Seismic Response of Jumbo Container Cranes and Design Recommendations to Limit Damage and Prevent Collapse

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Many terminal operators have been told that their wharves will be operational after the operating level earthquake (OLE).   For most Ports this is an earthquake with a 72 year mean return interval (MRI).

While the wharves themselves may be operational after an OLE, recent studies indicate the jumbo cranes on the wharves may not be.

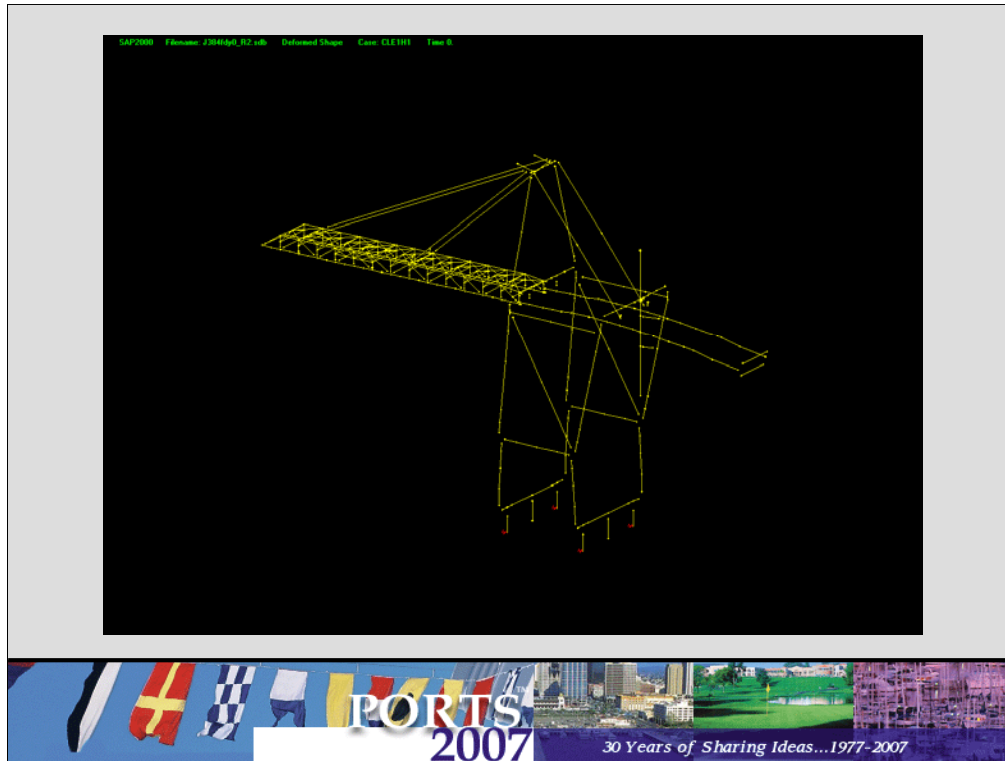The seismic risk to cranes may be unacceptable to many crane owners. What changed?

Cranes are larger and heavier. The rail gage has increased to 100' or more.

This next series of slides contain videos of 50' and 100' gage container cranes.

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 near the Port of Los Angeles.

Only the accelerations in the trolley travel direction are applied.

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

Due to modeling limitations, the boundary elements will stretch when the crane lifts, so focus on the sill beams.
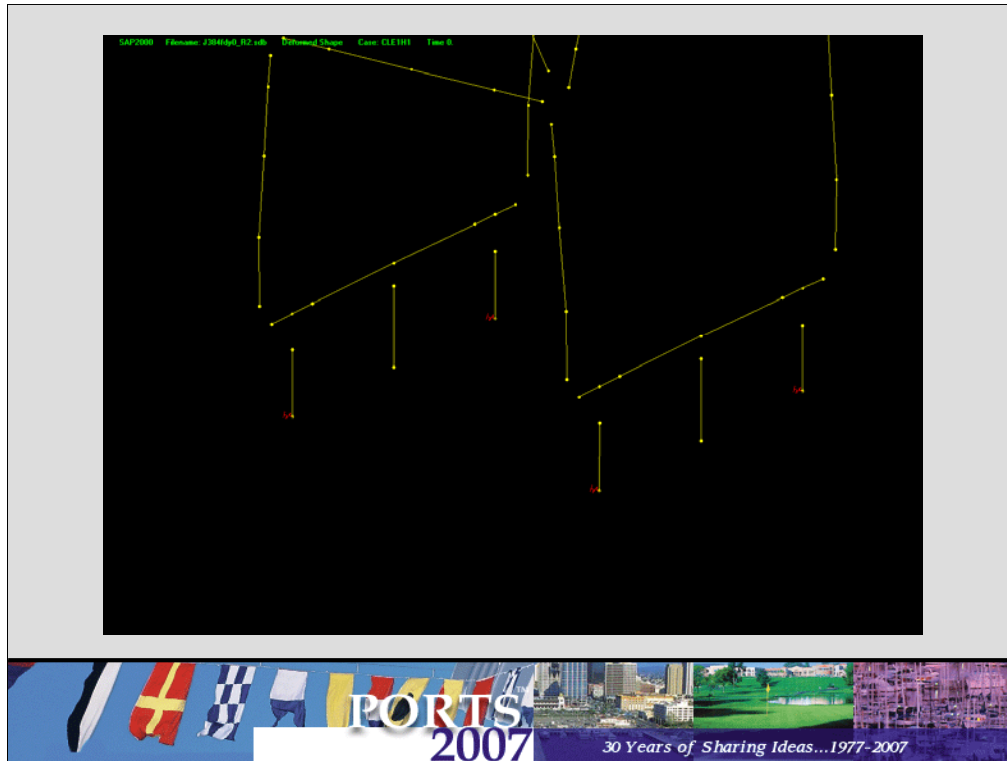
This is the same analysis with the focus on the lower portion of the crane. Notice when the crane lifts from the wharf. The corner members stretch instead of lift, so focus on the sill beams.
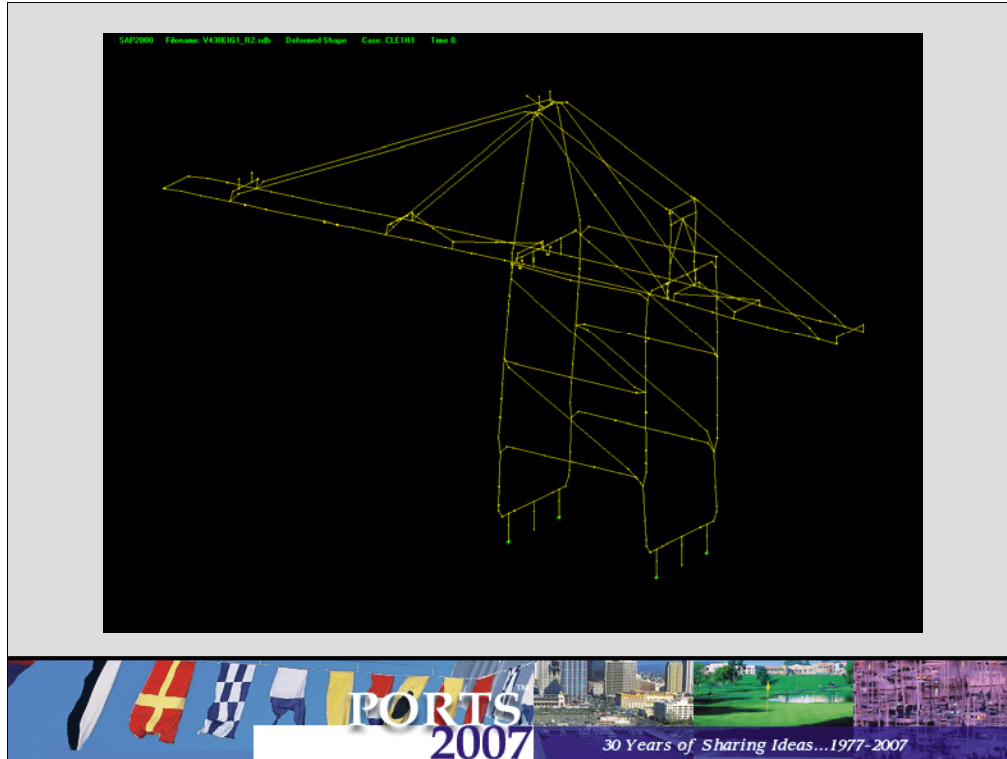
This is a model of a recent 100' gage crane. It is modeled on the same wharf and analyzed using the same acceleration time history.
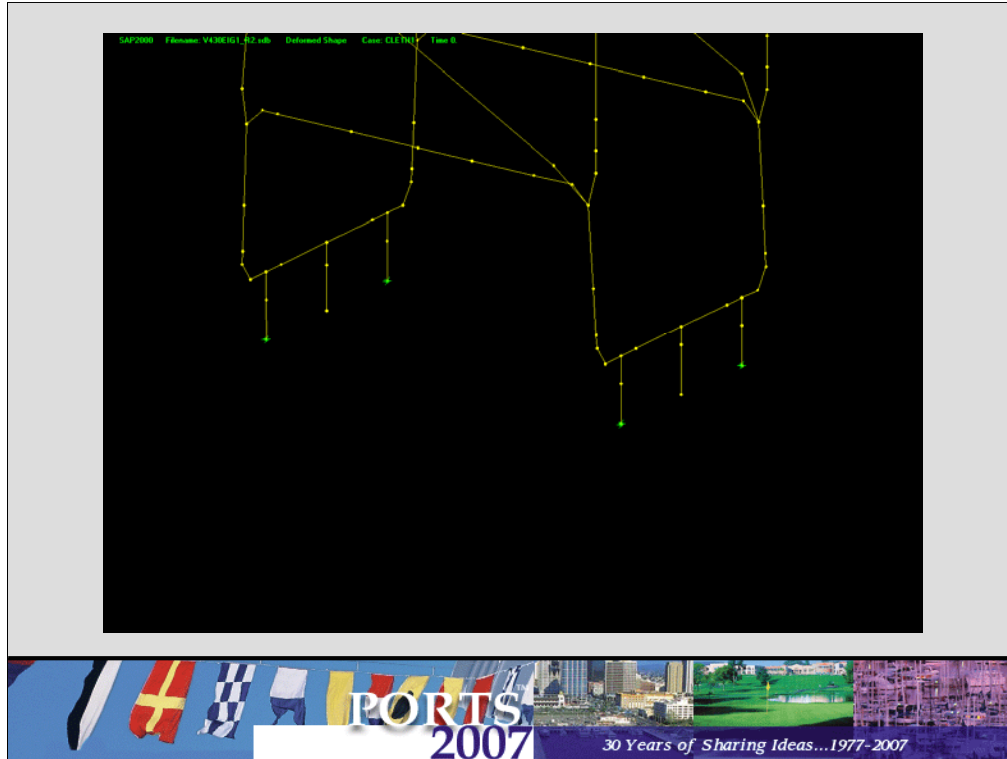
Again, this is the same analysis with the focus on the lower portion of the crane. Notice when the crane lifts from the wharf.
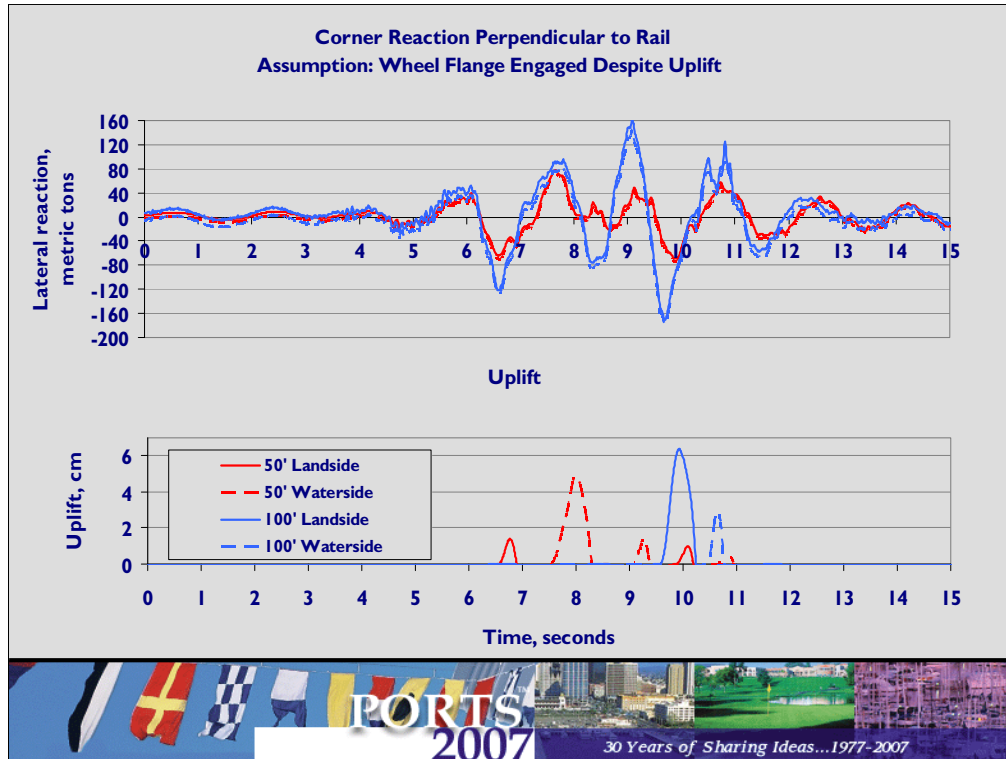
This slide presents the leg lift and lateral forces calculated in the previous analyses.

The blue lines represent the lateral reaction and uplift for the 100' gage crane.

Notice that the legs of the 50' gage crane lift more frequently than those of the 100' gage crane.

Notice that the maximum lateral reaction that develops between the crane and wharf is significantly larger for the 100' gage crane.

The 50' gage crane has a mass of 950 metric tons, the 100' gage crane 1450 metric tons.

Notice that if no lateral load is taken by the lifting side of the crane, that the lateral reactions presented will double.
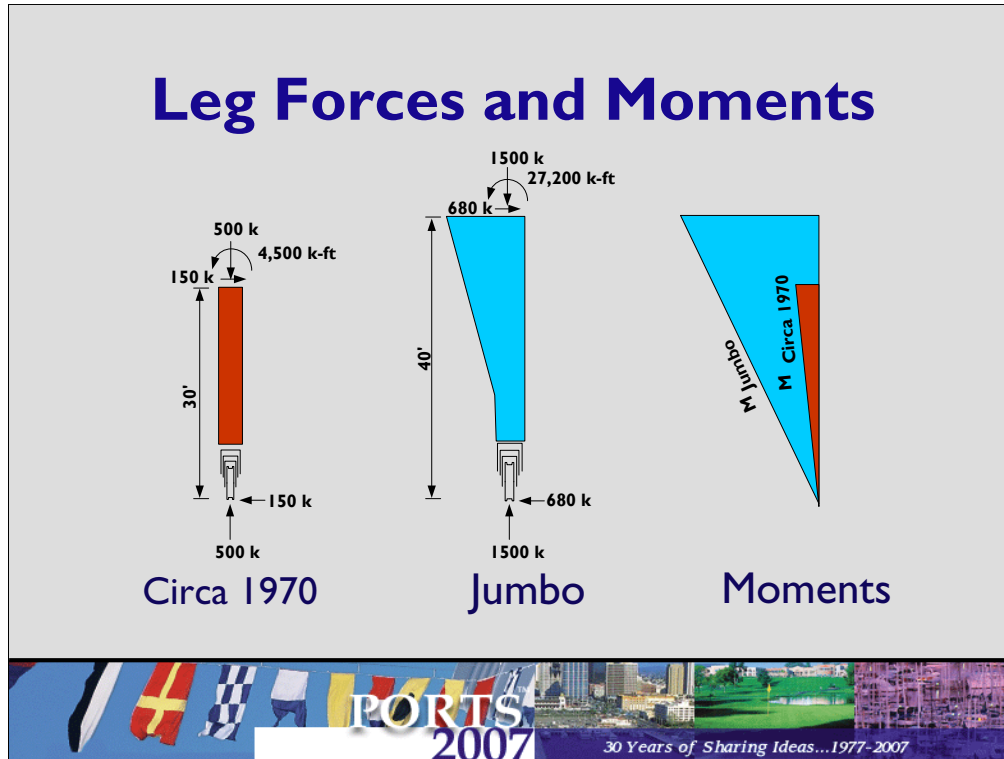
If a crane tips far enough, and all of the load is resisted by one side of the portal frame, that side will resist the reaction shown. The reaction on the 100' gage crane is significantly larger due to the increased crane mass as well as the larger inertia loading required to tip the crane.

If tie-downs engage, extremely large 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

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

This slide presents the forces 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.
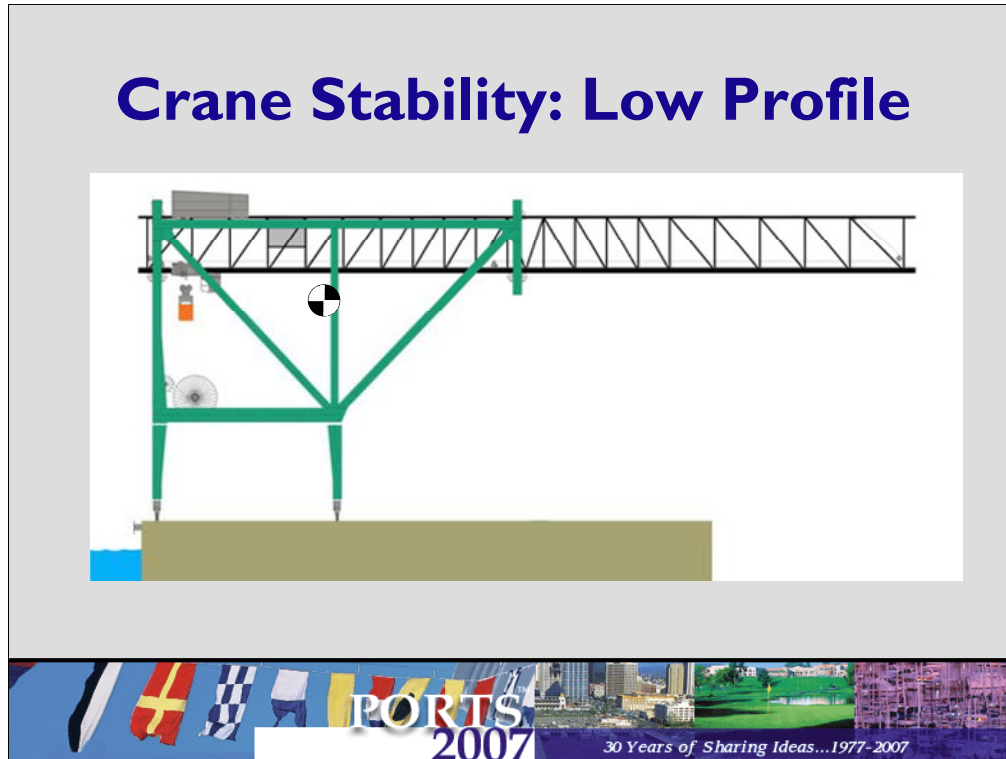
Tipping of A-frame cranes in an earthquake is good since it disrupts the build up of shaking that develops in the crane structure.

The uplift amount is small. Provided the lower legs do not buckle, the crane will not fall over.

With modern low-profile cranes, the center of mass, when the boom is stowed, may be nearly over the landside rail. Relatively little uplift will topple the crane.

Tie-downs prevent the crane from tipping over during storm winds; however, the tie-downs are not normally engaged and should not be engaged during earthquakes.

To ensure stability in an earthquake, significant ballast must be added to the crane structure.

A recent study indicated that for a low profile crane capable of servicing a 22-container-wide ship, 750 metric tons of ballast was needed over the waterside rail.

Where are we now? Wharf design criteria has evolved and specifies allowable strains, damage, and movements in great detail. Until recently, it was believed excessive strains would not develop in crane structures. A seismic design loading of 0.2 g was prescribed.   With this criteria, the wharf may be usable after a earthquake, but the cranes may not.

After recent studies, the Liftech crane design criteria has been changed so the crane design requirements are similar to those of the wharf.

Crane rail damage is expected. It is more economic to repair the rail after the earthquake than to provide a rail system that can resist the earthquake loads.

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Compatible Design Criteria

Design crane for one of following:

Tipping load – no damage

Ductile yielding – some damage

Isolation – no damage

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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.

Specifications currently provide the following options to the crane designer:

- Design the crane so it can tip without damage
- Design the crane so that portions of it will yield in a ductile manner and accommodate the design displacements for a CLE, or
- Provide an isolation mechanism in the crane structure so that it can deform without damage.

Design for Tipping

Designing the crane to tip 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.

For the recent CUT terminal in Los Angeles, ZPMC opted to design the crane to tip. This approach resulted in approximately 50 metric tons of additional steel, a marginal cost for the improved performance.
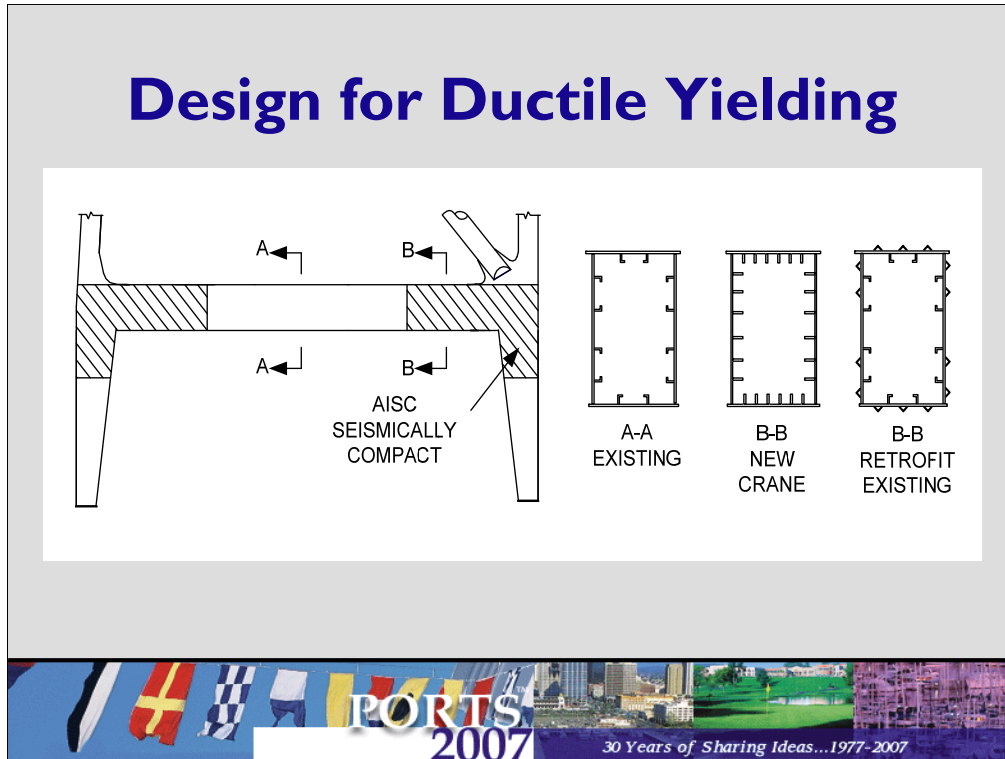
Designing for ductile yielding requires that the thin walled plate sections be made seismically compact in accordance with AISC. This requires significantly more stiffeners.   This option is more practical for retrofit of an existing crane where the clearance under the portal beam must be maintained. If the clearance can be reduced, it may be practical to add pipe struts so the crane can carry the tipping forces.

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

Design For Isolation

## Isolation Between Main Equalizer and Sill Beam
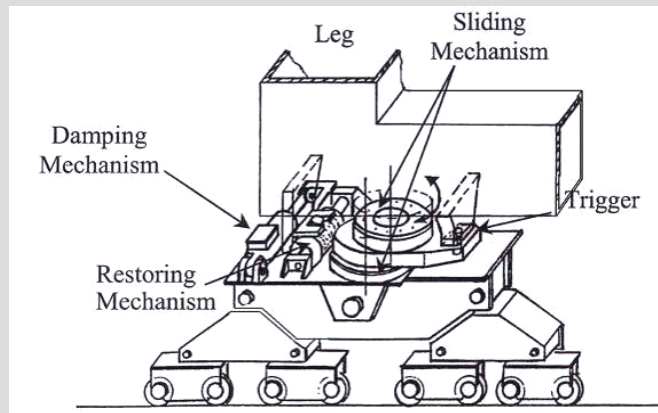
Mitsubishi Heavy Industries

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.

Design For Isolation
Isolation Between Lower Leg and Portal Beam
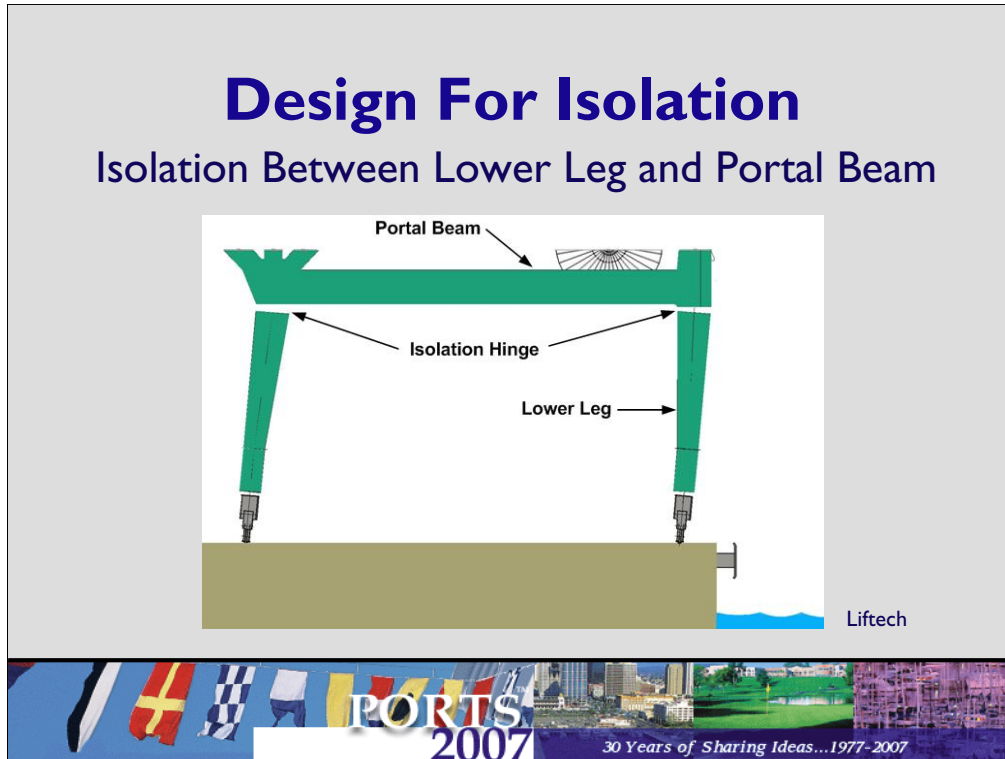
A concept recently developed provides an isolation hinge between the lower legs and the portal beam.
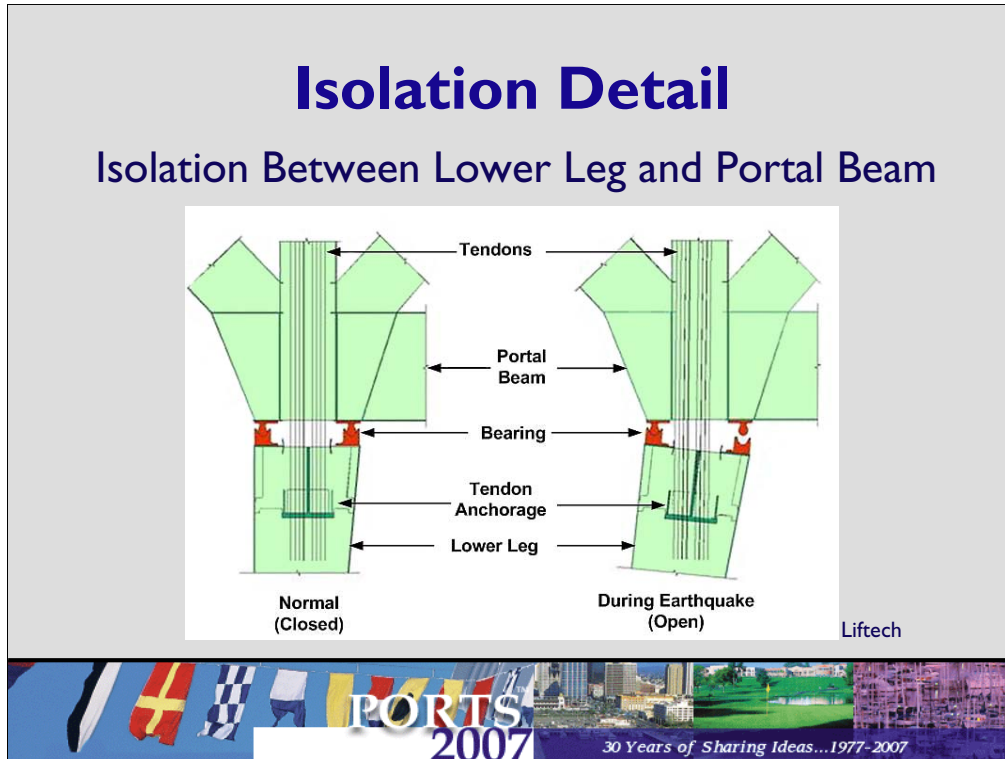
The design uses bridge prestressing tendons and hardware to tension the lower leg to the portal beam. The tendons are sized and pretensioned so that the joint does not open during operating conditions, but does open during seismic events and typhoon winds.
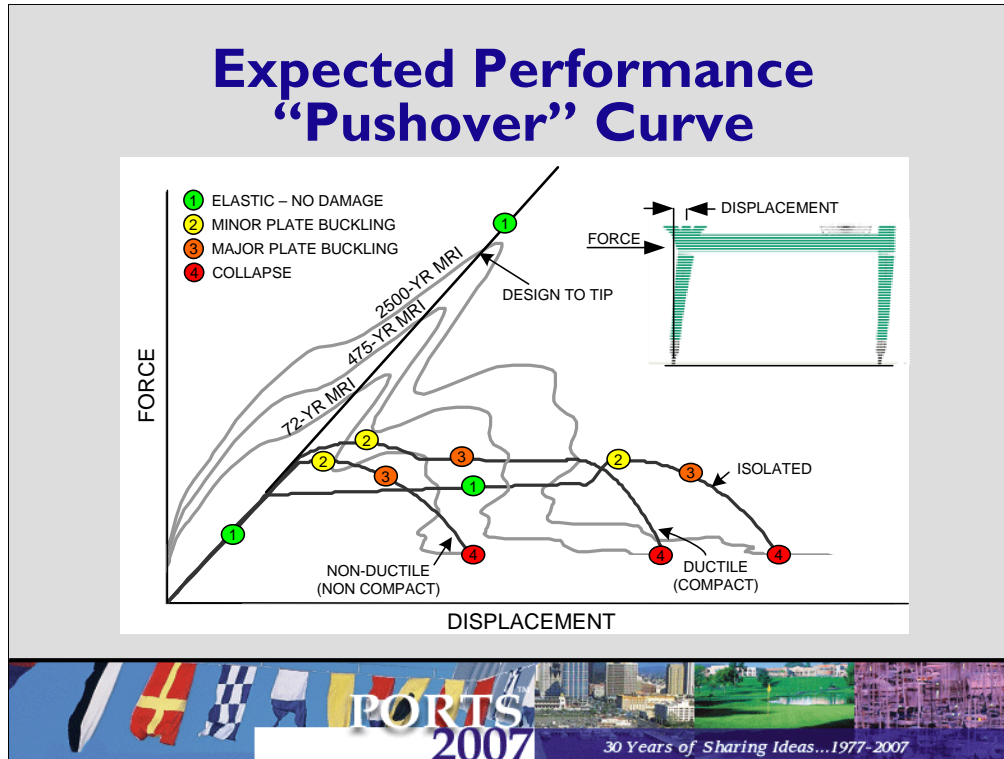
The expected performance of these approaches is presented in this slide using a pushover curve.

The curve presents the displacement of the crane structure for a given lateral force, and the seismic force and displacement demands for three design earthquakes of varying mean return intervals.

If the displacement of the structure does not surpass that required by the earthquake, then it collapses.

For the design methods discussed:

- If the crane is designed to tip, the structure remains elastic and the forces increase until either the maximum force developed during the earthquake occurs or the crane tips.

- If an isolation mechanism is provided, the crane will deform until the isolation mechanism is tripped and deformation in the mechanism system occurs. As shown, it is practical to design the mechanism to accommodate the maximum displacement that will occur, even for severe earthquakes.

- If the structure is seismically compact, but not strong enough to tip before the maximum earthquake forces occur, the crane structure will yield and deform to accommodate the design deformations. To avoid collapse, the structure must deform beyond the deformation caused by the earthquake.

- Modern cranes with non-ductile, non-compact structures may be damaged in small earthquakes. If the earthquake is large enough, and the strength and stiffness at the damage location degrades enough, the structure will become unstable and collapse.

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Retrofit Options

Option	Pro	Con
Strengthen structure	Reduces probability of damage	Costly
Improve ductility by adding stiffeners	Least costly, avoids collapse	Probability of damage unchanged
Add isolation mechanism	No damage	May be expensive

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

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

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

Strengthening the crane is probably not economic unless the clearance under the portal beam can be reduced and pipe struts added.

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Summary

Be aware of seismic risk to jumbo cranes.

Use recommended seismic design criteria for new cranes that is compatible with the wharf.
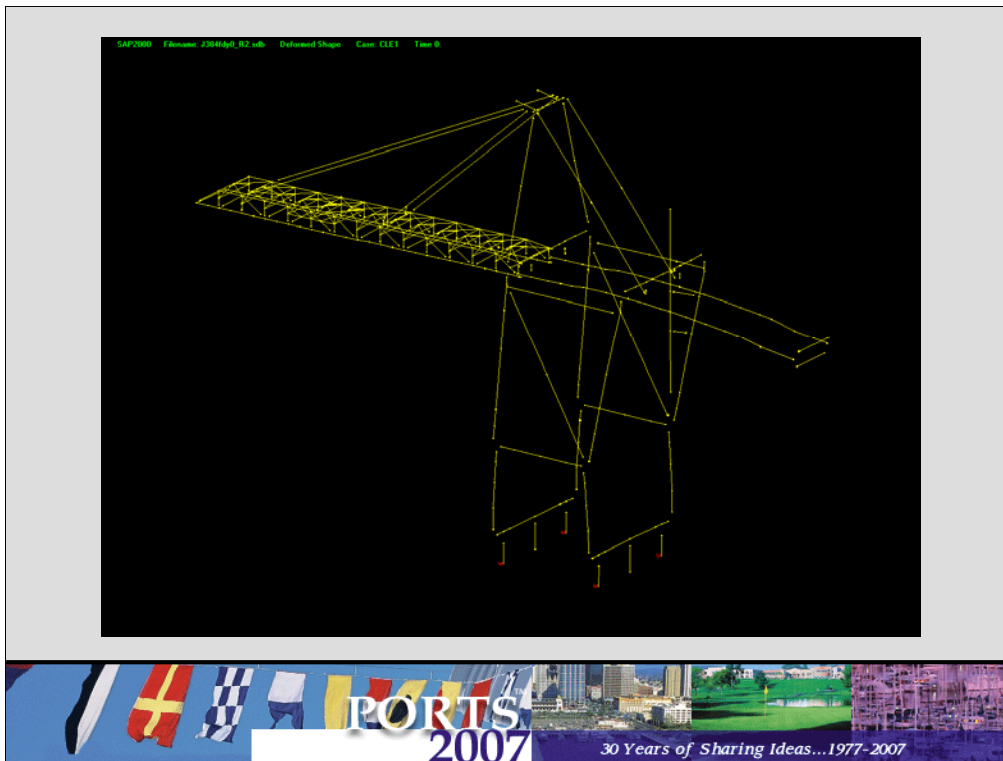
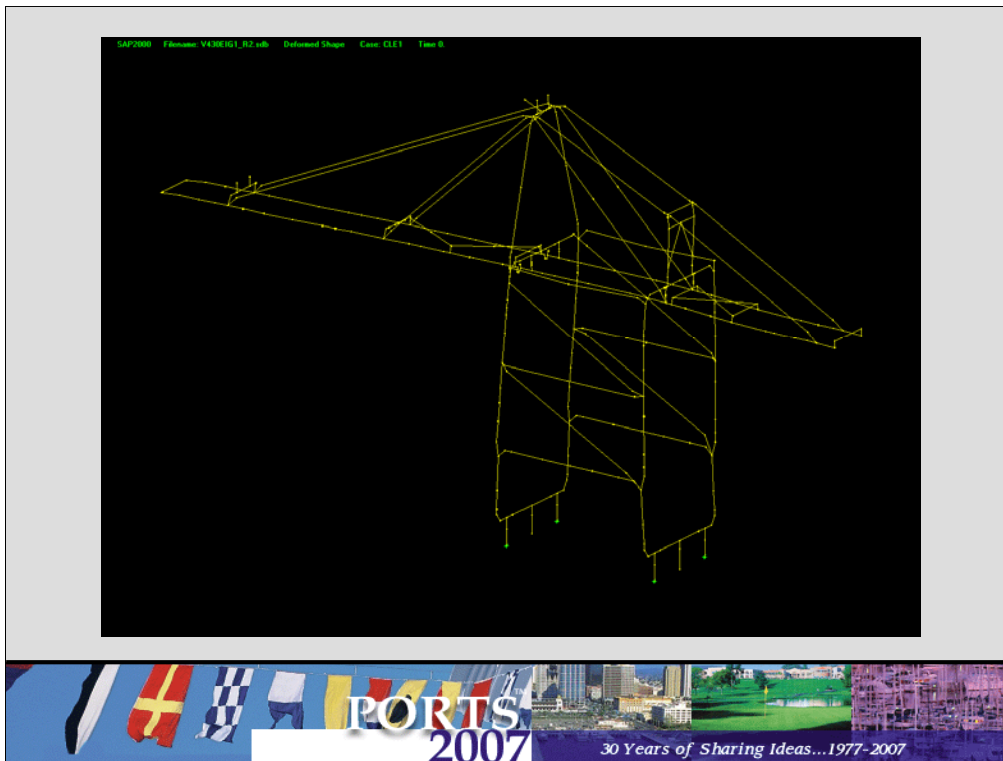Retrofit is an option - more practical when making other modifications.

In summary, be aware that the seismic risk to cranes has increased.

Use current seismic design criteria when purchasing new cranes.

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

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50' gage crane with seismic accelerations in trolley travel and gantry travel directions.

100' gage crane with seismic accelerations in trolley travel and gantry travel directions.

Thank you. See the paper on our website for references and more information.

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