Seismic considerations for existing quay cranes

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This is the last article of a three-part series on quay crane seismic issues. The initial article in the first summer 2012 edition of Port Technology International, 'Seismic protection of quay cranes,' addressed the application of friction dampers in quay cranes. The next article in the second summer 2012 edition, 'Seismic considerations for new quay cranes,' presented several design approaches to improve the seismic performance of new cranes. This article looks at existing quay cranes and presents several seismic retrofit options for existing cranes.

Seismic issues with existing cranes

Since the introduction of the first quay cranes in 1959, cranes have usually been designed for lateral seismic forces equal to 0.2 g, and elastic response. This design criterion was acceptable for many years because cranes could lift off the rails at low lateral inertia loads without damage. Lifting from the rails limits the seismic response and forces that develop in the structure. Historically, small existing cranes have performed well in earthquakes for this reason.

As crane sizes have increased, the traditional seismic design criteria are not suitable. Large modern cranes require up to 0.6 g of lateral inertia before they lift off the rails. Such cranes designed to traditional criteria are likely to perform poorly even in moderate earthquakes. This is particularly of concern for cranes located in low wind speed regions where wind design loads are less severe than the traditional seismic design load.

Is seismic retrofit necessary for existing cranes?

Most building codes do not require improvement of an existing structure to meet current codes unless an alternation to the structure increases the seismic loading or reduces the strength of the structure by 10 percent or more. This is reasonable, as the cost to modify an existing structure is typically much greater than for new construction. While no such requirement exists for cranes, we believe a similar logic is appropriate. Regardless, it is important that stakeholders understand the expected performance of their existing cranes and the seismic risk so they can make an informed decision.

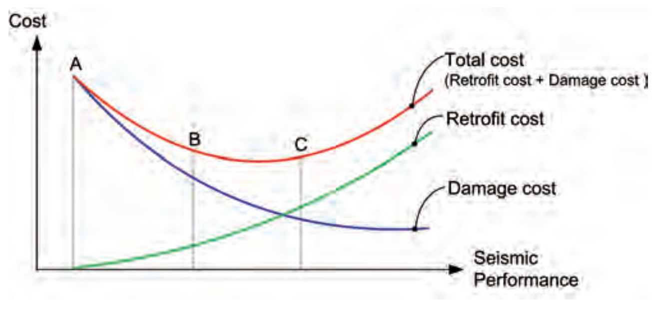

Figure 1: Retrofit cost and damage cost curves

In the previous article, the concept of balancing risk and performance for new cranes was presented. The same idea applies to existing cranes. By adding the cost of doing something now, i.e., retrofit cost, and the cost associated with risk, i.e., damage cost, the evaluation of whether retrofit is worthwhile becomes clearer. This is demonstrated in Figure 1 with the points explained as:

- Point A: No seismic retrofit. The risk of damage or damage cost equals the total cost.
- Point B: Some retrofit. The retrofit reduces the risk of damage or damage cost. The total cost is reduced from Point A, but could be reduced with more retrofit.
- Point C: More retrofit. The cost of retrofit begins to exceed the reduction in the risk of damage or damage cost. Less retrofit results in less total cost.

The cost associated with retrofit will eventually outweigh the benefit, as in Point C. There is an optimal seismic retrofit level where the total cost is minimised. Stakeholders can use this method to decide if and how much retrofit is worthwhile.

Retrofit options

There are several approaches to improve seismic performance for existing cranes. One approach is to strengthen the lower portal frame with diagonal braces such that the legs can lift off the rails, allowing the crane to rock without damage. A second approach is to stiffen the lower portal frame so it can deform plastically in

TABLE 1: RETROFIT OPTIONS

Option	Advantages	Disadvantages	Comment
Strengthening for rocking	Structure can tolerate large lateral load without damage	Imposes large lateral loads on wharf	Least costly if clearance under portal can be decreased
Stiffening for ductility	Maintains portal clearance	Plastic yielding will require repairs after a design event	Can also strengthen portal frame to tip without damage
Installing isolation or dampers	No significant damage, limits lateral loads on crane and wharf	May be expensive to implement	Requires testing of special devices

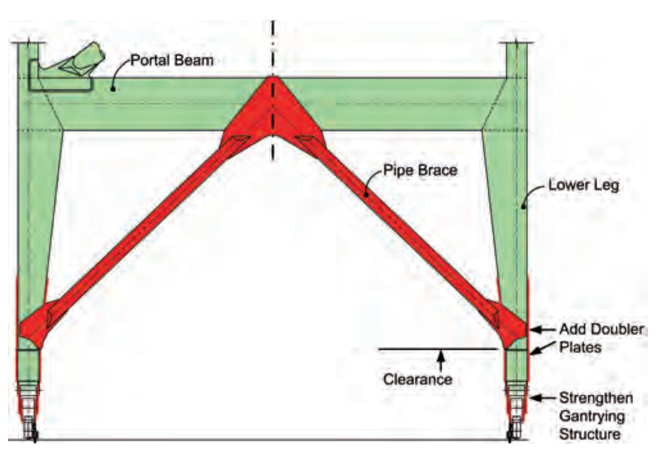

Figure 2: Portal frame pipe brace strengthening

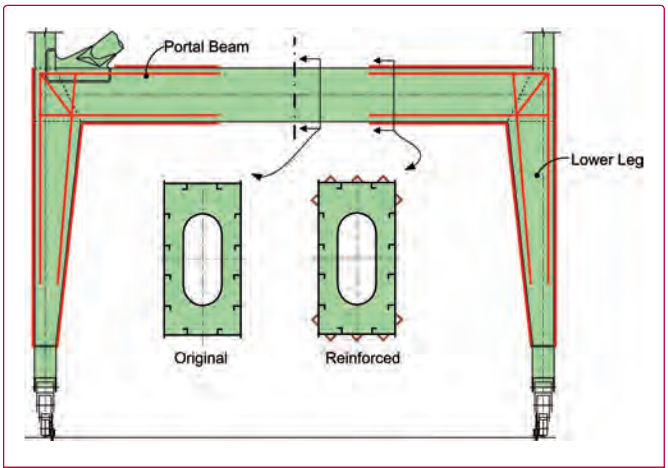

Figure 3: Improved portal frame ductility

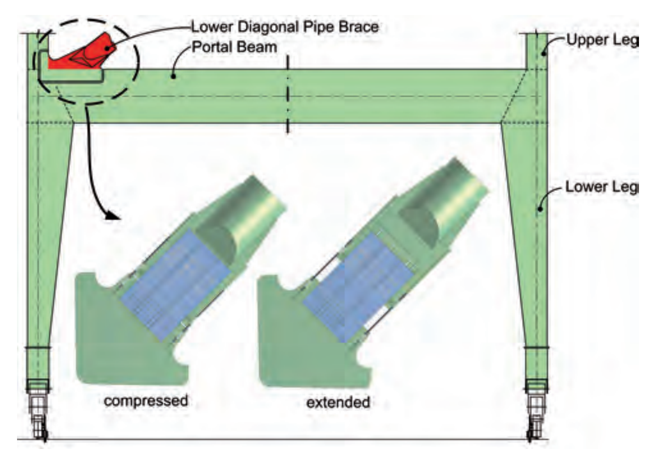

Figure 4: Friction damper

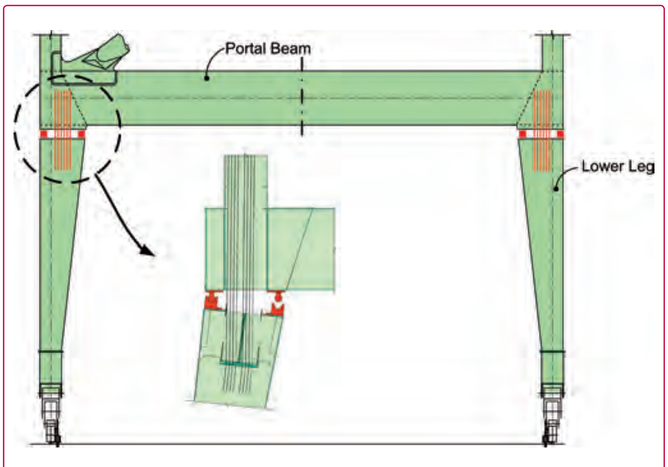

Figure 5: Isolation hinge modification

a controlled manner without collapse. A third approach involves adding a seismic isolation or energy dissipation device to reduce seismic forces. The approaches are summarized in Table 1.

Strengthening for rocking

Modifying an existing crane to rock is most worthwhile if the portal clearance can be reduced and braces installed as shown in Figure 2. The modification involves installing four pipe braces from the lower end of each leg to the centre of the portal beam. The area where the new diagonal pipe braces frame into the legs, including the gantrying structure, may also need strengthening.

The modification is estimated to take roughly one month of downtime and cost about US$300,000 per crane for construction not including design and loss of operation costs. This modification is not an option where straddle carrier or RTG operations occur, or when the vertical or lateral load capacity of the wharf is limited.

After the modification, the crane frame will remain elastic in earthquake events. Operations can resume soon after an earthquake. The crane may need to be reset onto the rails; however, this can be done relatively quickly.

Stiffening for ductility

Modifying an existing crane for ductile response is most easily done by adding external stiffeners as shown in Figure 3. The modification involves installing additional stiffeners along lower legs and at the ends of the portal beam where large forces and moments due to seismic loads are expected. The additional stiffeners increase the buckling resistance of thin plates, allowing the stiffened steel plates to yield and undergo large strains before the plates buckle.

This modification is estimated to take roughly two months of downtime and cost about US$500,000 per crane for construction. This modification is most suitable when portal clearance is required and strengthening with portal frame bracing is not practical, or when the wharf capacity is low and limiting the lateral loading is important.

Since the stiffening for ductility approach relies on the crane's ability to deform plastically, there will be permanent deformation after a major earthquake and the crane frame may need realignment. Bent plates may need to be restored by heat straightening or sections may need to be replaced. Repairs and downtime will take longer than for the strengthening approach. In addition to improving ductility, the strengthened portal frame will reduce the damage that will occur without the stiffening.

Adding a damper or isolation system

The cost and construction time for adding an isolation or energy absorbing system will vary considerably depending on the system used. One of the less expensive retrofit methods is to install friction dampers at the lower diagonal pipe brace connections as shown in Figure 4. The dampers slide and dissipate energy when the seismic force in the joints exceeds the friction. In addition to energy dissipation, friction dampers allow the crane's upper structure to flex laterally, reducing the forces in the lower portal frame, an area most prone to seismic damage. The modification simply involves cutting the lower end of the diagonal braces and inserting the friction damper connection, but may require stiffening of the upper legs.

A more effective but more costly method of improving the seismic response of cranes is adding an isolation system such as the one shown in Figure 5. For this system, the post-tensioned steel strands, which act as restoring springs, hold the joint closed for operation and allow it to open for seismic events when the pre-tension force is overcome. The cost of adding isolation hinges will be much less if the seismic retrofit is combined with other modifications such as a crane raise. Post-tensioned strands can also be added externally.

With a damper or isolation system, the cranes are likely to be immediately operable after an earthquake. Neither system will alter the portal clearance or create obstruction in the lower frame.

Summary and recommendation

Stakeholders should consider the seismic risk for their existing cranes. A number of retrofit approaches are available to achieve acceptable seismic performance at relatively little cost. Retrofit will require some investment now but the damage and repair costs will be less in the event of a major earthquake, particularly if a crane has significant risk of collapse or is a critical link in the shipping system. The questions that stakeholders should consider when deciding whether to upgrade their cranes are how much does protection cost and what is it worth.

ABOUT THE AUTHORS

Michael Jordan is a Liftech structural engineer and CEO with over 50 years of experience. He is an internationally recognised expert in the container crane industry. He has been involved in the container industry evolution since participating in the structural design of the first container crane for Matson in 1958. Since then, he has designed the structures of hundreds of duty cycle cranes, prepared numerous specifications for the design of duty cycle cranes, and investigated fatigue damage problems and major failures caused by fatigue crack growth and brittle fracture.

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ABOUT THE COMPANY

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

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