Extreme Loading of Wharf Crane Girders

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ABSTRACT

Wharf crane girders are designed for loads that are likely to occur. Although rare, extreme loads that are not considered in design do occur. Extreme loads result from severe wind, earthquakes, missing piling, crane collisions, crane collapse, and other abnormal conditions. Extreme loads significantly exceeding the conventionally computed wharf crane girder strength often do not cause significant damage.

This paper presents what happens when wharf crane girders are subjected to extreme loads near or beyond their calculated design capacity, the performance that can reasonably be expected when extreme loads occur, and which extreme loads should be considered in the design of wharf crane girders.

Topics presented in this paper include: (1) sources and descriptions of extreme loads; (2) case studies of extreme loading events and the resulting wharf crane girder performance; (3) explanations of wharf crane girder performance and implications for girder design and capacity evaluation; and (4) a discussion of, and recommendations for, reasonable extreme load design criteria.

INTRODUCTION

Events that cause extreme crane loads on wharves are rare. Although these loads are anticipated by the crane designer, they are typically not reported to the wharf designer and are usually not considered in the wharf design criteria. Interestingly, most extreme wheel loads have never caused more than superficial damage to typical heavy short span concrete wharves.

This paper presents some of the most common extreme loads, discusses why most do not damage the wharf, and recommends wharf design criteria for these loads.

TYPICAL EXTREME LOADS

Extreme loads are severe loads that rarely occur. Some of the more commonly occurring extreme crane loads on crane girders are presented below.

Crane Tipping. Crane collisions, extreme wind, vessel contact, and earthquakes can cause cranes to tip, as shown in Figure 1.

Figure 1. Crane tipped onto four wheels and close-up of stability block

When tipping in the gantry direction, if "stability blocks" are present, the block moves the point of rotation from the main equalizer pin to the block, causing the entire vertical load on the waterside or landside rail to be carried by four wheels instead of sixteen. For a jumbo crane that is tipped onto its stability blocks, the waterside wheel load is increased from a maximum operating load of about 75 t/wheel[1] to about 185 t/wheel. Often eccentric dynamic forces can cause the crane to derail. A significant impact loading occurs when the wheels fall back to the wharf.

The typical heavy, short-span concrete wharf structure supports the loads that occur during tipping even though the wharf is not intentionally designed for such an extreme load. Crane girders resist the extreme loads through inertia forces and increased strength due to the high rate of loading.

Crane Collisions

Crane-to-crane and crane-to-end stop. Cranes often collide at low speeds during operations, but can also collide at greater speeds during severe winds that exceed the design operating wind. Collisions at speeds greater than the operating speeds result in crane and wharf loads beyond the design criteria, as discussed below. During these events, the cranes may rotate onto the stability blocks as discussed previously.

Cranes have bumpers that convert kinetic energy to heat. Fluid flows through an orifice with an obstructing metering valve, see Figure 2.

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[1] "t," as used in this paper, refers to metric tonne, or 1000 kg.

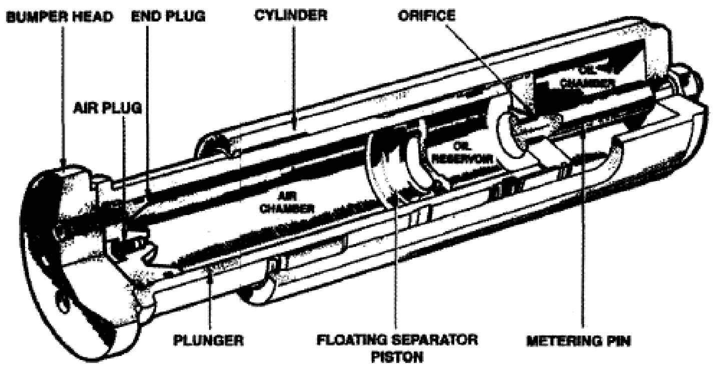

Figure 2. Oleo bumper schematic[2]

The force in the bumper is developed by viscous forces as the fluid flows through the orifice. The meter valve reduces the size of the orifice as the crane speed is reduced so that the load displacement curve is nearly rectangular. The maximum energy absorption is developed over nearly the full stroke **of a particular bumper compression speed**, typically the rated gantry speed of the crane. During collision at normal maximum operating gantry speeds, the bumpers act as intended and the collision forces equal the bumper rated force. If the speed is excessive, as with a runaway crane, the bumper is, effectively, infinitely stiff, and the bumper force is much greater than the force reported by the manufacturer. The crane collision force with the crane stop is limited by the lateral strength of the crane frame, the stop, or the force required to tip the crane.

Crane girders resist the extreme collision loads through inertia forces and increased strength due to the high rate of loading.

Figure 3. Boom damaged from vessel collision

[2] Design copyrighted by Gantrex, printed with permission.

Vessel-to-crane. Vessel-to-crane collisions are common. Most cranes have a device that senses an imminent collision and stops a crane from rolling into a vessel, but these devices may not function as designed or the collision may be the result of a moving vessel. The damage to the crane is usually limited to the boom, although occasionally the crane derails or collapses.

During derailing, the load on one leg of the crane is reduced to almost nothing due to lateral and torsional forces. When a derailed leg comes to rest on the wharf, it is usually less than two meters from the rail. The wharf damage is negligible, as the typical concrete wharf can carry the derailed wheel loads.

In some special cases, the crane rails are on isolated girders, so the derailed leg could be displaced enough so that the leg would not land on the girder and the crane could collapse.

Crane Collapse. Cranes can be knocked over by ships, be blown over when stowage hardware fails during storm winds, fall over after severe collisions, and have even toppled over during load testing as a result of improper design, fabrication, or both.

Figure 4. Six cranes collapsed cranes on wharf after typhoon

Collapsed cranes have resulted in only superficial damage to the wharf. Three reasons include: significant energy is absorbed by the crane structure as the crane members bend and crush; the loading occurs over many seconds[3]; and the loading is spread over a significant area. The significance of these factors is apparent when comparing the superficial damage when a 1200+ t crane collapses to the severe damage from a 60 t piston that slipped from its lashing during offload and fell onto the wharf, see Figures 4 and 5.

[3] One video of a crane collision accident demonstrated that 75-m tall crane takes eight seconds to collapse.

Dent in wharf – view from wharf

Punching and spalling failure – view from below wharf

Figure 5. Damage from dropped 60 t piston

Boom Collapse. Booms can collapse when the boom hoist, the forestays, or the tension struts extending from the apex to the trolley girder fail. Boom collapse usually does not cause the crane to collapse, but the resulting dynamic impact forces can cause extreme rail loads.

On several occasions, dropped booms caught by the stays resulted in extreme loads on the wharf where the landside legs lifted and returned to the rail. In one case, the impact of the wheels dented the rail. Denting requires loads many times the design load. The wharf and piles were undamaged—even the grout under the rail was undamaged.

Crane girders resist the extreme impact through inertia forces and increased strength due to the high rate of loading.

Figure 6. Collapsed boom

Wind. The most common extreme load on wharves is caused by large winds during hurricanes. The crane loads that develop from these winds are considered in the wharf and wharf hardware design; however, failures are still common.

Another extreme wind load can be developed by a microburst. A microburst occurs during certain atmospheric conditions when a mass of cold air forms at some height above the earth's surface and suddenly falls to earth causing an aerodynamic splash. This effect is analogous to pouring a bucket of water onto a surface. When the cold air contacts the surface, it spreads with extreme speed, as high as 50 m/s. The resulting forces are formed suddenly and are of short duration. Microbursts may cause runaway cranes and subsequent crane collisions.

Extreme wind loads such as these are rare, but expected. The storm wind design criteria, in ASCE 7 for example, is such that there is a 63 percent chance that the design wind speed will be exceeded during the stated time interval. That is, a 100-year design interval wind speed will probably be exceeded during a 100-year interval. So winds exceeding the design criteria are likely.

Many wind-caused failures however, are not from wind in excess of the design wind, but are from poor design or construction of wharf hardware. This topic has been discussed in detail elsewhere. See Reference 1.

Earthquake. The effect of earthquakes has not been serious for small, early-vintage cranes, provided the soils do not fail and the crane girders are connected to prevent spreading. For these cranes, one leg lifts, usually causing excessive vertical loads and derailing, but limiting the forces between the crane and wharf. Usually there is no serious damage.

The behavior of jumbo cranes designed for vessels carrying 22+ containers abeam is quite different from that of the smaller, earlier cranes. Forces that are high enough to lift a leg may seriously damage the crane and can cause collapse.

The wharf loads due to the wharf-crane interaction will result in additional forces and damage to the wharf. If the wharf survives the earthquake with only minor damage, it will probably survive the falling crane if it collapses. Increasing mass and wheel gage will result in larger lateral loads from the crane, which may overload the wharf structure. This topic has been discussed in detail elsewhere, see Reference 2.

Crane Relocation. Extreme loads are rare during crane moves because moves are usually engineered and carefully controlled—but sometimes things can happen.

Figure 7. Crane collapse during offloading

Equally remarkable to this accident, shown in Figure 7, is that the wharf was not seriously damaged. A forklift was crushed under the machinery house, but the only evidence on the wharf was superficial surface damage. The wharf performance was better than expected for the same reasons mentioned in Crane Collapse section.

EXTREME LOAD DESIGN CRITERIA

Many of the extreme wheel loads are known to the crane designer but are not reported as wheel loads in wharf design criteria, and they should not be.

Most extreme loads are applied suddenly and for a short duration. The wharf shudders but resists the loads through inertia forces and increased strength under the high rate of loading. To our knowledge, extreme wheel loads have never caused more than superficial damage to typical heavy, short-span concrete wharves. For all but a few of the loads, the wharf designer is justified in neglecting the effects of extreme loads. Recommended design criteria for many extreme loads are presented below.

***Caveat**: The following recommendations are based on conventional concrete crane girders supported on piles at three meter or less spacing. They are intended to help the designer and are not intended to be used as a code. Following the criteria may not produce an acceptable result. The designer and stakeholders need to study the issues and determine the acceptable risk.*

Crane tipping. We do not know of any case where the wheel loads resulting from a tipped crane have damaged a wharf. Be aware that high wheel loads may occur, but do not design for this loading unless the wharf has some unusual conditions.

Crane collision. For vertical loads, see the "crane tipping" section above. For lateral loads, design the crane end stops and crane girders for the load that tips the crane because designing for the rated bumper load is inadequate. The cost of the crane end stop is insignificant.

Do not put a bumper on the crane stop. As explained previously, the bumper is usually ineffective during runaway collisions as it can only be tuned for a specific crane speed.

Derailing. The wharf adjacent to the rail should be able to support the load from a derailed crane leg. A competent support surface extending two meters on both sides of the rails will usually be adequate.

Wind. Design the crane girders at the stowage location considering the extreme wheel loading, and keep in mind that there is a chance that the design loads will be exceeded. Consider the duration of the storm when determining the design soil capacity.

Design the tie-downs considering the misalignments from construction tolerances, crane movement, and gaps between the tie-down system components.

Provide deep stowage sockets so that if the crane lifts, the pin will remain engaged in the socket. Provide a locking mechanism on the crane stowage pin to keep the pin fully extended. These are particularly important for cranes without tie-downs.

Earthquake. Vertical earthquake loads from the crane should not be considered in wharf girder design. For lateral loads, the interaction between the wharf and the crane should be considered, particularly when cranes are spaced closely, when significant ballast is used low in the crane, or when large rail gages are used.

It is not practical to expect a flexible crane in the trolley travel direction since operations usually require a crane natural period of 1.5 seconds or less, see Reference 2.

CONCLUSION

There are many extreme loads on wharf crane girders that are commonly not reported to the wharf designer or considered by the wharf designer.

Most extreme loads occur suddenly and for a short duration. The typical short span concrete girders resist the short duration loads through inertia forces and increased strength due to the high rate of loading. Other extreme loads such as a collapsing crane are not as severe as they appear, and some, such as those from hurricanes, must be carefully considered.

The wharf designer should be aware of the possible extreme loads and their design considerations and implications.

REFERENCES

1. McCarthy, P. W., Soderberg, E. G., and Dix, A. (2009). "Wind Damage to Dockside Cranes: Recent Failures and Recommendations." *TCLEE 2009*, Oakland, CA.

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