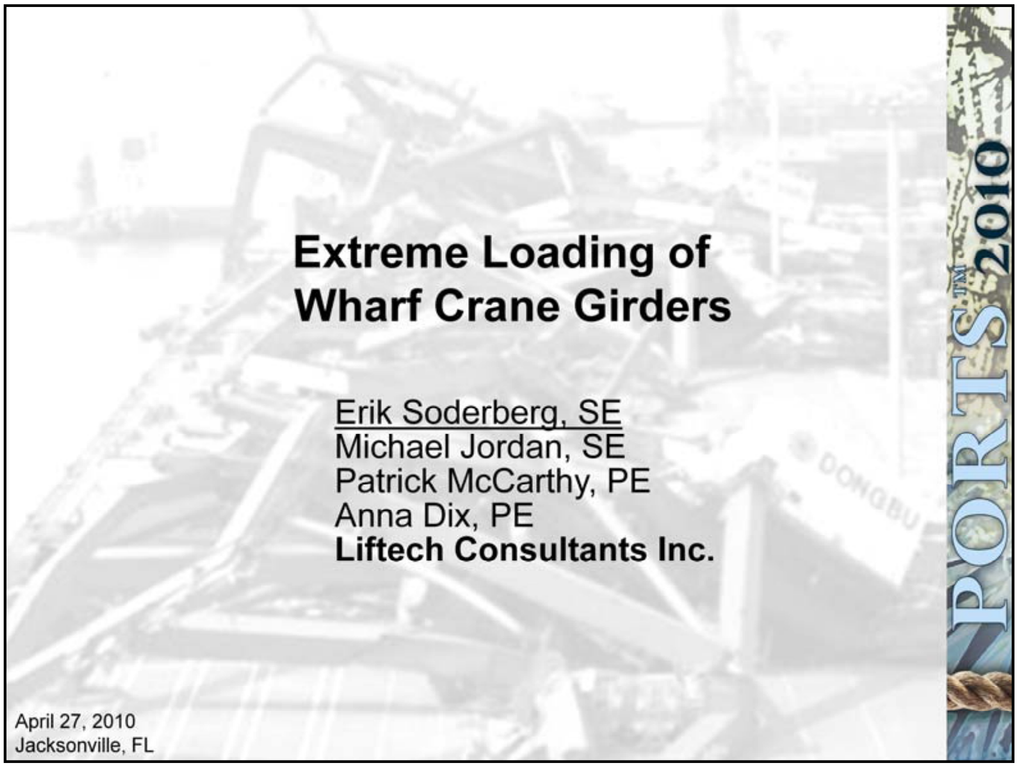
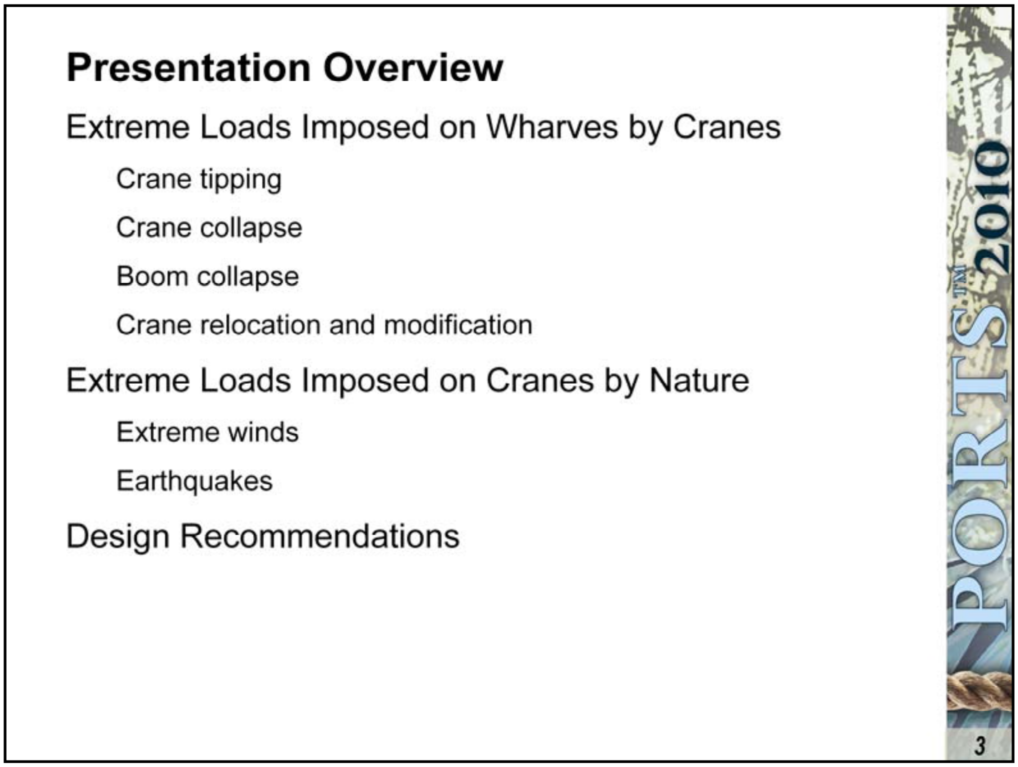
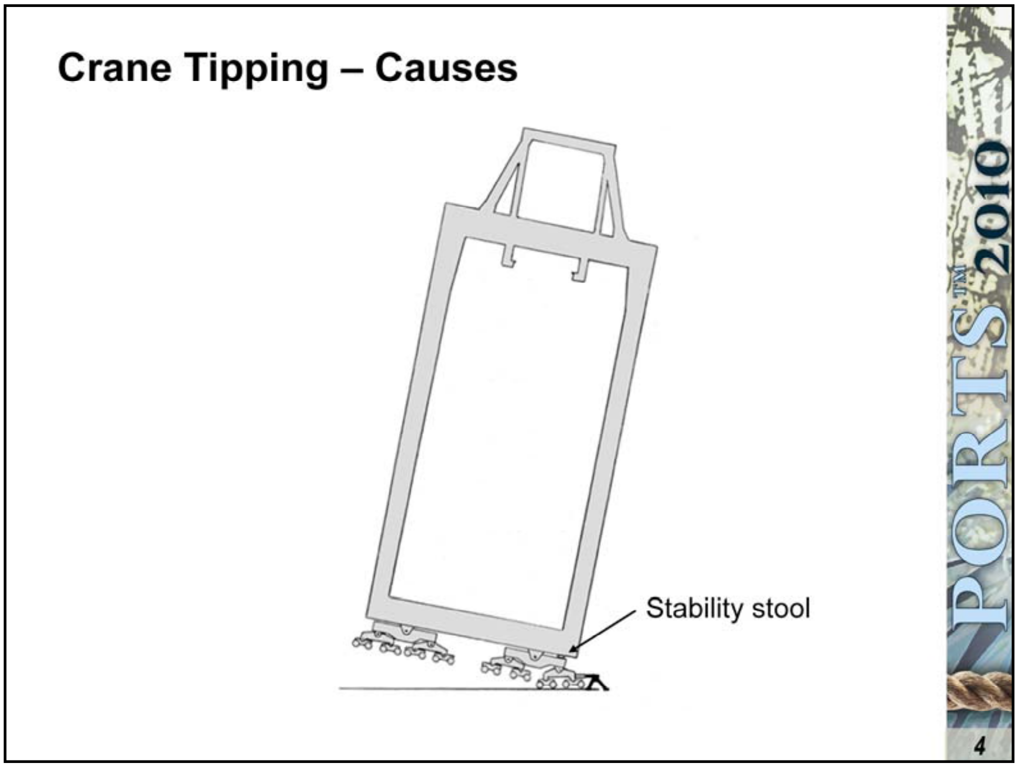


Pusan, South Korea: 6 cranes collapsed in background (other view of next slide photo)

Liftech engineers have been intimately involved in the container crane industry for over 50 years and are aware of hundreds of extreme loading events over the years, having studied their impact to crane structures and wharf structures first hand.



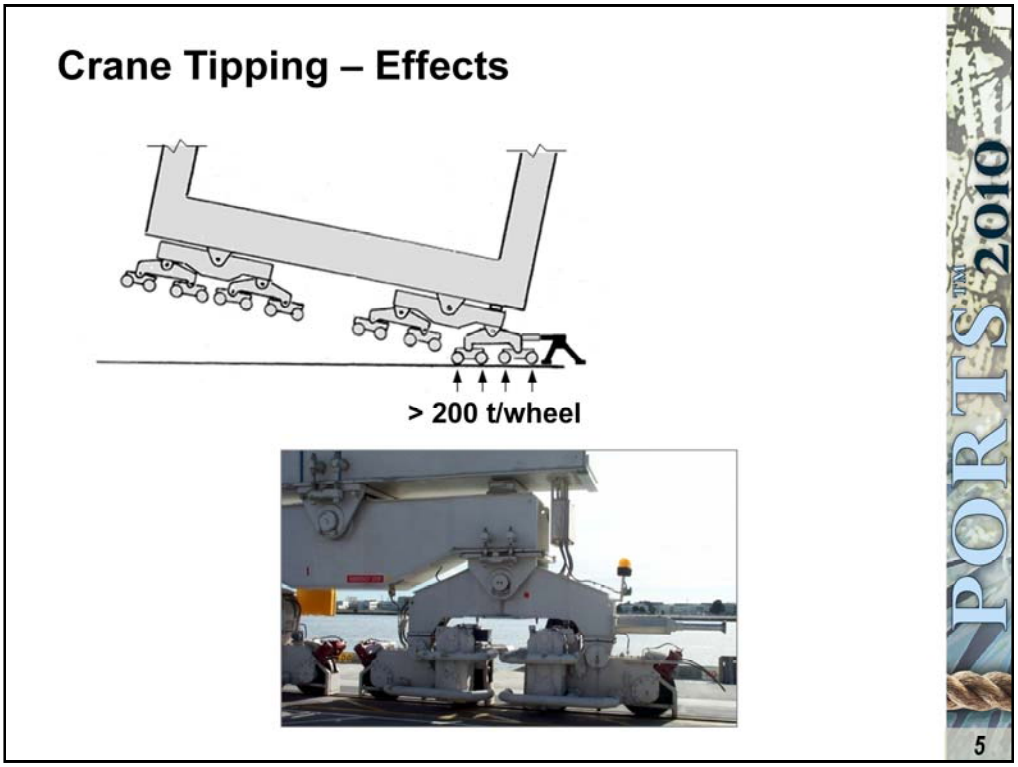
This presentation provides some causes and effects of extreme loads on wharves, some natural causes of extreme loads on cranes, and recommended wharf girder extreme load design criteria.



Cranes can tip from inertia loads in earthquakes, from collisions, and from extreme wind events.

Tipping is defined as two corners lifting.

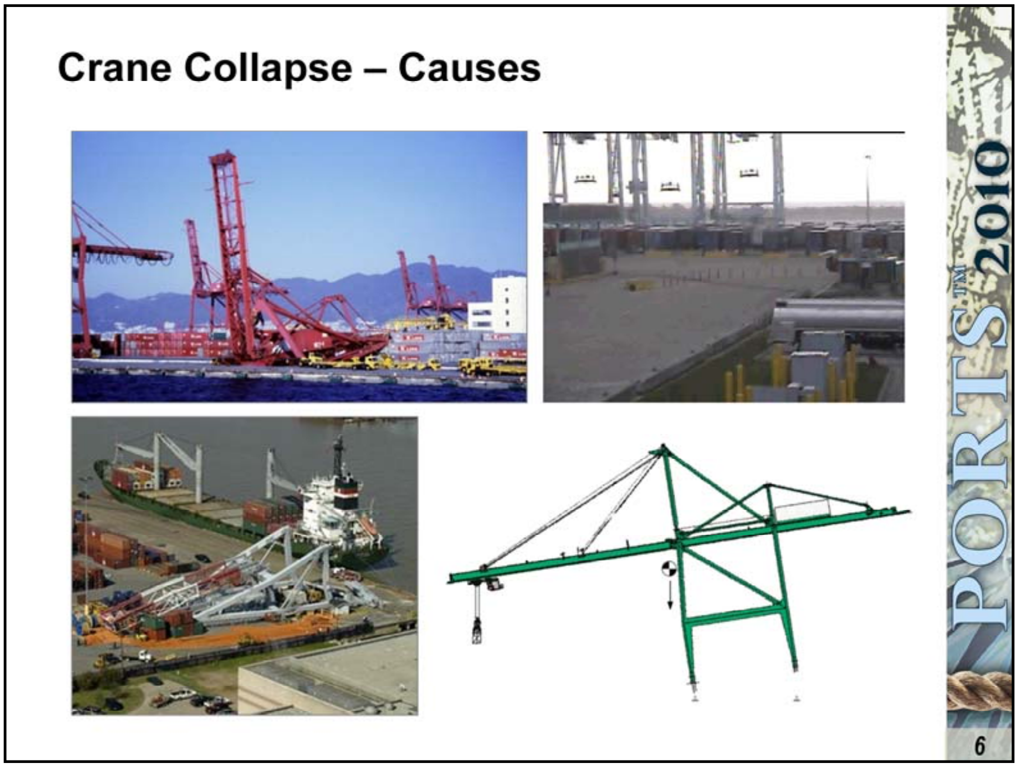
The vertical reaction is transferred through ½ to ¼ of the wheels depending if the crane rotates onto its stability stool.



When the crane rotates onto its stability stool, the crane weight is spread across only ¼ of the wheels for a short duration.

There is an impact load when the crane lands back down on the wharf, which is also a short-duration load.

The impact loads are not considered for wharf girder design, but the girder and stop should be designed for the load to tip the crane.



Wind is the most common cause of crane collapse.

Ship collisions are the next most common.

A few collapses have occurred due to spreading supports such as in the Kobe earthquake. If the girders are not tied together, the rails may spread due to ground movements.

One unusual collapse was due to a severely overweight trolley.

The fabricator used components that were much heavier than those shown on the design drawings.

This video is of a runaway crane due to an unexpected gust of wind. Notice how long it takes the cranes to fall to the wharf.

Despite the severity of the event, crane collapses result in little damage to the wharf structure including the girders and deck. The loading occurs over many seconds and significant energy is absorbed by the failing crane structure. Damage is usually localized and minor.

As this crane tipped and fell over, the entire waterside reaction was applied on two stowage pin brackets.

The wharf was not damaged except for the minor spalling. The loading occurred over several seconds.

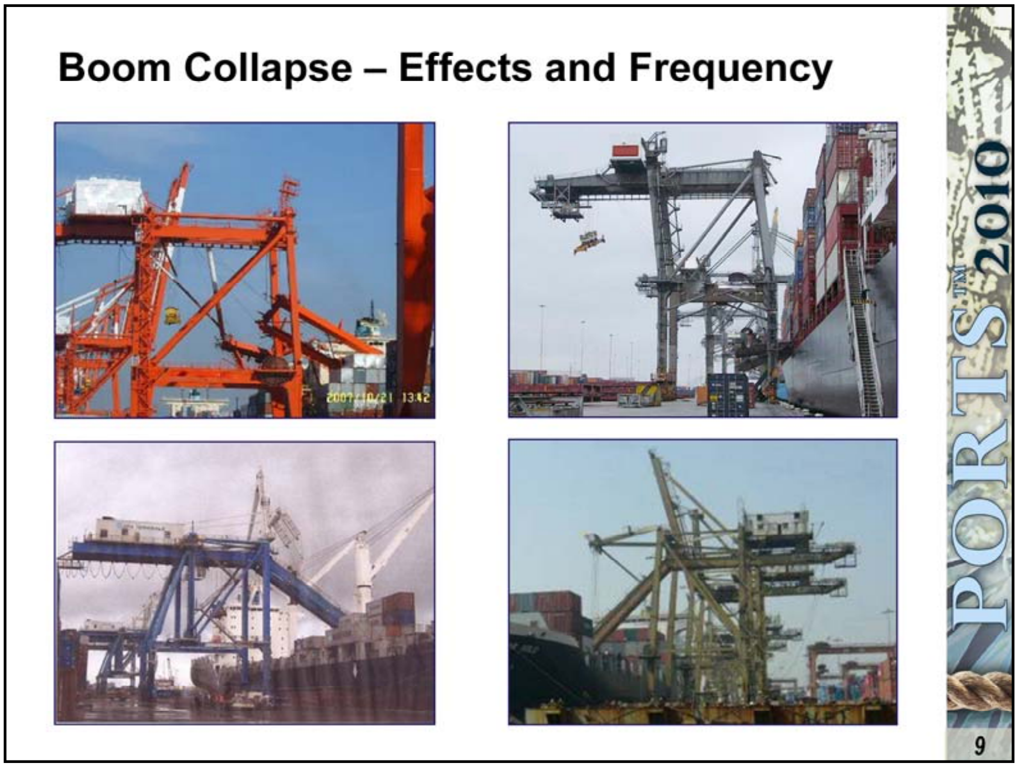
Crane collapse loads are not considered for wharf girder design.

Causes of boom collapses are hoist rope failure, rope connection failure, fatigue failure of a fracture critical member and connection, and other accidents.

This is a video of a failure in Gwangyang, Korea, in 2007.

Based on the shadow of the boom in the video, it appears that the hoist system failed when the boom was fully raised.

It appears that the upper crane structure failed early in the accident preventing the forestays from trying to catch the boom when it became nearly horizontal. The inability of the forestays to resist load prevented a large impact loading on the crane and the crane girders.



Boom collapses are not publicized, but happen more frequently than most people realize.

There were four boom collapses over the course of a one year period starting the end of 2007, and there was another in 2009.

This is about one in a thousand. One in a thousand sounds tolerable to a layman. Engineers and owners do not accept such a high failure rate.

For example, Liftech crane criteria are based on a chance for collapse of one in 100,000 including planned structural inspections and maintenance.

When the crane structure is competent and a boom falls, the stays will try to catch the falling boom. Sometimes the crane structure is strong enough to catch the falling boom, but usually it is not. Regardless of the outcome, a large impact loading occurs on the crane structure and the waterside crane girder. If the impact is large enough, the crane will tip and lift off the landside rails, resulting in an impact loading to the landside crane girder as well.

We have observed dents in the rails from these large impacts. We have never observed damage to the girder structures. Although the loading is extreme, it occurs over a very short duration.

Boom collapse loads are not considered for wharf girder design.

Crane Relocation and Modification

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Extreme loads are frequently applied to wharf girders during container crane relocation and modifications.

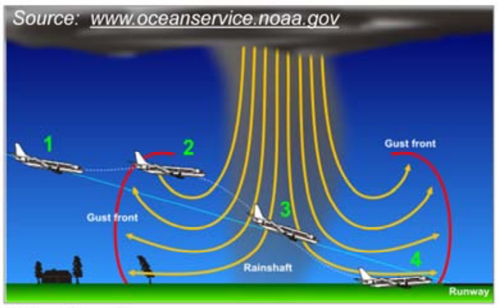
The extreme load usually involves concentrated loads when temporarily lifting the crane. The wharf crane girder structure is usually adequate even for this large loading.

Pile capacities often control the acceptable load. Keep in mind the allowable pile capacity from the short-term loading is usually more than for a long-term loading.

Extreme loadings from crane relocation and modification are significant to the girder structure and should be engineered.

Extreme Wind Loads

Tropical cyclones



Microbursts

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The stowage locations of wharves see extreme loads during severe wind loads.

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

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

Extreme Wind Loads – Effects

Typhoon Maemi, Pusan, South Korea

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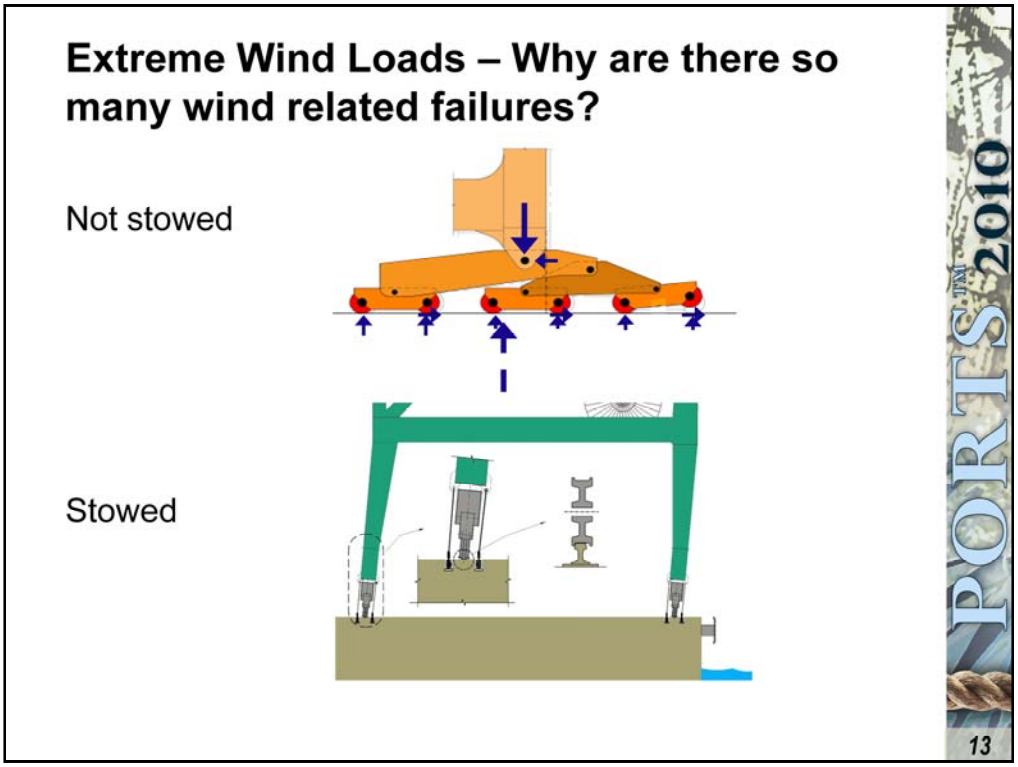
Winds cause extreme wharf girder loads even when bad things don't happen.

They also cause extreme loads by blowing cranes over in place or by blowing a crane down the rails. A "runaway crane" can collide with other cranes or the crane stop resulting in tipping, collapse, or both.



Wind loadings on cranes are expected, so why all the unexpected extreme loads from tipping and collapsing cranes?

Moderate winds often cause runaway cranes. The reasons:

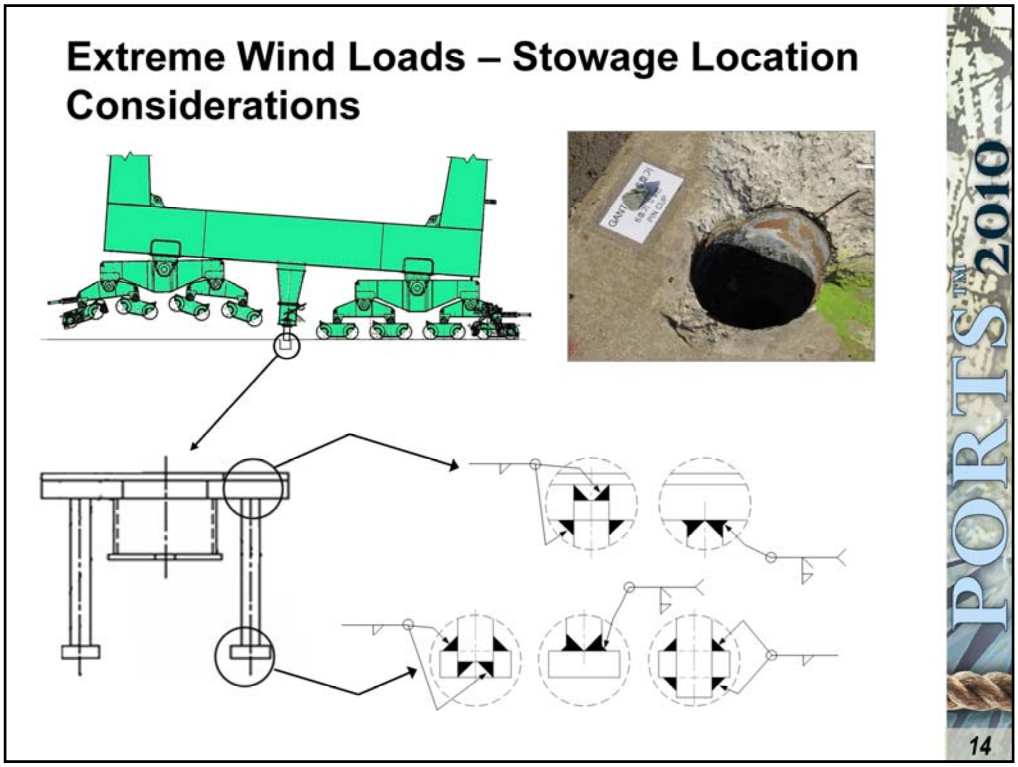
1. malfunctioning braking systems
2. brakes that are not sized considering prying effects that reduce the maximum braking capacity
3. moving stopped cranes and not being able to stop them again due to the significant difference in the static and dynamic coefficient of friction

Sometimes the cranes were not properly stowed.

Even when cranes are properly stowed, extreme winds have caused stowage system failures due to poor construction, poor design, or both.

Designs problems are usually due to:

1. neglecting normal crane motions that cause unequal load distribution to the tie-downs
2. neglecting the inclination of tie-downs
3. neglecting the misalignments within the tie-down system due to gaps
4. neglecting the prying forces from stowage pins located on the equalizers
5. inadequate penetration of the stowage pins



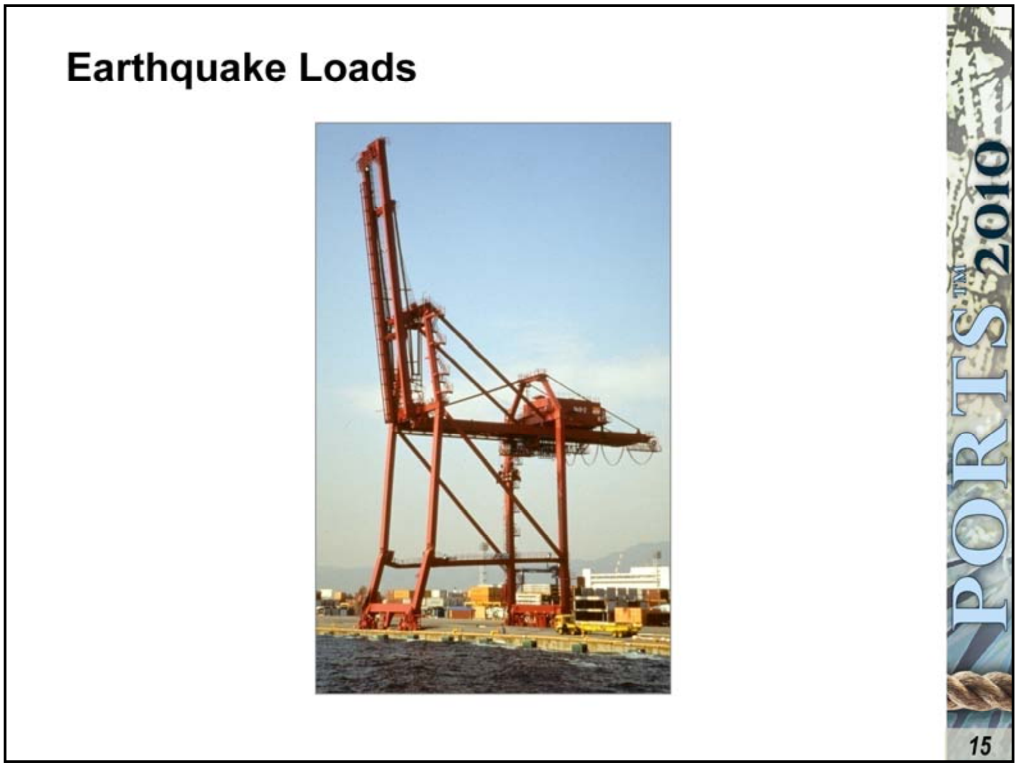
Stowage pin socket loads are very localized and do not govern the girder design as a whole.

Sockets should be deep enough, and pins long enough, to accommodate some pin lift.

The pins should be restrained so they do not disengage if the crane lifts off the rails a small amount.

Embedded hardware should be designed to remain ductile when subjected to extreme loads.

Most extreme loads have short durations, in many cases seconds, so if the anchorage is ductile the momentary load will deform but not break the anchor.



Most container cranes have survived significant seismic forces with minor damage. If the wharf remains intact, the crane has a good chance of standing.

One important consideration from the extreme loading during an earthquake is tying the landside and waterside girders together so that the rail gage does not change.

Moderate West Coast earthquakes may result in tipping but not toppling and large vertical impacts.

Large lateral loads will occur, which may damage the post-Panamax crane's rail, result in derailment, or both, and may cause some large mega-cranes to collapse.

It is impractical to design the lateral strength of the rail and the rail-to-wharf connections to resist the lateral loads that may develop in an earthquake since the lateral loads are large. It is not difficult to repair the rail.

Design Recommendations

Typical concrete girder > 1.5 m depth,
piles < 5 m spacing

Do not consider extreme short duration loads.

Do not consider potential loads from collapsing cranes or crane booms.

Do consider extreme loads during crane moves or modifications.

Do not design crane rail system for extreme lateral loads during earthquake. Repairs are localized.

Most important: Do consider extreme wind loads at stowage locations and at crane stops. Design crane stop to tip crane. Consider localized loads at the stowage hardware and consider the potential misalignments in the tie-down hardware loading.

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Caveat: The following recommendations are based on conventional concrete crane girders supported on piles at three meters or less spacing.

They are intended to help the designer and are not intended to be used as a code. Following the criteria may not produce an acceptable result.

The designer and stakeholders need to study the issues and determine the acceptable risk.

Crane tipping: We do not know of any case where the wheel loads resulting from a tipped crane have damaged a wharf.

Be aware that high wheel loads may occur, but do not design for this loading unless the wharf has some unusual conditions.

Crane collision: For vertical loads, see the “crane tipping” section above. For lateral loads, design the crane end stops and crane girders for the load that tips the crane because designing for the rated bumper load is inadequate.

The cost of the crane end stop is insignificant.

Do not put a bumper on the crane stop. The bumper is usually ineffective during runaway collisions as it can only be tuned for a specific crane speed.

Derailing: The wharf adjacent to the rail should be able to support the load from a derailed crane leg. A competent support surface extending two meters on both sides of the rails will usually be adequate.

Earthquake: Vertical earthquake loads from the crane should not be considered in wharf girder design. For lateral loads, the interaction between the wharf and the crane should be considered, particularly when cranes are spaced closely, when significant ballast is used low in the crane, or when large rail gages are used.

It is not practical to expect a flexible crane in the trolley travel direction since operations usually require a crane natural period of 1.5 seconds or less.

Wind: Design the crane girders at the stowage location considering the extreme wheel loading, and keep in mind that there is a chance that the design loads will be exceeded. Consider the duration of the storm when determining the design soil capacity.

Design the tie-downs considering the misalignments from construction tolerances, crane movement, and gaps between the tie-down system components.

Provide deep stowage sockets so that if the crane lifts, the pin will remain engaged in the socket. Provide a locking mechanism on the crane stowage pin to keep the pin fully extended. These are particularly important for cranes without tie-downs.

Summary

Some extreme wharf loads are considered in the girder design and some are not

Extreme wharf girder loads occur more frequently than most people realize

The design extreme wind loading is more likely to occur than not to occur

Most extreme loads are of short duration

Some extreme loads are not as extreme as they seem

Localized extreme loads on stowage sockets and tie-downs require special consideration

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Main Street Bridge, Jacksonville (cityscape in background)

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Author: Erik Soderberg

Editor: Patrick McCarthy

Principal: Erik Soderberg

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