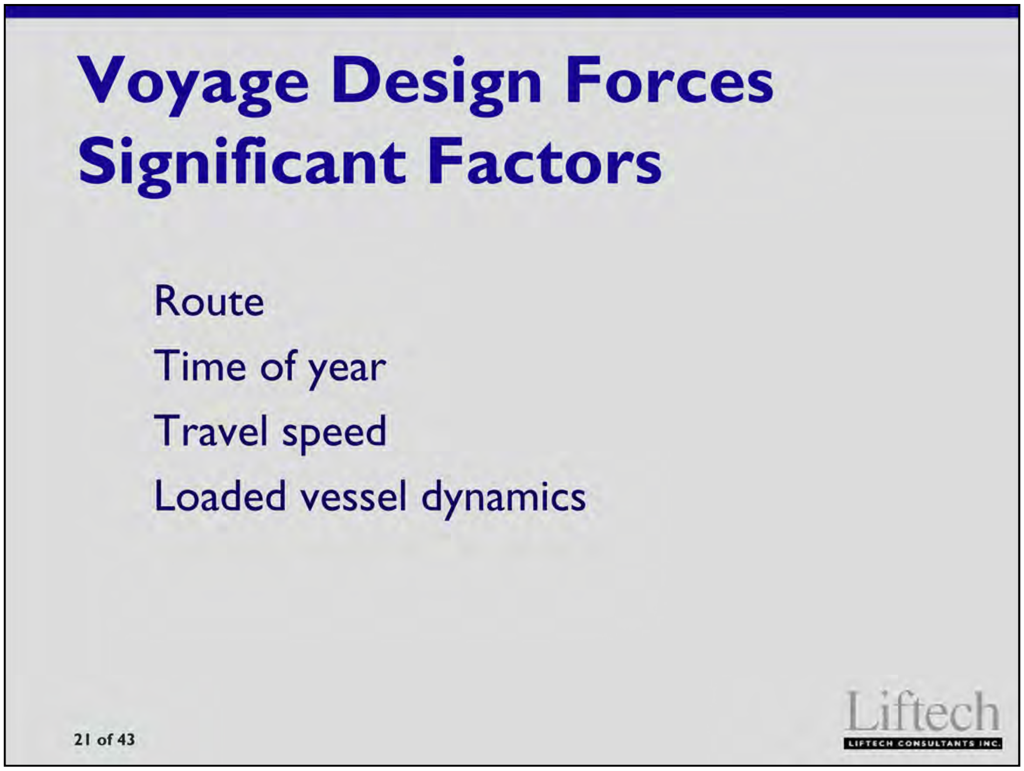
As the ship rolls and pitches and the wind loading direction changes, the crane structure and bracing are fatigued.

Fatigue loading is difficult to define, is usually not a problem during the voyage, and is not often designed for.

The purpose of the criteria is to reduce the risk of low cycle fatigue during the voyage and to avoid premature cracking in the crane structure.

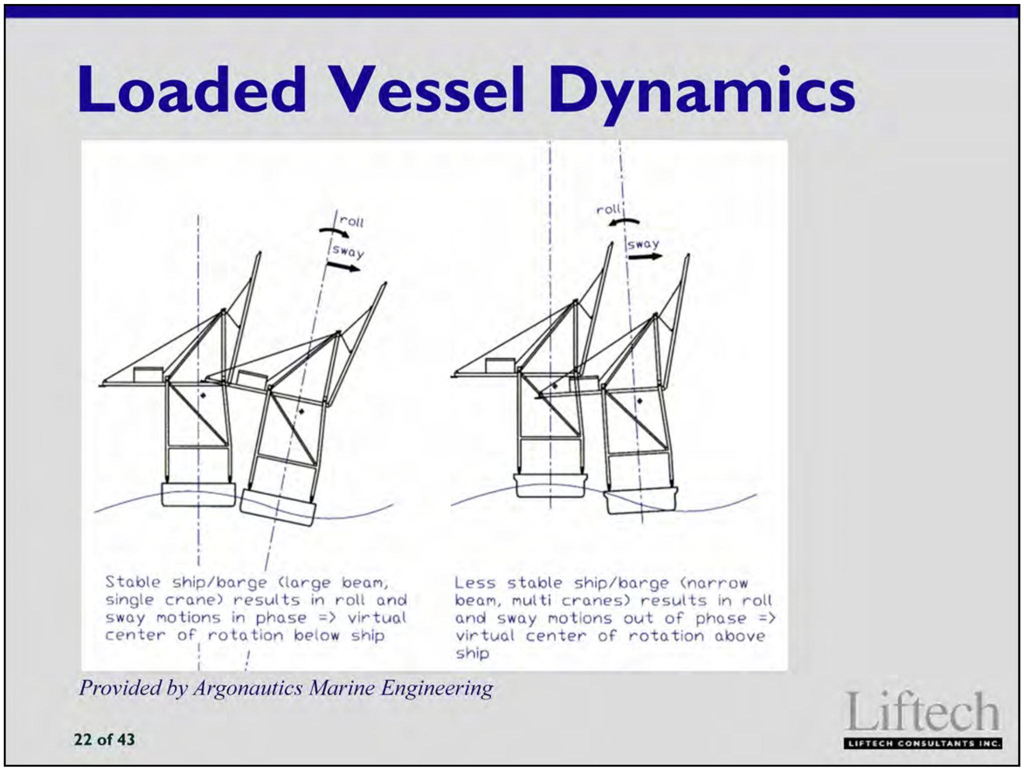
An inspection of the highly stressed members and welds is performed soon after delivery if rough seas were encountered.



The sea states will vary depending on location and time of year.

Faster travel reduces the exposure time and permits for some avoidance of severe sea states.

Vessel dynamics is controlled by vessel shape, size, and loading condition.



A more hydrodynamic shape will be less affected by waves.

A longer vessel will experience less pitch.

As shown in the diagram, a more stable vessel and cargo combination will experience more severe rolling as the vessel tends to follow the wave surface. When the wave period equals the roll period, resonance can occur.

Using the voyage parameters, the marine engineer will:

1. Calculate period of motion of loaded ship for design sea state

2. Calculate design accelerations

This is a photo of four Port of Oakland cranes loaded on a ZPMC ship in Shanghai with the bracing installed. The primary bracing used for this transport are the darker pipe members. The red crane to the left is nearly completed without bracing. The sill beams and trucks for another crane is to the left of the red crane. A 1600 t lift capacity barge mounted crane that is used to assemble pieces of container cranes is shown in the background.

As shown in this photo, the voyage forces are much larger than the operating forces requiring significant bracing.

Current commonly used bracing consists primarily of pretensioned pretressing strands within the O-frame and portal frames.

This is a photo of two Matson cranes being transported from the Port of Oakland to Hawaii by barge.

For smaller barge structures, booms are commonly shipped lowered to minimize voyage forces.

Notice the boom of the aft crane rests on the machinery house of the forward crane, while boom of forward structure supported by pipe truss strut.

Arrangement is often dictated by voyage interferences such as bridge clearances.

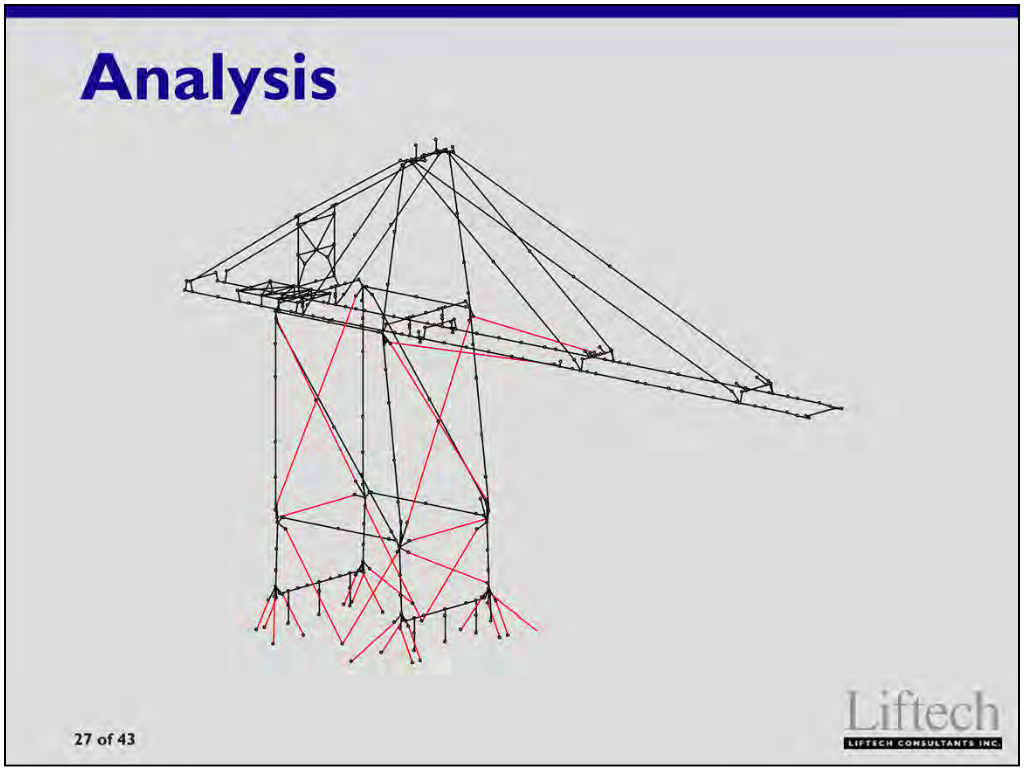
This is a photo of the Berth 32 cranes delivered last year to the Port of Oakland just after they passed under the Golden Gate bridge. The ship was also ballasted to obtain 3’ of freeboard.

The upper works of the crane structures were lowered just outside of the Golden Gate bridge by removing a connection pin in the upper diagonal and rotating the apex struts and upper diagonals forward using the reeving system shown.

A pipe truss strut is provided to support the boom. A temporary king post system is provided to support the cantilevered length of boom.

This is a photo of the same B32 cranes clearing the Bay Bridge.

Notice the prestressing strand tie bracing in O-frame. This type of bracing is now used instead of pipe struts because it is easier to install and remove.



Using the estimated maximum design voyage forces, a structural analysis is performed to calculate:

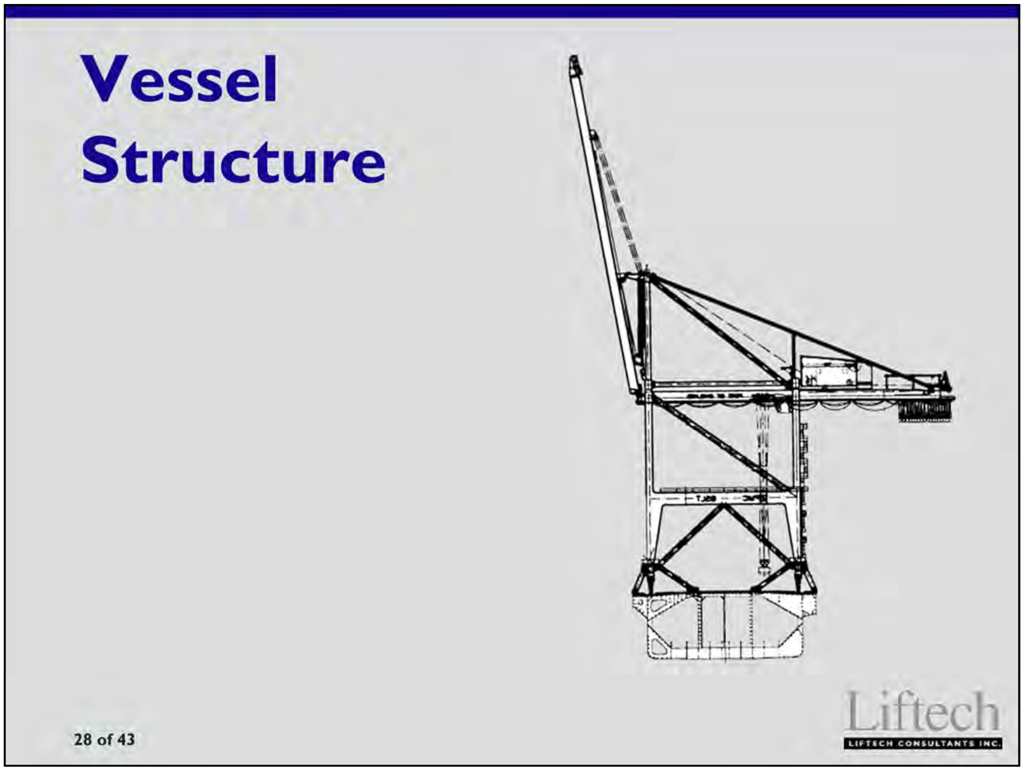
Brace forces and stresses

Reactions on the vessel structure

Stresses in crane structure for both strength and fatigue.

Deck of the vessel assumed to have equal stiffness. Need to verify this is true and that certain braces not resisting more load than others.

Although crane bracing and bracing connecting crane to ship are sometimes designed separately using simplified models, it is best to model all bracing with crane structure.



The vessel structure will dictate the bracing layout.

Braces are arranged to align with the vessel structure below deck.

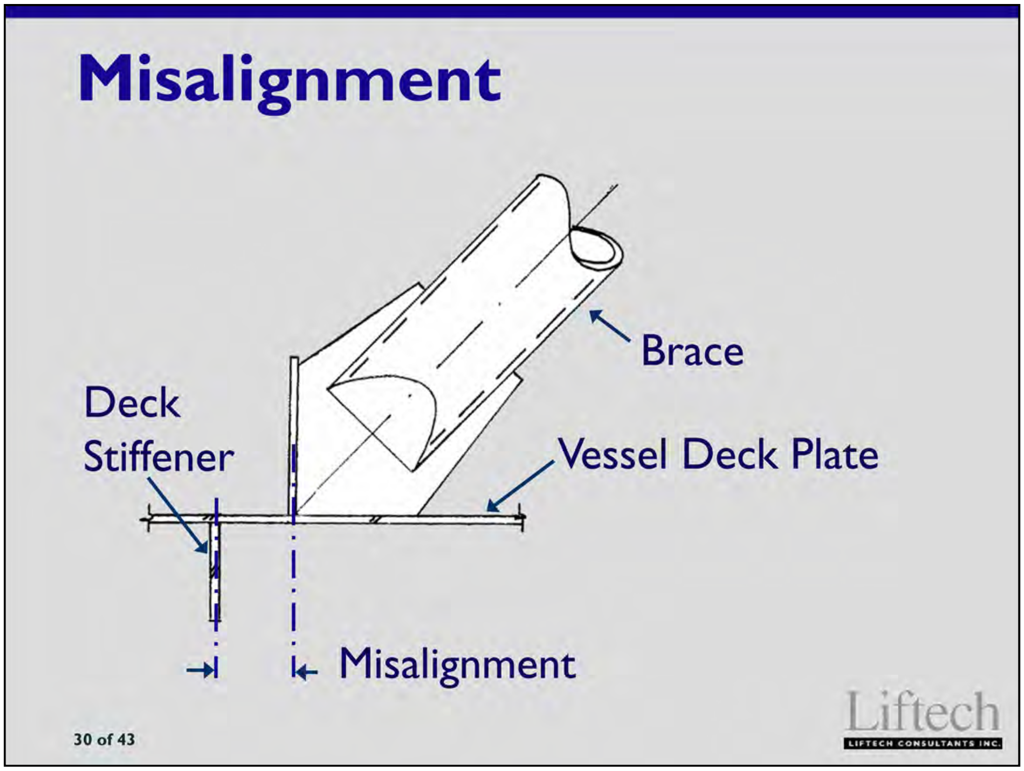
Although not common, sometimes it is necessary to locally strengthen the deck structure.

It is common to perform field reviews.

Mistakes are very common.

There are not more problems because most voyages are mild.

The pipe to deck connections will be discussed in the next slides.



Most common mistake is improper alignment of the braces with the vessel structure.

Misalignment will result in significant bending stresses in both the bracing and vessel structure.

Typical alignment repair is to extend connection plates to transfer the bracing forces into the deck stiffeners below.

Aligned

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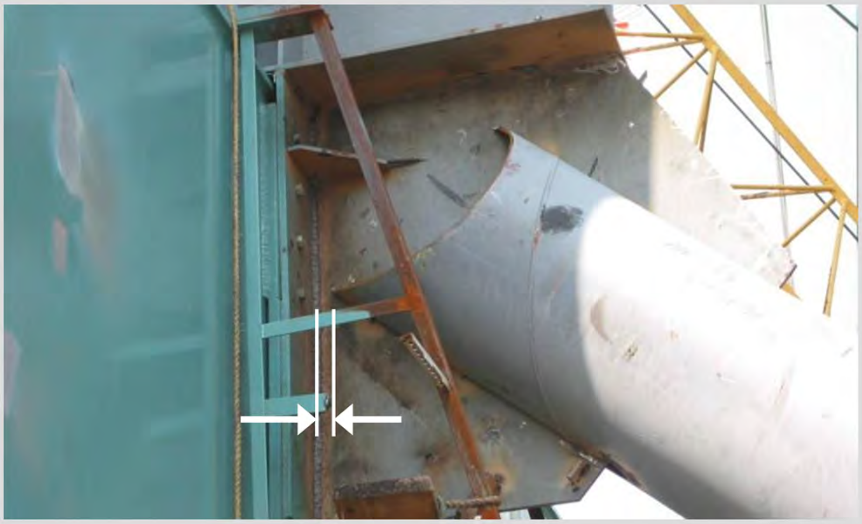
Example of well aligned bracing.

Clearances



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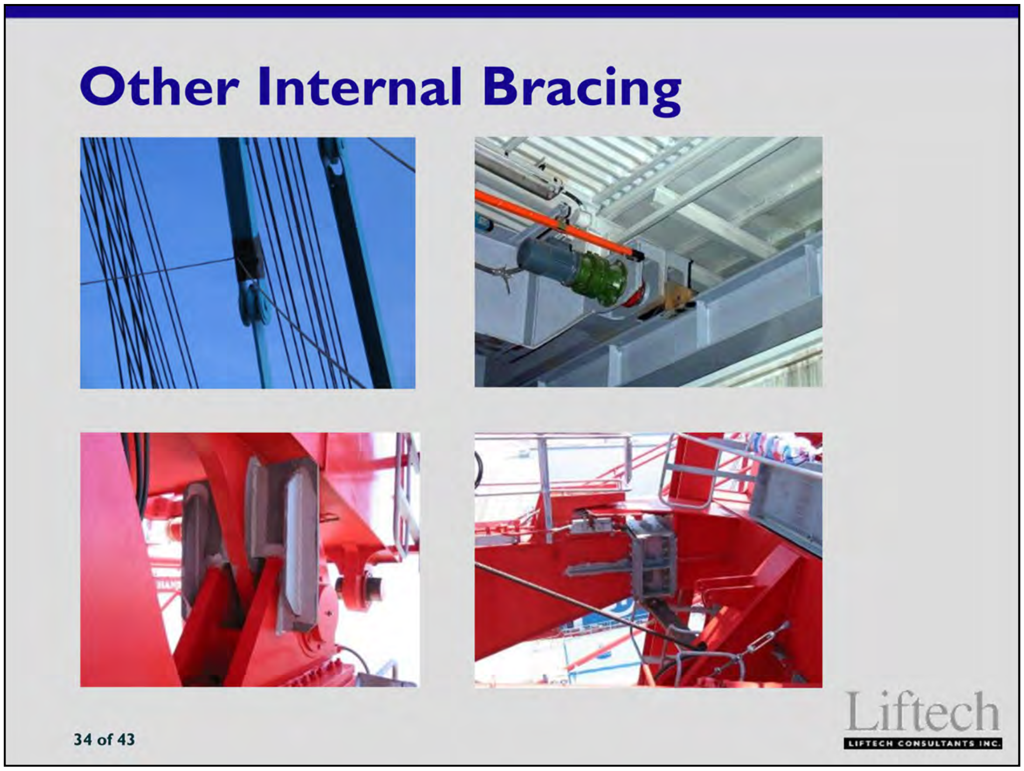
Clearances are important to provide connection plate out-of-plane flexibility. Inadequate clearances have resulted in fatigue failures.



Some other bracing includes:

lashing the forestays

shear plates to limit the movement of overhead cranes and trolleys

strengthening at the boom hinge

bracing or shimming the boom latch connection

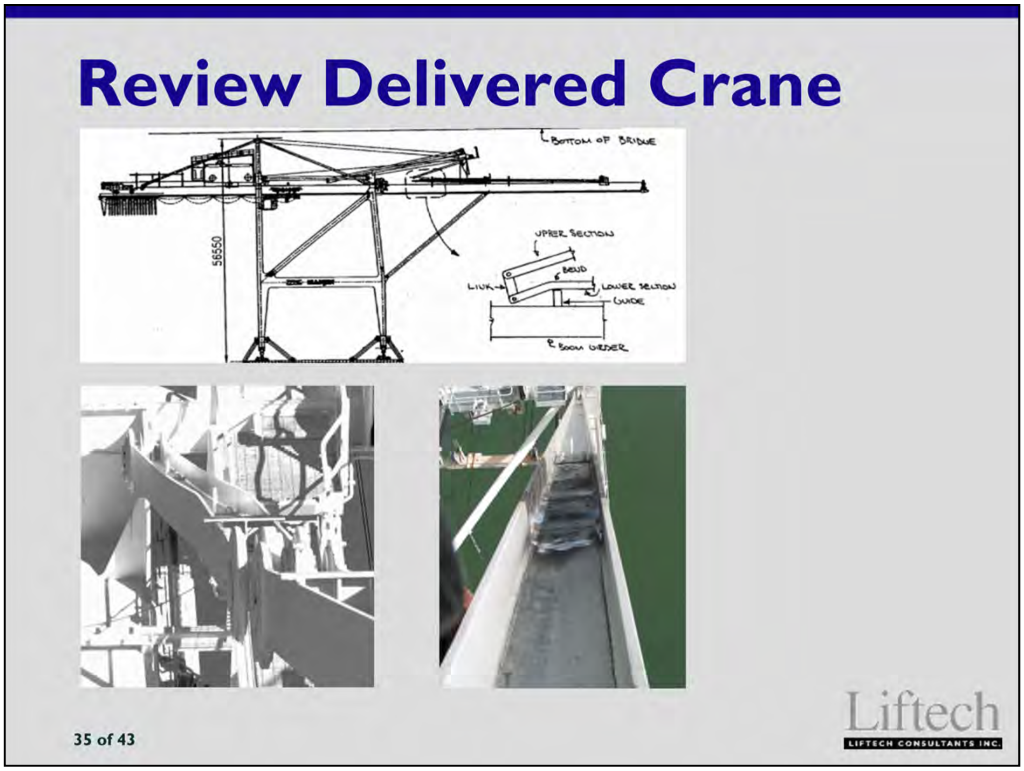
lashing the festoon cables

securing the hoist and spreader bar

securing the elevator

The machinery and electrical equipment mounts are typically adequate for the voyage accelerations but this should be verified.

Many other non-structural preparations.



Most voyages are completed without mishaps. However, occasionally damage occurs which requires repairs.

Upon arrival:

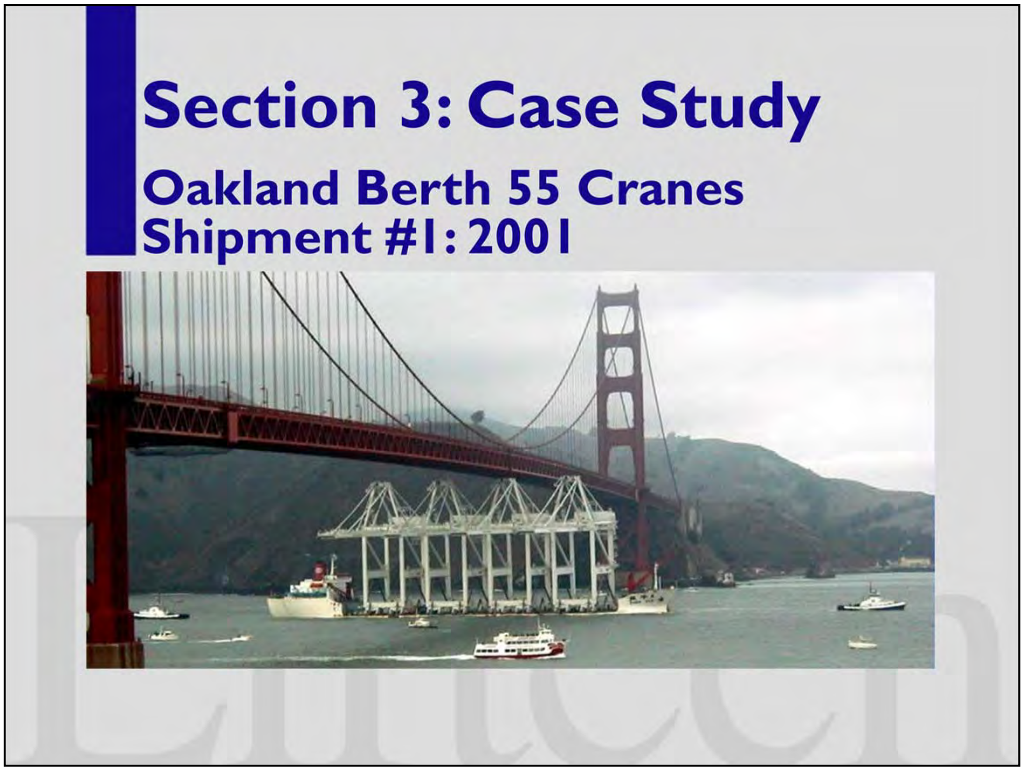
1. Survey the crane structure for damage

2. Review removal of bracing

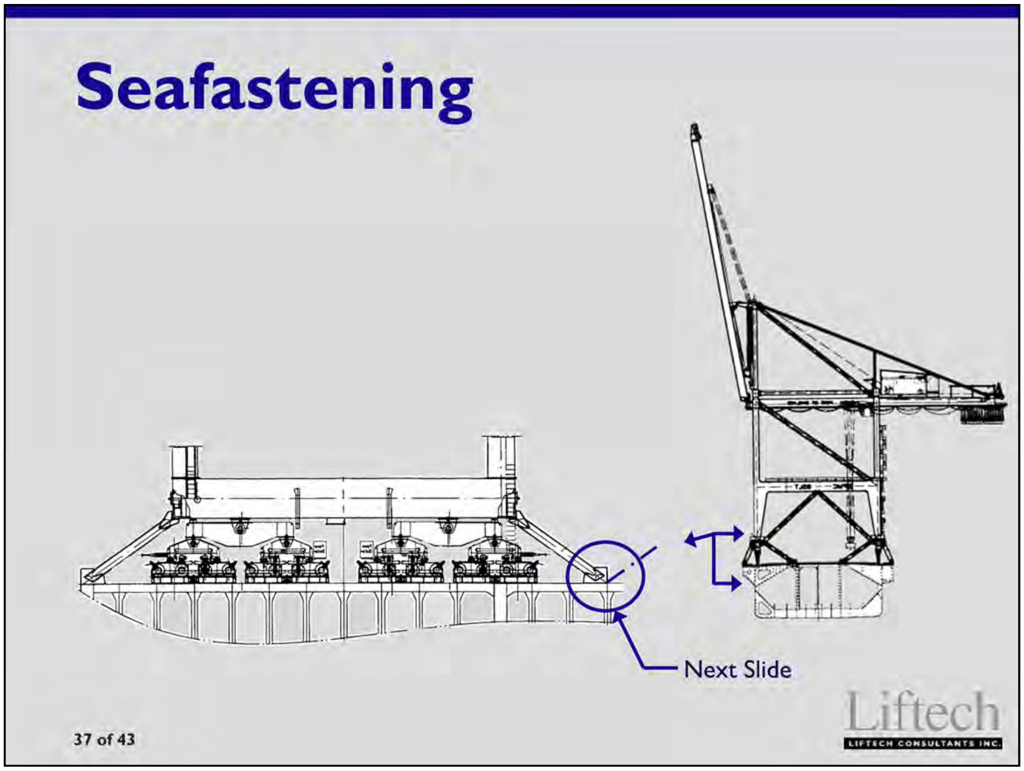
3. If necessary, provide repair procedures for damaged structure

For the Port of Oakland B32 cranes, the forestay was bent on one of the two cranes when the apex structure was lowered too far.

The bend forestays were heat straightened in two days to within AWS tolerances.



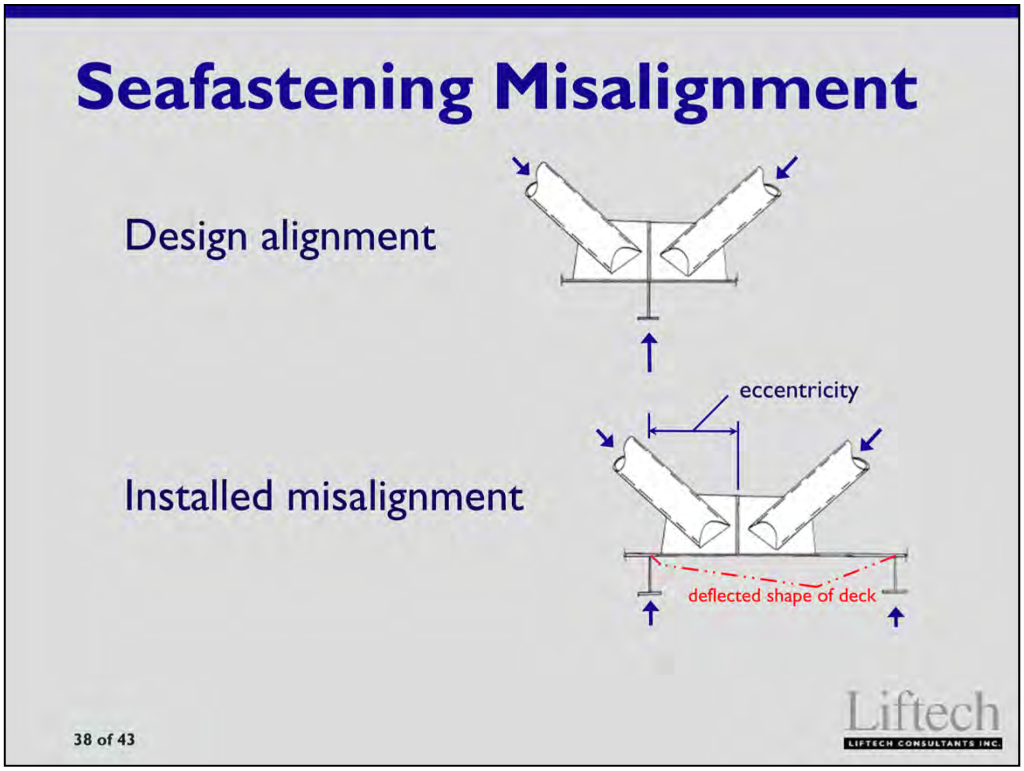
The first shipment of B55 cranes experienced severe weather off the coast of California. The wind speeds and sea state conditions likely exceeded the design criteria. Ship personnel report that the ship roll resulted in the boom tips entering the water, however no salt water damage was observed to the boom tip equipment. Although the reported roll was exaggerated, it was significant.



The longitudinal bracing was designed to align with the transverse bulkheads.

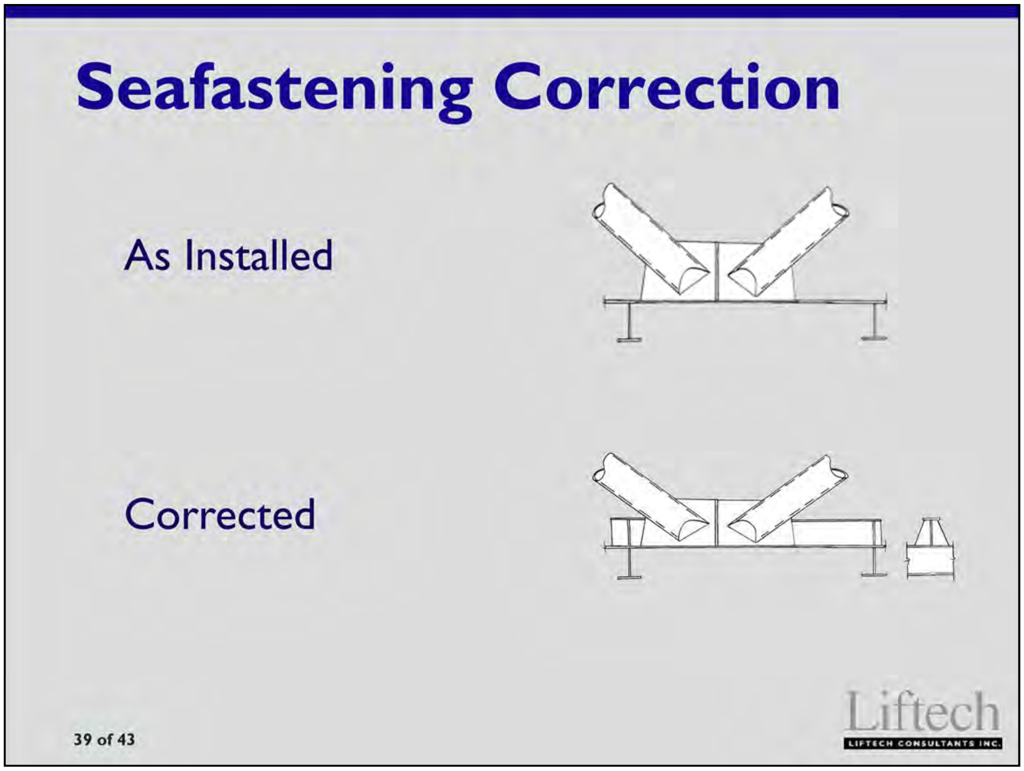
Only one crane and brace shown in this sketch.

The brace from the adjacent crane will share this connection and will be shown in the next slide.



The design alignment results in the brace forces being resisted concentrically by the ship bulkhead as shown. No bending occurs.

The cranes were located improperly on the ship resulting in a 6' misalignment. The design loading would have resulted in failure.



To correct the misalignment, the installed gusset plates were modified into a beam to span between the vessel deck beams.

Seafastening Correction:
Deck Beam

Photo of the correction.

Notice the perpendicular gusset plates at either end of the beam used to transfer the forces into the structure below.

Questions?

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In summary, there are many things to consider when transporting container cranes over long distances however they can be reliably shipped over long distances reliably with adequate engineering.

Thanks for your attention.

Feel free to contact me if you have questions.

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Acknowledgement

Thanks to Frank Van Hoorn of Argonautics Marine Engineering who provided comments and photos for this presentation. Argonautics Marine Engineering is a marine consulting company specialized in marine heavy-lift transportation. The company was founded in 1992 by Frank van Hoorn, a naval architect involved in marine salvage, ship design, and heavy-lift transportation since 1982. Refer to www.argonautics.com.

Quality Assurance Review:

Author: Erik Soderberg

Editor: Derrick Lind

Principal: Mike Jordan

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