TIE-DOWN DESIGN CONSIDERATIONS

STS CONTAINER CRANES

Simo Hoite, Patrick McCarthy, and Michael Jordan;
Liftech Consultants Inc, California, USA

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 thereby deserve more attention. The likelihood of catastrophes in ports can be greatly reduced if the design and fabrication is sound and the tie-downs are maintained.

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 US 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.

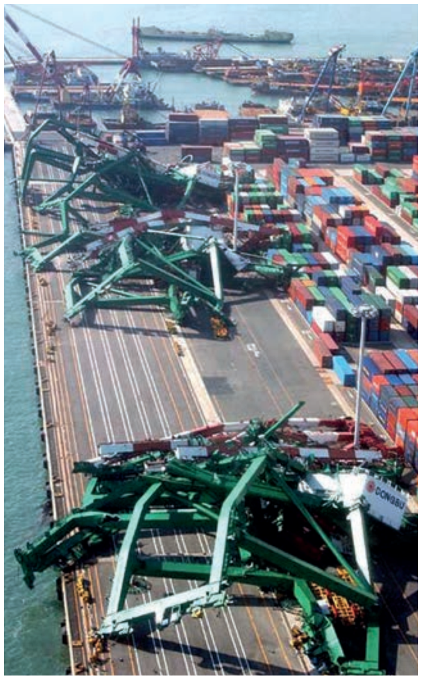
CRITICAL DESIGN CONSIDERATIONS

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.

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

Figure 1: Typhoon Maemi - 2003



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) programmes. 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 catalogue of shape coefficients and the effects of shielding. The catalogue 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 metres (m), 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 10m 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.

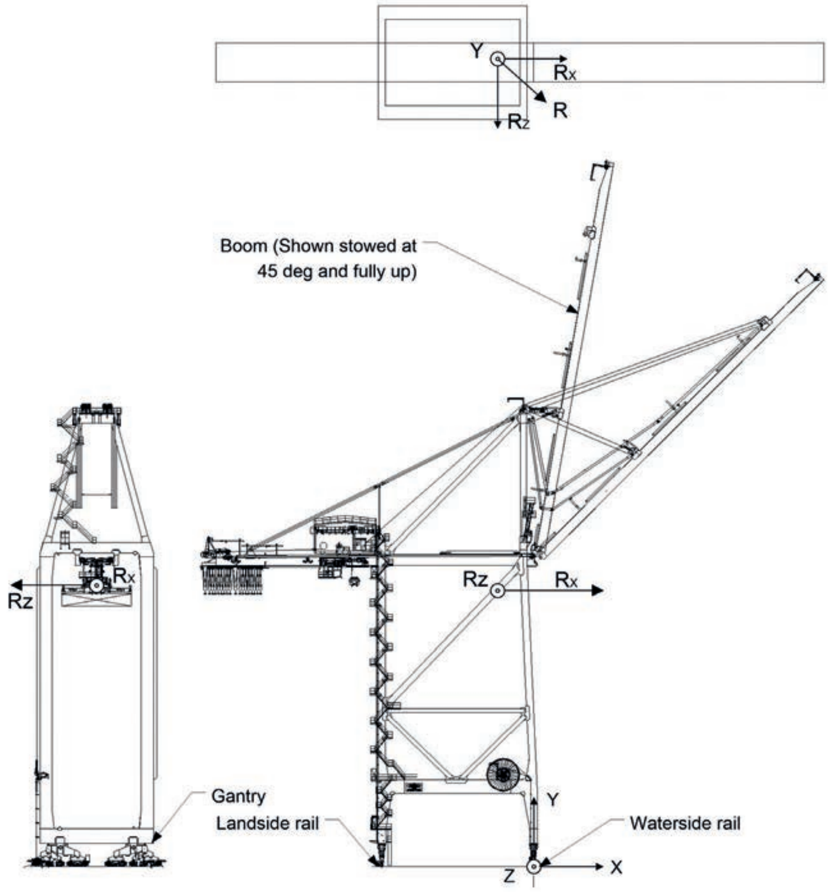


Figure 2: Wind resultants

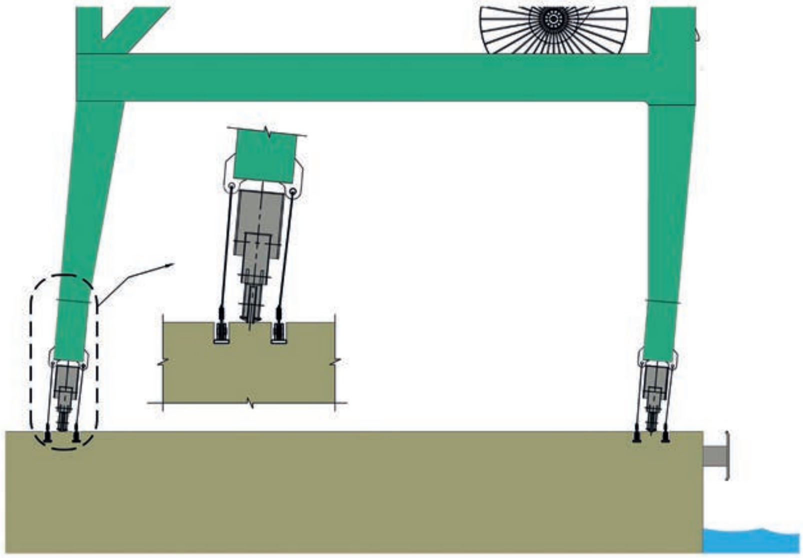


Figure 3: Crane deformation – effect on tie-downs

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 milimetres. 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.

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.

Figure 4: Wharf anchorage failure

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.

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 deserves more attention.

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

ABOUT THE AUTHOR

Simo Hoite is a Liftech senior engineer with extensive experience in container crane design, specifications, and procurement, as well as container and rail terminal operations. With a broad background in the container terminal industry for over 20 years, his experience also includes container terminal planning and analysis, container market intelligence, and development of innovative container terminal equipment and modes of operation.

Patrick McCarthy is a Liftech senior engineer and principal. He is experienced in container crane procurement, modification, design, structural life assessment, and writing technical specifications. In addition, he has been involved in wind tunnel and numerous other wind-related studies, and is an associate member of the Wind Load Subcommittee of ASCE 7.

Michael Jordan is Liftech's founding principal and technical director. 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 dockside 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.

ABOUT THE ORGANIZATION

Liftech Consultants Inc. is a consulting engineering firm, founded in 1964, with special expertise in the design of ship-to-shore container handling cranes and other complex structures. Our experience includes structural design for wharves and wharf structures, heavy lift structures, maritime buildings, container yard structures, and container handling equipment. Our 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
Email: Liftech@Liftech.net
Web: www.Liftech.net