Seismic protection of quay cranes

Michael Jordan, chief executive, **Yoshi Oritatsu**, engineer and **Erik Soderberg**, structural engineer, Liftech, Oakland, CA, US

What's the problem?

Container handling quay cranes have existed for 54 years and the only collapse due to an earthquake occurred in 1995 at Kobe, Japan. Liquefaction caused that collapse. Quay cranes have a history of successfully resisting earthquake damage. However, this is only because cranes were light and one or two legs could lift a few inches off the rails with only minor crane damage. This is no longer the case; large heavy cranes are different. The forces required to lift a heavily loaded leg are so great that the crane cannot resist them without damage, perhaps even collapse, and the crane lateral load on the wharf may be large enough to damage the wharf.

The Japanese were first to recognize this problem. Since the Kobe earthquake, all new quay cranes in Japan are designed to resist major earthquakes. Only recently has the danger of crane collapse been recognized outside of Japan. The Ports of Los Angeles (POLA) and Long Beach (POLB) recognize that seismic forces from cranes can damage wharves. The ports' recent codes have requirements that limit the crane's impact on the wharf. However, though the codes limit the effects of the cranes on the wharf, they do not address a crane's seismic performance.

Protecting the crane and the wharf

To protect the crane and the wharf, the usual practice in Japan

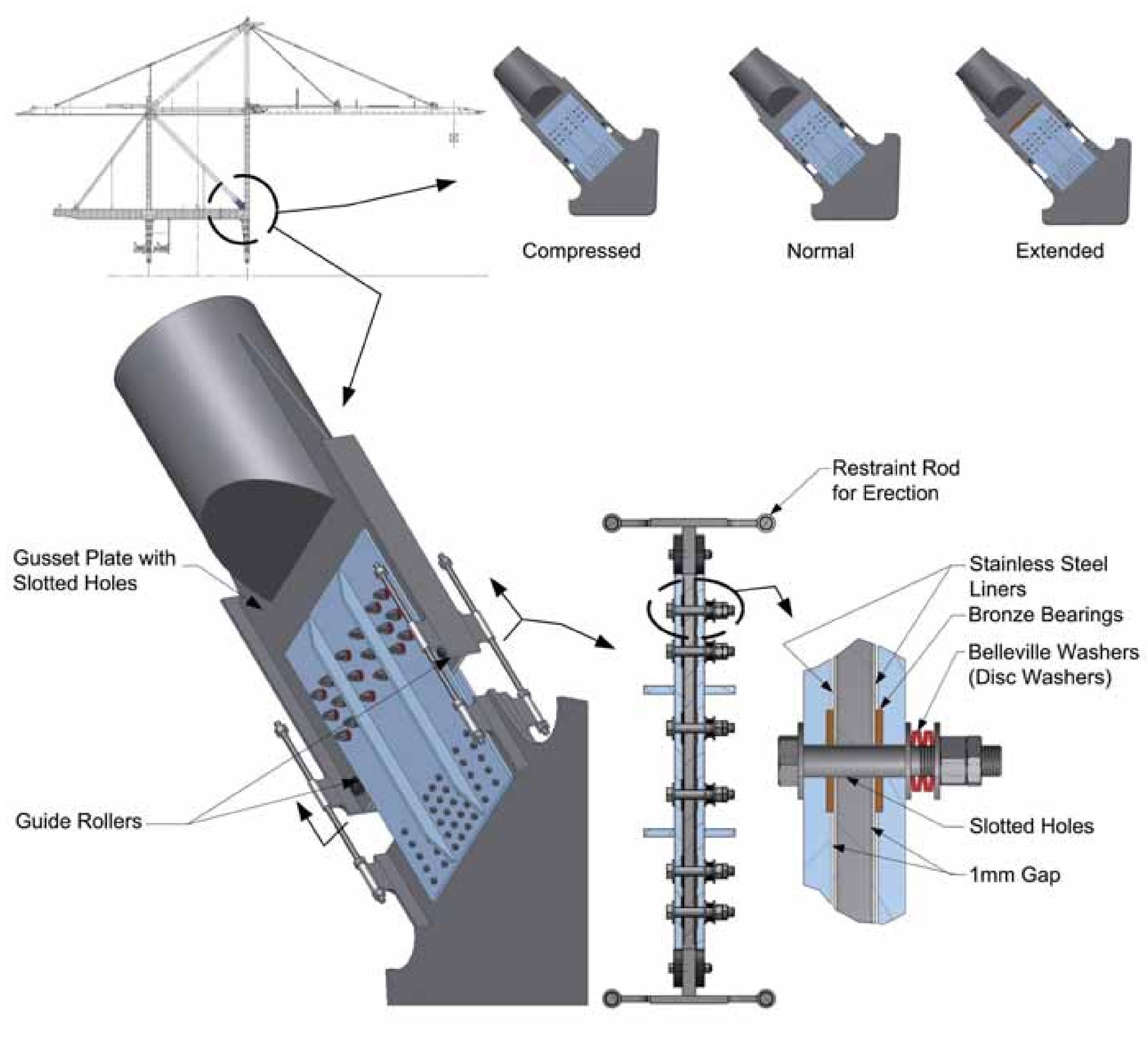

Figure 1. Liftech Friction Damper.

is to add base isolation systems to the cranes at the wharf level. The isolation systems include a trigger, a hydraulic damper, and a reset device. The system is complex and expensive. Fortunately, quay cranes have a structural element that can be easily converted to a device that will protect the crane. A friction damper can be inserted in the diagonal to portal tie connection (see Figure 1). The friction damper works by allowing the connection plates to slide as the crane structure deforms in an earthquake. The damper provides a large clamping force on the sliding plates to dissipate significant energy during the earthquake. The phenomenon is similar to braking a moving wheel on a car.

For new cranes, the cost of the friction damper is relatively small. For existing cranes, friction dampers are an economical retrofit. The friction damper needs little maintenance and can be easily reset after an earthquake.

Friction dampers on container cranes

The idea and use of a friction damper is not new. A number of researchers have studied friction dampers. Egor Popov and Carl Grigorian published *Energy Dissipation with Slotted Bolted Connection* in 1995, reporting their study of bolted friction dampers. Friction dampers have already been used in a number of building structures.

Four new container cranes with friction dampers are being delivered to APL terminals at the Port of Los Angeles in the summer of 2012. The cranes will have resettable friction dampers and are the first of their kind for quay cranes. The dampers will protect the cranes and the wharf.

The POLA and POLB wharf design criteria require that the wharf be functional after the 'Operational Level Earthquake' (OLE), with a 50 percent probability of exceedance in 50 years, and with no collapse after a 'Design Earthquake' (DE), a major earthquake level used for designing structures for life safety. However, most quay cranes were not designed to these criteria. The APL cranes are designed to remain operational after the OLE and to not collapse in the DE. Most likely, the cranes will be operational even after the DE, after the damper is reset and the crane frame is realigned by adjusting the restraint rods.

The POLA and the POLB codes

The codes contain requirements for both new container cranes and modifications to existing cranes to protect the wharves from overload during earthquakes.

The design of four APL terminal cranes presented many challenges. The project schedule was tight. Fabrication needed to start before the design of the wharf was complete. Consequently, many wharf design parameters were unknown during the crane design process. The new wharf was expected to be more flexible than a typical wharf. A reasonably stiff crane was needed to meet operational requirements. Making the crane structure unusually flexible to limit its impact on wharf response was not an option, some type of seismic isolation mechanism was required. Studies of several seismic isolation concepts indicated that friction dampers are the most practical and economical solution.

The Liftech friction damper

The friction dampers are located at the bottom of lower diagonal braces as shown in Figure 1. The dampers have bolted shear connections with the bolts located in long slots. The damper includes a center gusset plate with long slotted holes, lap plates (shown in blue), conical washers, and tensioned bolts. The sliding surfaces are bronze bearings and stainless steel liners. Restraint rods provide added safety, hold the diagonal brace during erection, and can be used to restore the joint to its original geometry after sliding occurs.

Friction developed from the bolt clamping forces restrains the joint until a predetermined threshold force occurs. Once the threshold is exceeded, the joint slips, resulting in an increase in the crane's effective period and dissipation of seismic energy as heat. Both phenomena reduce or 'damp' the seismic response and reduce the seismic forces. Since container cranes need to be reasonably stiff to operate properly, the friction joints do not slide during normal operation. The joints also will not slide in storm wind conditions.

Performance

Nonlinear time history analyses were performed to quantify the crane and wharf seismic response. Figure 2 shows a time history plot of wharf displacements. As the plot indicates, the crane with dampers reduces the maximum wharf response. Figure 3 is a comparison of crane response, with and without the damper. As the time history plots indicate, in addition to reducing the forces on the wharf, the friction dampers reduce the lower portal frame movement, which reduces the strain in the lower legs. The upper frame's drift, however, increases when the friction dampers slide. The strains in the upper frame remain at acceptable levels.

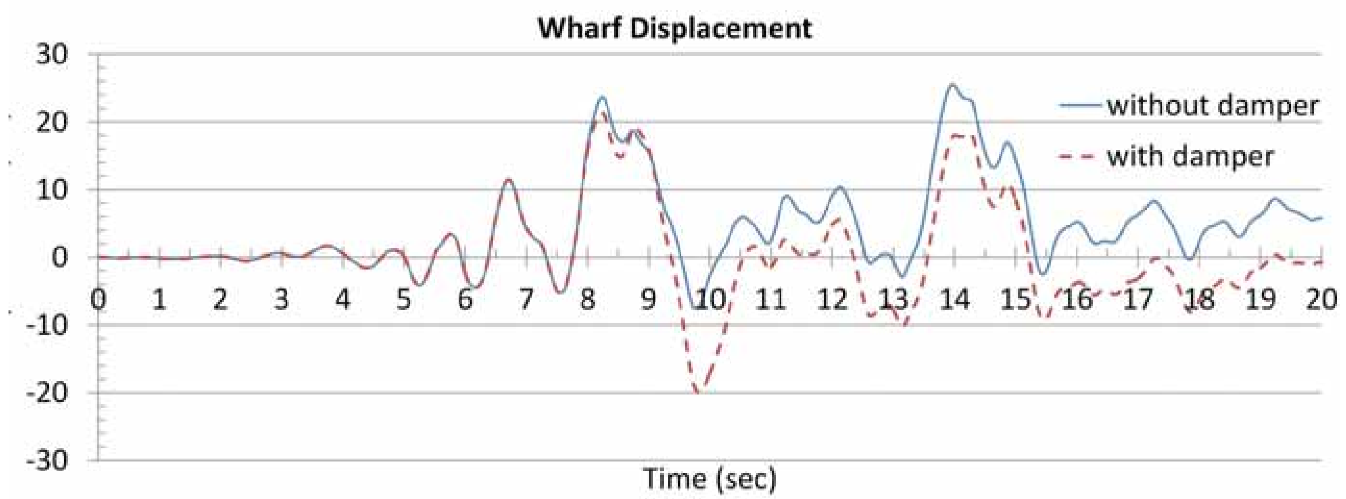

Figure 2. Wharf response.

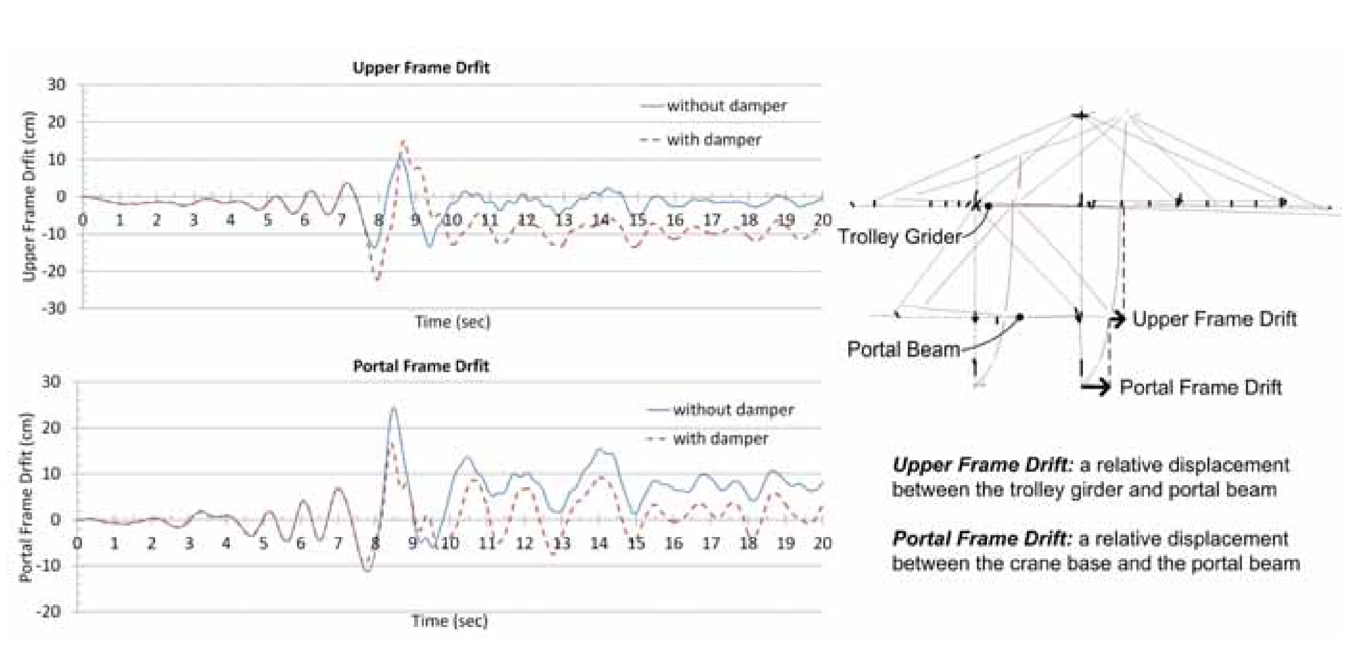

Figure 3. Crane response.

Recommendations

Seismic forces on quay cranes in seismically active regions should be carefully considered. The occurrence of a major earthquake is unlikely. However, the consequences can be catastrophic.

In some situations, the loss of a crane may be acceptable. In other situations, it may be unacceptable. Engineers can offer advice about what to expect and the consequences of selected criteria, but the stakeholders should decide how much risk is acceptable. The questions to answer are how much does protection cost and what is it worth?

If some seismic protection of quay cranes, wharves, or of both is desirable, friction dampers provide an economical and practical solution for new and existing cranes.

ABOUT THE AUTHORS AND THE COMPANY

Michael Jordan is a Liftech structural engineer and chief executive with over 50 years of experience. He is an internationally recognized 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.

Yoshi Oritatsu is a Liftech structural designer and registered professional engineer with five years of experience in the design, analysis, and modification of container cranes, large derrick cranes, bulk loaders, and wharf structures. His work includes the analysis of crane and wharf seismic response, including the effect of isolation and energy dissipation systems.

Erik Soderberg is a Liftech structural engineer and vice president with 17 years of experience in the design, review, and modification of a variety of structures including container cranes, wharves, buildings, heavy lift equipment, and various rigging structures. He has consulted on hundreds of cranes, participated in the design of several wharf structures, and has designed many crane transfer systems ranging from curved rails to shuttle systems. He has engineered repairs for dozens of container crane structures and for several bulk loaders. His field skills include an understanding of heat straightening techniques and the ability to develop repair procedures on site.

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. Their experience includes structural design for wharves and wharf structures, heavy lift structures, buildings, container yard structures, and container handling equipment. Their national and international clients include owners, engineers, operators, manufacturers, and riggers.

ENQUIRIES

Liftech Consultants Inc.
344 – 20th Street, #360
Oakland
CA 94612-3593
USA
Tel: +1 (510) 832 5606
Fax: + 1 (510) 832 2436
Email: liftech@liftech.net
Web: www.liftech.net