

## TIE-DOWN DESIGN CONSIDERATIONS FOR STS CONTAINER CRANES

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BY SIMO HOITE, PATRICK MCCARTHY, AND MICHAEL JORDAN  
LIFTECH CONSULTANTS INC.

### Introduction

When extreme winds blow, cranes sometimes collapse. If one tie-down fails, a crane can break loose and roll down the rails, destroying neighboring cranes. Although other crane structural failures can occur during extreme winds, crane-to-wharf tie-down systems are often the “weak link” for full crane collapse, and deserve more attention. The likelihood of catastrophes like the one shown below can be greatly reduced if the design and fabrication is sound and the tie-downs are maintained.



Figure 1. Typhoon Maemi - 2003

Locations that experience tropical cyclones (also called typhoons or hurricanes) nearly always require ship-to-shore (STS) cranes be tied down to the wharf structure to prevent overturning. Due to increases in crane height and outreach, without commensurate increase in the width and gage of cranes, overturning moments in storm wind conditions are now reaching magnitudes where tie-downs are being used even in “low” wind regions such as the Mediterranean, Northern Europe, and the USA West Coast.

Critical design considerations include: determining the tie-down force, considering the effects of misalignments and deformations, and coordination with the wharf hardware designer.

### Critical Design Considerations

#### *Tie-down Design Forces*

Winds may blow in any horizontal direction. The winds from tropical cyclones rotate about the storm center, so the wind direction changes as the cyclone passes. The critical wind direction is different for each crane corner.

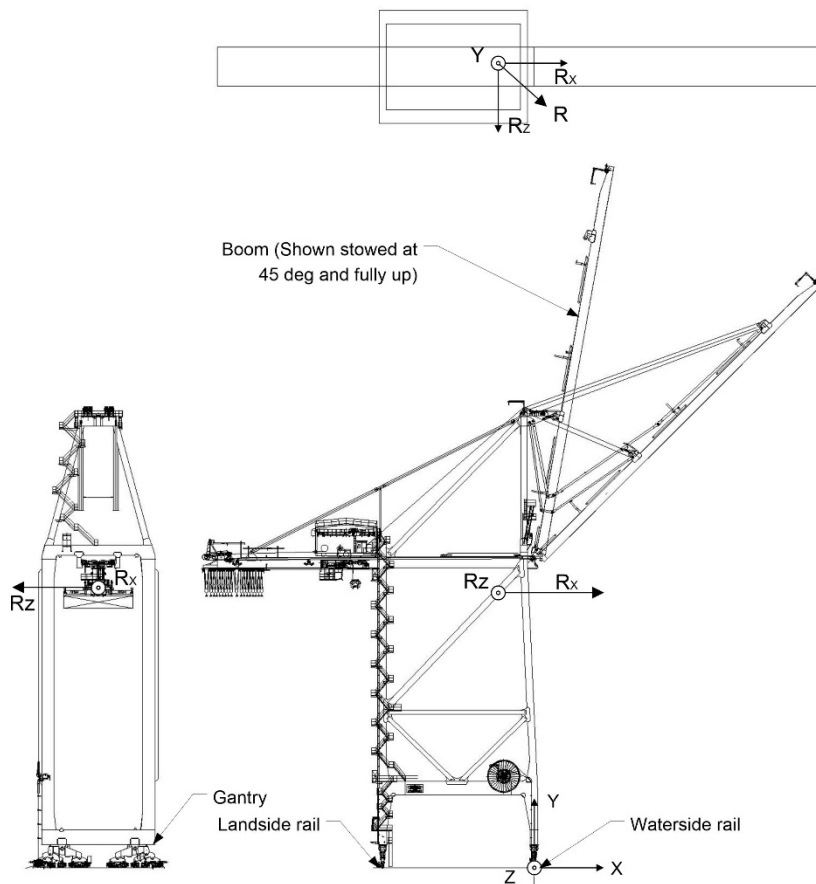


Figure 2. Wind Resultants

The crane frame stiffness affects the tie-down force. A simple analysis does not include the effect of the frame trying to warp or the distribution of loads due to sill beam rotation. A computer analysis is necessary to accurately estimate tie-down loads. The computer analysis reports the critical wind direction and the maximum wind uplift reaction at each corner. The wind reactions are different for each corner.

The calculations of wind loads on the frame are based on: member wind area, shape and shielding coefficients for each member, and the wind speed at each elevation.

Shape coefficients are determined from wind tunnel tests or computational fluid dynamics (CFD) programs. Wind tunnel test results are usually better than CFD results. Eventually, CFD results will be as good as wind tunnel test results. Often the cost of wind tunnel tests of a crane model is not justified. Coefficients, based on tests of individual members and the effects of shielding, are provided in various international standards. Liftech has developed a catalog of shape coefficients and the effects of shielding. The catalog values are based on tests of multiple STS cranes. The calculations of wind loads using Liftech coefficients have been verified by recent wind tunnel tests. However, wind tunnel tests of a model of the entire crane give the most accurate data, especially for unusual cranes.

The design wind speed is based on statistical analysis of wind data for a particular location and the surroundings. The wind speed criteria must include the gust duration, usually 3 seconds, the reference elevation, usually 10 meters, and the design speed, and be based on an acceptable probability that the speed will not exceed the design speed during a given time interval. Liftech recommends the probability of 7% in 50 years for the crane design and 3% in 50 years for tie-down system design.

The analysis accounts for increased wind speed with increased elevation. A gradient profile is used, based on the surrounding topography. The speed at the top of the raised boom may be 40% greater than a design speed at 10 m elevation. Since the wind force increases as the square of the speed, the pressure at the raised boom tip is nearly twice that at the sill beam.

As noted above, Liftech recommends the tie-down forces be based on a probability of exceedance of 3% in 50 years. This increases the tie-down force by as much as 30%. The increased cost is small and easily justified by the reduced chance of failure.

### *Design Details*

The detailed design of the tie-down system is paramount. The tie-down system includes the crane ear plate, links, a turnbuckle, if there are tie-downs on each side of the sill beam, an equalizing mechanism such as a ductile link to handle the effects of sill beam rotation, and the wharf hardware. Each element has special requirements.

The crane ear plate design must consider the tie-down load and the effect of misalignment due to crane deformation and construction tolerances. The tie-downs may be out of vertical from the wharf hardware to the ear plate by up to 100 mm. The tolerance of each site needs to be determined. An inclined tie-down affects the stresses in the crane ear plates and the wharf hardware. A small incline in the tie-down does not significantly affect the tie-down force.

The turnbuckle is needed to adjust the length of the tie-down and to tighten it. Turnbuckles are heavy and difficult to install on large cranes. A counterweight system can be used to balance the tie-down weight and facilitate handling.

If there is only one tie-down at a corner, equalization is not needed. If there are multiple tie-downs, sill beam rotation may be more important, so some equalization may be needed. If the tie-down loads are equalized by a rocker, the design should be such that failure of one tie-down should not trigger the

failure of the system. Regardless of the number of tie-downs at a corner and if they are equalized, tie-downs should be ductile to accommodate some plastic deformation.

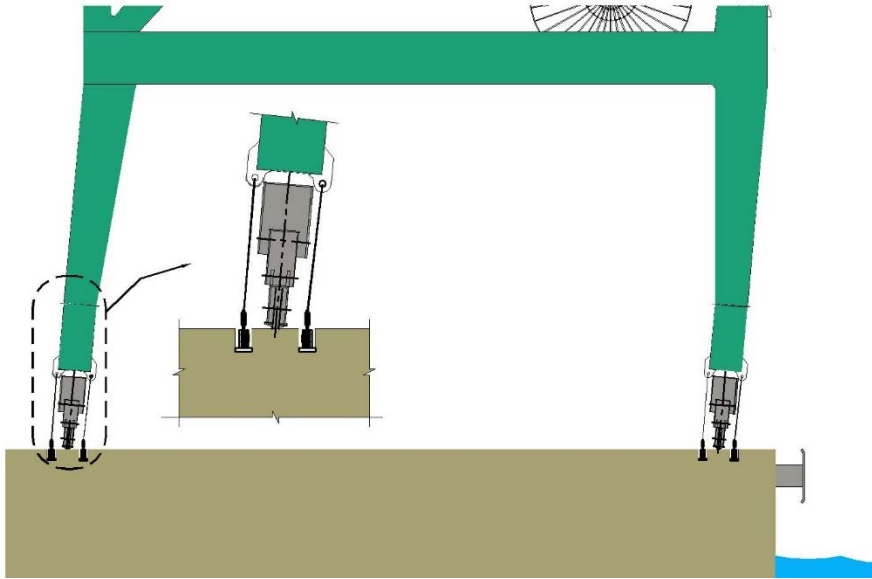


Figure 3. Crane Deformation – Effect on Tie-downs

Sill beam rotation can also be accommodated by other means, such as the ductile link developed by Liftech. Under extreme tension, the link stretches plastically. The plastic strength is controlled by the link material properties, which are measured, and the shape of the link. A redundant safety link on each side of the ductile link limits the stretch in the ductile link. After an extreme load, the stretched ductile link may need replacing.

#### *Wharf Hardware*

The wharf hardware is often designed by a wharf designer who is unfamiliar with crane design. For example, the effect of crane deformations and construction tolerances that are important are often ignored. The inclined tension and gaps between plates and pins can cause significantly unequal forces in plates, pins, and anchors. Also, the need for the links to rotate about the pin axis and the axis perpendicular to the pin may not be understood.

In one failure, the bolts anchoring the hardware pulled out of the concrete, all for the lack of a hook, head, or nut at the end of the bolt.



Figure 4. Wharf Anchorage Failure

### Horizontal Wharf Loads

How horizontal loads are transferred to the wharf should also be considered in tie-down design. Loads perpendicular to the rail are transferred by the wheel flanges. The rails may tend to rotate when the vertical wheel load is small due to uplift. This is usually not a problem, although sometimes extra rail clamps are required.

Loads parallel to the rails are best transferred to the wharf through a central bracket on the sill beam. If this load is transferred in the gantry equalizer system, the resulting moment on the main equalizer may increase the tie-down force due to prying that develops in the gantrying system. The tie-down system should be designed for the increased load.

### Conclusion

Although other crane structural failures can occur during extreme winds, crane-to-wharf tie-down systems are often the weak link for full crane collapse. Tie-down system performance and design deserve more attention.

Critical design considerations include accurate calculation of forces, accounting for misalignments and deformations, and coordination with the wharf hardware designer.