Crane Accidents
How to Prevent Them

TOC Americas 2011, Panama

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Liftech Consultants Inc. is a consulting engineering firm, founded in 1964, with special expertise in the design and procurement of dockside container handling cranes and other complex structures. Our experience includes structural design for wharves and wharf structures, heavy lift structures, buildings, container yard structures, and container handling equipment. Our national and international clients include owners, engineers, operators, manufacturers, and riggers.

Erik Soderberg is a Liftech vice president with over 15 years of experience in the design, review, and modification of a variety of structures, including container cranes, wharves, buildings, heavy lift equipment, and various rigging structures. He has consulted on hundreds of cranes, participated in the design of several wharf structures, and has designed many crane transfer systems ranging from curved rails to shuttle systems. He has engineered repairs for dozens of container crane structures and for several bulk loaders. His field skills include an understanding of heat straightening techniques and the ability to develop repair procedures on site.

Statistics – Port Insurance Claims

	Claim Numbers	Claim Costs	Comments/Recommendations (paraphrased)
Operational	79%	45%	20% costs: STS crane driver. Training and simulators, cameras, anti-collision devices, load sensors, speed limiting, automation
Maintenance	16%	26%	61% costs: crane structure. Maintain regularly—do not wait for failures
Weather	4%	29%	36% costs: due to cranes. Tie-downs, braking system design and maintenance, ship berthing procedures
Other	1%	0%	

Source: Lawrence Jones, TT Club

Crane Claim Costs ≈ 35% of Total

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Operational: human operational factors or errors

Maintenance: equipment failures or other maintenance issues

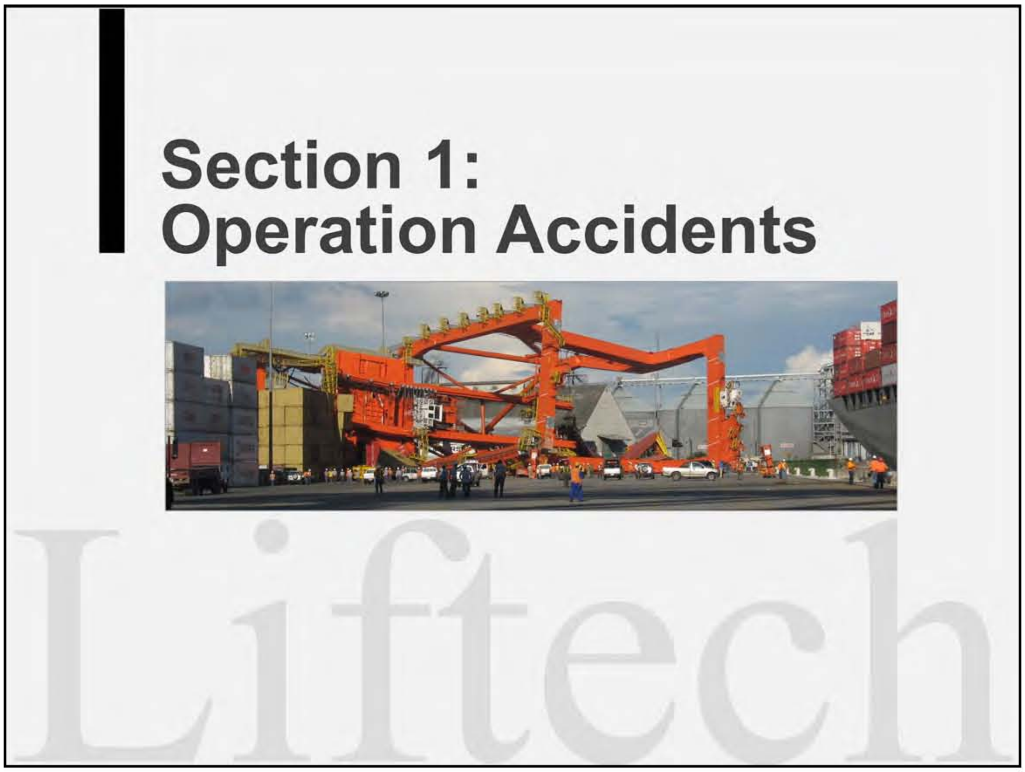
Weather: due to severe weather

Cite TT Club

Liftech engineers have been providing structural engineering services to the container crane industry for over 45 years and have experience with many crane failures.

Catastrophic failures occur rarely, but they do occur, reminding the industry of the ever present risks.

This presentation will review a variety of accidents and ways of preventing them.



We will start with operational failures.

Operation Accidents

Vessel collisions

Boom hoist accidents

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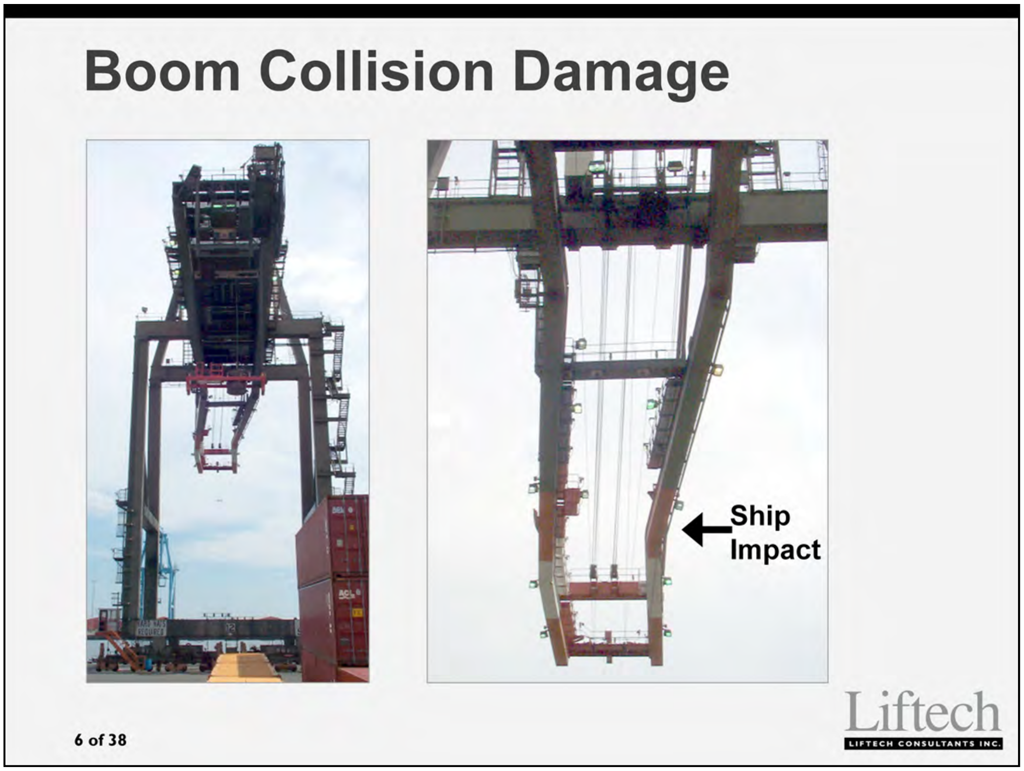
I will first discuss vessel collisions.



The most common vessel collision is between the ship and crane boom.

This collision occurred in New Jersey when a vessel berthed out of control.

The ship impacted the right girder pushing the boom laterally. Despite the severity of the damage, the crane frame was undamaged and the crane did not derail. Repairs were completed within a month by lowering the boom to the wharf and repairing damaged sections using a variety of methods including replacement, stiffening, and heat straightening. Repairs were completed in a month at a construction cost of around $600,000 in 2001.

Frame Collision –Vessels

Moving Vessel

Ballast Failure

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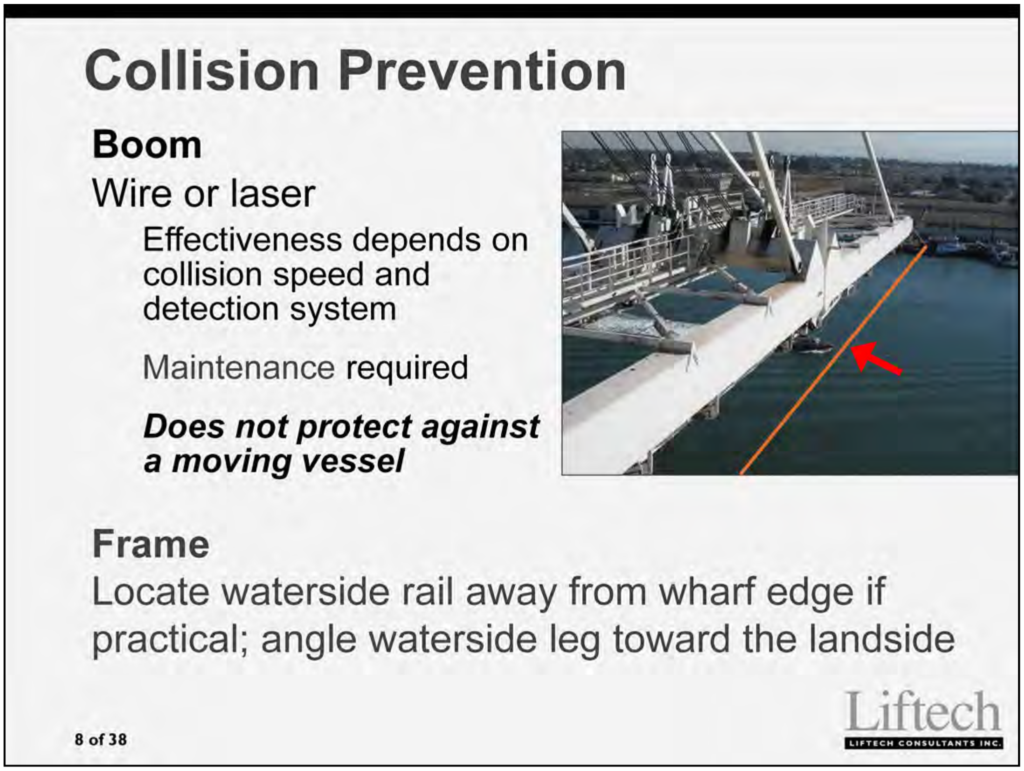
Frame collisions are less frequent. Many collisions occur due to vessels berthing in bad weather.

Sometimes the damage is repairable; sometimes it is catastrophic.



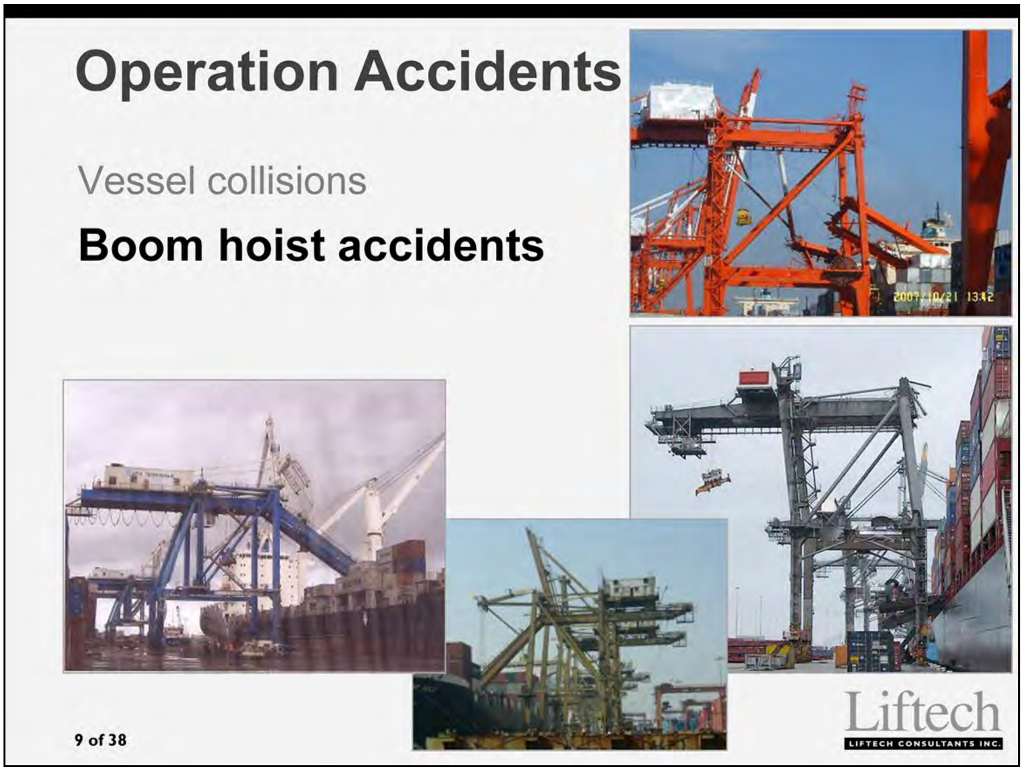
Boom collisions are common.

To mitigate boom collisions, we suggest using a tripwire or a laser system.

Be aware that these systems will not guarantee that collisions will not occur. For example, when vessels move into booms, the system cannot stop the vessel and a collision will still occur. Also, the tripwire may not protect a fast-moving crane from collision.

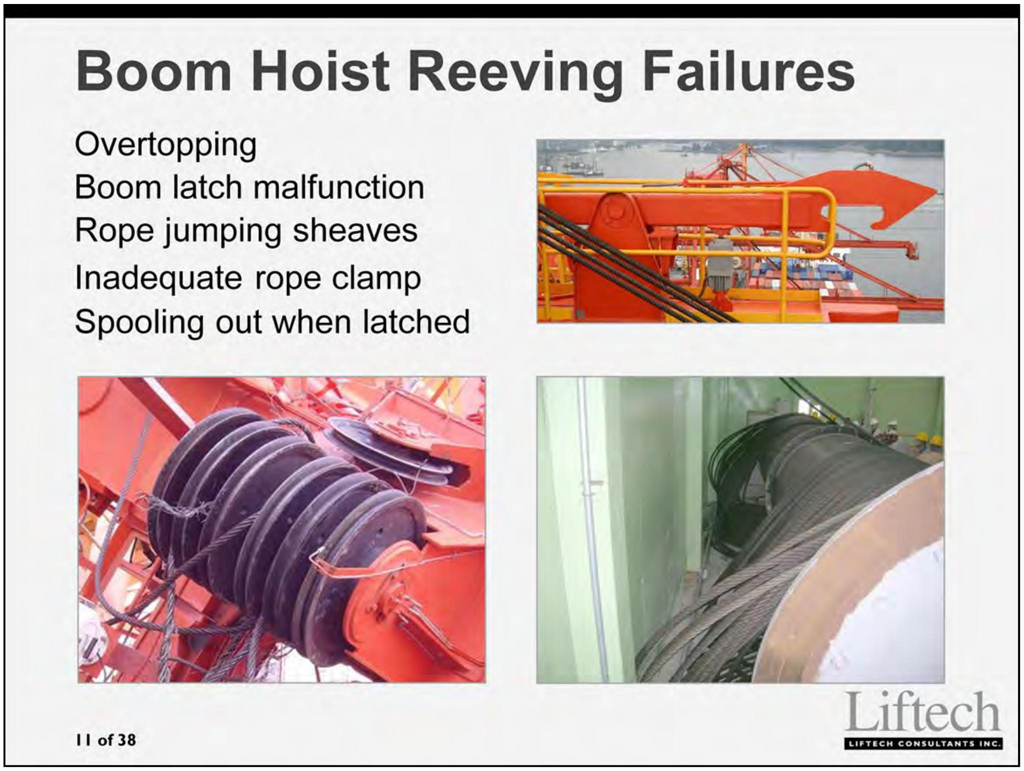
The tripwires require regular maintenance to be effective.

It is difficult to prevent and mitigate vessel collisions to the frame. One way is to set the waterside gantry rails back from the face of the wharf to provide additional clearance.



Four boom hoist accidents occurred in 2008.

This 2008 failure occurred during raising with the boom nearly raised. The forestays could not catch the falling boom. The boom landed on the ship and pulled the upper A-frame members from the crane.

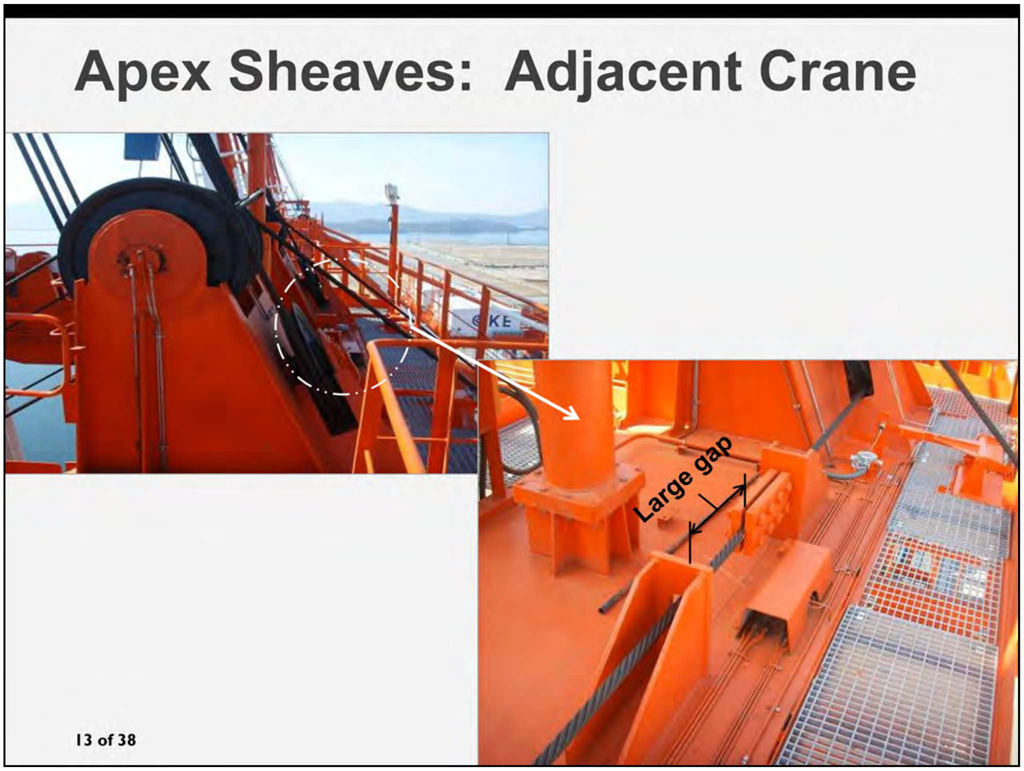


Boom hoist system failures have occurred for a variety of reasons, including:

- overtopping – trying to raise the boom beyond the apex
- latch malfunctions
- ropes jumping sheaves
- damage to the rope
- rope spooling off the drum while the boom is latched
- inadequate rope attachments

This is the same crane after the failure. The boom and A-frame members separated from the frame.

The next slide shows the adjacent crane.



This photo shows reeving at the apex of the adjacent crane including the stop clamp and stops.

On the failed crane, the rope on the side of the reeving failed. The exact cause of the rope failure is unknown.

The stop clamp did not hold the rope after the rope broke. The clamp may not have been installed properly—notice the large gap.

Prevention

Design

Redundant, equalized reeving

Design structure for one side rope breaking

Properly design and test clamp

Inspect connections, use inspectable fittings

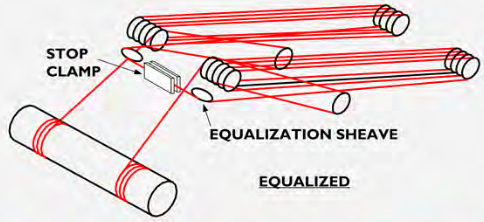
Operations

Stow boom on ropes

Use stow pin instead of latch

Provide limit switch and slack rope detection

Lower boom from boom operating station



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Design
Provide redundant systems, equalize hoist ropes, properly design clamps and stops, design the crane structure for impact from failure of one side of the reeving system, inspect connections, and inspect the rope after overload or after work near the rope that may compromise it, e.g., welding.

Operations
Stow the boom on the ropes. If stowing at the apex, use pins instead of latches. Provide limit switches for boom location and for slack rope conditions, and lower booms from the operating station.

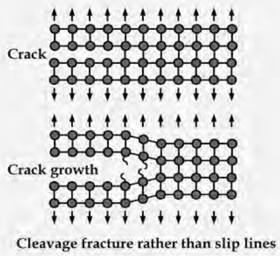
Section 2: Fatigue Accidents

Next, I will talk about fatigue failures.

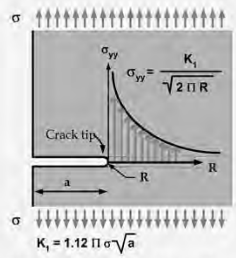
Fatigue

When steel is subjected to fluctuating stress, small cracks grow

When the cracks are large enough, the steel fractures suddenly without warning—this is called brittle fracture



Cleavage Failure



Stress at a Crack Tip

Fracture Surface

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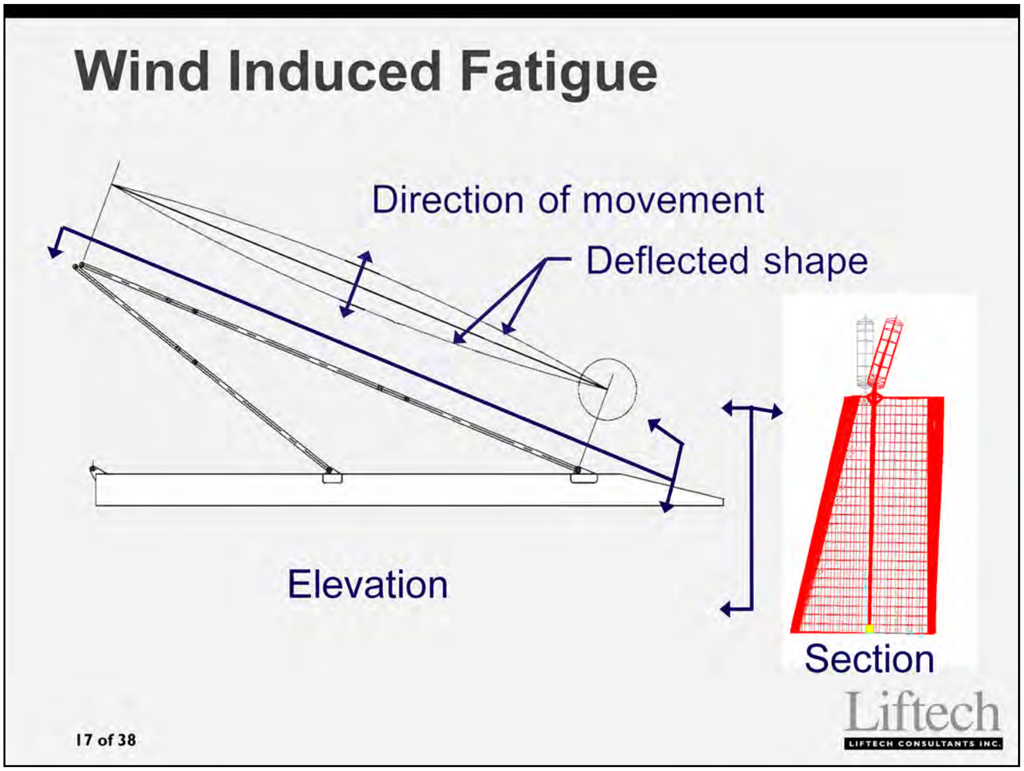
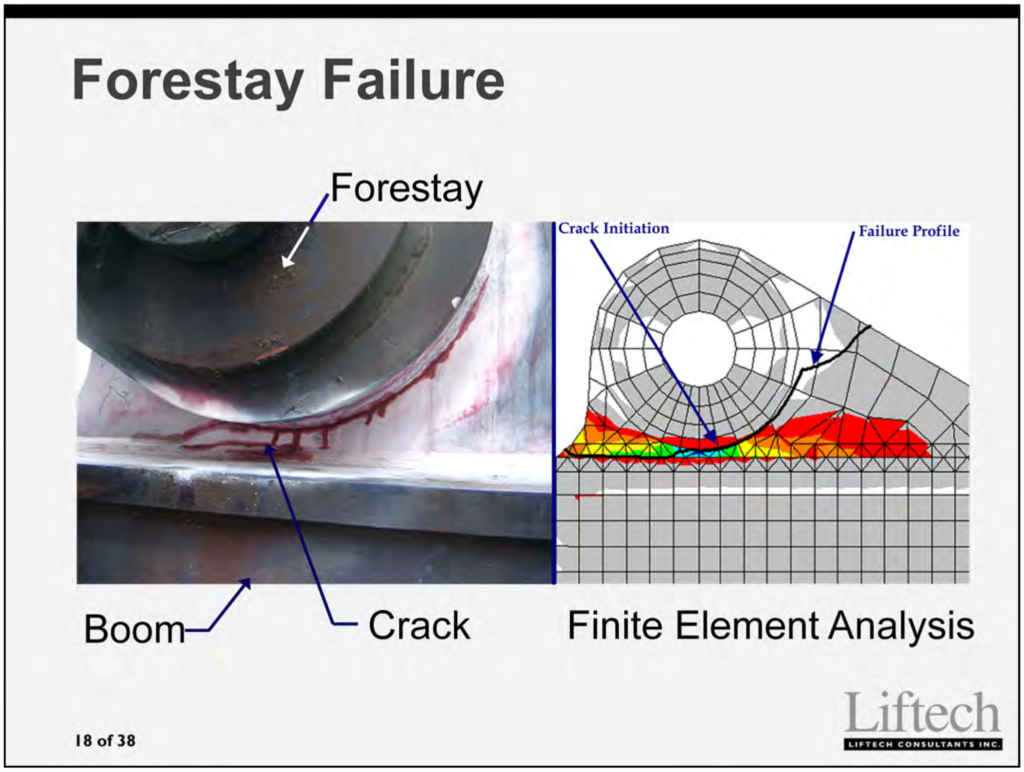
Fatigue occurs when there are fluctuating stresses. Unrepaired, fatigue cracks will grow until fracture occurs. Fracture will occur when the energy induced by the loading exceeds the energy that can be absorbed by the material. The crack at which fracture occurs can be very small, less than an inch.



I will talk about a few select fatigue topics. The first is wind-induced fatigue. This phenomenon is often overlooked by designers and has resulted in premature fatigue cracking and some major failures.

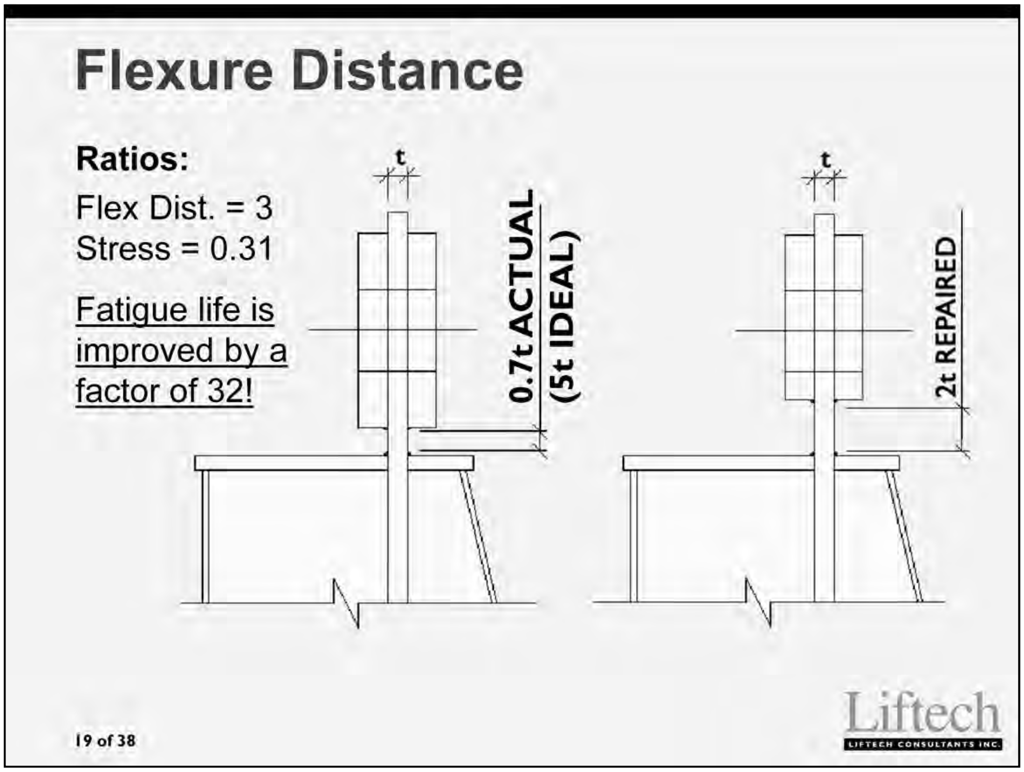
When wind deforms structural members on a crane, the connection plates at the ends of members must be flexible enough to accommodate the deformations without developing significant stresses.



On this project, a forestay connection failed but the remaining stays held the boom. The forestay failed, but luckily the boom did not fall.

The cracks initiated at the stress concentration at the toe of the boss weld and propagated across the plate in both directions.

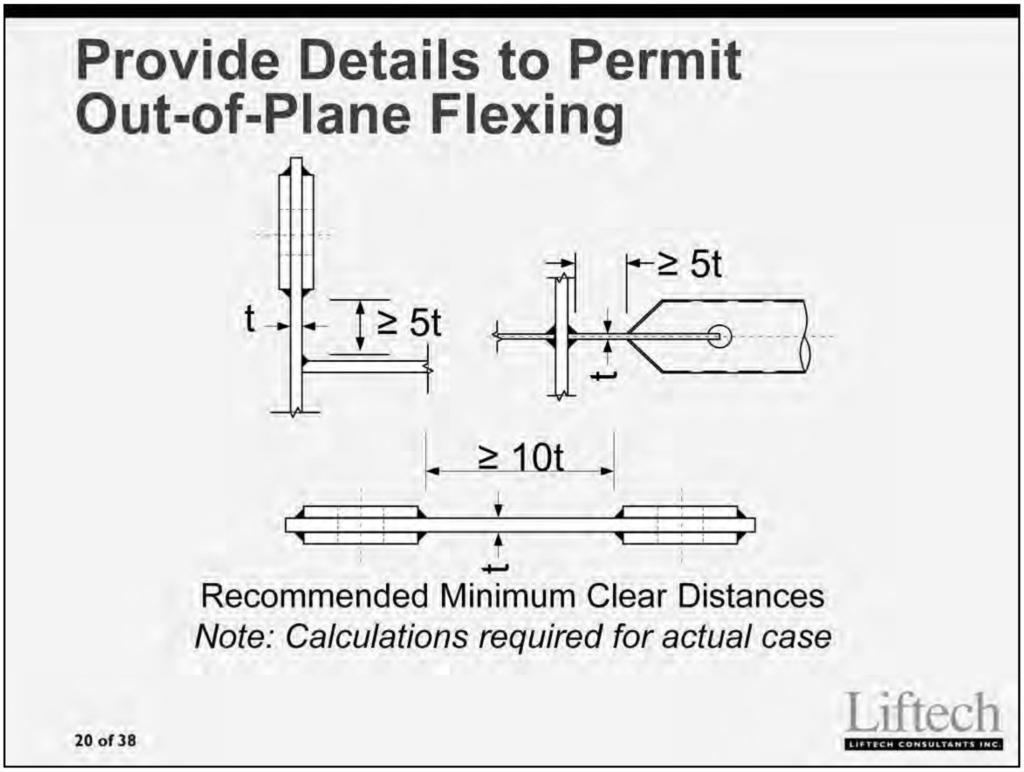
Note:
The photo on the left is a cracking detail that has not yet failed.
The FEA plot on the right shows the stress in the uncracked plate with the failure profile of the failed plate superimposed.



The stresses in the previous slide are due to a weak axis flexing when the boom sways to the side and from the forestay bending.

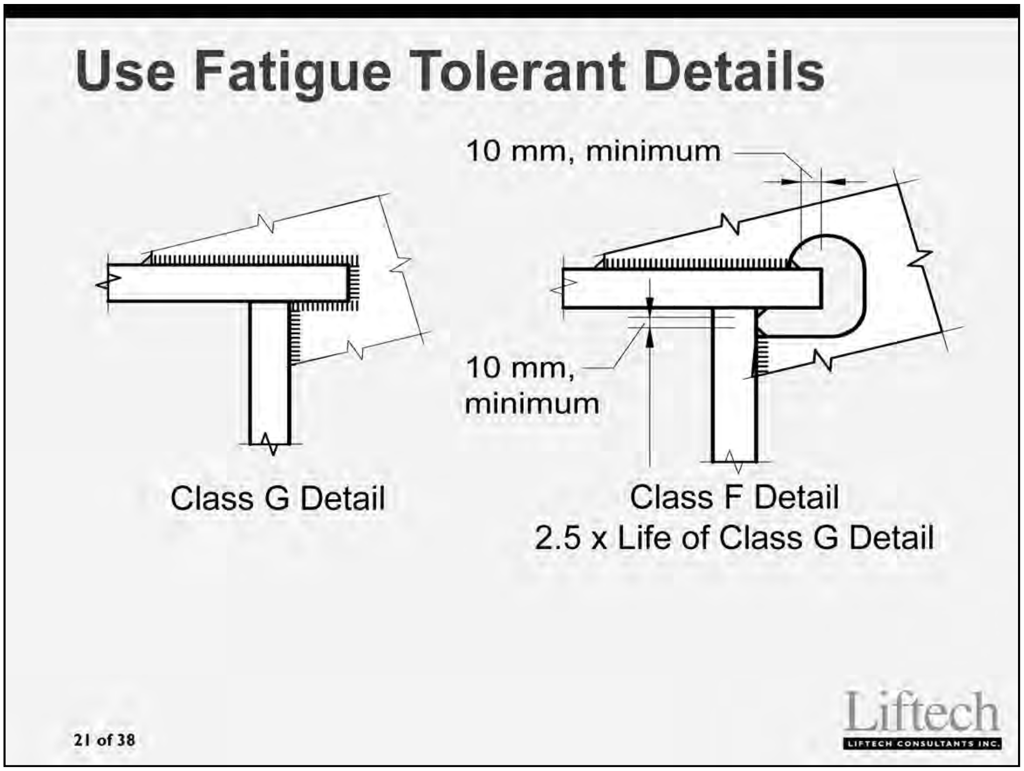
If the flexure distance between the boss and the boom upper flange welds is small, the stress is considerably higher than if the flexure distance is large.

We recommend 5 t flexure distance for fracture critical members (FCMs). By increasing the flexure distance in the problem detail from 0.7 t to 2 t, the stresses were reduced and the fatigue life was greatly improved. Fortunately, a small change in flexing distance has a major impact on the fatigue damage.



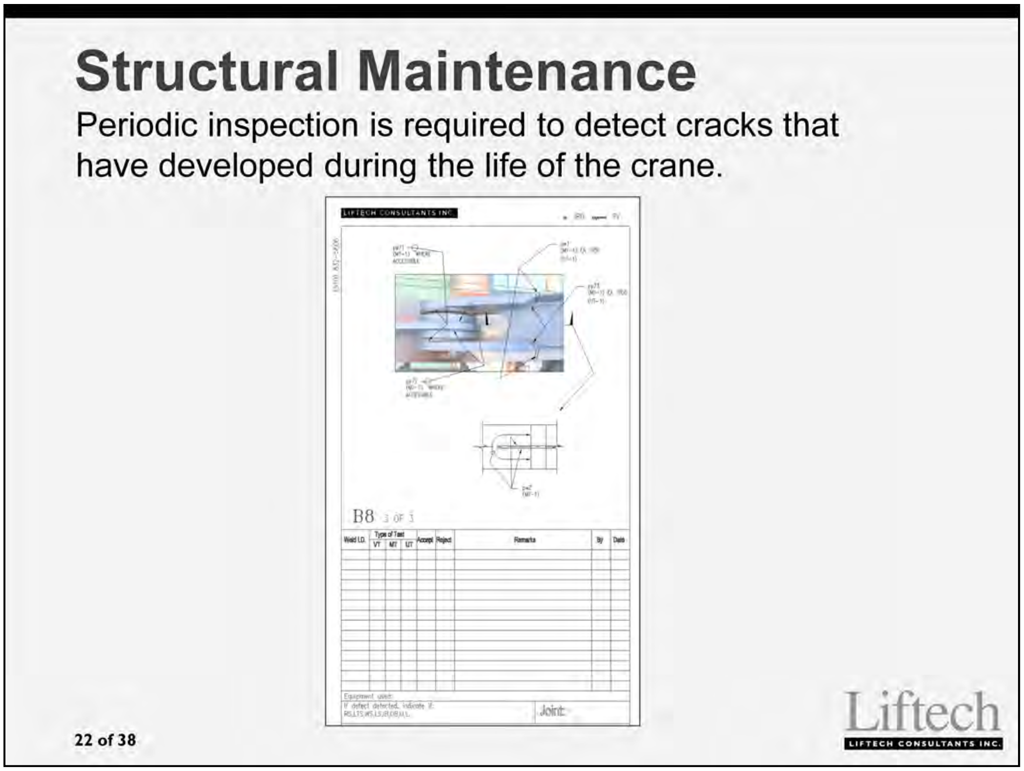
These standards are applicable to most arrangements and should be evaluated for a particular arrangement and condition.

If the required rotation is unusually large, the required clear length between welds should be calculated.



Another topic worth discussing is detailing. Fatigue tolerant details can greatly improve the fatigue life of a crane. Using fatigue tolerant details requires little or no additional effort.

As shown in this image, the fatigue tolerant alternative is easier to build and has 2.5 times the fatigue life of the alternative detail shown.



The specified allowable fatigue damage in the Liftech specification, BS 7608, and the EN standards is based on "***damage tolerant design***" criteria, which requires periodic inspection so cracks are discovered before they reach a critical size.

Fatigue cracks will develop.

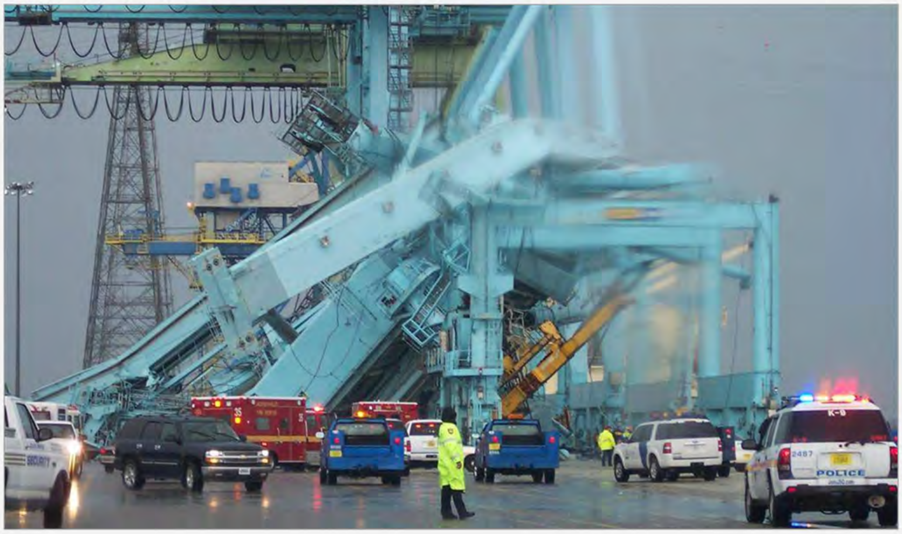
The structural maintenance program is a detailed program developed to maintain structural reliability. The program addresses what inspections are required, what is to be inspected and how, how often each detail is to be inspected, how the findings should be reported, and what the repair procedures should be.

Next, I will talk about wind-related failures.

In addition to the expected severe wind loading that can be predicted days in advance, cranes can experience unexpectedly large wind loads from microbursts and other localized wind phenomena.

The design wind is expected to be exceeded during the design return interval.

Operational Considerations



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This is a photo of collapsed cranes.

Failures similar to this due to runaway cranes occur more frequently than expected.

It is often difficult to pinpoint why braking systems fail. Some design and operational considerations are presented.

Gantry Braking Design

Component	Intent	Typical Minimum Design
Motor	Operations (dynamic)	Rated speed, WLO (25 m/s wind)
Motor brakes	Static hold	150% WLO (30 m/s)
Wheel or rail brakes	Static hold	200% WLO (35 m/s) combined with motor brakes
Anemometer	Wind speed	35-40 mph operating warning 45-55 mph high wind alarm

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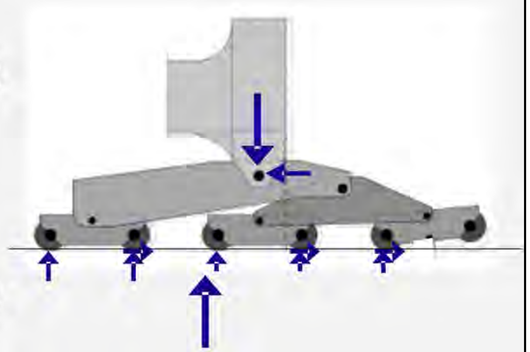
The following discussion represents typical minimum specified braking system capabilities and operating parameters.

The motor stops the crane during operations (dynamic).
The motor brakes hold the crane statically. When control power is lost, motors will not work, but the motor brakes set.

The wheel (or rail) brakes are also static. Also, if set during an E-stop, if dynamic, some damage will occur. We recommend wheel brakes instead of rail brakes (less damage and more vertical reaction at wheels).

Anemometers should be at the highest point of the fixed structure.
Audible alarms are set at wind speeds decided depending on location, etc., 16-18 m/s (35-40 mph), 20-25 m/s (45-55 mph).
Motor brakes engage at operating warning alarm.
At high wind alarm, usually a bypass is needed to attempt to move a crane.

Prevention



- Consider effects of light corner and prying in design
- Maintain brakes
- Engage stow pin during maintenance
- Establish stowage procedures
- Provide enough time to stow the crane
- Provide adequate braking capacity

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Stowage plans will vary depending on many factors.

Each port or terminal should develop its own stowage plan.

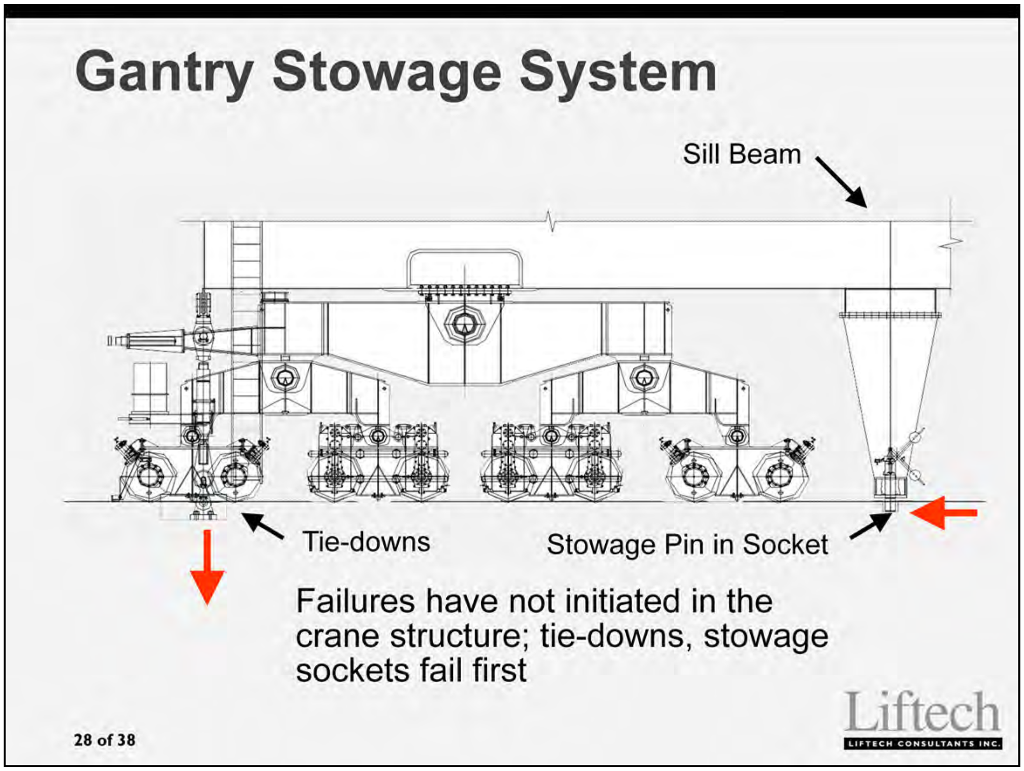
Some operational considerations include providing ample time to stow the crane and realizing that the brake capacity of a moving wheel is less than that of a stopped wheel.

The static coefficient of friction is often significantly larger than the dynamic coefficient of friction. A moving crane also has significant inertia.

Hurricanes cause damage. The risks are real.

This photograph shows six collapsed cranes due to Typhoon Maemi in Pusan, South Korea.

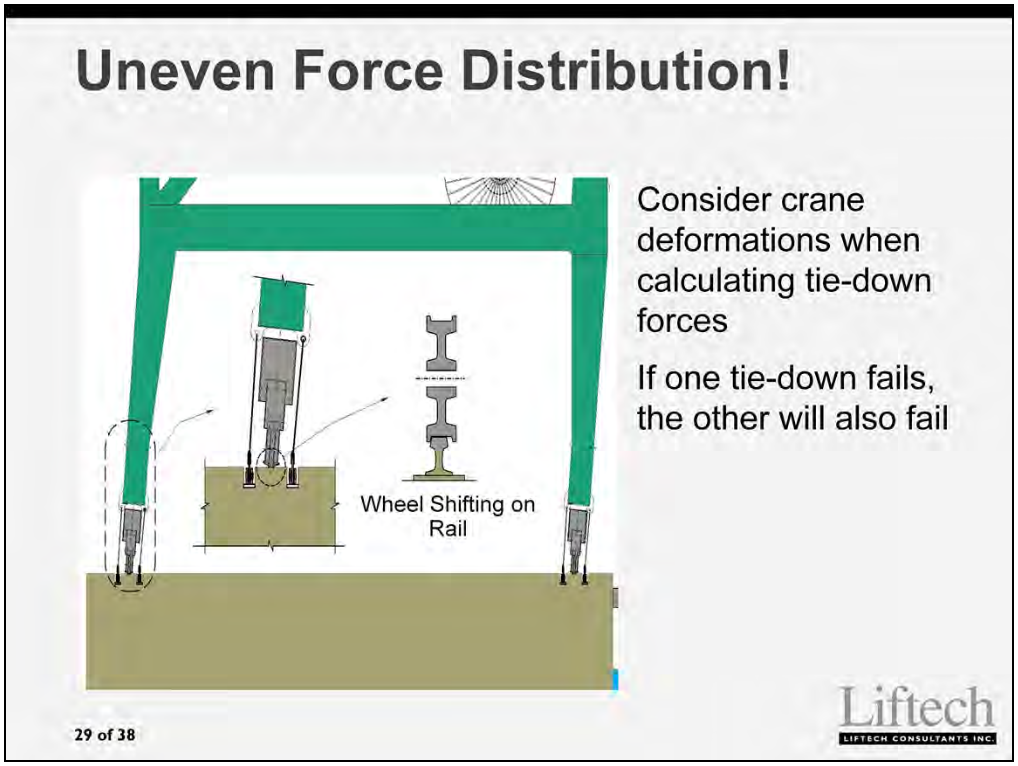
The tie-downs failed. After failing, progressive failures ensued as cranes collided with each other.



Stowage pins resist lateral loading. Tie-downs resist the uplift due to the overturning moment.

Ballast is an acceptable alternative to tie-downs. If a crane corner will lift, stowage pins should be long enough to accommodate the lift.

Failures never initiate in the crane structure. Failures have always initiated in the stowage hardware connecting the crane to the wharf.



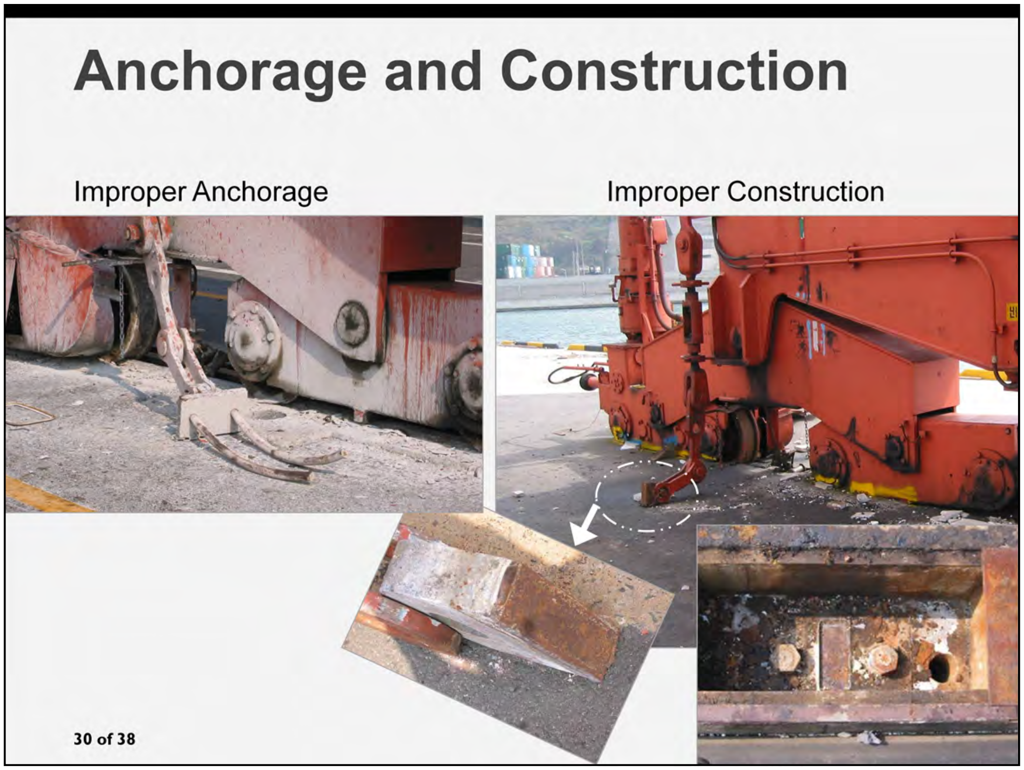
Cranes are flexible and hurricane forces cause cranes to deflect and move.

When there are multiple tie-downs at a corner, the forces in the tie-downs are **not evenly distributed**.

Why?

Crane structure deforms, translating and rotating.

- Gantry wheels can shift.
- Gap in stowage pin socket allows gantry wheels to roll (or slide) along the rail.
- Links are not perfectly straight.
- Wharf pins are not symmetric.
- (**See enlargement with tie-downs.**)



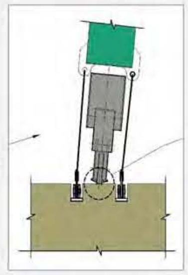
<u>Anchorage</u>
Smooth anchors pulled out of the wharf.

Design = headed
Fabricated = no heads

<u>Construction</u>
60 mm plate; only a 4 mm fillet weld, with filler plates added in some places.

Prevention

Proper wind criteria and design. Consider crane deformations. Focus on wharf hardware.



Monitor fabrication & installation.

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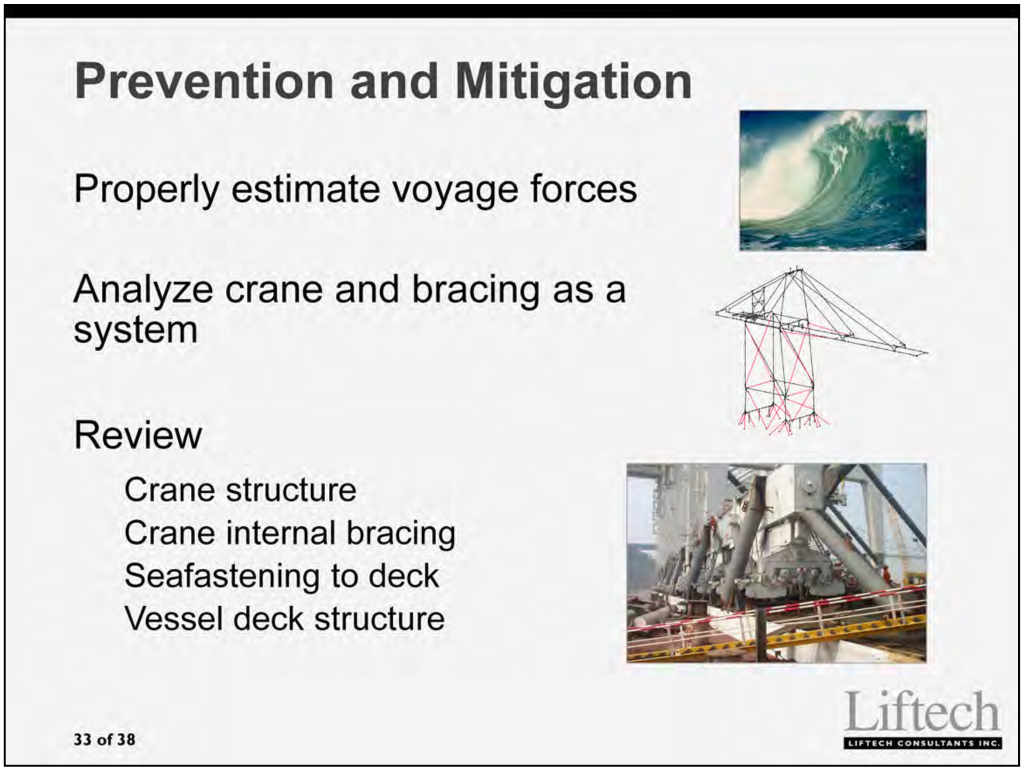
The reasons for failures can be equally attributed to incorrect calculations, poor design, and poor fabrication. Each of these should be addressed.

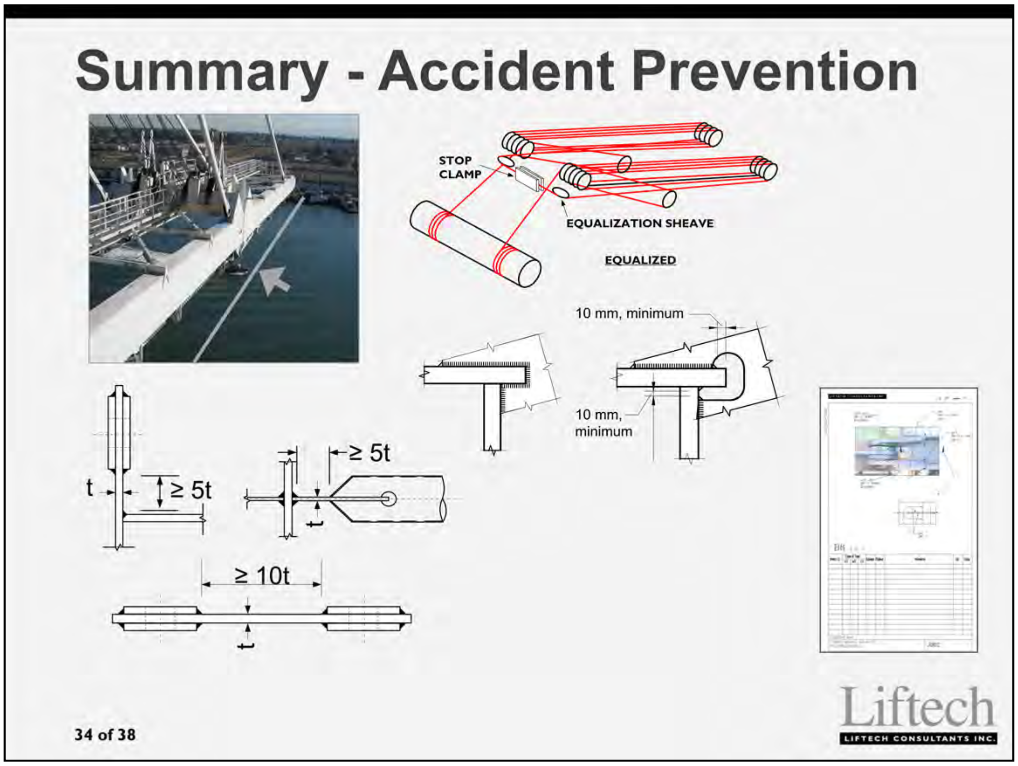
Finally, I will talk briefly about transport failures.



Estimate voyage forces correctly considering the conditions and an appropriate criteria. Do not relax accepted design criteria regardless of how mild the weather is expected to be. Unexpected weather commonly occurs.

Accurately calculate the forces and stresses in the bracing and crane structure. This usually requires analysis using a finite element program and considering the crane structure and bracing together.

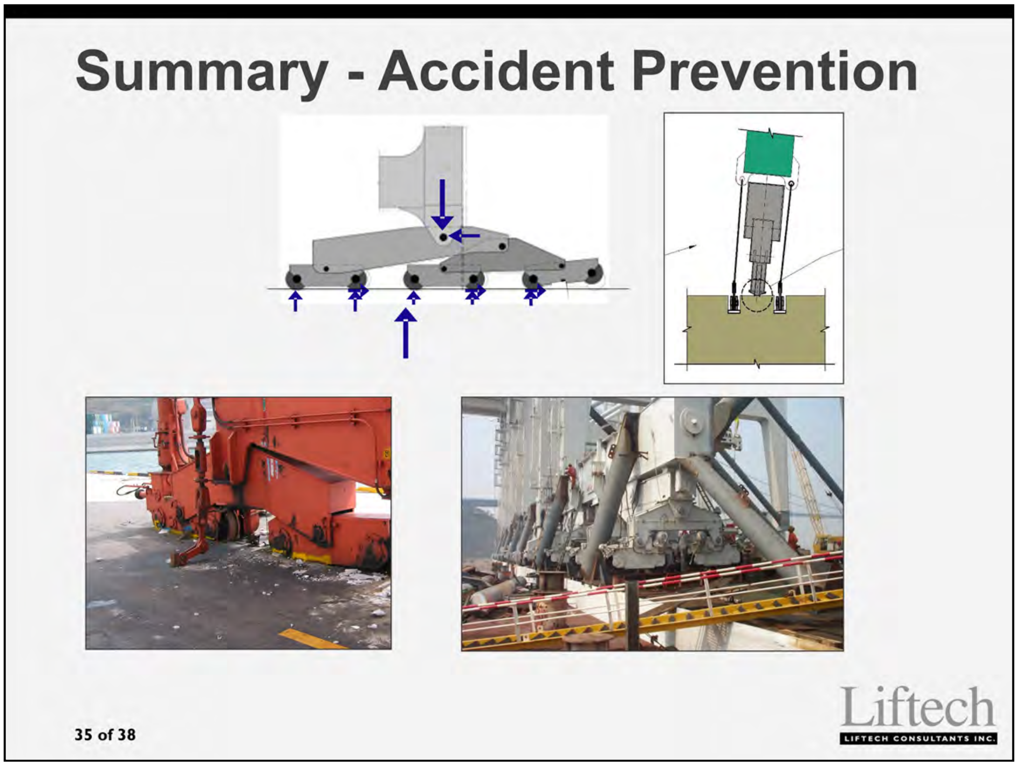
Be sure to review the entire load path from the crane structure down into the structure of the vessel. **The load does not stop at the deck of the vessel!**



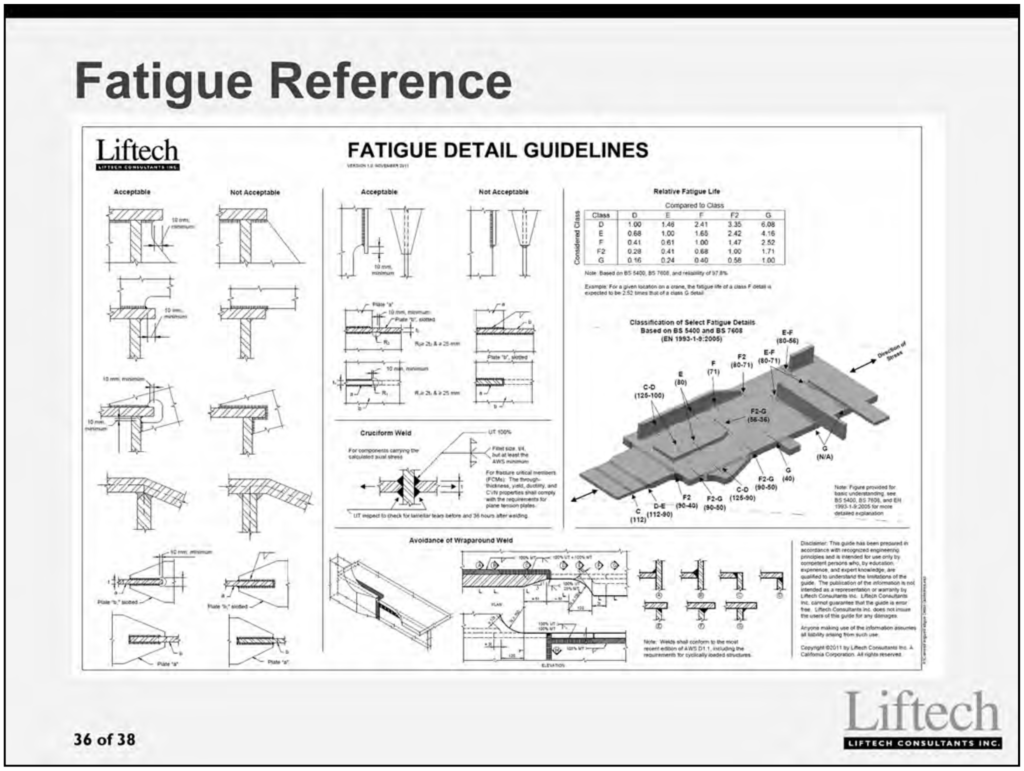
Use and maintain collision prevention systems.

There are many causes of boom hoist failures. Be familiar with them and be diligent.

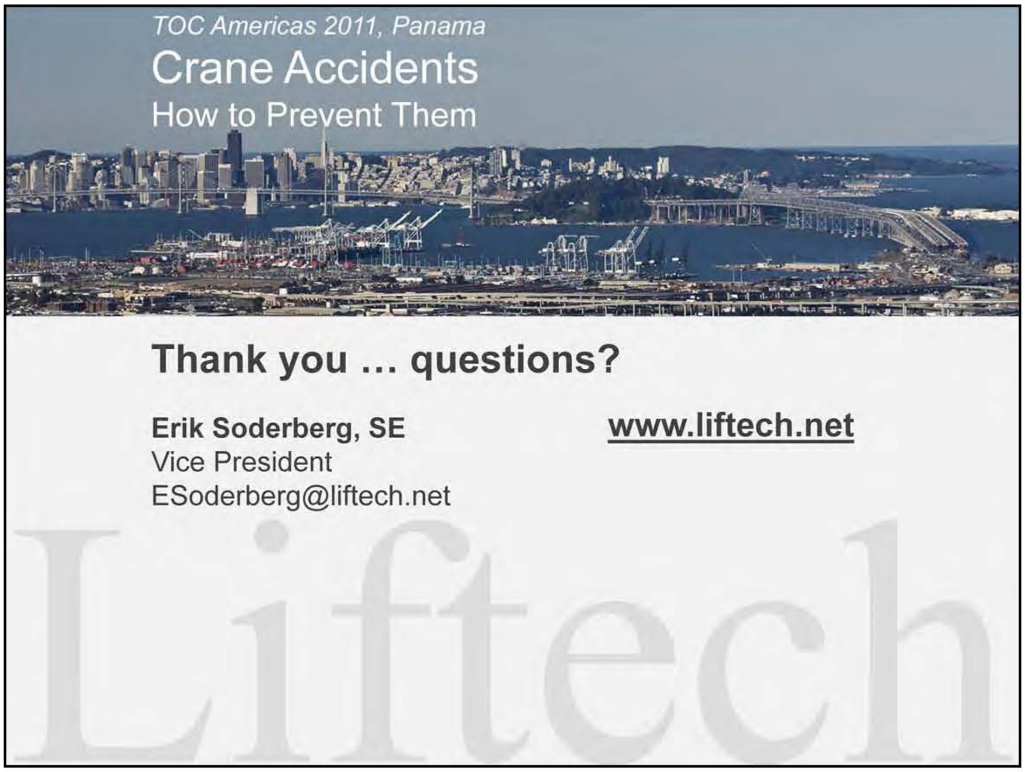
Performing structural maintenance is necessary to maintain a healthy, reliable crane.



Many things can go wrong.



The following fatigue reference was developed for our presentations at this TOC event. This reference is available on our website: www.liftech.net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Thank you … questions?
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