Seismic Guidelines for Container Cranes

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My name is Erik Soderberg. I am a licensed California Structural Engineer. I graduated from Virginia Tech University in 1992 and the University of Texas in 1994, and I have been working for Liftech ever since. I have worked on the designs of container crane structures, bulk loaders, hydraulic excavators, wharves, buildings, among other things

Topics

- Historical crane seismic performance and design criteria
- Crane evolution
- Expected seismic performance of modern Jumbo cranes
- Changes to crane design criteria
- Changes to crane performance requirements
- Considerations for existing cranes

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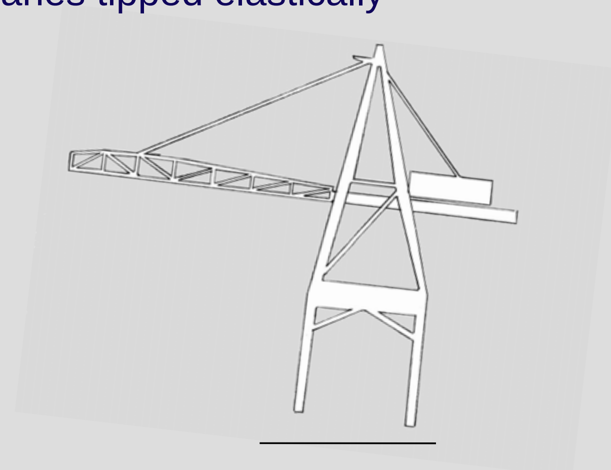
Early Seismic Design Requirements

- Pre 2006 – Force-based design – elastic response for 0.2g lateral loading
- Cranes tipped elastically



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Early on, the industry studied the seismic loading issue and determined that the cranes could tip with only elastic strains, that is without damage. The seismic loading was not significant to the crane structure. Minimal seismic design loads were prescribed to ensure reasonable lateral strength.

Historic Seismic Performance

Typical Kobe - Liquefaction

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Historically, when supports have not failed, cranes have performed well in earthquakes, the cranes lift from the rails disrupting the buildup of motion in the crane structure.

50’ gage cranes have come off of their gantry rails with little damage.

In Kobe, the wharf foundations failed causing significant damage to some cranes.

Crane Evolution

Circa 1970
50’ gage

Modern Jumbo
100’ gage

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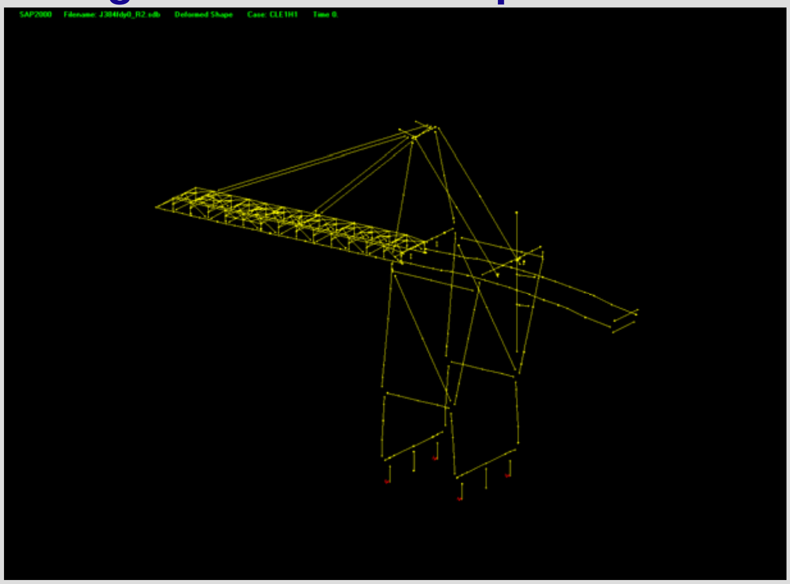
Recent studies indicate that the seismic risk to container cranes has increased.

What changed?

Cranes are larger and heavier. The rail gage has increased to 100’ or more, making the cranes more stable.

50’ Gage Crane CLE Response



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This and the next slide contains videos of time history analyses for a 50’ and a 100’ gage container crane.

This is a time history analysis of a 50’ gage crane subjected to one of the Port of Los Angeles time histories for a contingency level earthquake (CLE) having a mean return interval of 475 years.

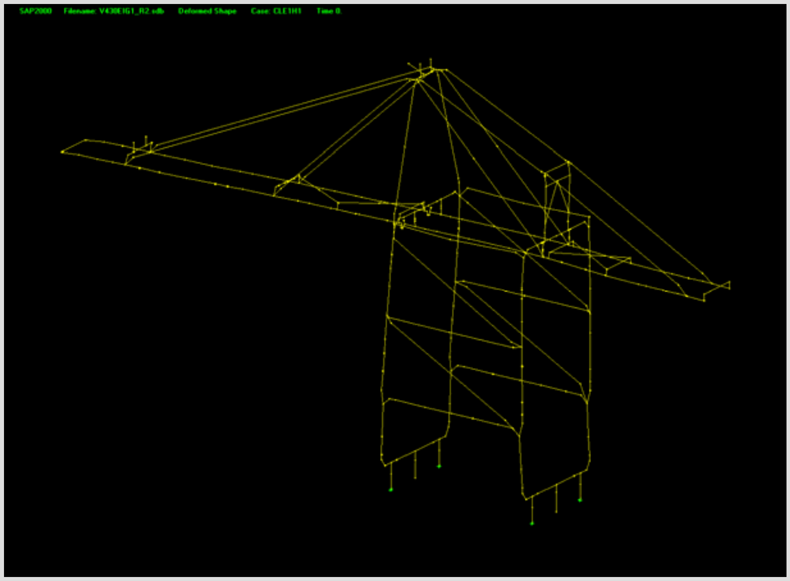
In the analysis, the crane is modeled on the Port of Los Angeles Berth 100, a wharf representative of many of the wharves recently constructed on the West Coast.

Only the accelerations in the trolley travel direction are applied in the model.

Due to modeling limitations, the boundary elements will stretch when the crane lifts, so focus on the sill beams.

Notice how often the crane lifts from the rails.

100’ Gage Crane CLE Response



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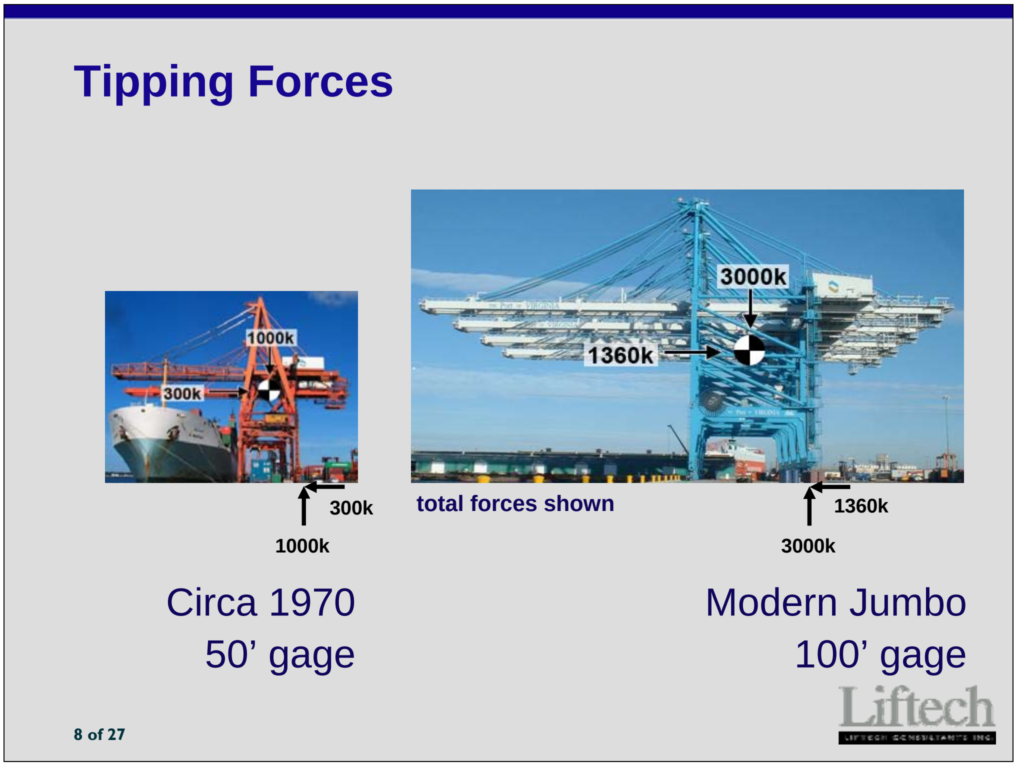
This is a model of a recent 100’ gage crane. It is modeled on the same wharf and analyzed using the same acceleration time history. The crane is more stable and only lifts from the rails after a large lateral load develops.



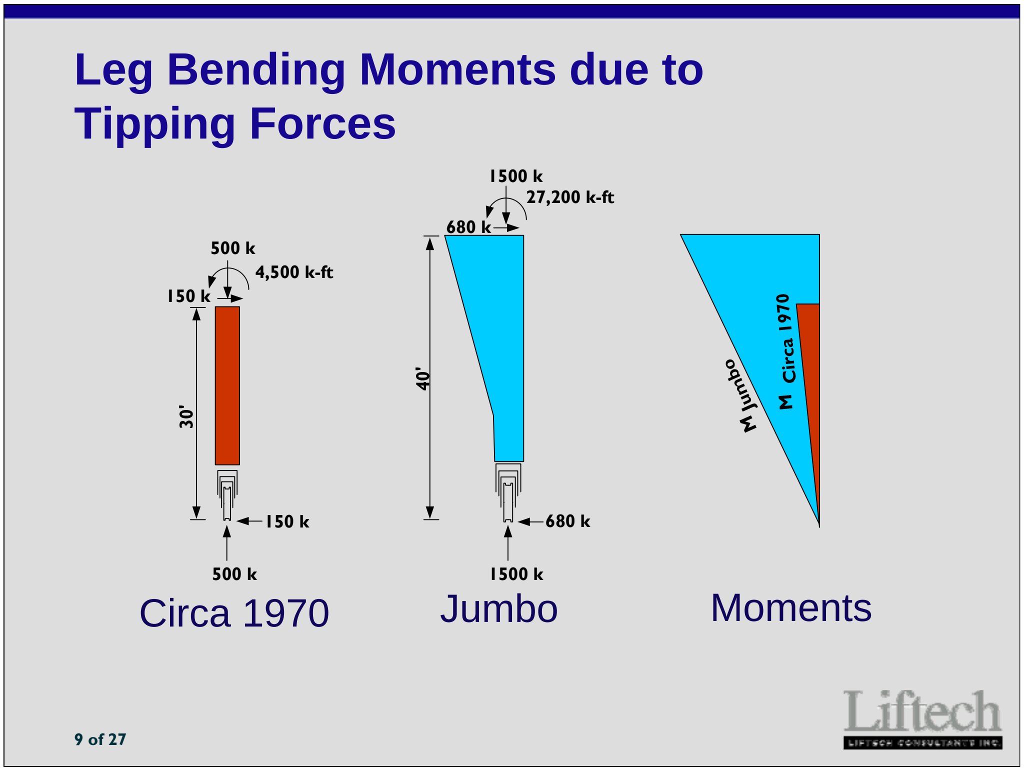
When a crane tips, all of the load is resisted by one side of the portal frame and will resist the reaction shown. The reaction on the 100’ gage crane is significantly larger due to the increased crane mass and stability.

If tie-downs are engaged, even larger forces can develop in a crane. Tie-downs are undesirable in high seismicity regions.

There are no tie-downs on West Coast jumbo cranes.

Notice that 300 k = 0.3 g

1360 k = 0.45 g

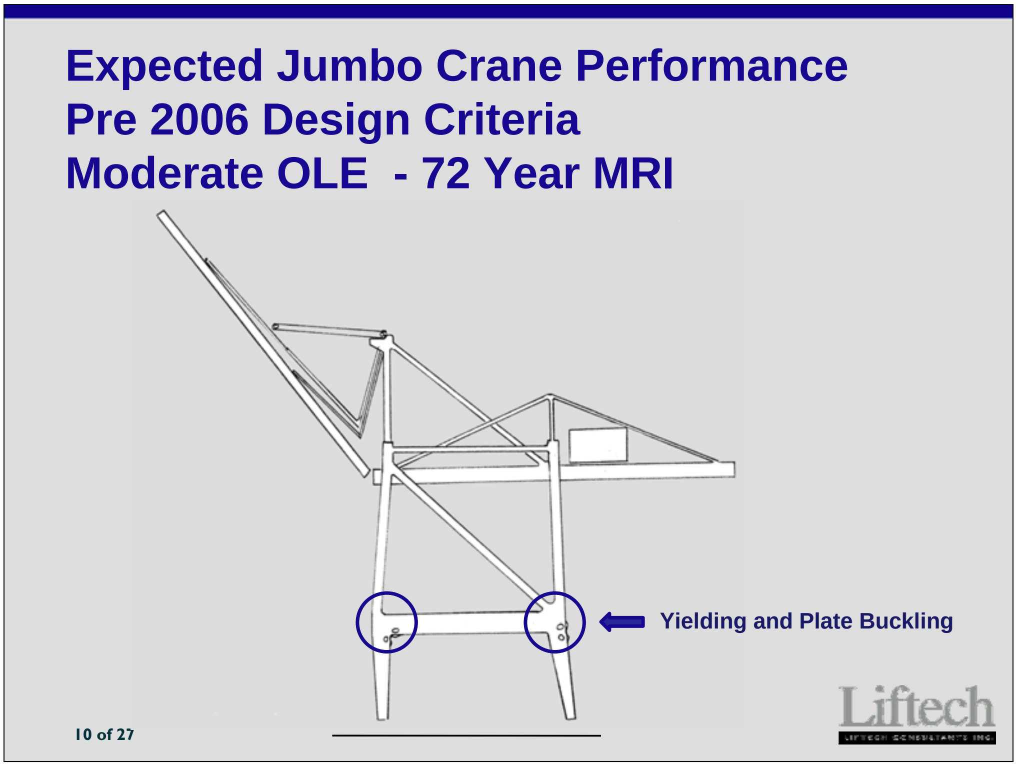


Although the legs of Jumbo cranes are stronger, the forces are even larger.

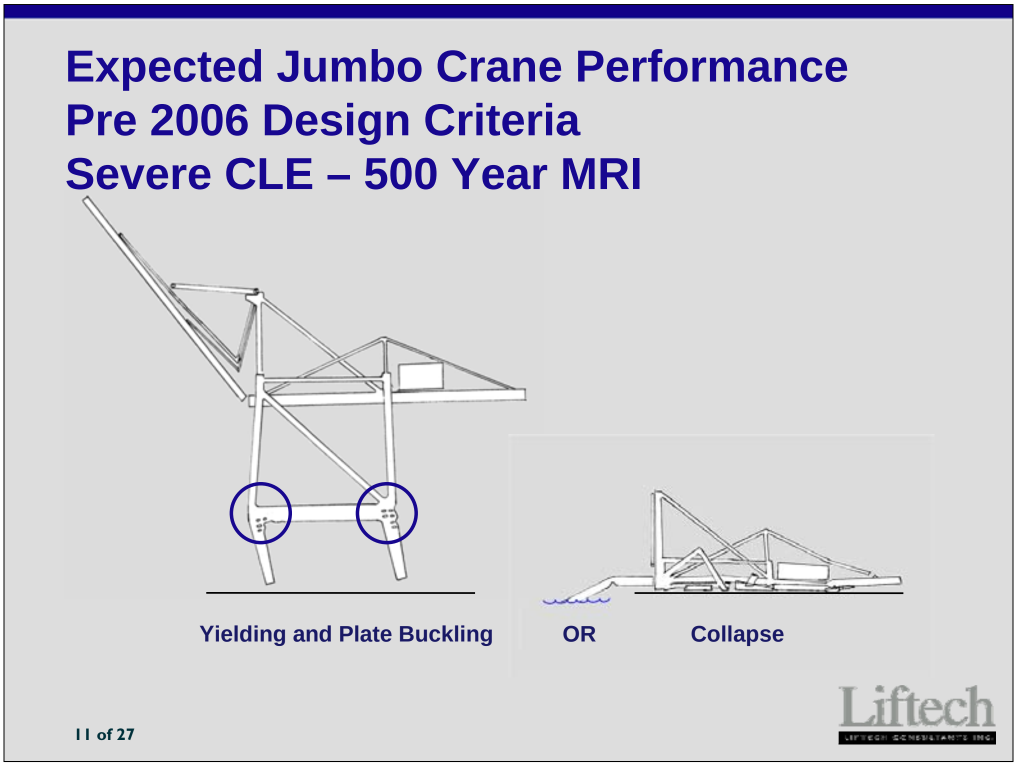
This slide presents the tipping forces and moments on one leg for the circa 1970's crane and the modern jumbo crane.

In addition to the larger forces, the clearance under the portal beam is larger. Combining these effects, the moments in the modern crane's legs are significantly larger.

Although the older cranes had smaller leg sections, the leg was usually strong enough to carry the tipped crane elastically, that is without damage. Most modern 100' gage cranes, particularly in areas with low storm wind speeds will be damaged before tipping.



Jumbo cranes designed to the pre-2006 design criteria are expected to experience yielding and plate buckling at the leg to portal connection in the leg, portal beam, or both in the moderate Operating Level Earthquake (OLE).



Jumbo cranes designed to the pre-2006 design criteria are expected to experience significant yielding and plate buckling at the leg to portal connection in the leg, portal beam, or both, and possibly collapse in the more severe Contingency Level Earthquake (CLE). Collapse is dependent on how well the leg-portal joint will perform under multiple cycles of loading.

Liftech Post 2006 Crane Design Criteria

Operating Level Earthquake:
- Elastic strains – no damage to crane

Contingency Level Earthquake:
- Tipping load – no damage to crane
- Ductile yielding – some damage to crane
- Isolation – no damage to crane

Reference: http://www.liftech.net/LiftechDesignNotebook/designcriteria.pdf

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Current Liftech crane specifications require the crane remain elastic in the OLE, or operating level earthquake, and require that the crane remain stable in the CLE or contingency level earthquake.

Similar to the earlier criteria, no tie-downs are permitted on the West Coast.

Current and Upcoming Requirements

Standard	Expected Adoption Date	Required Crane Seismic Performance	
		Minor Damage in 72 Year MRI Earthquake	No Collapse in Largest Design Earthquake
ASCE Seismic Design Standard for New Piers and Wharves	2010		X
Port of Los Angeles	2007	X	X
Port of Long Beach	2009		See note 2
Port of Oakland	2008		X
Port of Tacoma	2009	X	

Notes:
1. Based on conversations with Port personnel and published materials.
2. Port of Long Beach currently does not have a standard that specifically addresses crane performance but requires that the crane be designed to not collapse based on the requirements of the California Building Code.

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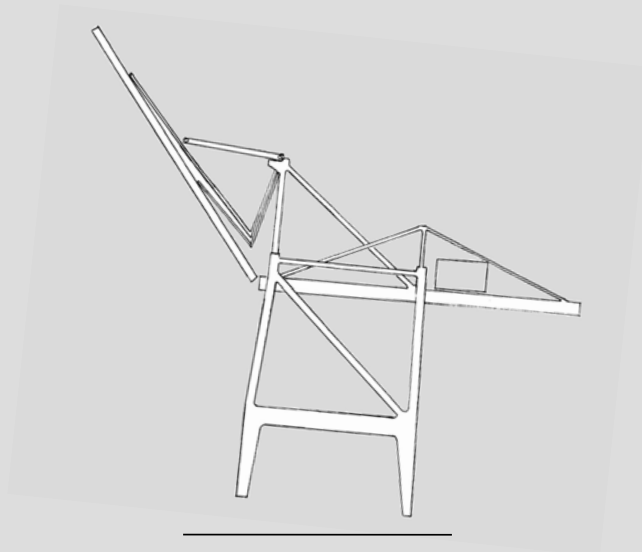
The good news is that the industry has recognized the increased seismic risk to cranes and has begun to specify performance requirements for new cranes.

How the requirements are specified is changing due to the relationships between the stakeholders.

The upcoming ASCE seismic standard will simplify how these requirements are applied.

Design for Tipping



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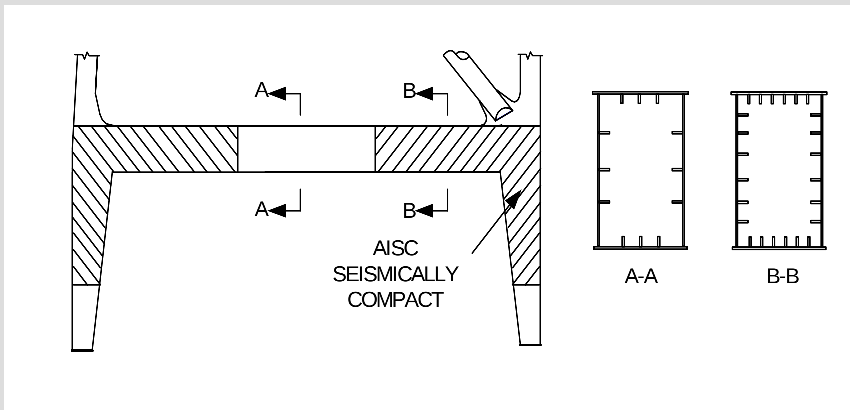
Designing the crane to tip elastically is a good option for new cranes, particularly those in typhoon wind regions where the portal frame is nearly strong enough to carry the tipped crane anyway.

If tie-downs are in place, the crane will not tip and large forces may develop in the structure.

In 2008, relative to the pre-2006 seismic design criteria, the additional cost to design and provide cranes that tip elastically in a non-hurricane region to tip was about $180,000 per crane, about 2% of the crane cost. The additional crane weight was less than 5%. The increase in the crane girder design load was less than 3%.

For a project this year in a hurricane region, relative to the pre-2006 seismic design criteria, the additional material is estimated at 25 t and additional cost of less than $100,000 a crane.

Design for Ductile Yielding



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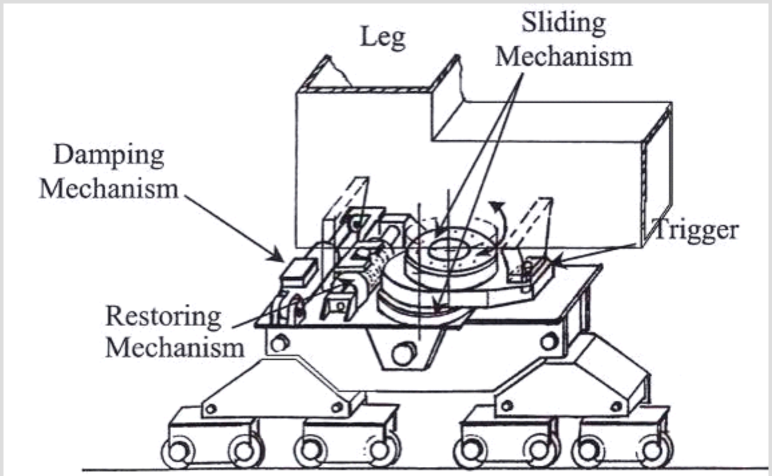
Designing for ductile yielding requires that the thin walled plate sections be made seismically compact in accordance with AISC. This requires significantly more stiffeners, however the increased cost and weight will be insignificant, estimated at less than 1%.

Design For Isolation

Isolation Between Main Equalizer and Sill Beam



Source: Mitsubishi Heavy Industries

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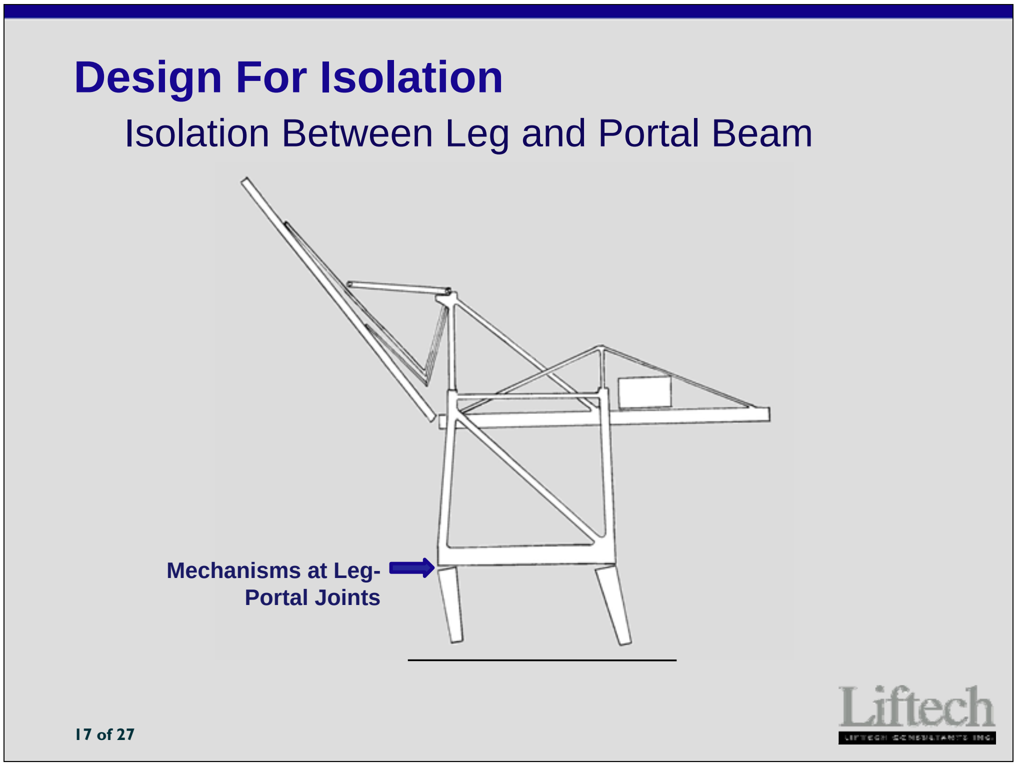
Designing for isolation is the most expensive option. If done properly it will result in the least damage. It is practical to design a mechanism that will prevent damage in the CLE.

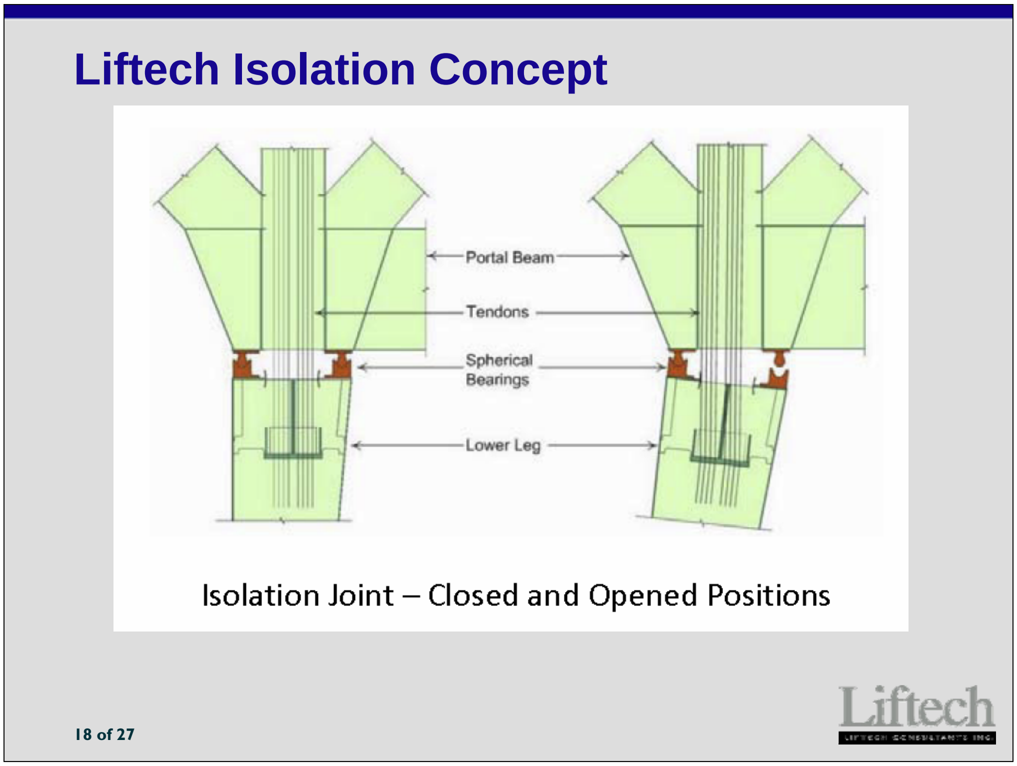
MHI has built a crane with the mechanism shown. This mechanism permits the gantrying system to displace with the wharf while the crane structure above the mechanism remains isolated from the movement.

The MHI mechanism requires damping, trigger, sliding, and restoring mechanisms.



Concepts by IHI and Liftech provides an isolation hinge between the lower legs and the portal beam.

This type of mechanism requires no damping, trigger, sliding, or restoring mechanisms.



The Liftech concept uses bridge prestressing tendons and hardware to tension the lower leg to the portal beam joint. The tendons are sized and tensioned so that the joint does not open during operating conditions, but does open during seismic events. The joint may open during hurricane winds.

What about Existing Cranes?

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The increased seismic risk can be addressed at little additional cost for new cranes.

What about existing cranes?

Retrofit Questions

What is the seismic risk?

What performance criteria are acceptable?

At what magnitude earthquake is collapse acceptable?

Should different criteria be used for different cranes?

Should cranes be upgraded when the wharf is upgraded?

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Stakeholders should evaluate the risk and consider what damage is tolerable for cranes individually and for the port as a whole.

Some questions should be considered.

Factors Affecting Seismic Risk

Location – Seismicity

Stability – Rail Gage

Portal Strength

Mass

Portal Ductility

Portal Stiffness

Trolley Mass

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How does one evaluate seismic risk for container cranes?

Some factors significant to seismic risk are discussed below.

1. The seismicity at the crane's location is a significant factor. Most West Coast Ports are located in areas of high seismicity and have similar seismic risks.

2. The rail gage is a significant factor. The greater the gage, the more stable the crane is, the greater the lateral forces that can develop in the crane structure, the greater the seismic risk.

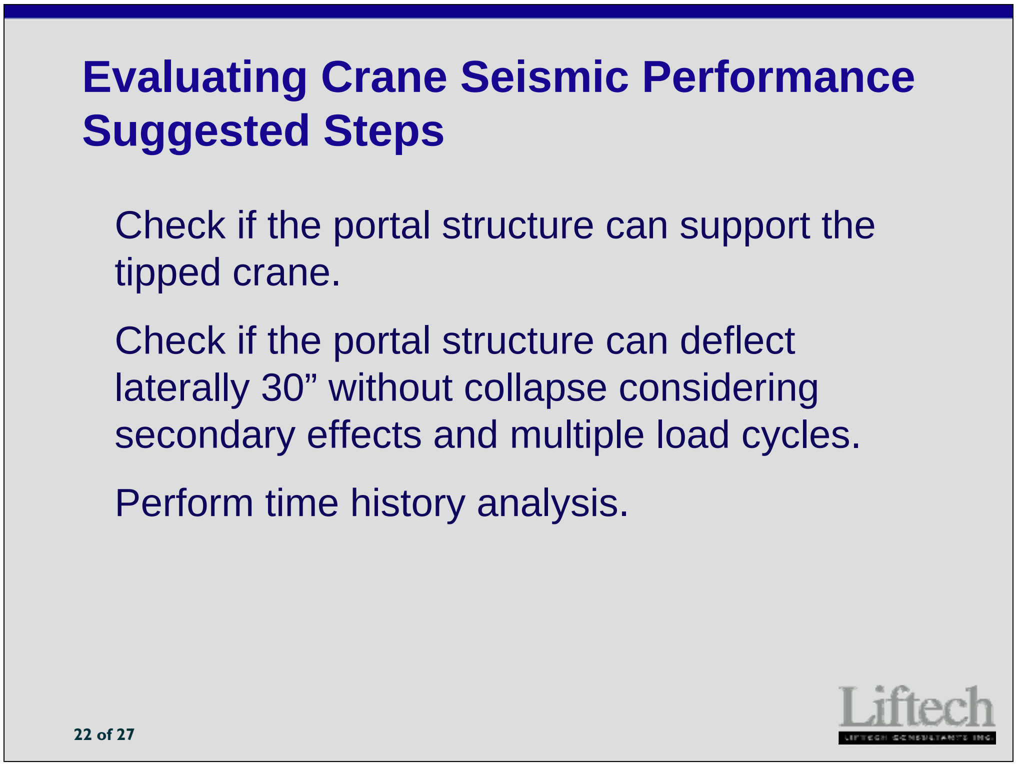
3. Ductility is the ability of the structure to deform after yielding without failing and while maintaining its strength. The greater its ductility, the lower the risk of damage.

4. The heavier the crane is, the greater the seismic forces and greater the risk.

5. The stronger the portal frame, the lower its risk

6. The more flexible the portal frame, the more the crane may deform before being damaged, the lower the seismic risk.

7. The heavier the trolley, the more it will dampen the crane excitation.



Some steps that are practical to evaluate the seismic performance of existing cranes are provided.

If the portal structure can support the tipped crane, the crane will likely perform well in an earthquake.

If the portal structure can deflect laterally 30” without collapsing, the crane may be damaged, but will probably perform well in even large earthquakes. Be sure to consider secondary effects and strength degradation from multiple cycles of loading.

Otherwise perform a time history analysis to determine more accurately what forces and deformations will occur.

A structural engineer can evaluate expected performance of the portal frame. A crane expert is not required.

Retrofit Options

Option	Advantages	Disadvantages	Comment
Modify structure to tip elastically	Structure can tolerate larger lateral load without damage	Imposes the largest lateral load on wharf	Less costly if the clearance under portal can be decreased
Improve ductility by adding stiffeners	Maintains portal clearance	Plastic yielding will require repairs	Can also strengthen the portal frame to tip without damage
Add isolation mechanism	No significant damage, limits lateral loads on crane and wharf, resilience	May be expensive	Less expensive if added with crane raise modification

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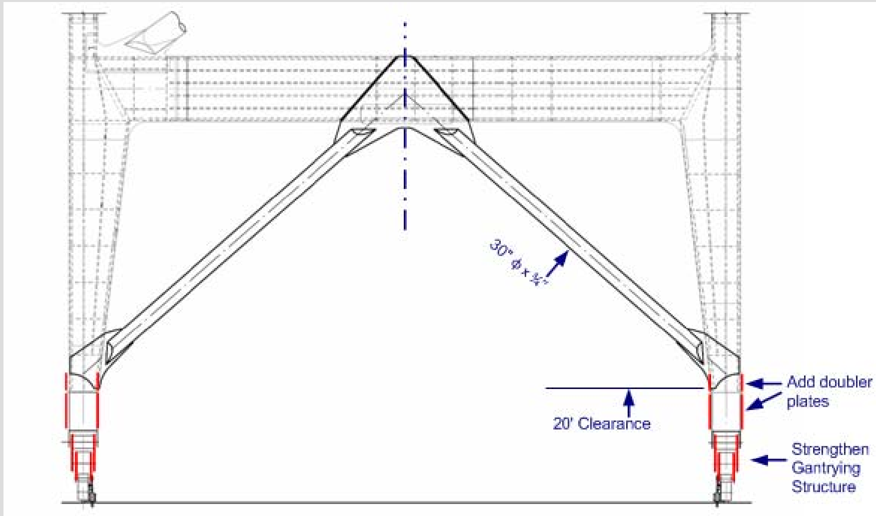
If crane retrofit is justified, choosing the right option depends on several factors.

If the portal clearance can be reduced, strengthening the portal by adding pipe braces will be practical.

If some damage can be tolerated, adding stiffeners to obtain ductility and strength is practical.

If the crane is being raised, adding an isolation mechanism may be practical.

Add Portal Braces – Tip Elastically



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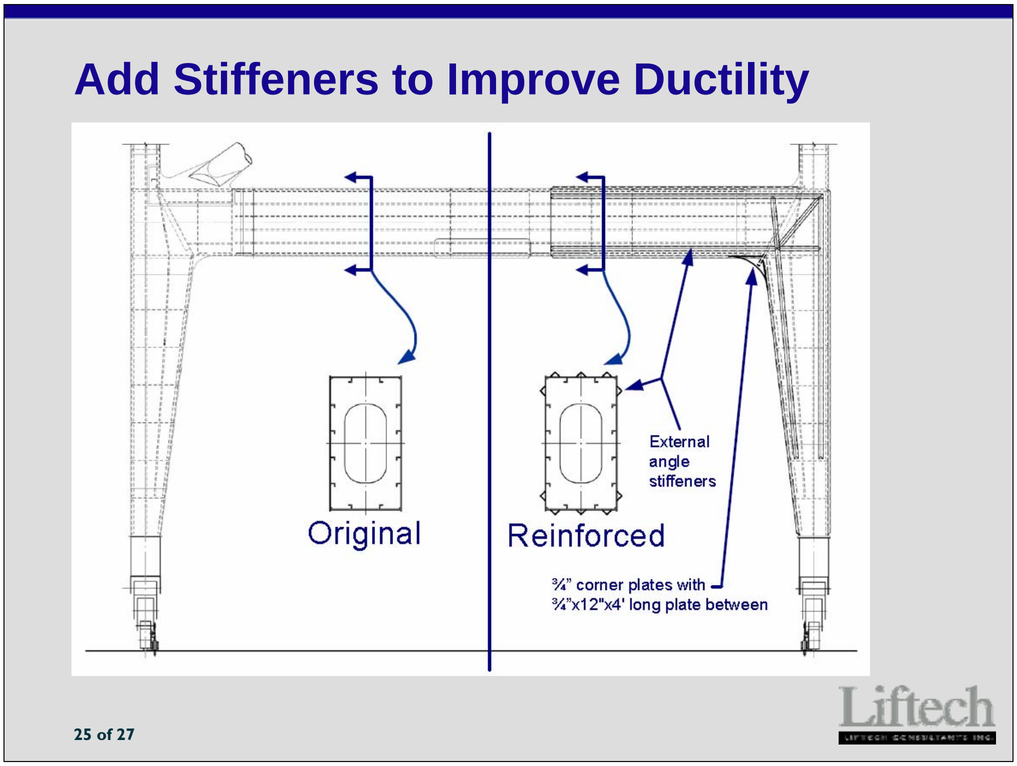
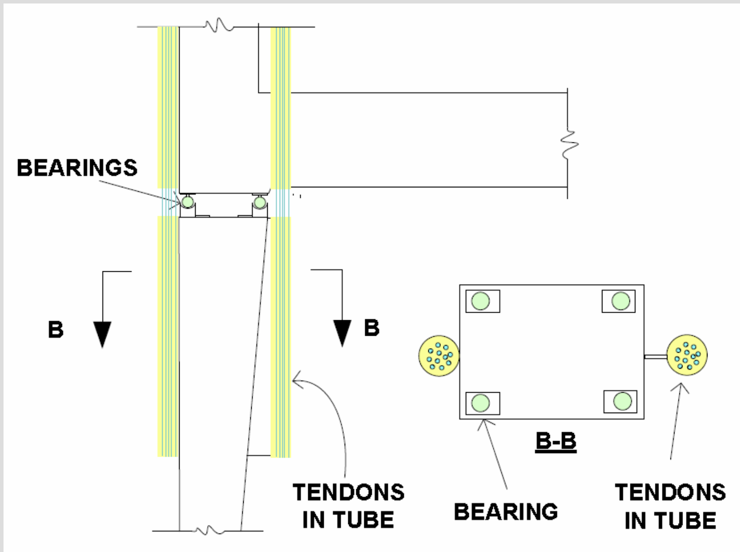
Designing the crane to tip is a good option, particularly if the clearance under the portal can be reduced. Pipe braces are the least expensive strengthening option, estimated at $300,000 per crane (2009) excluding downtime costs.



Adding stiffeners, particularly continuous stiffeners so the thin walled sections are compact in accordance with AISC will significantly improve the ductility of the portal frame box sections. This option is more practical for retrofit of an existing crane where the clearance under the portal beam must be maintained. This modification is estimated at about $500,000 per crane (2009) excluding downtime costs.

Notice that only the areas that are required to be ductile must meet the ductility detailing requirements.

Add Isolation Mechanism



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Adding a isolation is the most expensive option. Cost estimates have not been made. This option will be most practical when a crane is being raised and leg sections are being added.

Summary

Early crane seismic design standards are not appropriate for modern Jumbo Cranes.

Several recent and pending standards adequately address seismic performance requirements for Jumbo Cranes.

Use state-of-the-art performance criteria when purchasing new cranes.

It is practical to evaluate seismic risk.

Retrofit is an option and is most practical when making other modifications.

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In summary, be aware that the seismic risk to cranes has increased as cranes have gotten larger.

Early crane seismic design standards may not be appropriate for modern cranes

Use current seismic design criteria when purchasing new cranes.

It is practical to evaluate the seismic risk to existing cranes. Seismicities are well known. A structural engineer can evaluate expected performance of the portal frame. A crane expert is not required.

If raising an existing crane, particularly one with a 100’ rail gage or larger, consider retrofit.

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