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Knowledge Sharing for a Better Tomorrow

STS Crane Stowage Design: Key Considerations and Case Study

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Anna Dix, principal and structural engineer at Liftech Consultants Inc. I will present considerations for designing stowage hardware for STS cranes. The aim of this talk is to share from a crane-expert's perspective the subtle, but important details that we recommend for the wharf-side of the design. This is mainly intended for wharf designers.

Overview

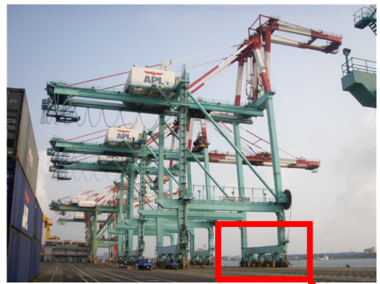
Crane stowage system

Design considerations for stowage pins

Design considerations for tie-downs

Design and fabrication coordination

Port Everglades case study: fabrication issues and solutions



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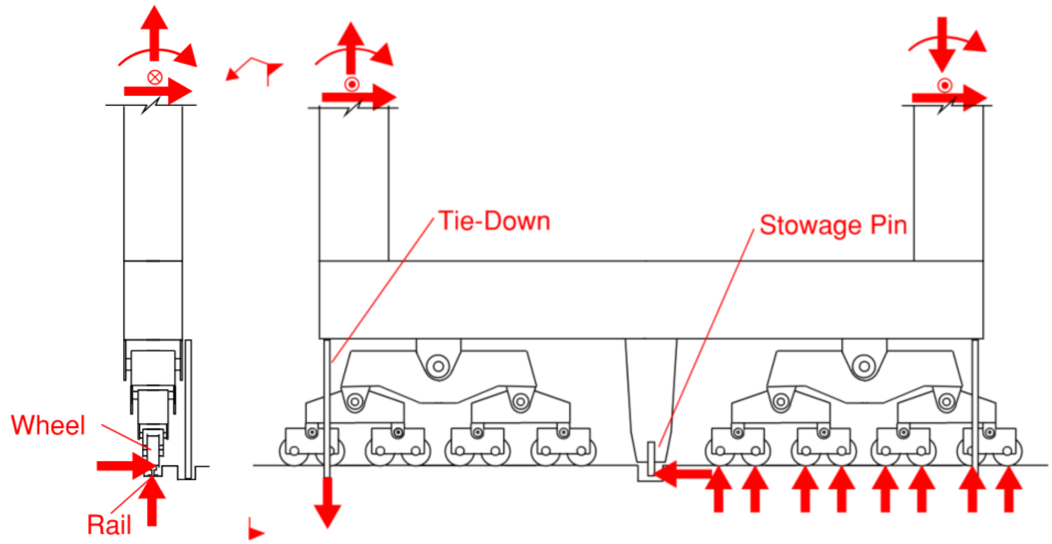
First, the overall STS crane stowage system, to present the various forces and crane movements that affect the design.

Next, the design considerations for each stowage component in the wharf.

Last, a case study from Port Everglades.

Crane Stowage System



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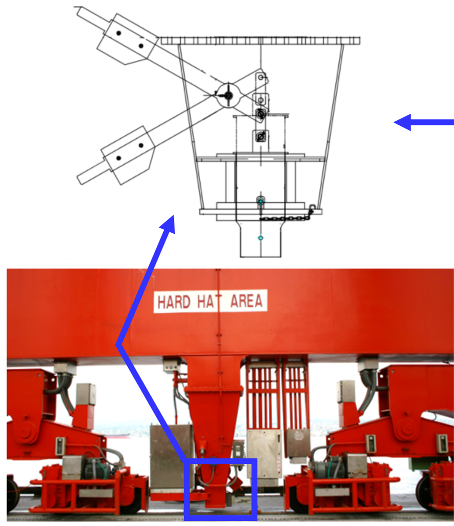
Shown: illustration of a basic STS crane stowage system. To resist large wind forces, the crane needs to be constrained in three directions: horizontally in the gantry travel direction, horizontally in the trolley travel direction, and vertically in the uplift direction.

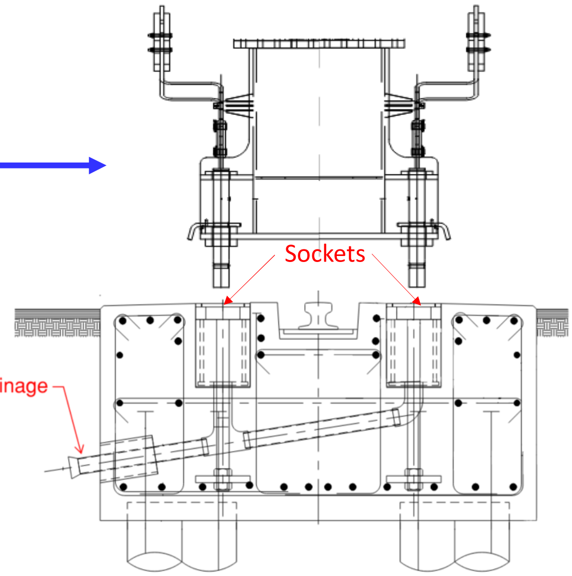
The crane and wharf components that resist those loads are the stowage pin, the wheel, and the tie-down, respectively.

Not all cranes need tie-downs. It depends on crane stability in the design wind, but I have included them in this discussion.

Stowage Pin System



Stowage Pins on Crane



Stowage Sockets in Wharf

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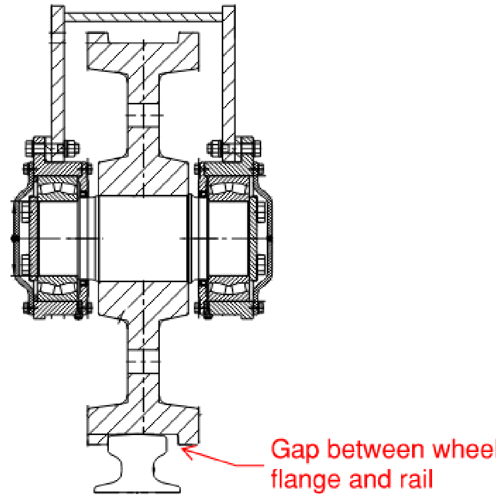
Stowage pin system: The crane stowage pin assembly above the wharf sockets is on the right. There can be one or two stowage pins at each rail, and they are usually located at the crane centerline. Note that we do not recommend locating the stowage pin(s) at the gantry equalizers, as this results in prying and could increase tie-down loads.

The crane stowage pin assembly consists of a bracket, a retractable pin, and a mechanism to lift and lower the pin.

The wharf socket consists of a void in the wharf girder, lined with steel plates, with a reinforced opening for the pin to bear on. You can picture it like a steel tissue box embedded in concrete. There is also a lighter steel cover to keep larger debris out when the socket is not in use, and a drain to clear water and smaller debris.

Rail System



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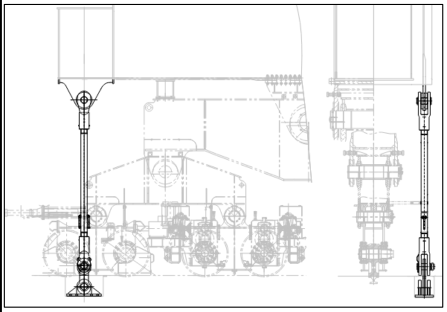
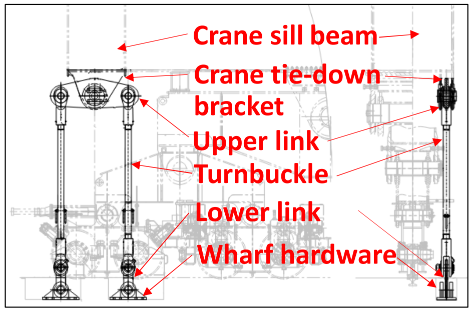
The rail system is the simplest component of the stowage system, but the wharf designer still needs to understand it. The crane wheel and rail system resist the crane's downward force through bearing of the wheel tread on the top of the rail, and it resists the force perpendicular to the rail, through friction and with the wheel flange against the side of the rail head. There is a gap of typically 20 mm to 30 mm (3/4 in to 1.25 in). This gap is important for gantry operation but also has implications for stowage system design.

Tie-down Systems

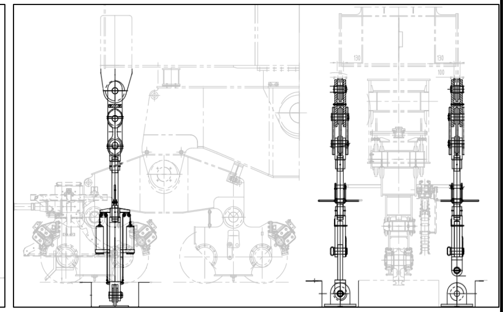
Configurations



One per corner,
one wharf link



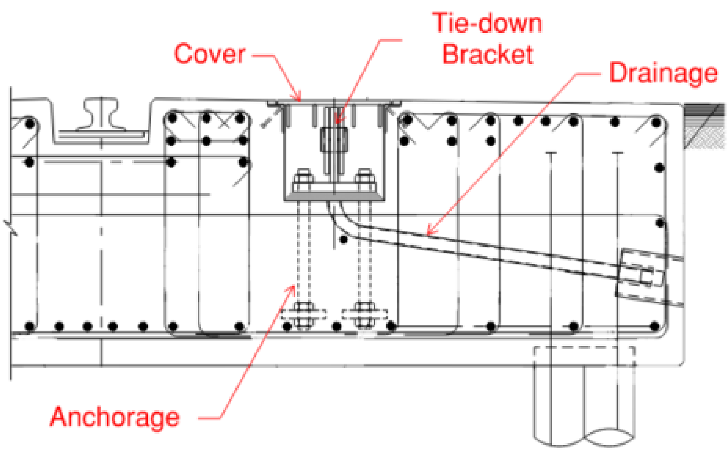
Two per corner,
two wharf links

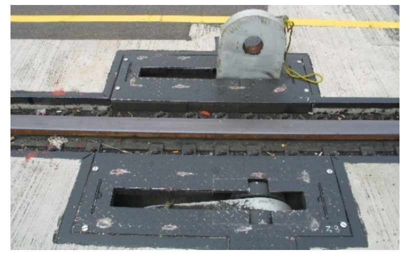


Two per corner,
two wharf ear plates

Crane tie-down systems consist of a bracket at each end of the sill beam, a large turnbuckle, and various links and pins connecting them with the wharf bracket. These images show a few different configurations of tie-downs: one tie-down per corner (left), two tie-downs per corner on the same side of the rail with equalization (center), and two tie-downs per corner on opposite sides of the rail (right). Each configuration has different considerations for design, which I will talk about later.

Tie-down Systems





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This is an example cross-section of the wharf crane girder. You can see that, similar to the stowage pin socket, the tie-down bracket is recessed into the concrete. The important pieces of the system are the tie-down bracket with base plate, the anchorage, the cover, and the drainage. The bracket may also incorporate links that rotate up out of the pocket to connect with the crane tie-down.

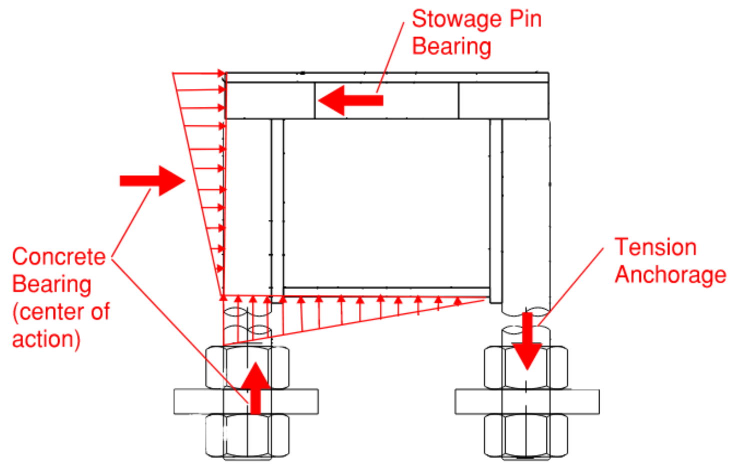
Design Considerations for Stowage Pin Sockets

Load Path

Bearing on top of socket

Bearing on concrete

Tension in anchorage



Next are design considerations, starting with the stowage pin socket.

This shows the basic load path. Not fully designing for the load path can lead to failure of the component, or worse, progressive collapse of the stowage system, and catastrophic losses. This has happened before.

Some main points:

The stowage pin from the crane is cantilevered downward, so having a bearing plate at the top to raise the center of action is beneficial.

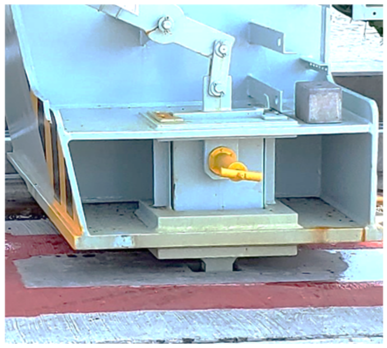
The designer needs to consider the large bearing forces on the top edge of the concrete to avoid spalling.

The overturning forces in the box may produce significant tension, so anchorage may be needed.

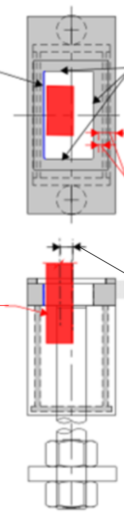
Design Considerations for Stowage Pins

Operational

- Transverse fit
- Longitudinal fit
- Drainage
- Cover design



Socket and pin



Transverse/longitudinal pin fits

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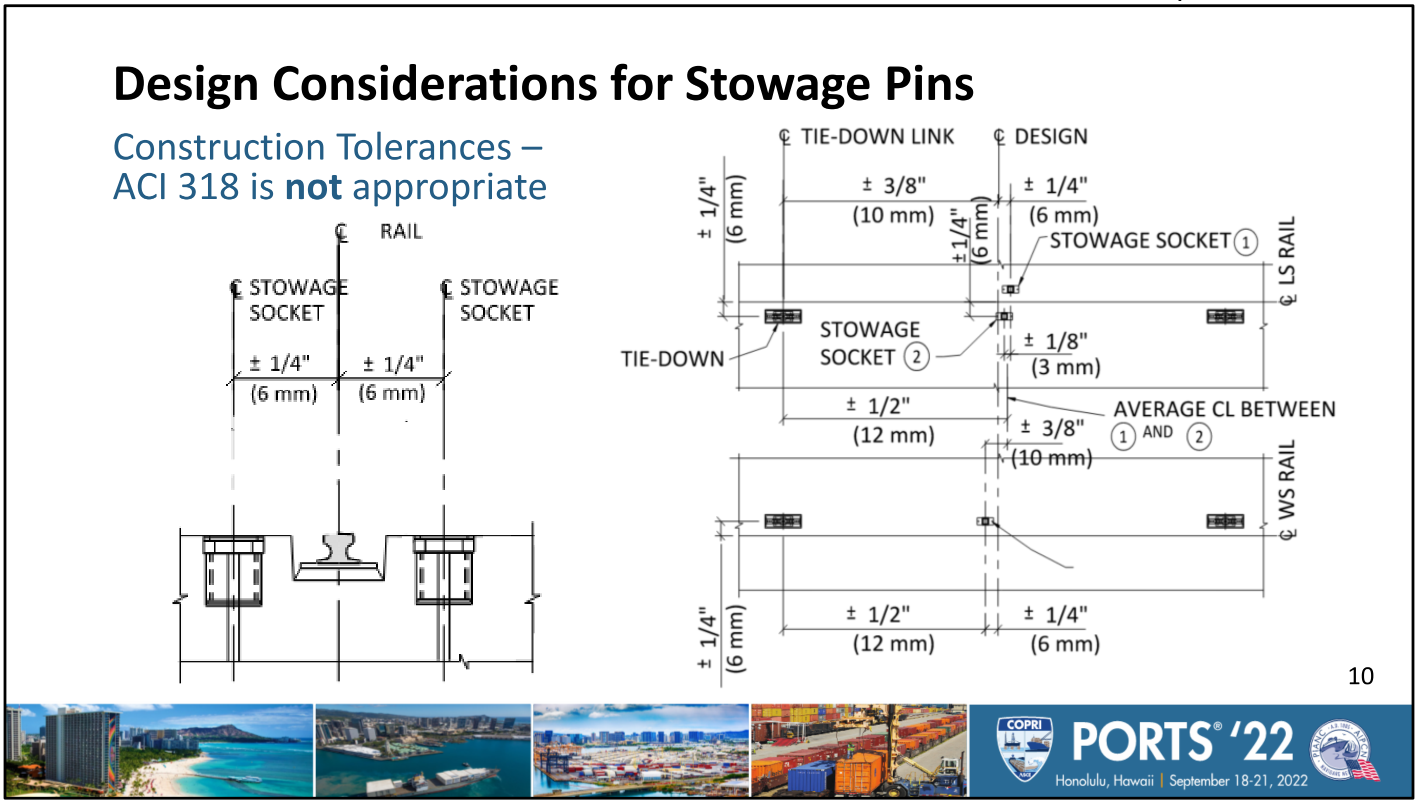
Next are operational considerations including transverse and longitudinal fits, drainage, and covers.

Transverse Fit: Recall the earlier slide with the wheel and the rail. Remember that there is a gap, which means the crane can shift laterally, perpendicular to the rails. In addition to this shifting, the crane stowage pin bracket has some construction tolerance. The wharf designer needs to accommodate this in the design, with room to spare, because the crane pin is only designed for loading in one direction. We typically recommend making the opening 50 mm to 75 mm (2 in to 3 in) wider than the pin.

Longitudinal Fit: Picture you are a crane operator and you're moving this 2,000 tonne (4,000 kip) crane to the stowed position. You are trying to match this pin with the hole. How much leeway are you going to want to have? In our experience, a reasonable total gap is 50 mm to 75 mm (2 in to 3 in).

Drainage: Simple, but important, we have found that 100 mm (4 in) diameter drains perform significantly better than 50 mm (2 in) drains.

Covers: The main considerations for the covers are that they need to be light enough for a worker to lift, and they should be stiff and strong enough for design tire pressures. We recommend at least 12 mm (1/2 in) thick plate to reduce the chance of the plate flexing and popping out after a tire passes over it.



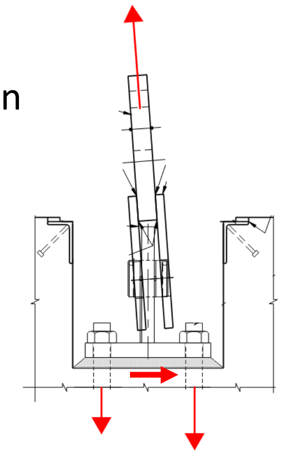
We also need to consider wharf construction tolerances. The slide shows some recommendations. There is a lot of information shown, but one main point:

> ACI 318 is **NOT** appropriate for this application. The reason is that ACI does not account for the relative positions of the different components of the stowage system. Often you will need greater precision of an individually cast component to avoid compounding errors. It is important to meet with the contractor to check what they can achieve in the field.

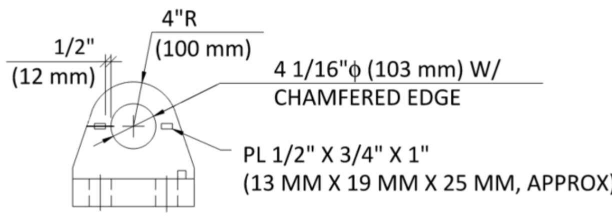
Design Considerations for Tie-Downs

Load Requirements

- Risk Category
- Load distribution
- Misalignments
- Pile load



Eccentric loading



Example: Rotation allowance at ear plate

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Tie-down design considerations. The wharf designer needs to consider the risk category, the load distribution, misalignments, and the pile loading.

Risk Category: Typically, in the US, crane structures are designed for ASCE 7, risk category II for wind. However, we recommend designing the tie-down system to risk category III. This includes all the components from the tie-down bracket and tie-down assembly on the crane to the anchorage in the wharf, but it does not include the crane, the wharf girders, or the piles. If we do this, we can get a much higher reliability in the systems more likely to fail, for a minimal cost increase.

Load Distribution: Recall back to the earlier slide when I showed the different tie-down configurations. The configuration dictates the distribution of load. If there is one tie-down per corner, all the uplift load goes to that tie-down. If there are two tie-downs per corner, flexing of the crane structure can still cause one tie-down to take nearly the full uplift load. Ideally, the crane designer provides a system to equalize the loads. But no equalization system is perfect, so we recommend using at least 60% of the total corner design uplift for each of the two wharf connections. If there is no equalization, we would recommend even more design load per tie-down and working with the crane designer to determine effects on the individual tie-down load due to crane deflections and offsets with respect to the wharf hardware.

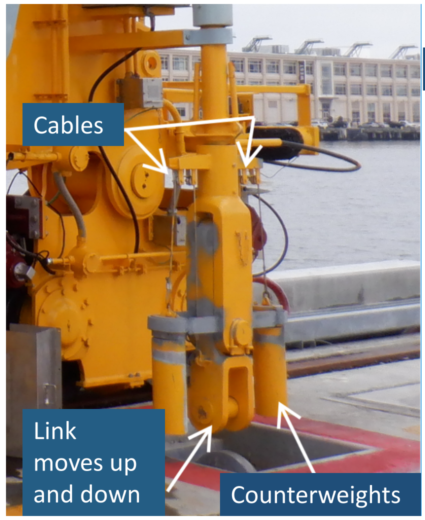
Misalignments and Movements: This one is often overlooked. Just like for the stowage pin design, the wharf designer needs to consider that the crane can shift on the rails, and components on the crane may be installed out of tolerance. The effect of the movement is a lateral load component and slight rotation of the tie-down. The magnitude of the eccentricity can be calculated, but the ballpark lateral load is around 2% to 3%. The bracket design should also accommodate for the calculated rotation in both axes.

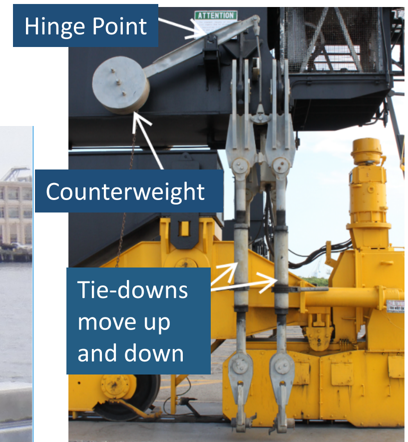
Pile Loads: Hurricane wind loads on cranes can be so severe that girders are pulled upward. There may be large tension forces on the girder piling and large bending moments in the girder. The wharf designer needs to consider this. And do not forget the complete load path from the bracket down to the piles.

Design Considerations for Tie-Downs

Operational Requirements

- Handling
- Drainage
- Cover design





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Tie-down operational requirements including handling, drainage, and cover design.

Handling: Generally, a reasonable amount of time for one to two workers to engage all the tie-downs on a crane is 30 minutes. There are two ways to help facilitate this in the wharf design. One is by specifying alignment requirements relative to the other stowage system components in the wharf. These things can be heavy and tough to maneuver laterally. Another way is by providing a retractable link in the tie-down pocket. If no link is provided, and the bracket only includes an ear plate, the crane designer may need to include a lifting/lowering mechanism on the tie-down. A couple of examples of those systems are shown on this slide.

Drainage: This is the same recommendation as for the stowage pin sockets. We recommend a 100 mm (4 in) drain over a 50 mm (2 in) drain, if practical.

Cover Design: The covers for the tie-downs tend to be larger than the covers for the stowage pin socket. That means heavier to handle. We recommend working with the owner to figure out whether they prefer to remove the covers manually or with a forklift. Then design for that.

Port Everglades (PED) Case Study

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Case study for Port Everglades in Fort Lauderdale, FL, including some lessons in wharf design.

Port Everglades is in the middle of a long-term capital investment program, which includes adding six new large low profile cranes and the infrastructure to support them. At the time of the design, the new cranes were the largest low profile cranes in the world. They are subject to extreme wind forces, because … southeastern Florida tends to be in the path of some big hurricanes. That means unusually large design stowage forces.

PED Case Study: High-Strength Material

Issue

High-strength material used for wharf hardware and pins

Lessons

If possible, use a material more forgiving for fabrication and galvanizing.

Use galvanizer experienced in galvanizing the specified material.

Cracked high-strength pin

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Because of the significant loads, we used 100 ksi (690 MPa) yield strength material to lighten the stowage system components. These components needed to be galvanized and welded. The problem was that the initial galvanizer did not follow practices suitable for high-strength material and multiple components cracked.

Lessons learned:

If it is possible to use a more forgiving material, like ASTM A709, there will be fewer headaches in fabrication. In this case study that was not practical.

Ensure that the fabricator and galvanizer are experienced with the specified material, and the proper procedures for galvanizing and welding are in place.

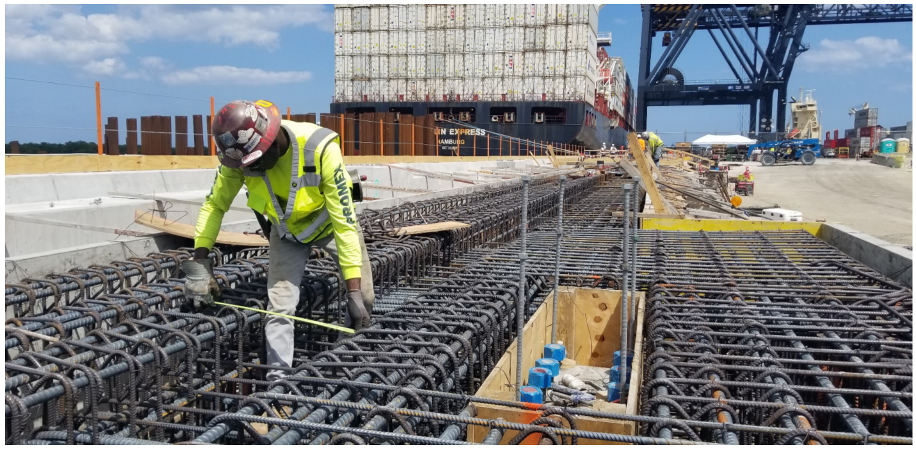
PED Case Study: Design Load Contingency

Issue

Wharf design loads unknown for conceptual crane

Lesson

Avoid costly changes with more contingency in the stowage hardware criteria.



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When the wharf design began, the crane was only a concept, and there were no other cranes to compare loads. When the crane design was complete, the loads were significantly different from the original estimated loads. However, a large contingency was included in the design loads for the wharf, and we were able to avoid bank-breaking changes. The lesson learned here is that an appropriate contingency should be used in the design loads. Extra contingency typically does not cost much for the stowage system.

PED Case Study: Tolerances

Issue

Crane and wharf as-built conditions were out-of-tolerance

Lessons

Expect larger misalignments will occur.

Design for flexibility in stowage hardware to account for construction tolerance deviations.

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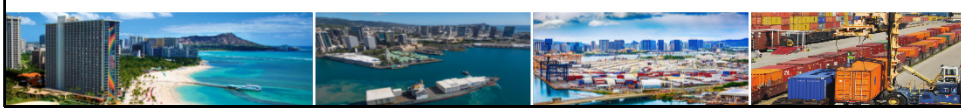

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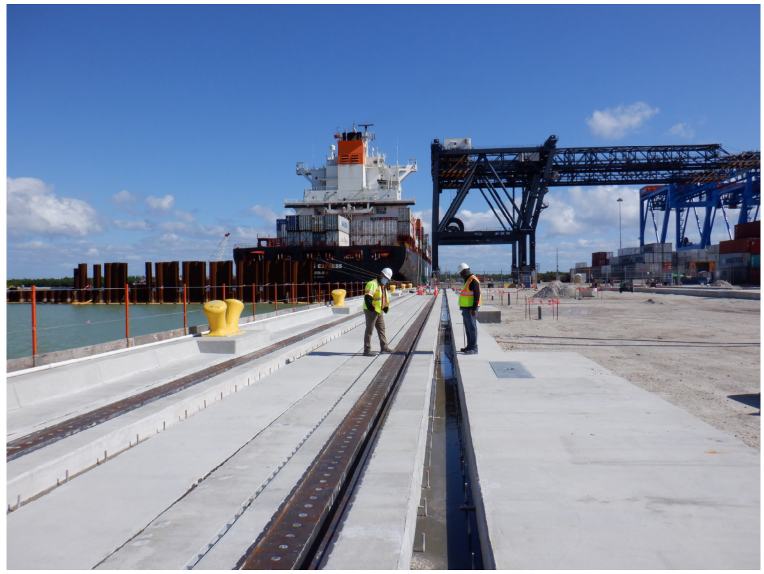
After the wharf and cranes were constructed, the as-built stowage system dimensions were checked for compatibility. Some stowage sockets were installed out-of-tolerance, as was a stowage pin bracket on one of the cranes. That caused a misalignment that needed to be corrected. So, the top plate of the stowage socket was trimmed and shimmed. Accommodating this out-of-tolerance was part of the design and was not costly. Sometimes misalignments can increase the eccentricity of design loads. The lessons here are that misalignments happen, and we need to anticipate them in the design to avoid expensive repairs later. Also, it is better to design the stowage system components to be easily modified to accommodate misalignments.

PED Case Study: Designing the Wharf Before the Crane

Consider coordinating with an experienced crane designer or consultant for stowage system design



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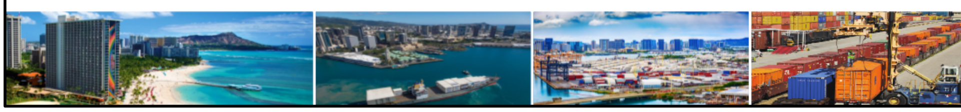

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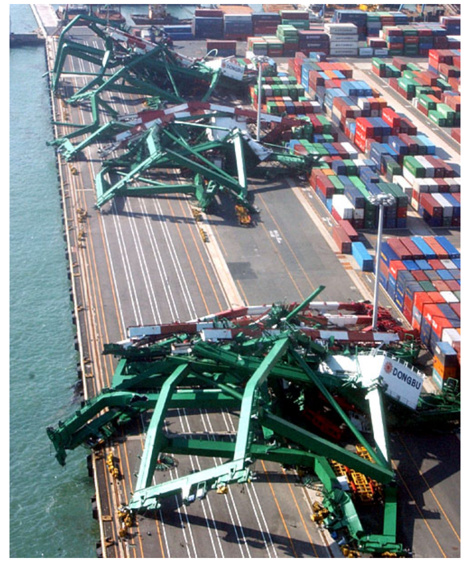
A common lesson among all projects is that early coordination with interested parties gets better results. But what if you need to design a wharf for a conceptual crane that has no selected manufacturer? That was the case for this project. We recommend the wharf designer reach out to a crane designer or consultant to help with the stowage system design. A good crane designer can help with all the ideas shared today.

Improve your odds



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With that, I'll leave you with a grim example of what can happen if the wharf hardware design does not consider the important, but commonly-overlooked facts. These photographs are from Typhoon Maemi, which hit South Korea in 2003. The wharf tie-down anchorage failed first, followed by stowage pin sockets failure, resulting in the catastrophic collapse of six cranes.

Thank you for listening. I hope you learned how to improve your odds with stowage hardware design. If you would like more detail on the PED Case Study, also refer to Erik Soderberg's presentation for this same conference. Thank you again.

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Thank you!

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