# Seismic Design of Container Cranes

## Port and Terminal Technology 2010

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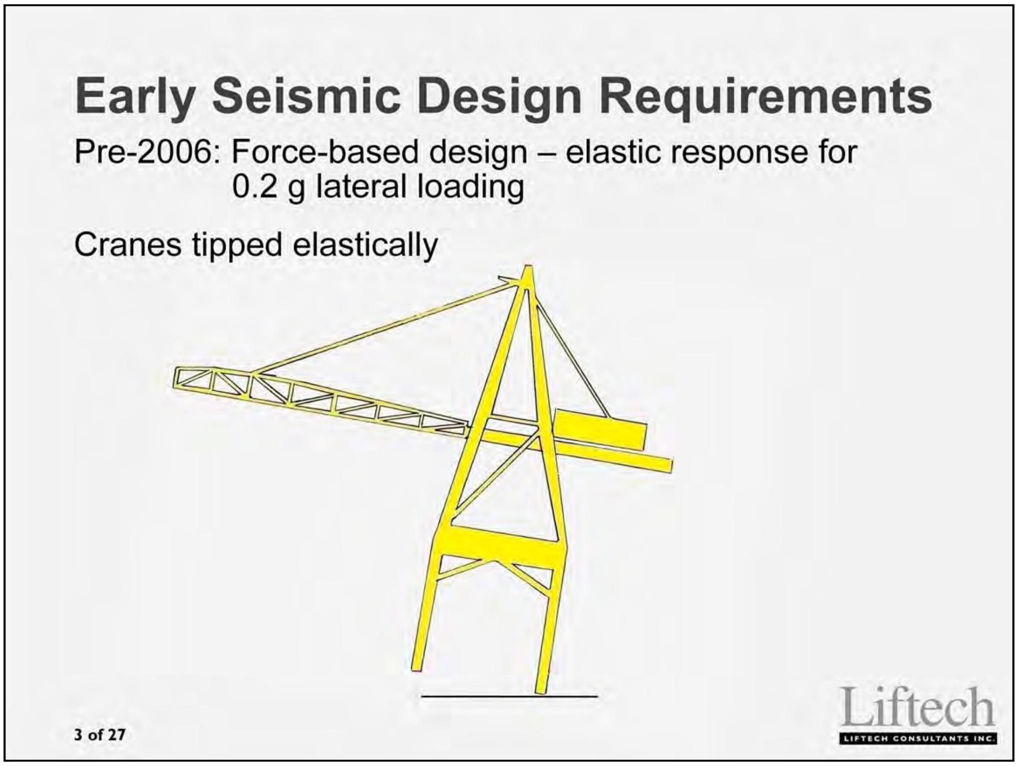
## Topics

- Historical crane seismic design criteria and performance
- Crane evolution
- Expected seismic performance of modern jumbo cranes
- Changes to crane design criteria and impact on crane weight and cost
- Approaches to evaluating existing cranes
- Retrofit options



In 2006, Liftech discovered some deficiencies in the container crane seismic criteria used in the industry. Since then, Liftech reported this finding to the industry and updated our seismic design criteria. Many cranes have been built to this criteria. In this presentation, I will discuss the following topics.




Early on, the industry studied the seismic loading issue and determined that the cranes could tip with only elastic strains, that is without damage. When the crane tips, the buildup in the response of the crane is disrupted, limiting the forces in that can develop in the crane structure.

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

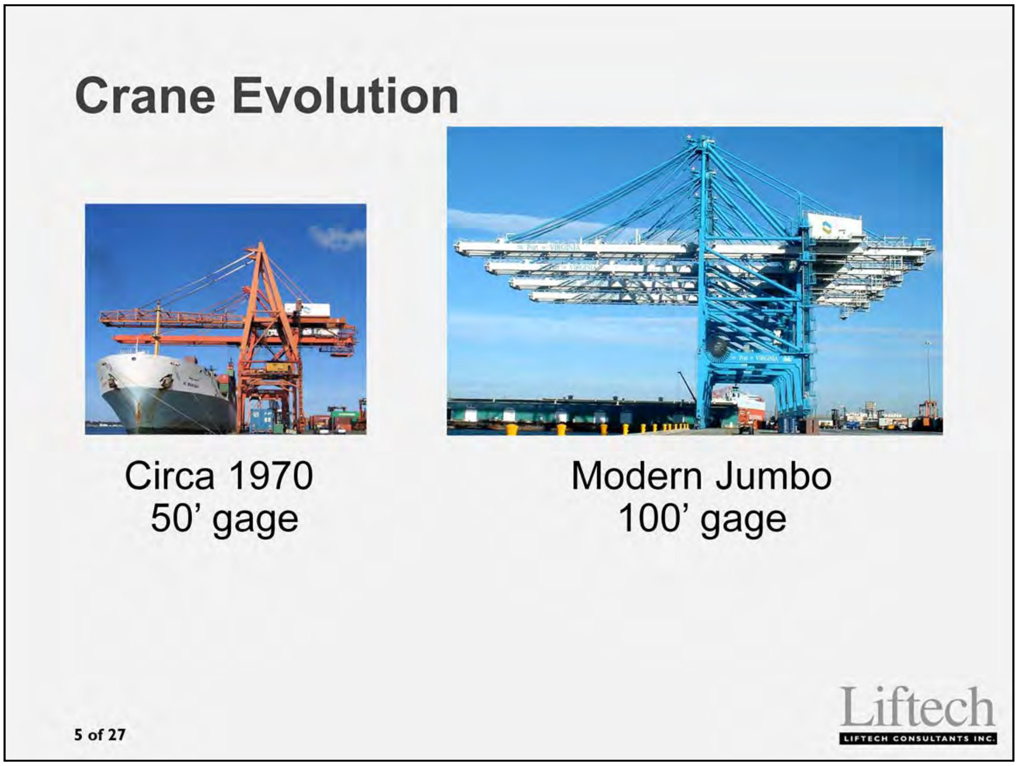
Kobe - Liquefaction

4 of 27

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.

Fifty foot (50') gage cranes have come off of their gantry rails with little damage. Cranes have been returned to the rails with little effort.

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



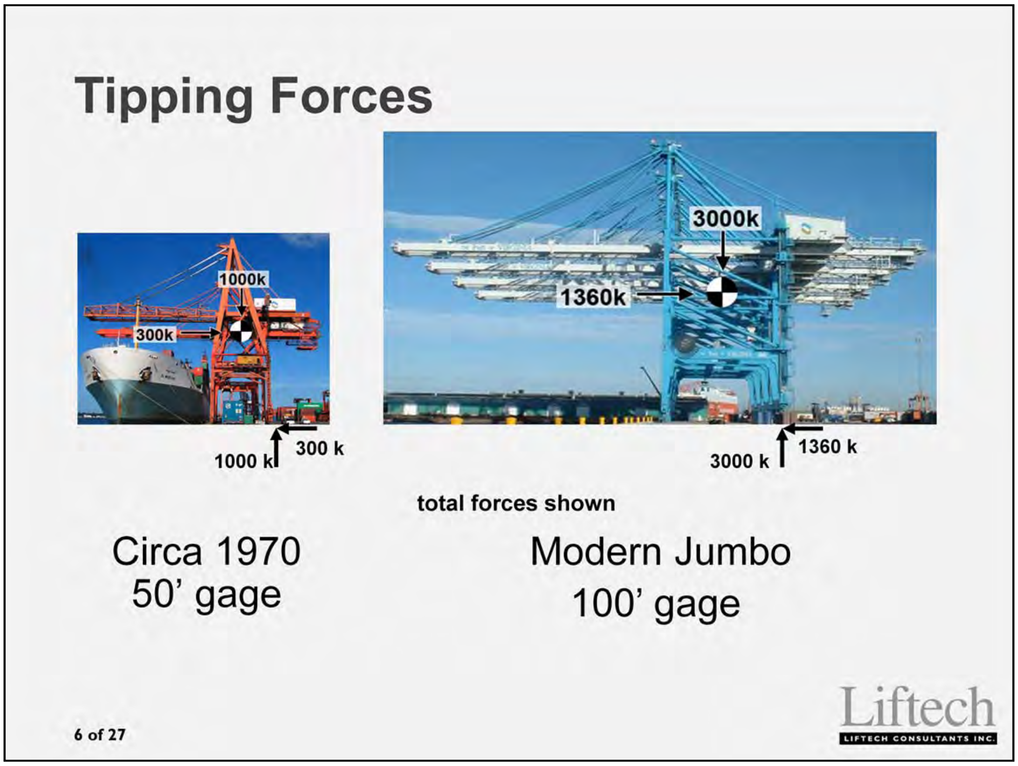

Recent studies indicate that the seismic risk to container cranes has increased.

What changed?

Cranes are larger and heavier.

The rail gage has increased to 100’ or more, making the cranes more stable.

The clearance under the portal beam has also increased.



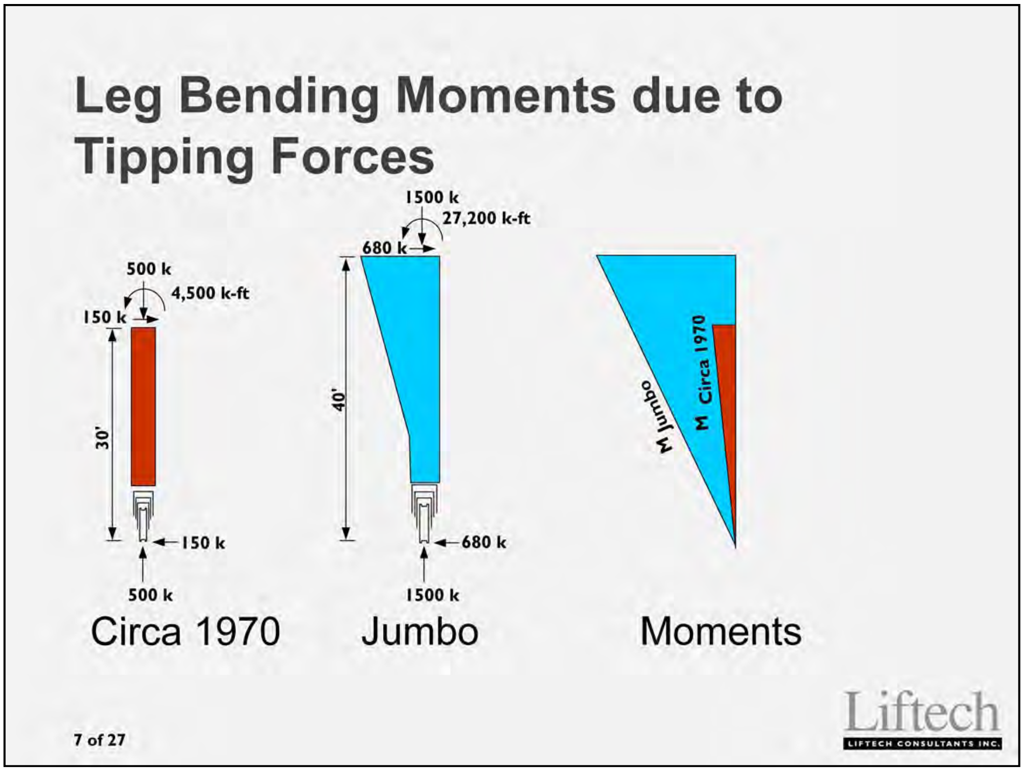

When a crane tips, all of the load is resisted by one side of the portal frame and will resist the reaction shown. The reaction on the 100' gage crane is significantly larger due to the increased crane mass and stability.

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

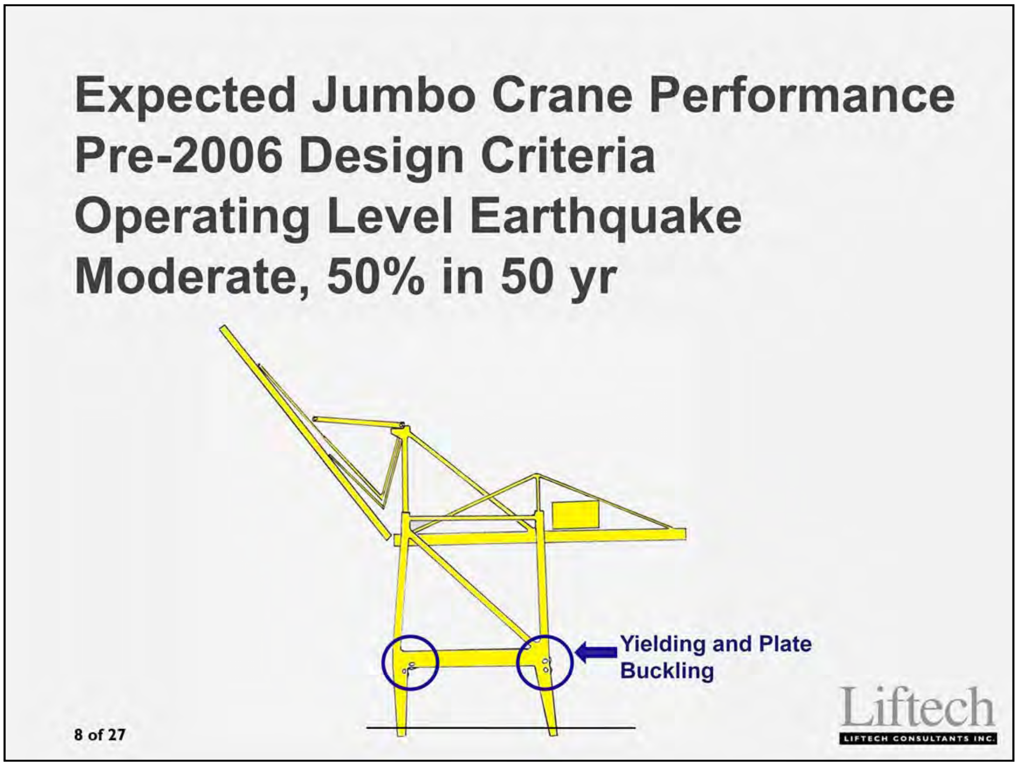



Although the legs of jumbo cranes are stronger, the forces are even larger.

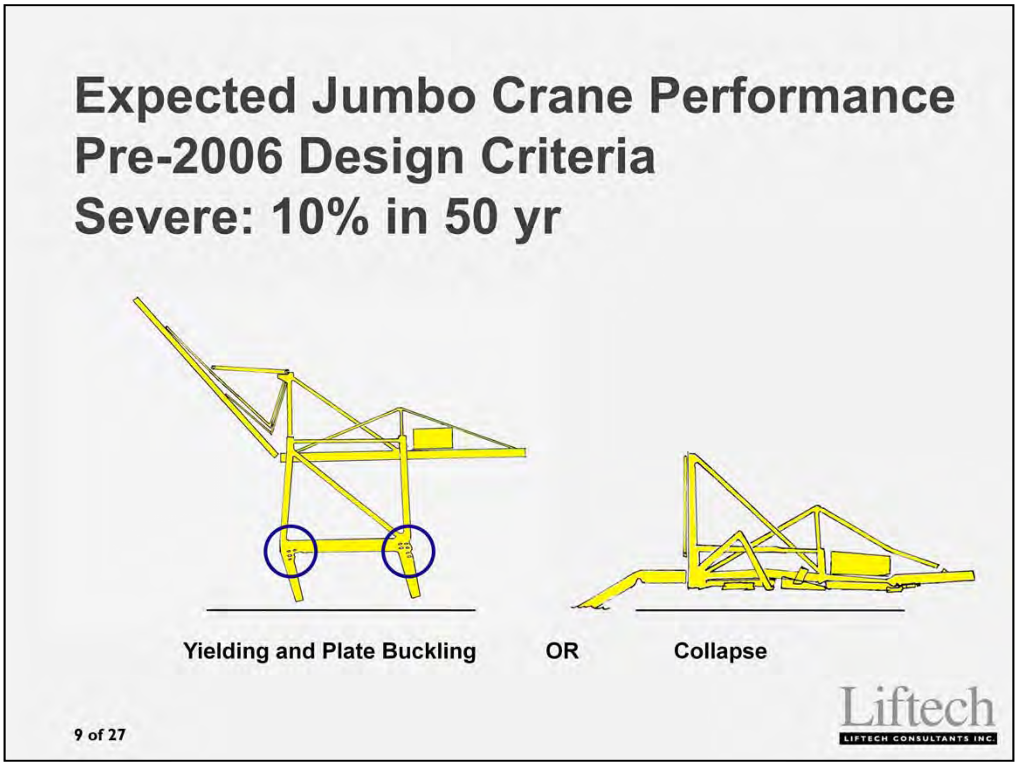
This slide presents the tipping forces and moments on one leg for the circa 1970's crane and the modern jumbo crane.

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.

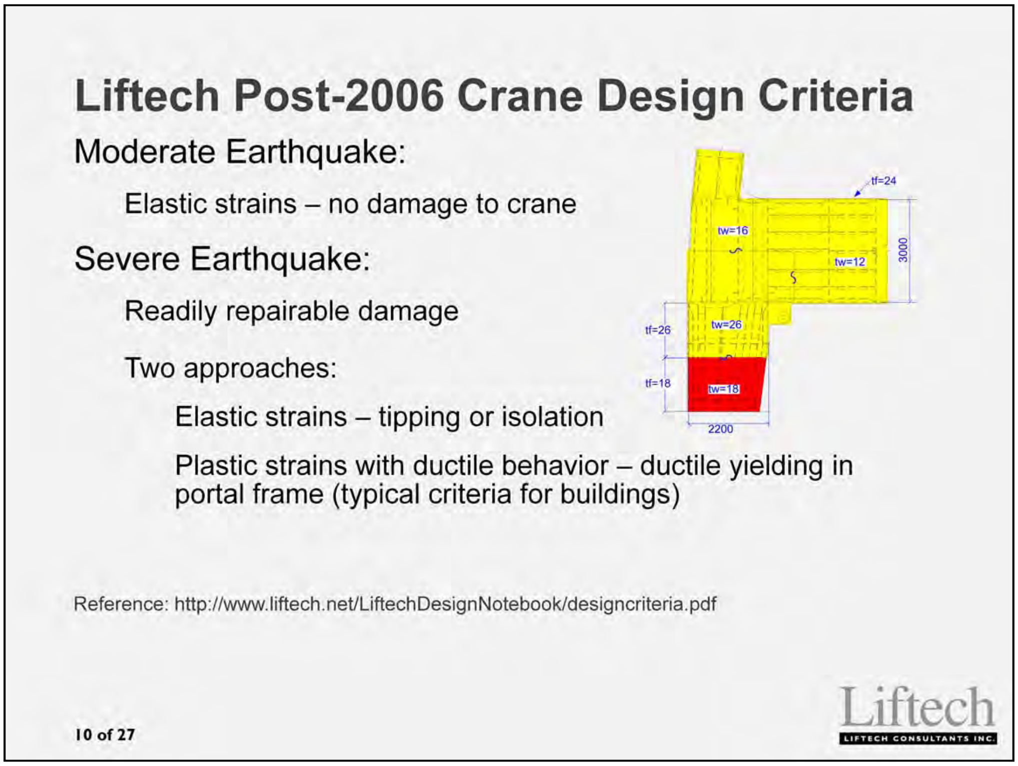
Although the older cranes had smaller leg sections, the leg was usually strong enough to carry the tipped crane elastically, that is without damage. Most modern 100' gage cranes, particularly in areas with low storm wind speeds, will be damaged before tipping.




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 typical West Coast moderate Operating Level Earthquake (OLE).

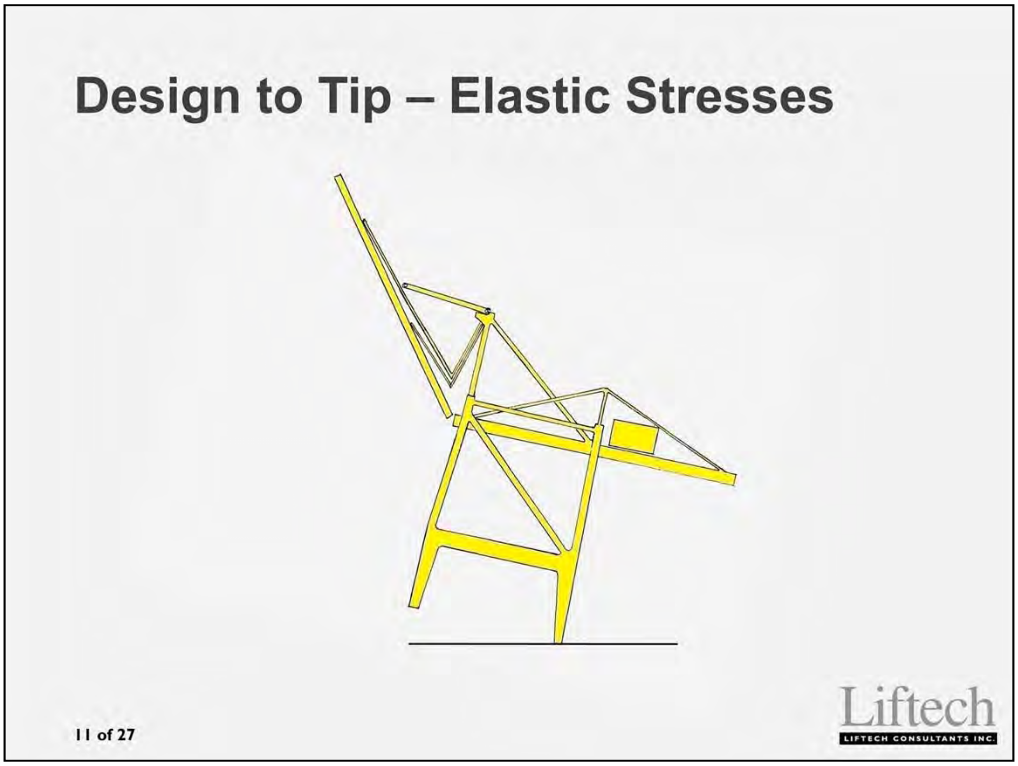



Jumbo cranes designed to the pre-2006 design criteria are expected to experience significant yielding and plate buckling at the leg to portal connection in the leg, portal beam, or both, and possibly collapse in the more severe West Coast Contingency Level Earthquake (CLE). Collapse is dependent upon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




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

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

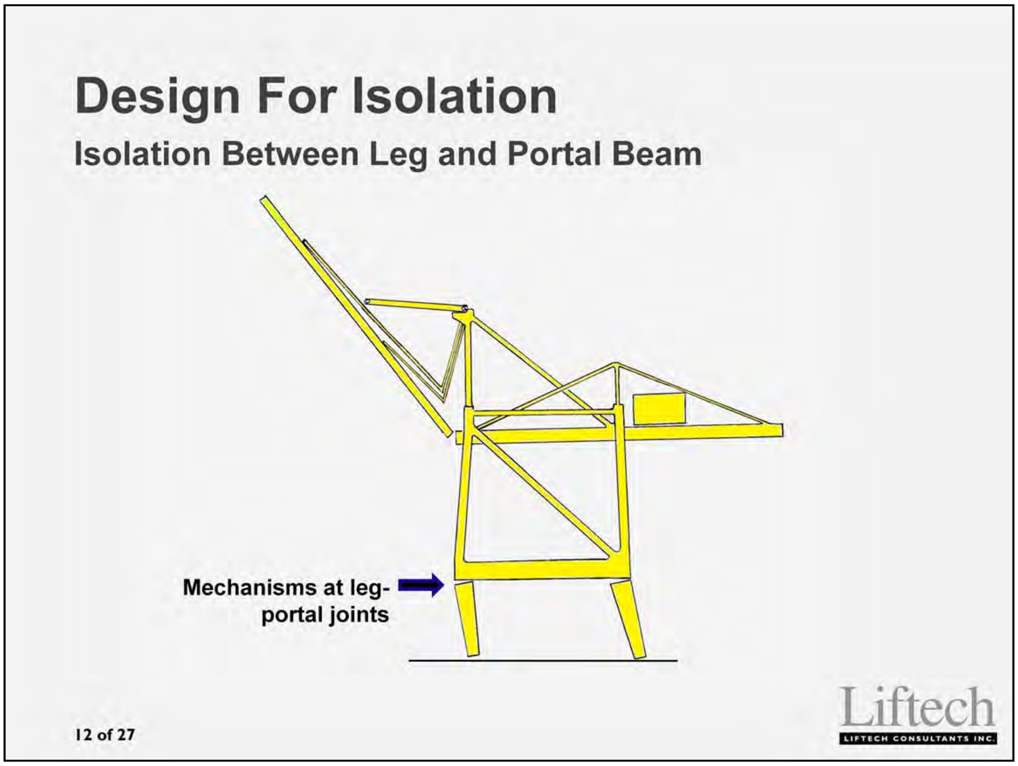



Designing the crane to tip elastically is a good option for new cranes, particularly those in typhoon wind regions where the portal frame is nearly strong enough to carry the tipped crane anyway.

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

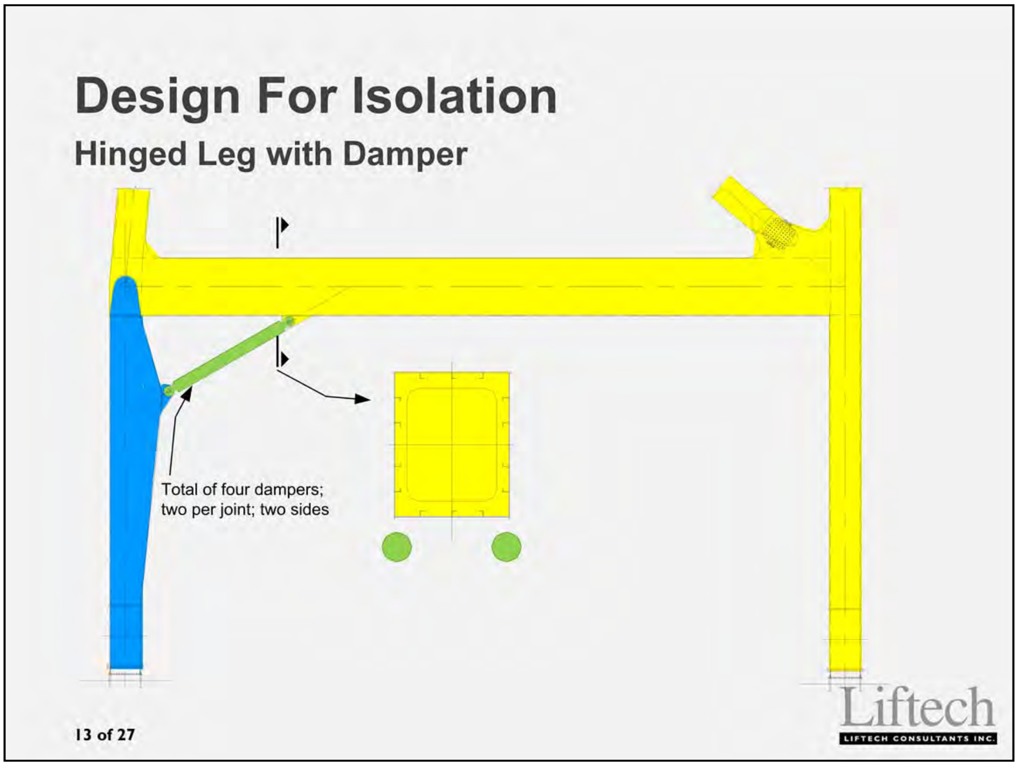
In 2008, relative to the pre-2006 seismic design criteria, the additional cost to design and provide cranes that tip elastically in a non-hurricane region was about $180,000 per crane, about 2% of the crane cost. The additional crane weight was less than 5%. The increase in the crane girder design load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



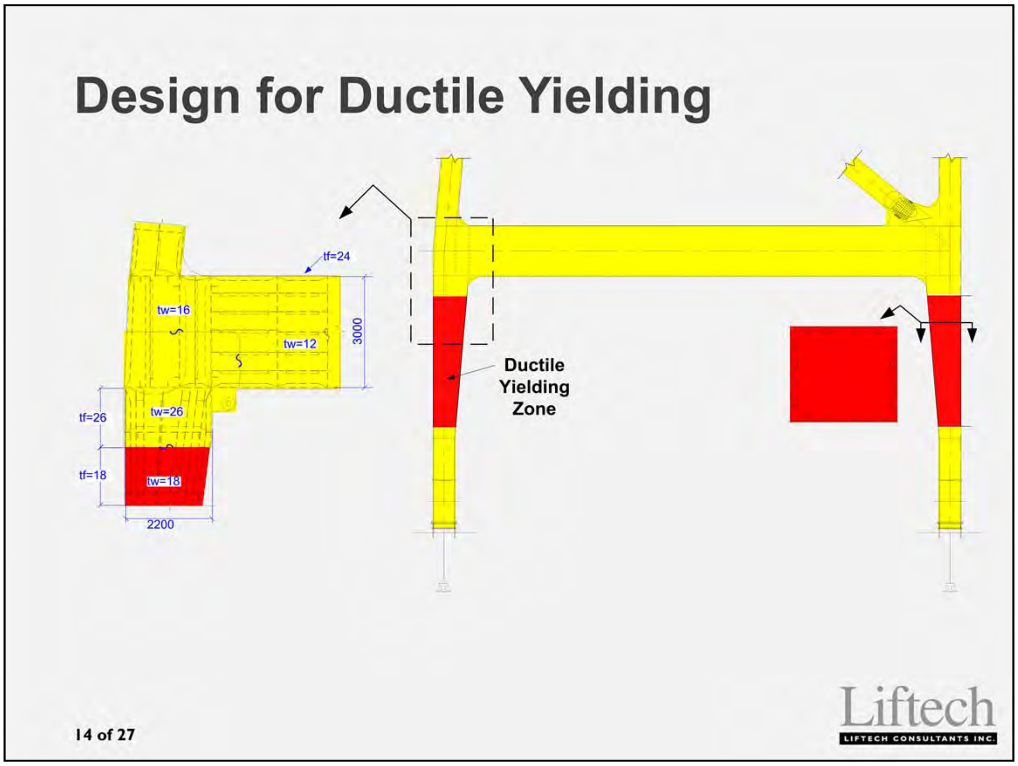

Concepts by IHI and Liftech provide an isolation hinge between the lower legs and the portal beam.

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

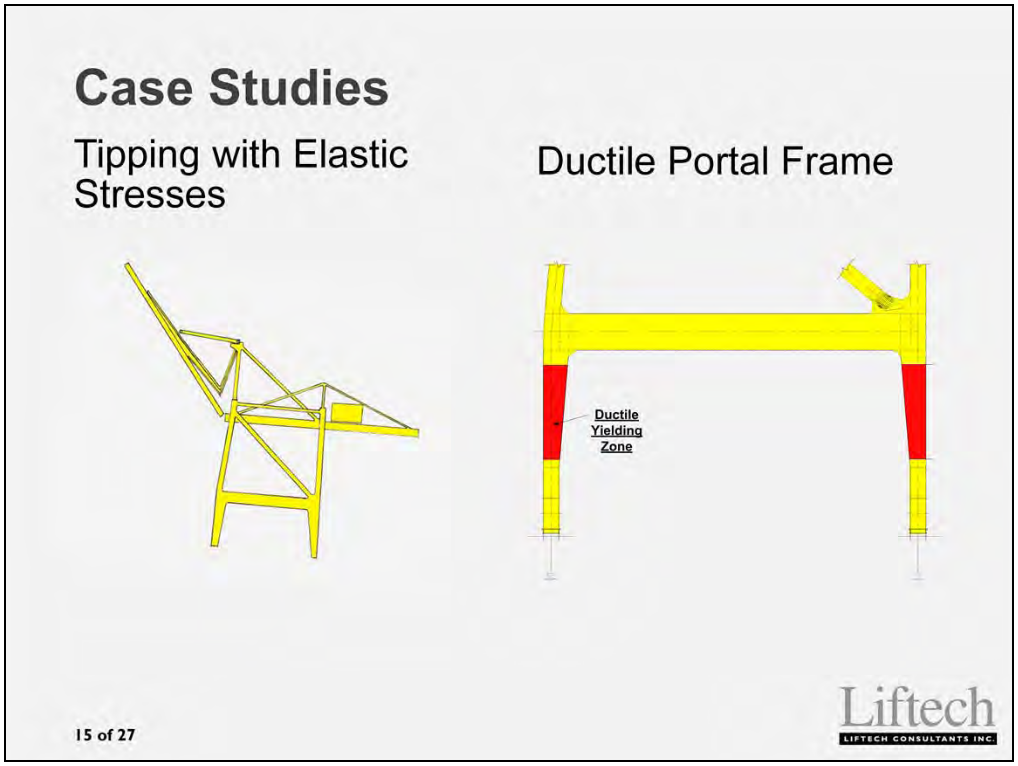



Liftech is currently developing a concept that uses hydraulic dampers to limit the crane movements and to keep the stresses in the crane structure elastic.

The damper will remain rigid and not engage until a large seismic force occurs. The damper will limit the response of the crane and the forces in the crane. The non-hinged leg will flex elastically and force the portal frame to its pre-earthquake geometry soon after the earthquake. Springs inside the damper can also help restore the geometry.

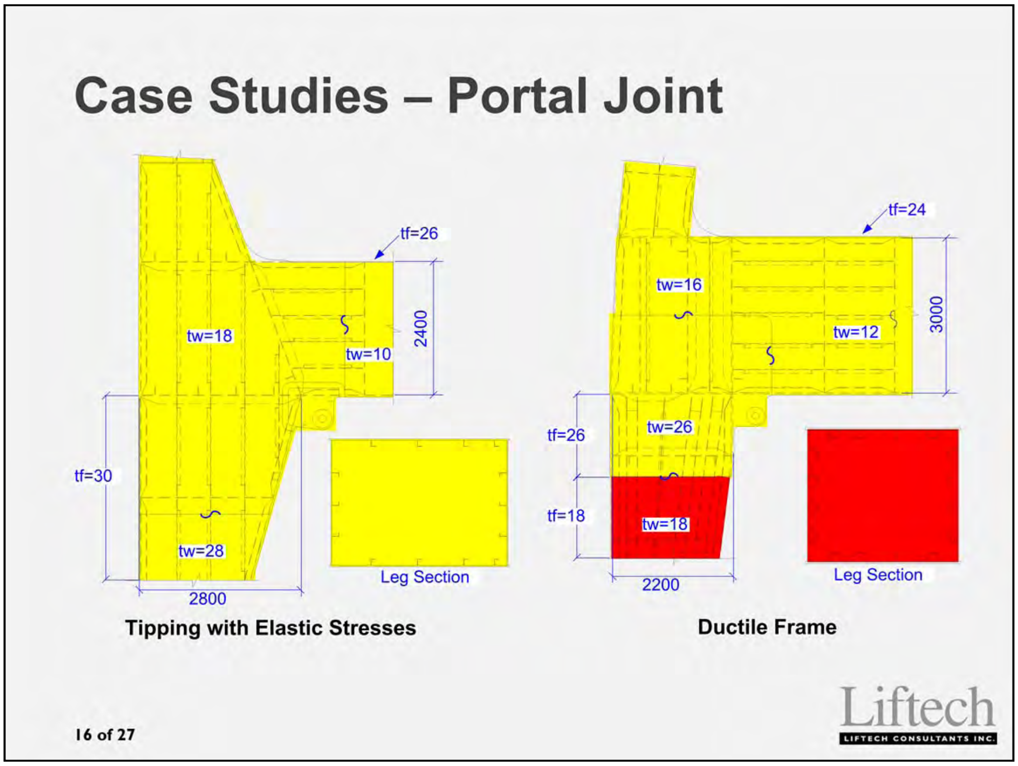



Designing for ductile yielding requires that the thin walled plate sections be made seismically compact in accordance with AISC. This requires significantly more stiffeners.




Two case studies are presented in the following slides. A 100' gage crane designed to tip, and a 100' gage crane with a portal frame that was recently built for the WBCT terminal at the Port of Los Angeles.

Many cranes have been built to tip elastically since Liftech updated their crane seismic design criteria. The ductile portal frame crane is the first designed to the updated Liftech criteria.




This slide presents the difference in portal design for the two cranes.

The crane designed to tip elastically has deeper, stronger leg sections.

The crane designed for ductile yielding has more closely spaced stiffeners. Additionally, U stiffeners are used to obtain torsionally stiff and strong cells within the yielding locations. A strong, compact T stiffener is used near the neutral axis of the section to help ensure that the axial strength is maintained through the yielded zone. The leg-portal connection is made much stronger than the yielding portion of the leg to ensure yielding only occurs where intended.

## Changes Relative to Crane Designed to Pre-2006 Criteria

| | Tipping with Elastic Stresses | Ductile Portal Frame |
|---|---|---|
| Added Cost | $250,000 about 3% | $120,000 about 1% |
| Added Weight | 60 t about 4% | 30-40 t 2-3 % |

17 of 27

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For the two projects discussed, the affect of the more stringent seismic criteria on cost and weight for both design methods is minor.

## What about Existing Cranes?

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 or when the crane structure is modified for other reasons?

18 of 27

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

What about existing cranes?

Liftech recommends that stakeholders evaluate the risk and consider what damage is tolerable for cranes individually and for the port as a whole.

We recommend stakeholders consider the following questions.

## Factors Affecting Seismic Risk

Location – Seismicity

Stability – Rail Gage

Portal Strength

Mass

Portal Ductility

Portal Stiffness

Trolley Mass

19 of 27

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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; the greater the lateral forces that can develop in the crane structure, the greater the seismic risk.

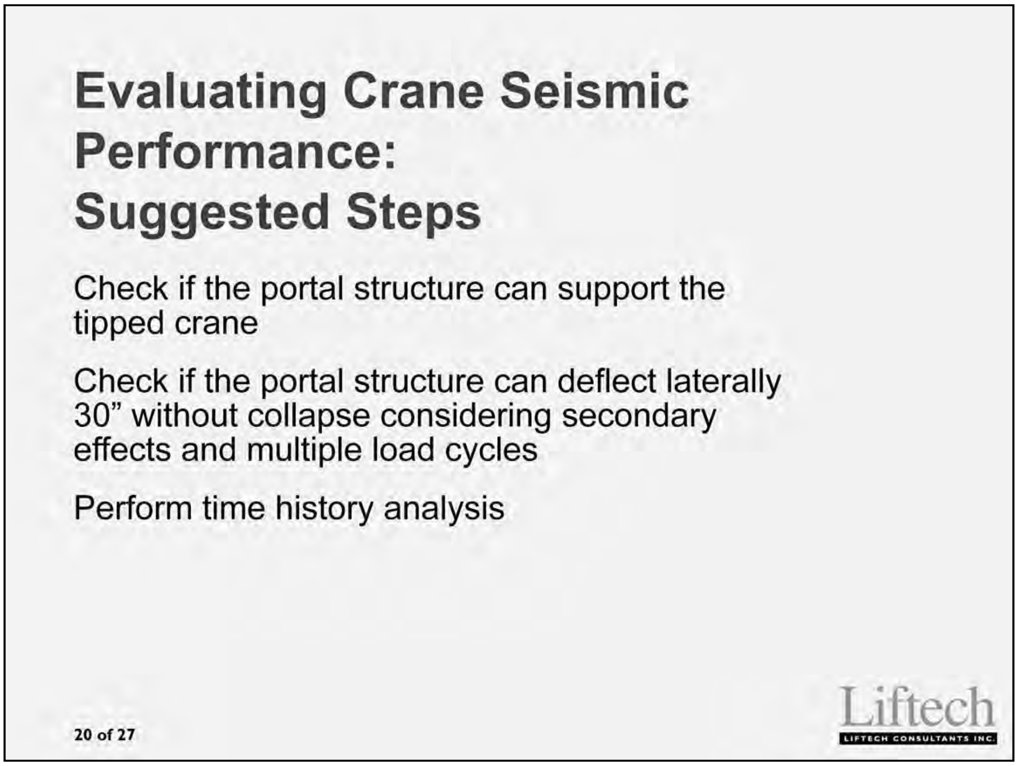
3. Ductility is the ability of the structure to deform after yielding without failing and while maintaining adequate stiffness and strength. The greater its ductility, the lower the risk of damage.

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

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

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

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




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 larger 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 |
|---|---|---|---|
| Strengthen 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 |
| Stiffen to obtain seismic ductility | Maintains portal clearance | Plastic yielding will require repairs | Can also strengthen the portal frame to tip without damage |
| Install isolation | No significant damage, limits lateral loads on crane and wharf, resilience | May be expensive | Less expensive if added with crane raise modification |

21 of 27

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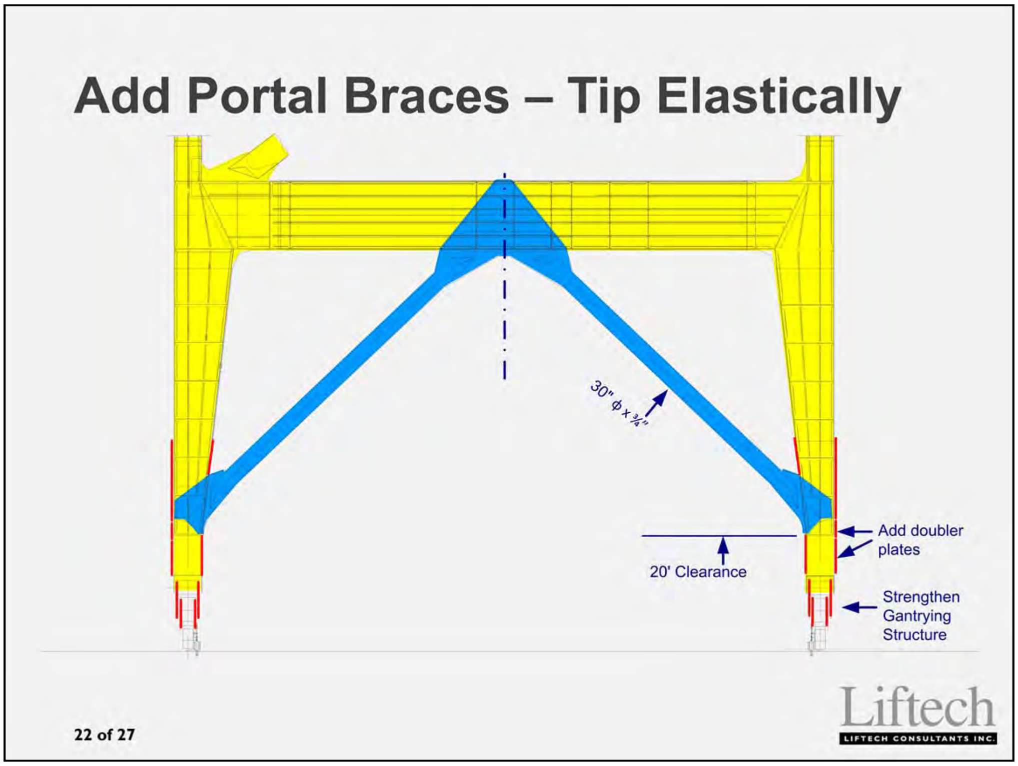
If crane retrofit is justified, choosing the right option depends on several factors.

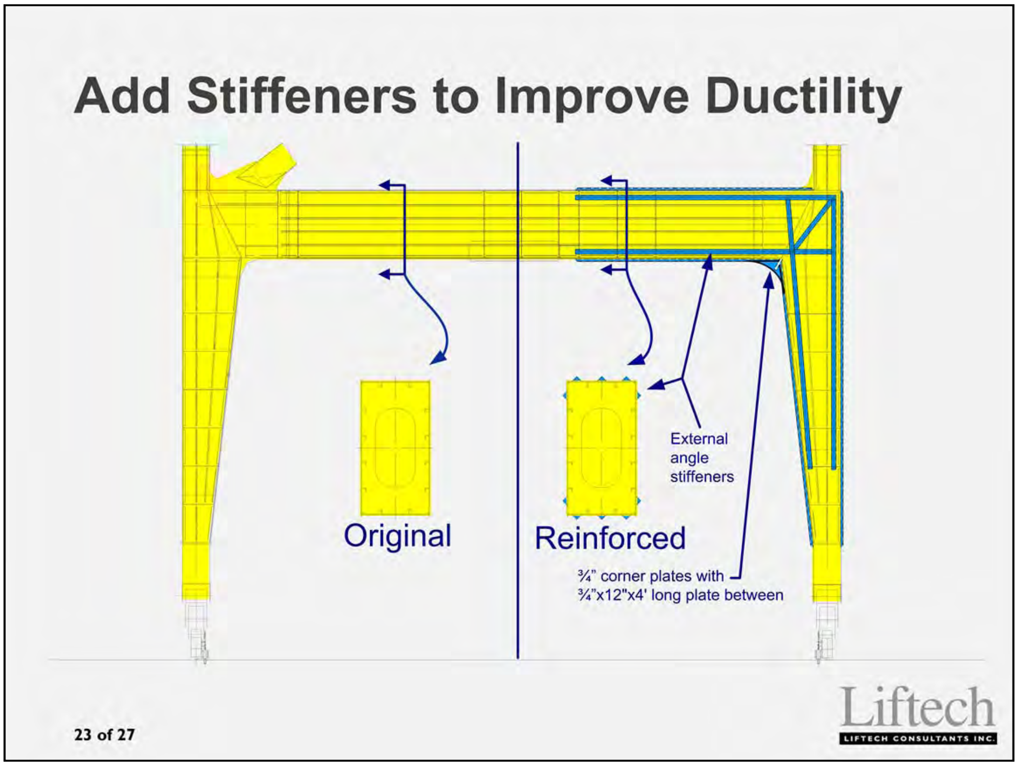
If the portal clearance can be reduced, strengthening the portal by adding pipe braces will most practical.

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.



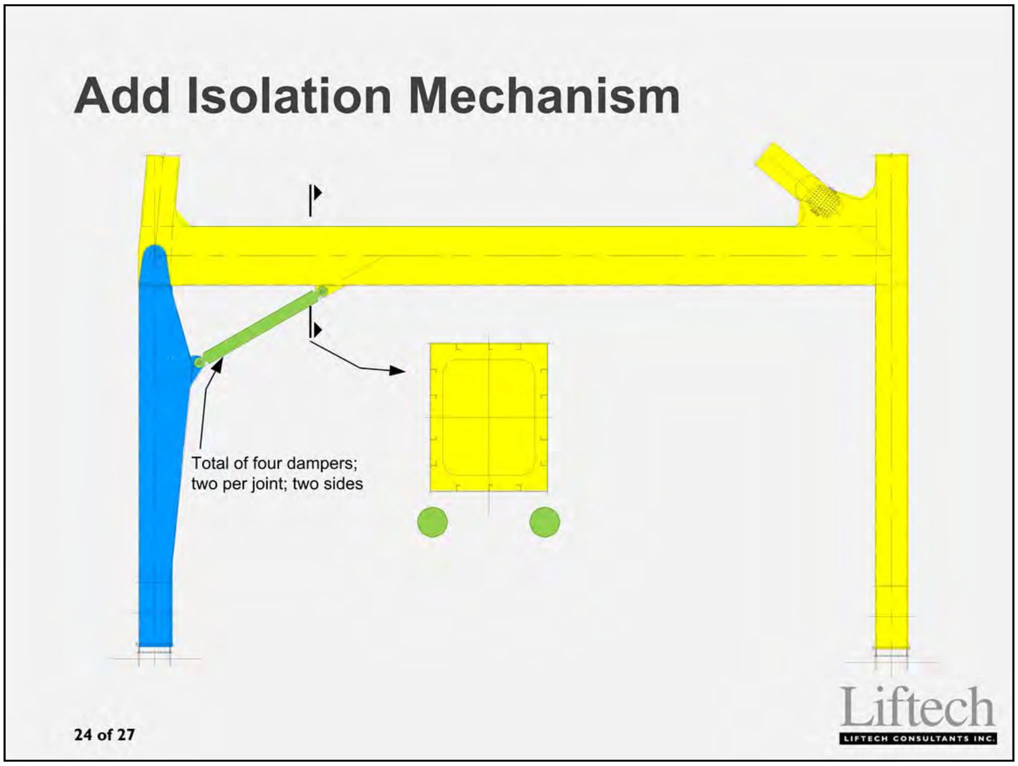

Designing the crane to tip is a good option, particularly if the clearance under the portal can be reduced.   Pipe braces are the least expensive strengthening option, estimated at $300,000 per crane (2009) excluding downtime costs.



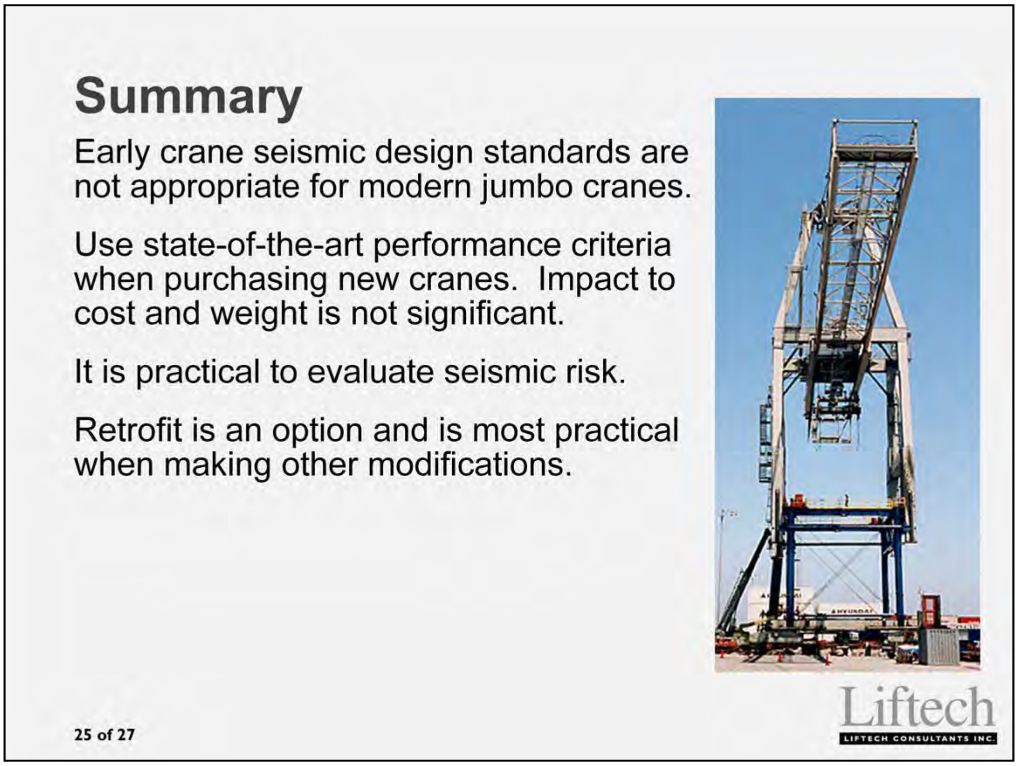

Adding stiffeners, particularly continuous stiffeners, so the thin walled sections are compact in accordance with AISC will significantly improve the ductility of the portal frame box sections. This option is more practical for retrofit of an existing crane where the clearance under the portal beam must 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.

The extent of stiffening will vary between crane designs. The costs will be less if stiffening of the portal beam is not required.




Adding an isolation mechanism 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.




To summarize, be aware that the seismic risk to cranes has increased as cranes have become larger.

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

Use current seismic design criteria when purchasing new cranes. Refer to the Liftech website for our updated container crane seismic criteria.

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.


Thanks for your time.

**Liftech Consultants Inc. file data:**

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