

Securing Cranes for Storm Wind: Uncertainties and Recommendations

Port's 2004, Houston, Texas

Patrick W. McCarthy, PE, Liftech Consultants Inc.

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Ports 2004



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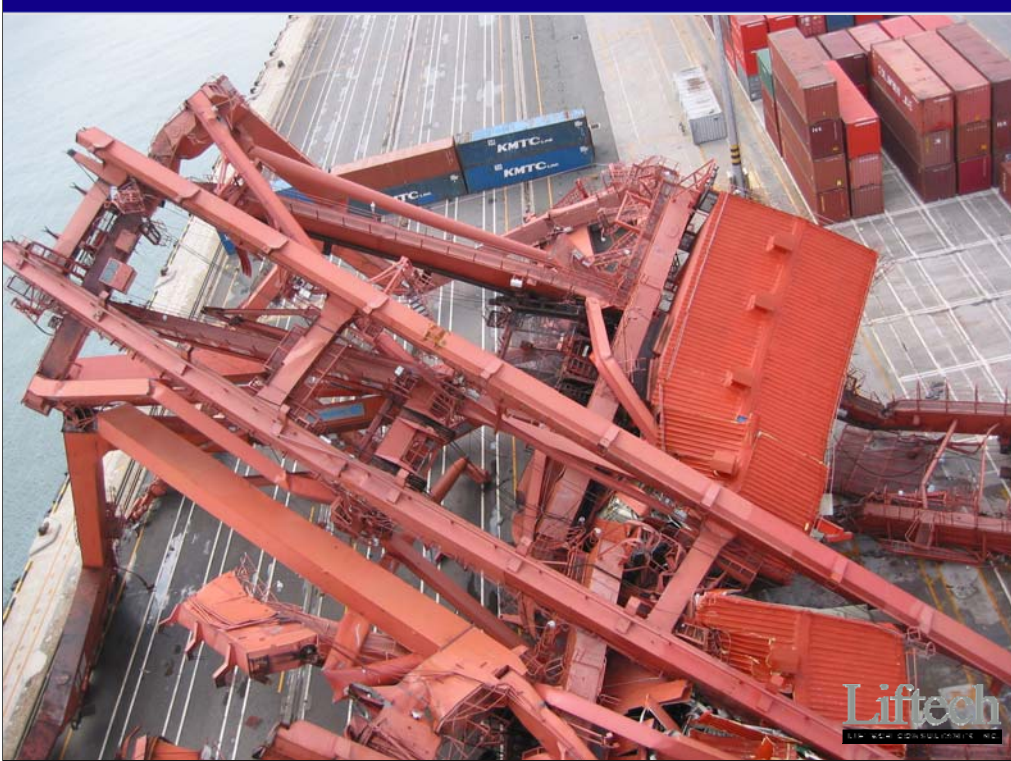
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Typhoon Maemi struck Pusan, Korea September of last year.

This photo shows two of the damaged cranes. Notice the underside of RHS crane boom.

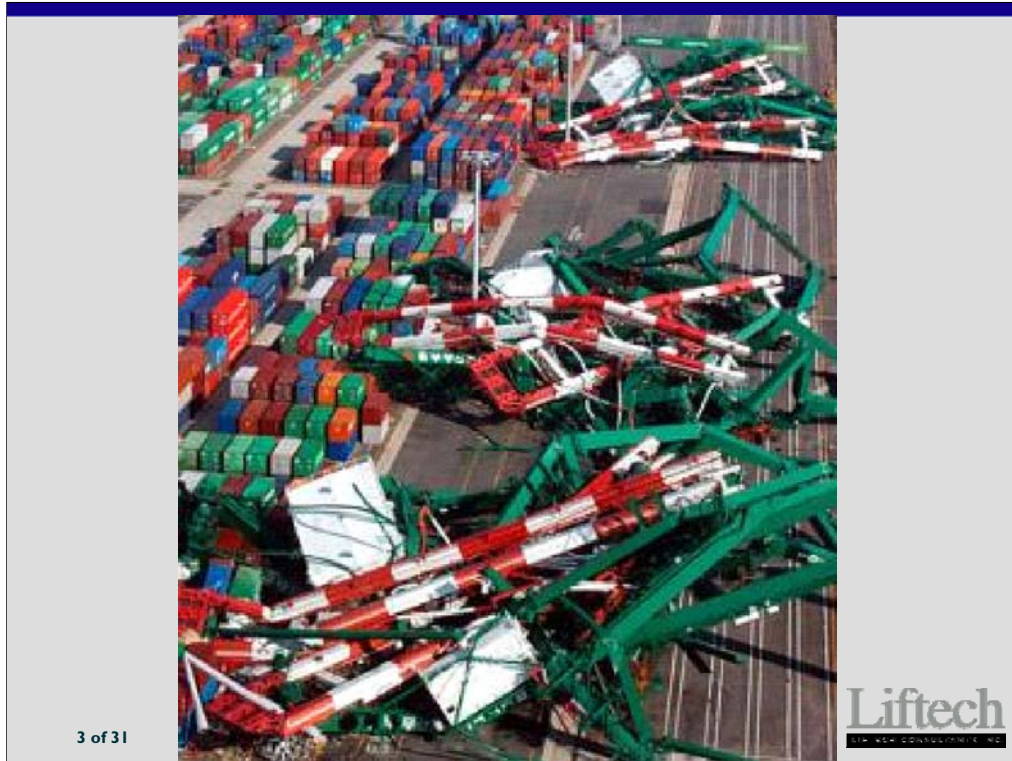
Initial failure occurred at the tie-down attachment to wharf.

Consequential damage consisted of one crane falling on another.

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We have not experienced a case where a collapse has resulted from the crane structure failing prior to a stowage system failure.

The photo here shows three pairs of two cranes--six cranes total (the booms are red & white.)

The failure sequence began when one crane's tie-down system failed. The crane came loose, ran down the rail, and collided with the next crane whose tie-down system failed, and so on, resulting in the eventual collapse of six cranes.

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This failure occurred in Puerto Rico, in 1998. The initial failure was not due to crane structure.

Topics

Stowage components

Uplift force calculation & error

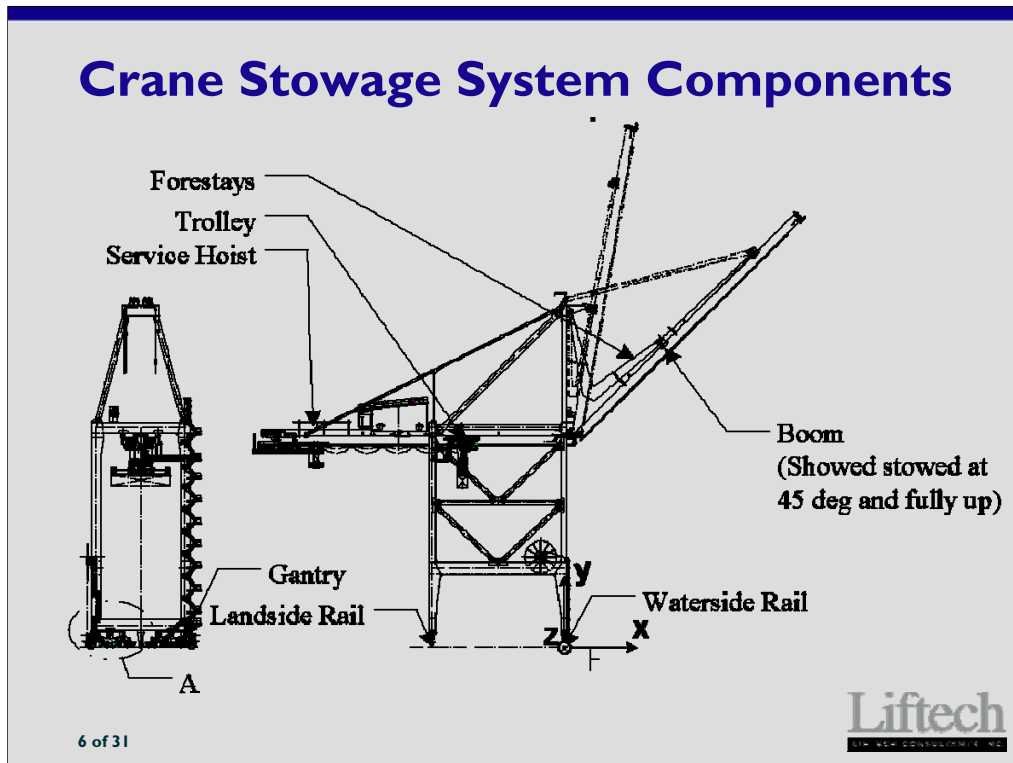
Recommendations

Recent failures

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These are the topics we will cover in today's presentation.



Principal directions: X, Y, & Z

Most failures are uplift-related

Next slide shows **view A** in more detail

Non-hurricane-prone regions:

- Stowage pins

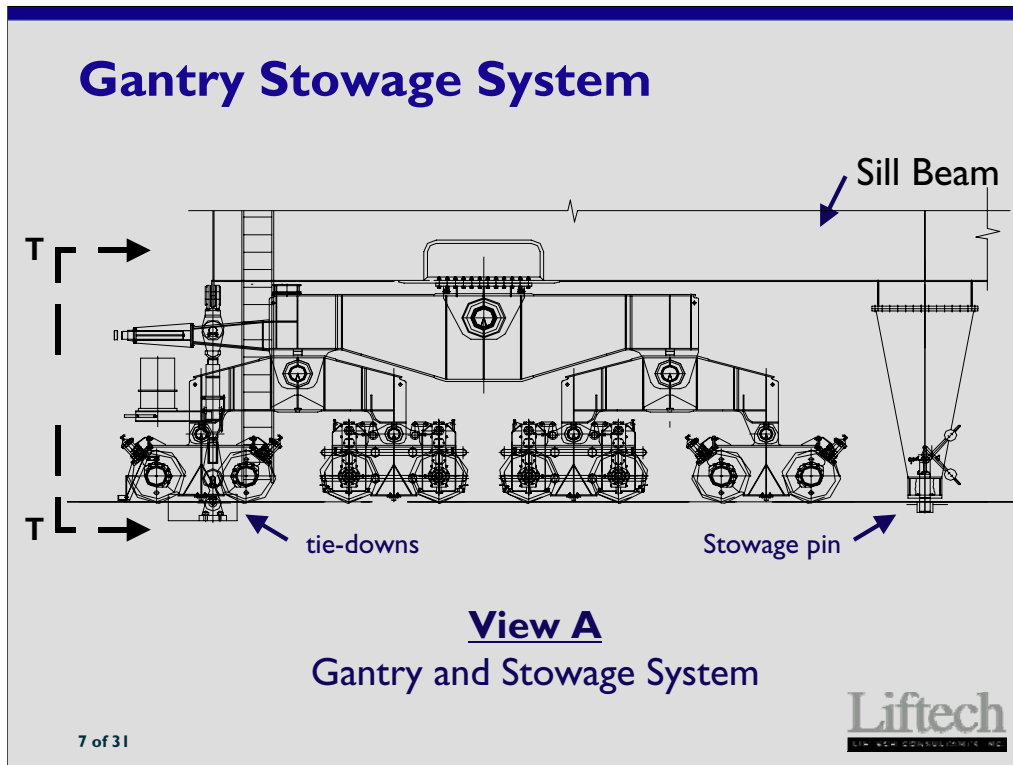
- Ballast (typically)

- One leg may lift

Hurricane-prone regions: (main focus of hardware examples)

- Stowage pins

- Tie-down systems



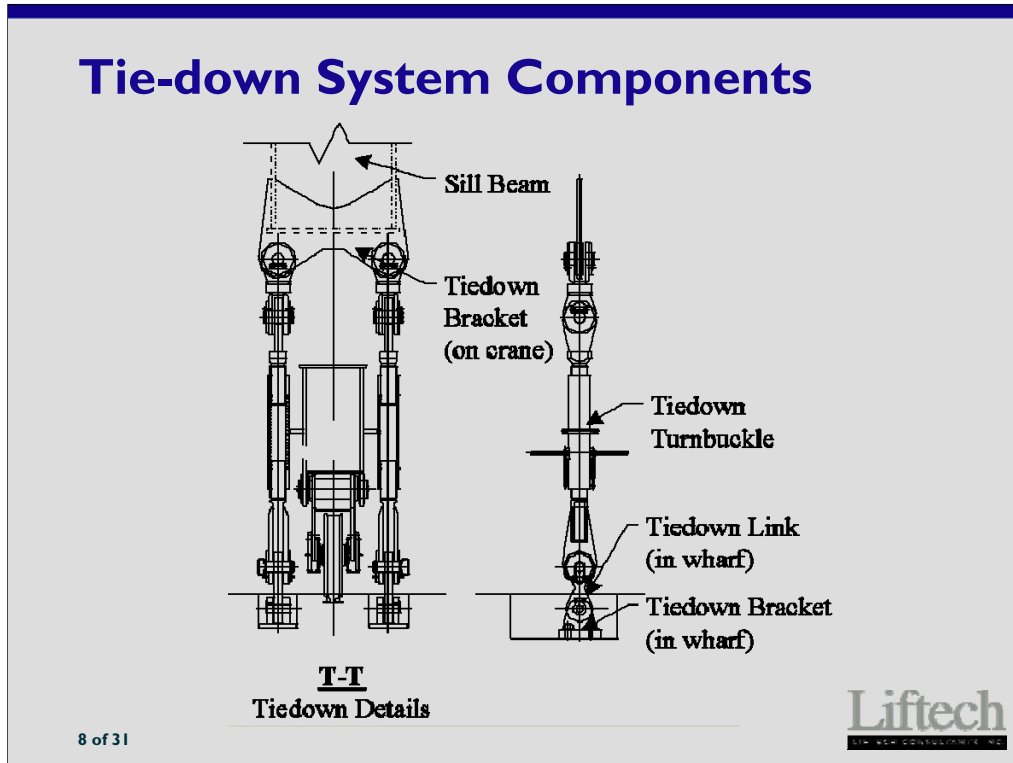
This is the typical gantry stowage arrangement.

The tie-down assembly, view T-T, will be shown on the next slide.

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Designed for rotation and displacement of the sill beam. Split calculated design load 60/40 due to unequal load sharing.

Note: We have since developed the “ductile link” system to evenly distribute and to limit the tie-down loads. Call for more information.

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Crane tie-downs

NIT South, VA



Port Everglades, FL



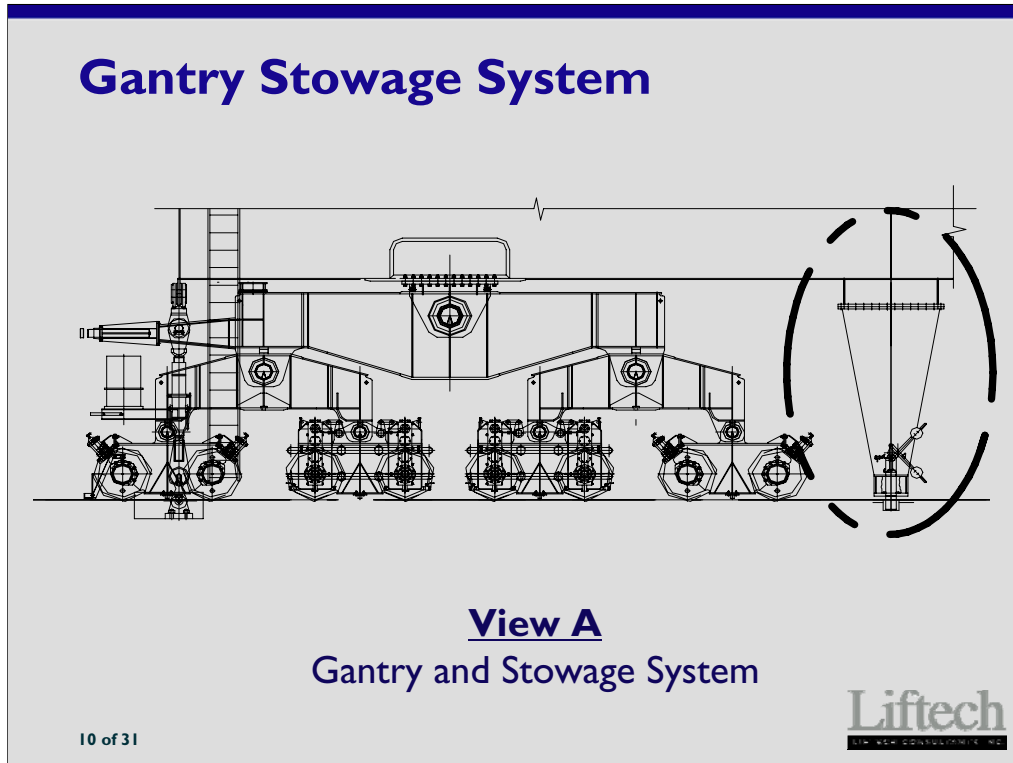
Left Photo:

New cranes, 2x/corner

Right Photo:

Low-profile crane, LS corner, 4x/corner

Assist lever to lift the wharf tie-down link



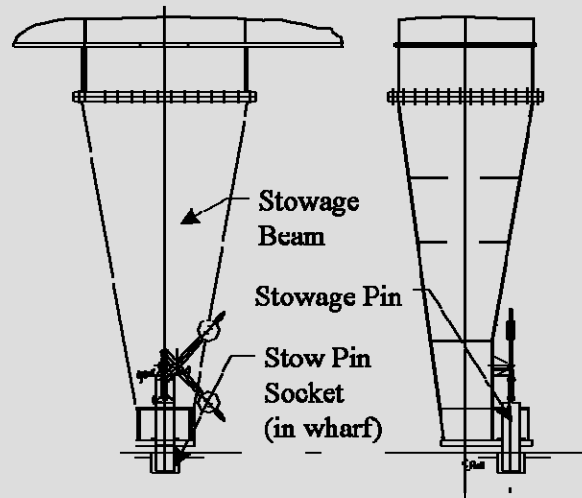
Stow pins at the center of the sill beam to prevent **leveraging** effects in the gantry system.

If the stowage pin was instead extended from a gantry equalizer beam or truck the resulting leveraging would cause:

- Increased load in tie-down

- Increased wheel load

Stowage Pin System Components



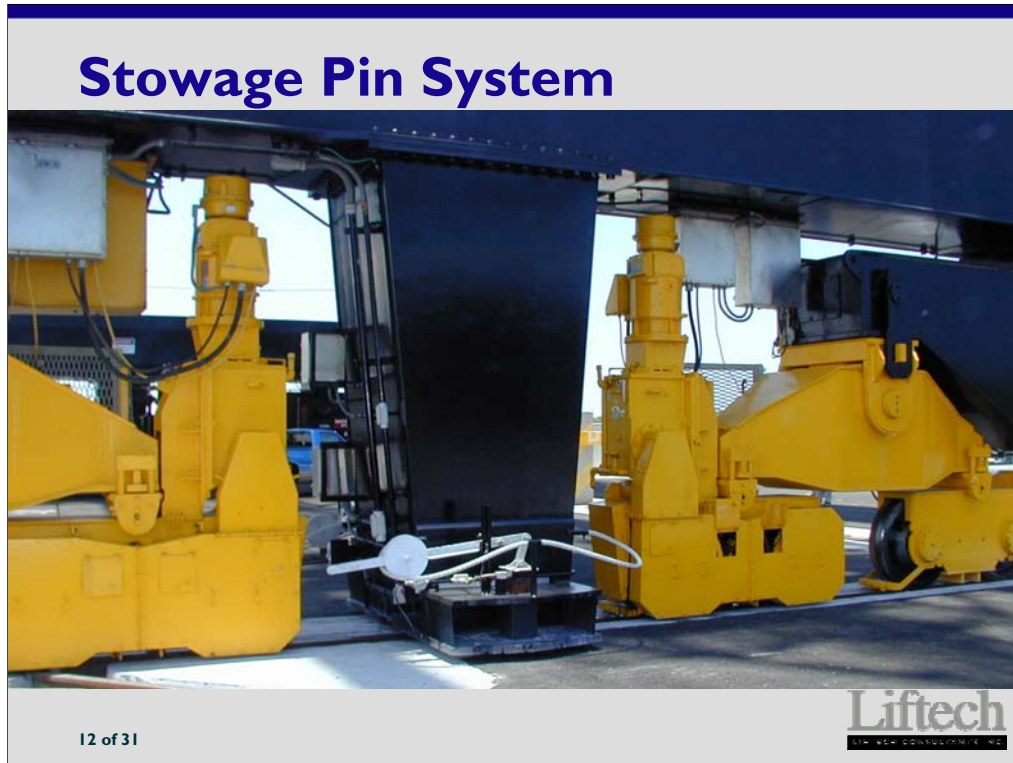
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Socket depth sufficient for strength and for non-hurricane corner uplift

Designed not to “ratchet”

Maintain holes so that the pin can be lowered fully into the socket!



The lever mechanism links the pins on each side of sill beam so both pins can be raised or lowered at the same time.

Stowage Pin at Truck



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This photo shows the stowage pin on truck. Because the stowage pin is only on one corner per side and only one side per rail, this torques the truck.

Calculations indicate, for this case, the tie-down force is increased by about 50% due to leveraging effects.

Wind Force Calculation

$$F = C \times A \times (qG)$$

where

C = shape coefficient(s)

A = area

(qG) = velocity pressure, including gust, G

$$q = 0.5 \times \rho \times V^2 \text{ (Bernoulli's equation)}$$

where

ρ = air density

V = wind speed, which varies with height

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ASCE 7-02 states that the code is not meant for cranes.

Biggest errors are in C & V

Wind tunnel testing to determine C. It is not economic to perform wind tunnel testing for all projects. Typically, the results from a wind tunnel test performed on a similarly-sized crane are used.

V varies with exposure category (surface roughness)

Wind speed is meaningless without duration and elevation where it is measured

Wind Speed Recurrence

Mean Recurrence Interval (MRI)

Probability of Speed Being Exceeded

MRI	Years in Operation				
	1	10	25	50	100
10 yrs	.10	.64	.93	.99	.99997
25 yrs	.04	.34	.64	.87	.98
50 yrs	.02	.18	.40	.64	.87
100 yrs	.01	.10	.22	.39	.64

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MRI = $1/\text{MRI}$ = probability of exceeding in one year (50 yr MRI = $1/50$ = 2% chance of exceeding in any given year)

Based on statistical analyses of maximum wind speed records at certain weather stations.

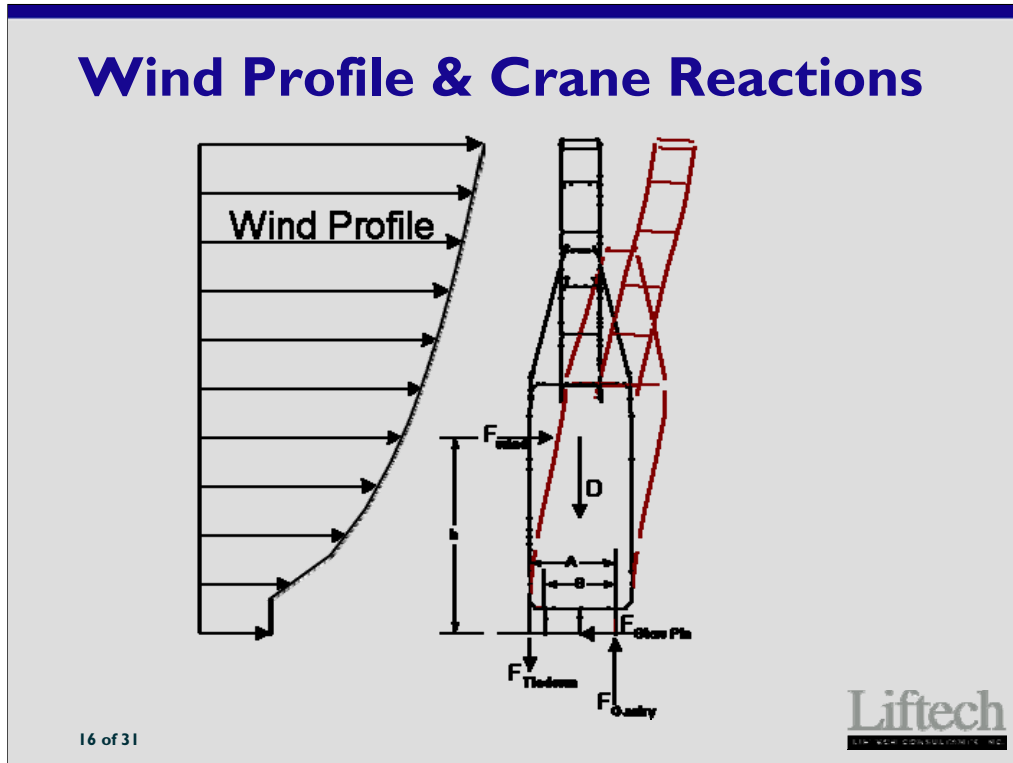
Even if you design for a 50-yr MRI wind, there's still a 22% chance of the crane seeing a 100-yr MRI wind in 25 yrs. ... cranes will likely see a wind at or higher than the design wind.

Typically:

50-yr MRI for crane design

25-yr MRI for modifications of older cranes may be reasonable

$$P(E) = 1 - (1 - 1/\text{MRI})^{\text{YRS}}$$



Proper load paths are required for loads in all directions.

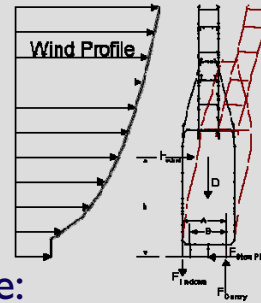
Z-direction wind is shown here.

Use finite element with correct boundary conditions and crane stiffness modeled – calculating uplift from a grid will not necessarily give the correct results!

Error in Calculated tie-down Force

Ratio of moments:

$$\gamma = \frac{F_{wind} h}{D \frac{B}{2}} = \frac{\text{Overturning Moment}}{\text{Righting Moment}}$$



Error in calculated tie-down force:

if “e” = error in wind force,

$$\frac{F_{Tiedown, Actual}}{F_{Tiedown, Calculated}} = \frac{\frac{1}{A} \left[(1+e) F_{Wind} h - D \frac{B}{2} \right]}{\frac{1}{A} \left[F_{Wind} h - D \frac{B}{2} \right]} = \frac{(1+e)\gamma - 1}{\gamma - 1}$$

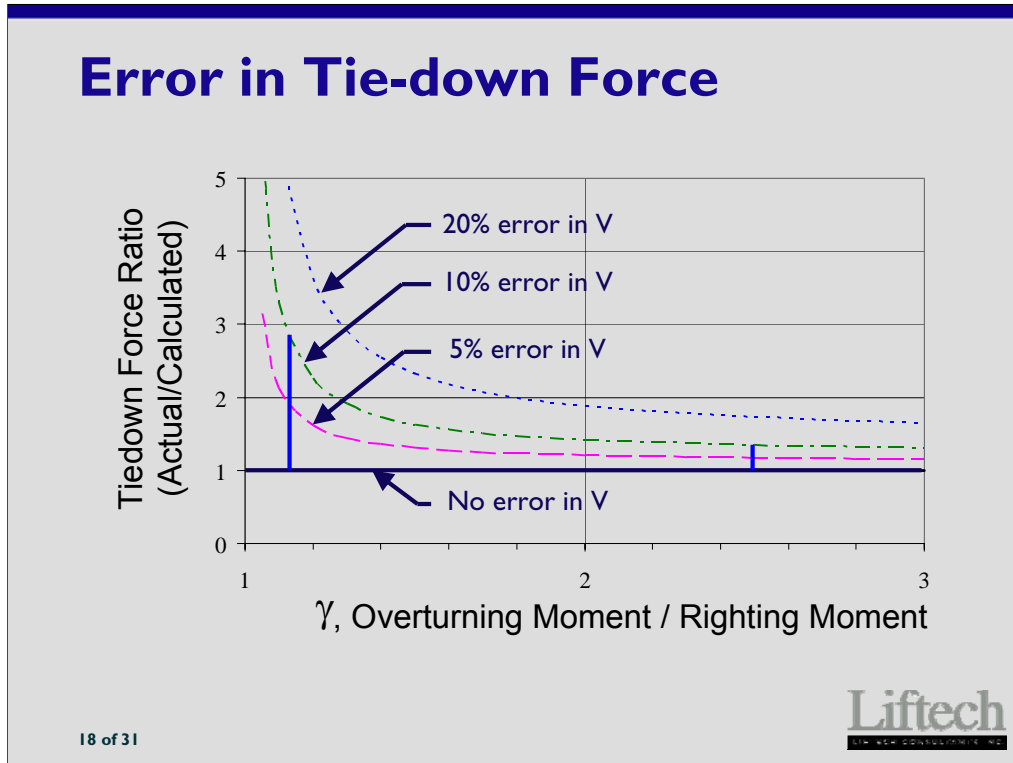
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gamma = ratio of overturning to righting moments.

e = error in force, which could consist of shape factors, wind speed, etc.

(neglecting other errors)



As the ratio of moments increases (bigger uplift), the error in the calculated tie-down force approaches the error in the wind force.

This may be an issue for the landside tie-down on older cranes in hurricane zones

Typical values of gamma:

LS: 1.0 to 2.5

WS: 2.0 to 5.0

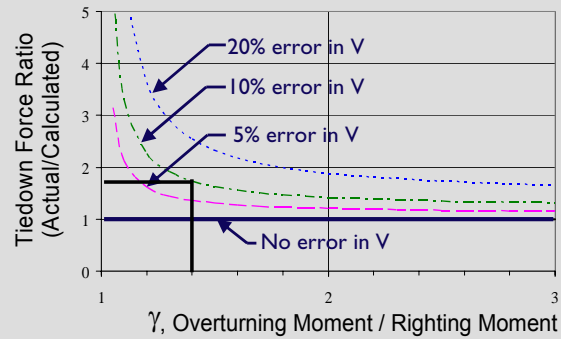
Avoid minimalistic design! We recommend to design the LS tie-down for at least 50% of calculated WS tie-down uplift force.

Example:

Error in wind speed = 10%

$$\gamma = 1.4$$

$$e = 21\%$$



Error in calculated tie-down force = 74% !

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overturning moment = 40% greater than righting moment

A 10% error in wind speed produces a 21% error in pressure (and therefore, force)
... and a 74% error in calculated tie-down force.

Check your cranes for possible minimal design on the landside. This is particularly important for low-wind zones, such as the U.S. West Coast.

Recommended Minimum Load Combinations

Load	SC1	SC2
Dead Load	0.9	0.9
Stowed Moving Load	0.9	0.9
Wind Load 20-year MRI	1.0	
Wind Load 50-year MRI		1.6*
Tie-downs secured?	No	Yes
Corners allowed to lift	1	0

* 1.3 without ASCE 7-02 "directionality factor"

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We typically allow a 1.0 DL factor if crane is weighed.

If wind directionality factor isn't applied to SC2 (ASCE 7-02), use 1.3 factor here.

SC1 is for basic storms that may come along while the crane is not tied down.

Note that most collapses are from collisions after the crane has broken free, not from the storm itself.

SC2 is for hurricanes, when advanced notice is provided and the crane requires to be tied down.

Limit State (Factored) vs. Service Loads

Communication between the crane and wharf designers is important!

Load	Service	Factored	
	SC2 _s	Load Factor	SC2 _F
Dead Load	-500	x 0.9 =	-450
Wind Load	+400	x 1.6 =	+640
Calculated Uplift	-100		+190
	No Uplift		Uplift

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Discussion of Factored vs. Unfactored

Limit State = "Factored" = "Ultimate"

(Ultimate Limit State, as opposed to Serviceability)

Sometimes, the wharf designer asks for the DL and uplift force at the corner and designs the wharf tie-down hardware based on the resulting unfactored uplift force. The crane designer has designed the crane tie-down components for nearly 200 tons, but the wharf designer may provide a minimal design for the tie-down bracket, since his calculations show that there is no or minimal uplift.

It is important to design based on the factored loads. An ASD approach can still be used if the factored loads are later reduced to service loads.

LRFD (Load & Resistance Factor Design) vs. ASD (Allowable Stress Design)

Recommended tie-down Strength Requirements

Turnbuckle breaking strength = $2.5 \times$ factored uplift force

Proof test tie-down mechanical components to 125% of the calculated tie-down force

Design structural components to an allowable stress of $0.9 \times F_{\text{yield}}$ using the factored forces

Design wharf hardware to the same requirements as for the crane!

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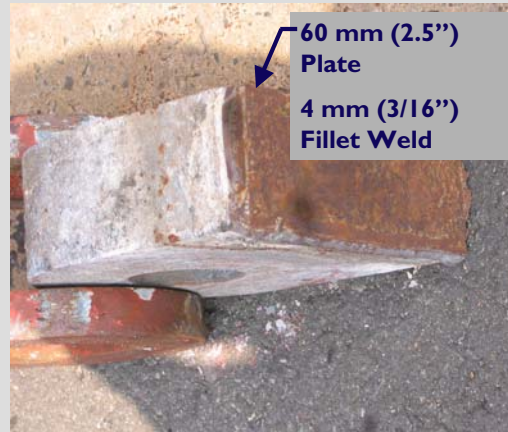
This in part compensates for possible uneven load distribution between tie-downs if there is more than one per corner. In addition, since the turnbuckle is a mechanical, high-strength, threaded component, it may fail in a brittle manner, unlike the main crane structural components. From our experience, the crane structure is not the “weak link.” We recommend that the wharf attachment be designed to the same loading and safety factor as the crane tie-down components.

The turnbuckle should show no permanent deformation and the screw should turn freely after the test. Ideally, we would like to see a proof test with the tie-down and wharf attachment assembly, but this is not practical.

Design structural components local to the tie-downs, such as the eye connection to the crane and the tie-down link bars be designed to an allowable stress of $(0.9 \times F_{\text{yield}})$, where F_{yield} is the yield stress, using the same tie-down force.

Typical Failure Modes : Fabrication

Wharf tie-down bracket failure: Insufficient weld capacity



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We suggest NDT inspections and proper installation review.

Typical Failure Modes: Fabrication

Wharf tie-down anchorage: Anchor rods pulled out



This photo shows the anchor rods pulled out of the wharf.

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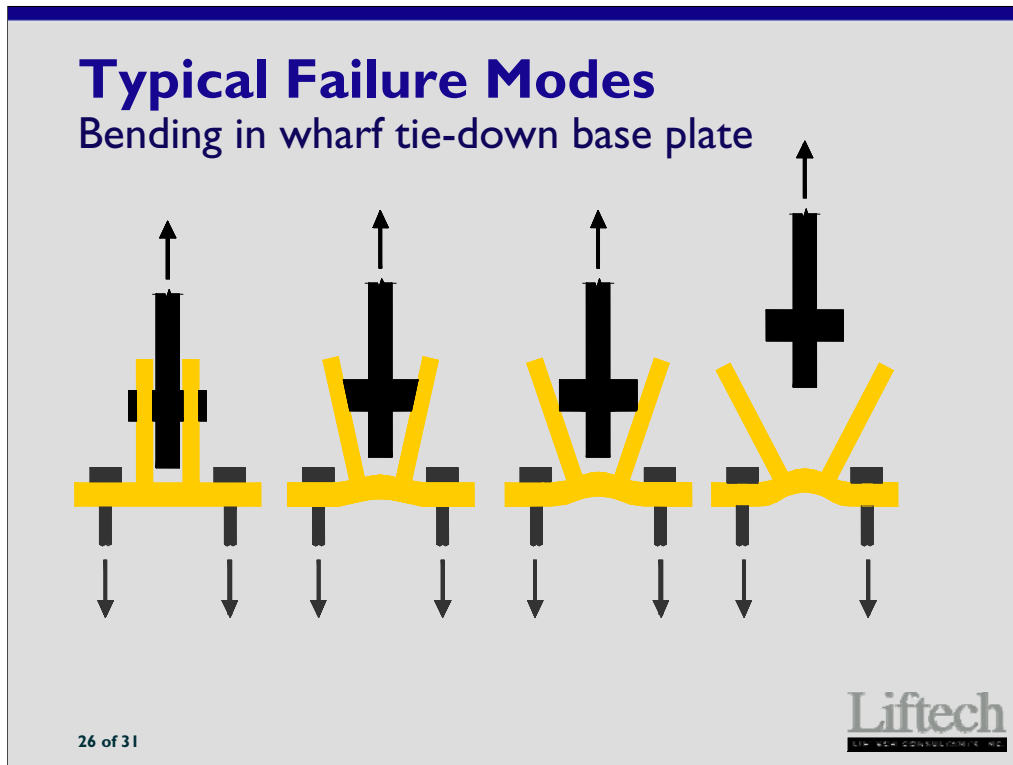
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On the left, tie-down link plates separated and released from the pin. (See the next slide for a schematic of a similar failure mode at the wharf bracket.)

Right photo shows wharf tie-down bracket torn away.



Improperly designed base plate. The base plate bends, allowing the bracket to open up, releasing the tie-down.

Typical Failure Modes

Stowage pin sockets: Failure & improper maintenance



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The stowage pin sockets are sometimes filled with debris. Photo on left shows a failure whereby the tie-down had already failed, but the amount of uplift required to lift out of the hole appears minimal.

Typical Failure Modes

Stowage pin sockets: Missing pipe sleeve & failure

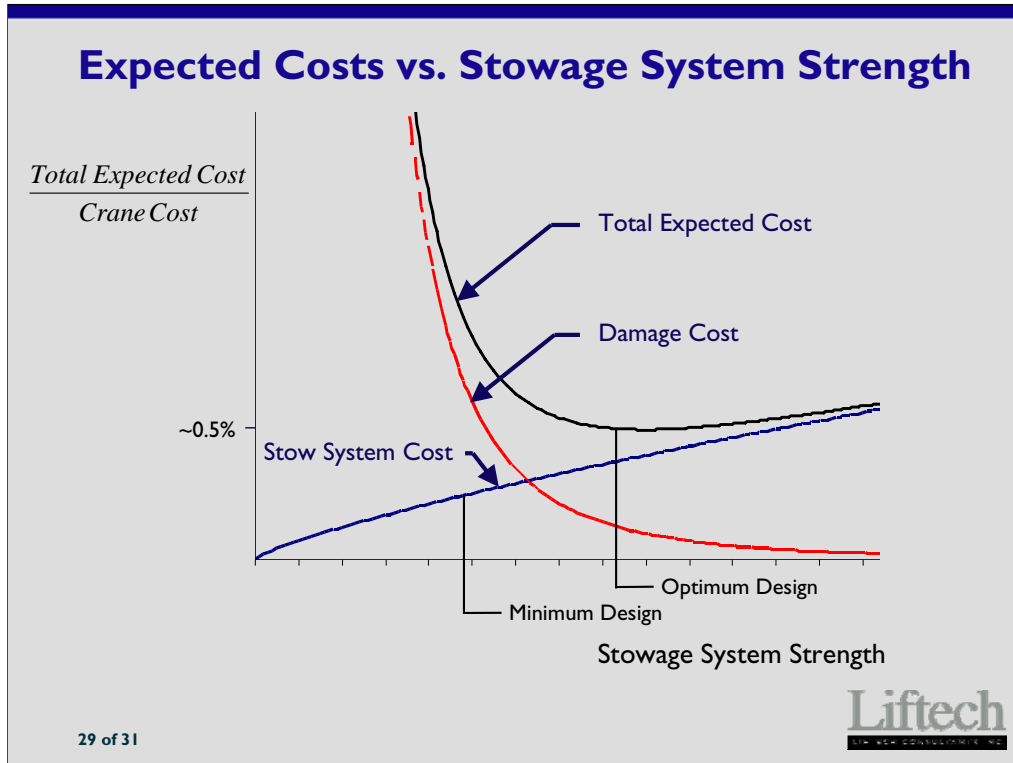


Socket on the left has no reinforcement pipe. This results in transfer of the entire load to the other pin.

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“Cost” is the expected hurricane-related cost over the life of the crane

If there is no tie-down system, or it is extremely under- designed, you will likely lose the crane. You would be very lucky not to.

If the stowage system is properly designed, there will be very minimal damage (local only).

The added cost to properly design the stowage system is a small fraction of the total cost, if improperly designed.

If you're trying to cut costs, minimal design of the stowage system is *not* the smart way to do so.

Summary

Wind forces are not easily predicted

If you're unsure, review your crane
& wharf stowage system

design

fabrication

The lower wind designs may be
under-designed

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In summary, review and maintain your crane-wharf stowage system.

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Thank you

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This crane ran down the runway, smashed through the end stop, and finally came to a rest after sinking into the wharf beyond the rail (similar to a runaway truck ramp).

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