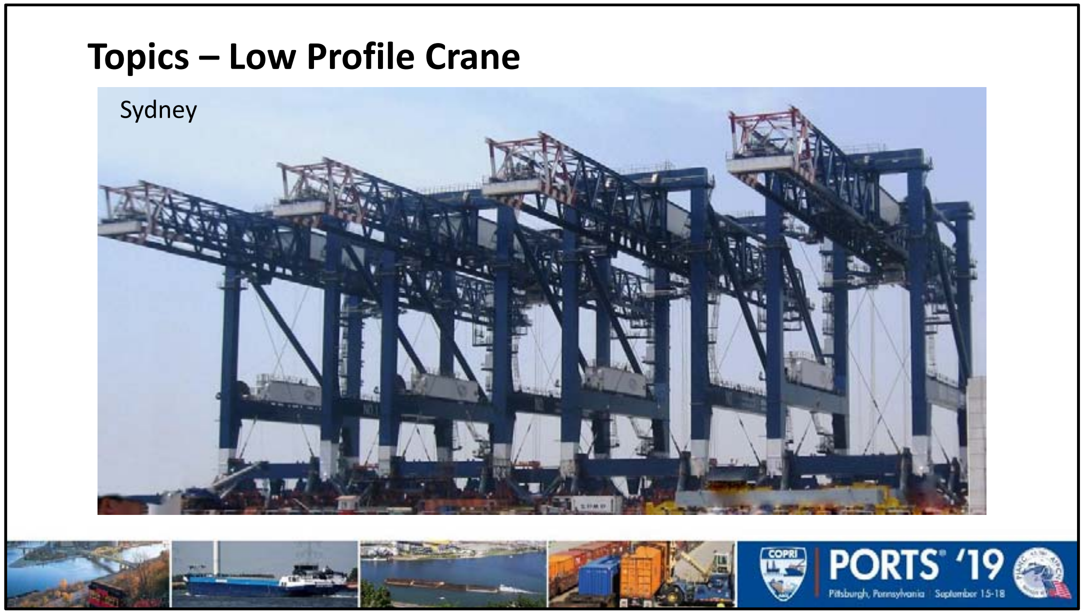
Liftech Consultants Inc. is a consulting engineering firm, founded in 1964, with special expertise in the design and procurement of dockside container handling cranes and other complex structures. Our experience includes structural design for wharves and wharf structures, heavy lift structures, buildings, container yard structures, and container handling equipment. Our national and international clients include owners, engineers, operators, manufacturers, and riggers.

Kenton is experienced in design, analysis, and project management of container cranes, floating cranes, rigging, and special structures. He specializes in container and floating crane procurement projects and crane modification projects. He is also involved in preparing structural maintenance programs. Some of the technical aspects of his work that are of special interest to him are steel connection design, wind effects on structures, wind tunnel testing, and structural fatigue of steel structures.

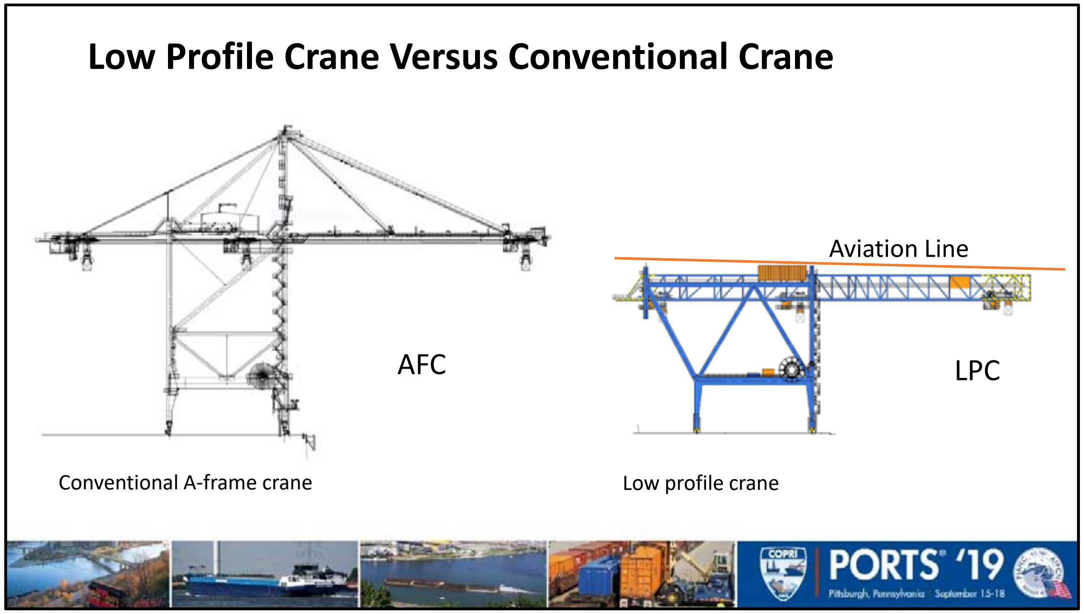
ASCE COPRI Ports 2019 Conference, Pittsburgh, PA
Presented by Kenton Lee, Liftech Consultants Inc.
September 17, 2019



Numerous container terminals have significant height restrictions caused by proximity to airports. Low profile ship-to-shore container cranes (LPCs) are vital to these terminals. LPCs servicing ultra-large container vessels are significantly heavier and more complex than conventional A-frame cranes (AFCs), and present a myriad of new challenges for crane and wharf designers.

The most significant difference between LPCs and AFCs is that the LPC boom is a truss that cantilevers over the ship and shuttles horizontally rather than rotating vertically, resulting in much larger wheel loads on the landside and waterside rails. A latest generation boom is 130 m (430 ft) long and has a massive 7 m (23 ft) deep truss.

This presentation discusses key design issues and solutions for projects in Australia (see Sydney image above), Florida, and Massachusetts. Issues include crane and component weights, geometry constraints, wheel loads, skidding, and fabrication challenges.



Note that the conventional A-frame crane (AFC) is much larger than the low profile crane (LPC).

LPCs also differ significantly from AFCs in other ways. AFC booms are usually box members or trusses supported by forestays. LPC booms are usually trusses that cantilever from waterside hangers. AFC booms rotate for ship clearance. LPC booms shuttle for clearance.

Latest Generation Low Profile Crane Size

Comparison of Older and Newer LPCs and a Recent AFC

Crane	Year Commissioned	Rail Span (m)	Outreach (m)	Lift Height (m)	Maximum Height (m)	Weight (tonne)
Older Generation LPC						
PED Samsung LPC	1992	30.5	44.3	32.4	46	1,400
New Generation LPC						
PED ZPMC LPC	Est. 2020	36.6	62.5	40.5	53	2,000
New Generation AFC, for Reference						
Recent 25-wide AFC	Est. 2019	35.0	73.0	53.0	138	1,500

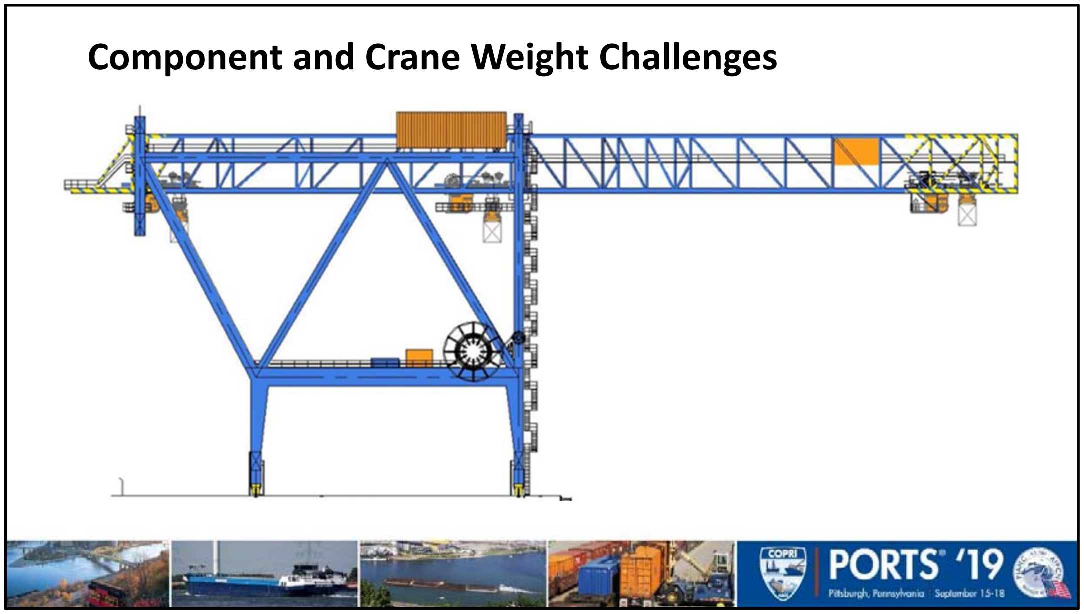
PED is Port Everglades Terminal, Florida; weights include crane dead load and trolley and lift system weights; 1 tonne = 1,000 kg = 2,204 lb

This chart shows that:

New LPCs are a lot bigger than older generation cranes.

New AFCs are a lot bigger than new LPCs although a lot lighter.

Also, not shown on the chart, LPC outreach serves ships about 20 containers wide; 24 wide for AFC.



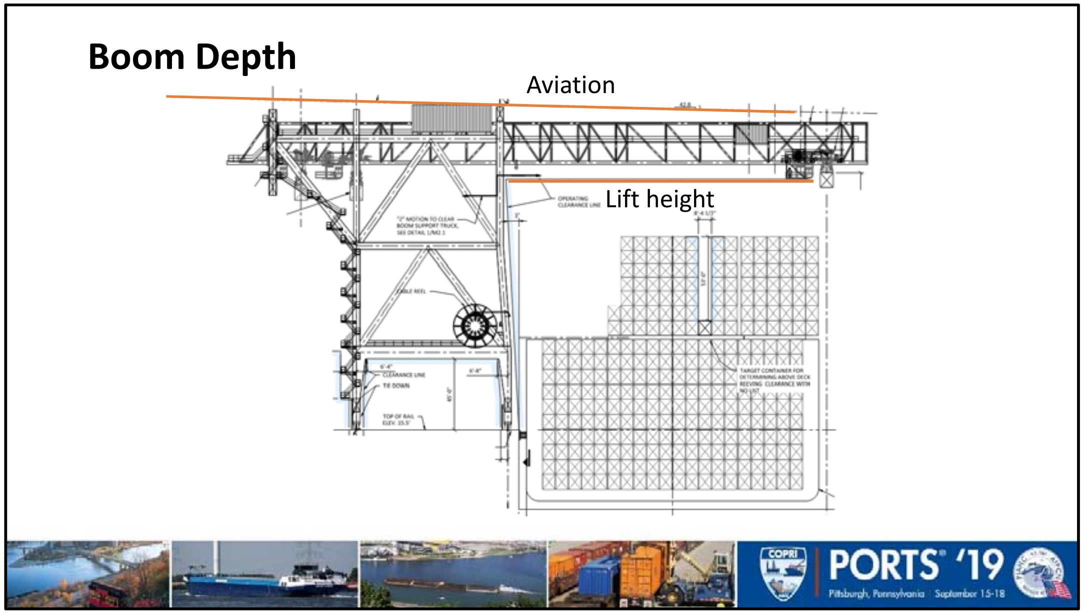
The next few slides are boom related.

The LPC boom is heavier than the AFC boom, as indicated in the dimensions below:

AFC Boom	200 t and rotates up for stowage
LPC Boom	580 t (30% of crane's weight)

LPC center of gravity shifts from waterside to landside significantly depending on boom position. Shifting weight creates need for significant ballast.

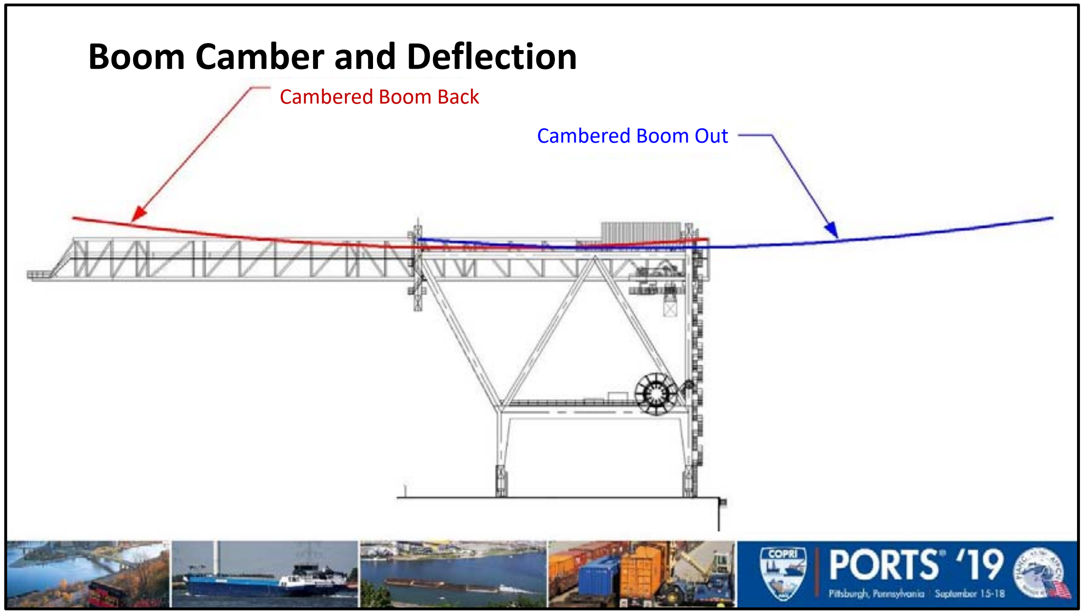
LPC boom weight and center of gravity are critical to wheel loads, crane stability, frame weight, and LPC movement control.



There are two conflicting constraints on boom depth as follows:

1. It is desirable to increase depth as much as possible. The boom must be stiff to control deflections and as light as practicable to control crane weight and wheel loads.
2. However, it is limited by overall height from above and the lift height below.

The depth of the Massport and Port Everglades LPCs, two current Liftech projects, is 7.3 m (24 ft).

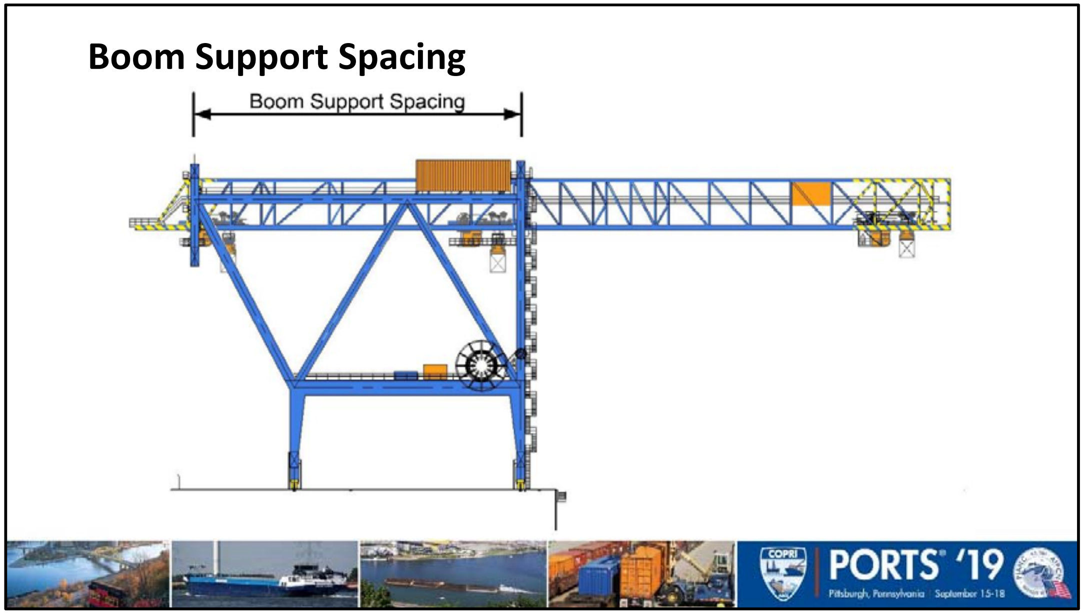


In the modern LPC, the boom deflection at the outreach with the trolley at the outreach is 30 in (760 mm).

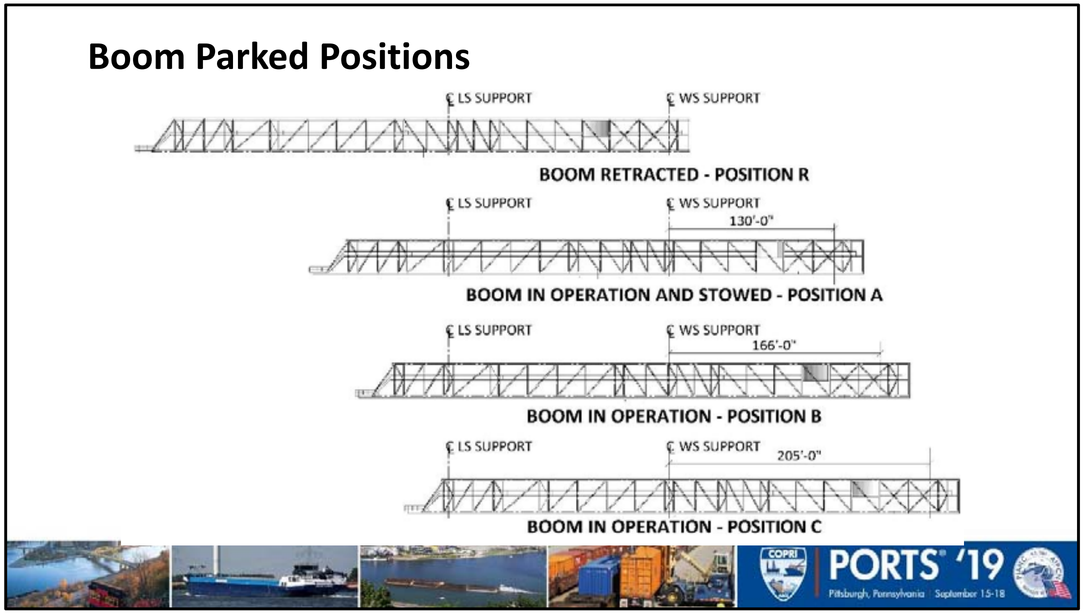
Camber is necessary to maximize lift height.

What happens when the trolley isn't at the outreach? The boom deflects upward, so we checked airspace clearance for that, and it nearly controls.

Note: Camber is exaggerated in the image.

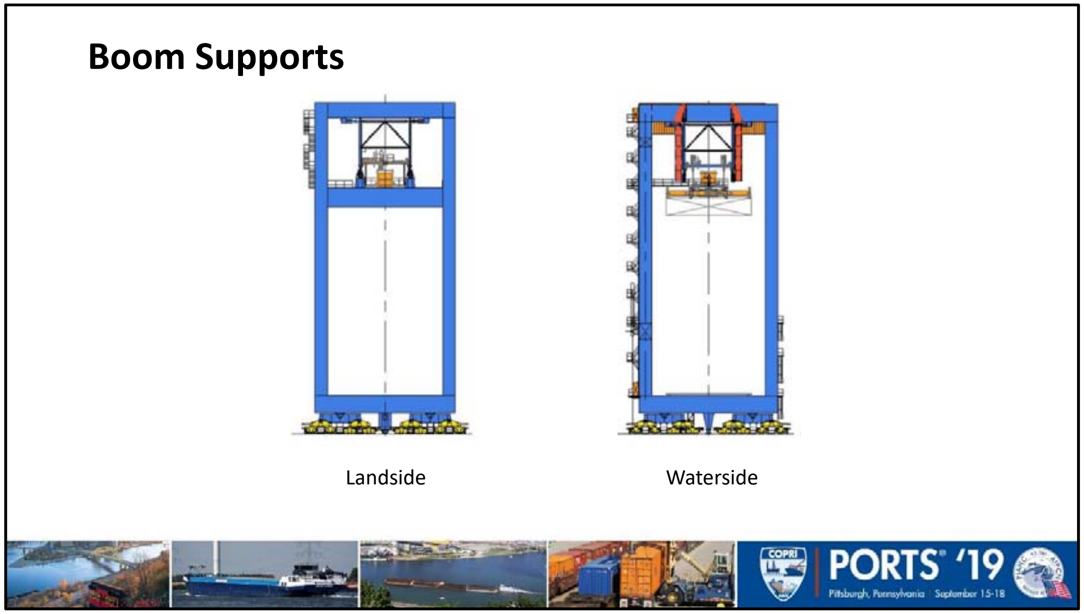


Spacing affects reactions, which affect the boom supports, and boom and frame structure and weight. Inclining landside legs increases boom support spacing, reducing the reaction and reducing the crane weight.



When the LPC is operating over a small ship, locating the boom at positions A or B reduces the boom reach from the face of the wharf and reduces boom positioning time. Position C is only used for operating over a large ship. During a hurricane, the boom is centered (position A), reducing the landside and waterside lateral wharf loads. Position R is necessary to allow the crane to clear a vessel during gantry travel and for normal stowage, when high winds are not forecasted.

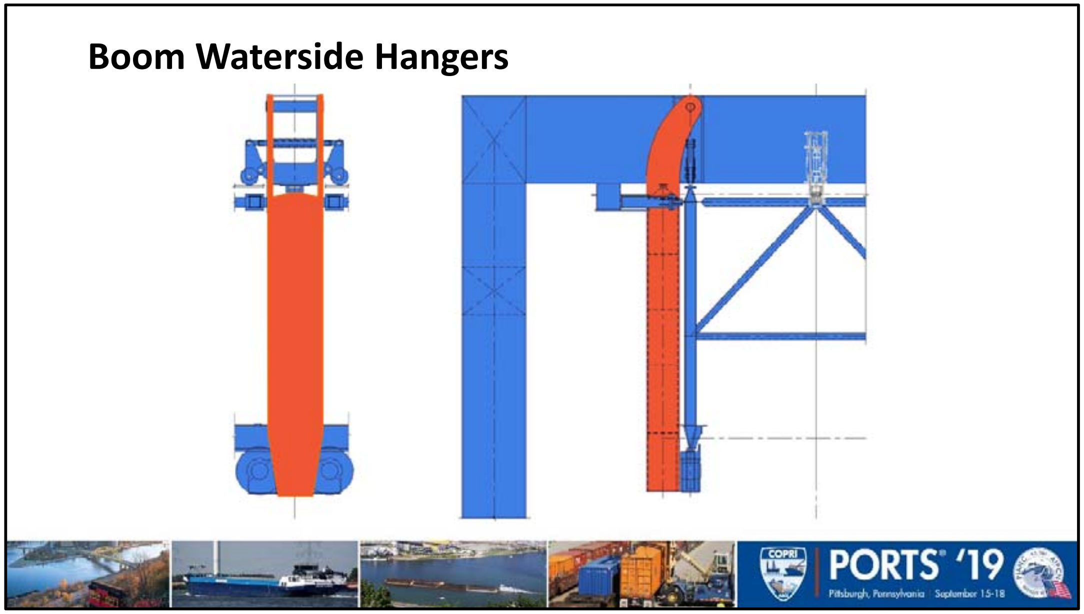
More boom positions result in a heavier and more complex boom. In addition to more boom securing sockets, the truss side members and the horizontal top panel lacing must be aligned with the boom supports.



Specially shaped waterside hangers are used for smooth and structurally reliable boom travel. The special shape of the hanger eliminates lateral loads on the hanger. The side rollers that bear on the upper chord resist boom lateral loads. An equalized truck with two boom support wheels bear on the rail bar below the lower chord.

Hold-down rollers bear on a bar on the upper chord. Upward reactions occur when the boom is retracted or when the trolley is in the full backreach at certain boom positions.

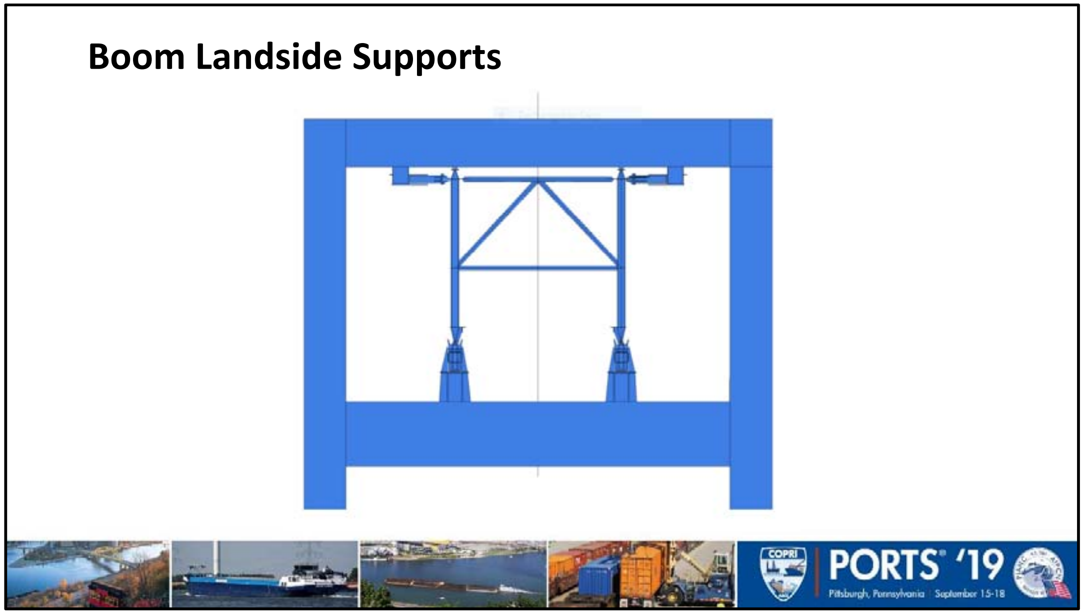
The landside vertical supports are cambered (rotated in plan view) to prevent lateral sliding as the frame deforms (due to change of vertical reaction) during boom shuttling.



Both images show the hanger in red.

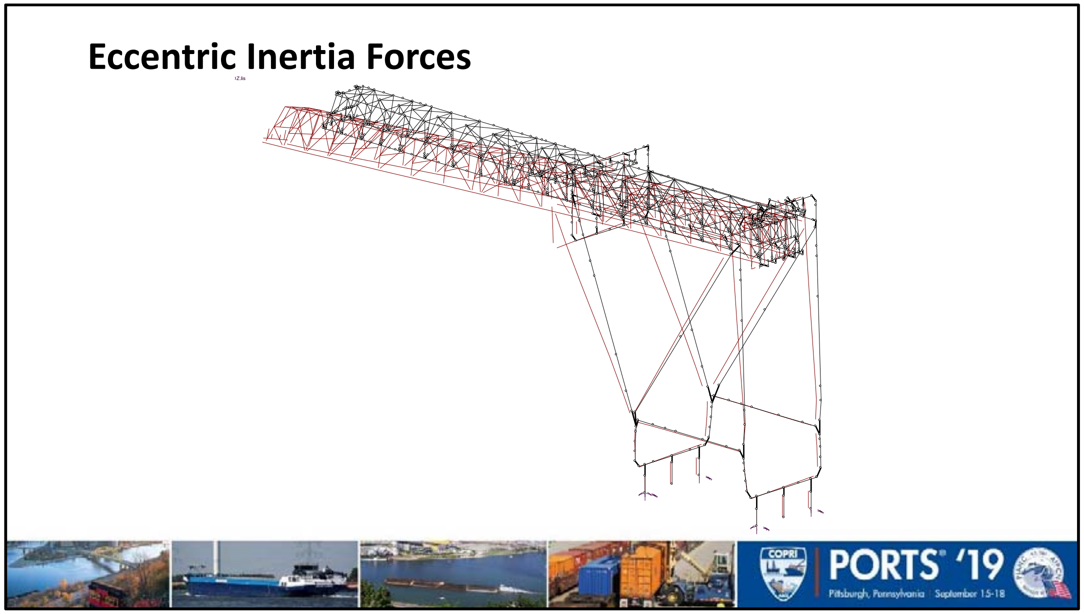
The image on the left shows preloaded, equalized hold-down rollers bearing against the top of the boom top chord, and the boom lower chord supported on the hanger-supported truck with two equalized boom support wheels.

The image on the right shows side rollers bearing against the side of the boom top chord. Notice the hanger pin is aligned with the rail centerline. The boom stow pin is shown in the center. The trucks and cross beam have multi-adjustable bearings.



The boom support wheel positions are adjustable to compensate for construction tolerances. Preloaded equalized hold-down rollers are provided at the top, similar to at the waterside (not shown in the image). The preload keeps the wheels in contact with the boom upper rail, even when the boom is at the full backreach position.

The lower beam (1) prevents the trolley from passing and (2) reduces fatigue on the upper beam, so the upper beam can be shallower, decreasing the clearance height.



When traveling along the wharf, with the boom out or retracted, eccentric inertia lateral and vertical forces tend to twist the crane, with calculated maximum of 1 m (3 ft) deflection (deflections shown are not to scale).

When the boom is retracted, the waterside wheel load is small, causing the waterside wheels to tend to skid, and vice versa when the boom is out. Skidding is bad for the wheels and rail.

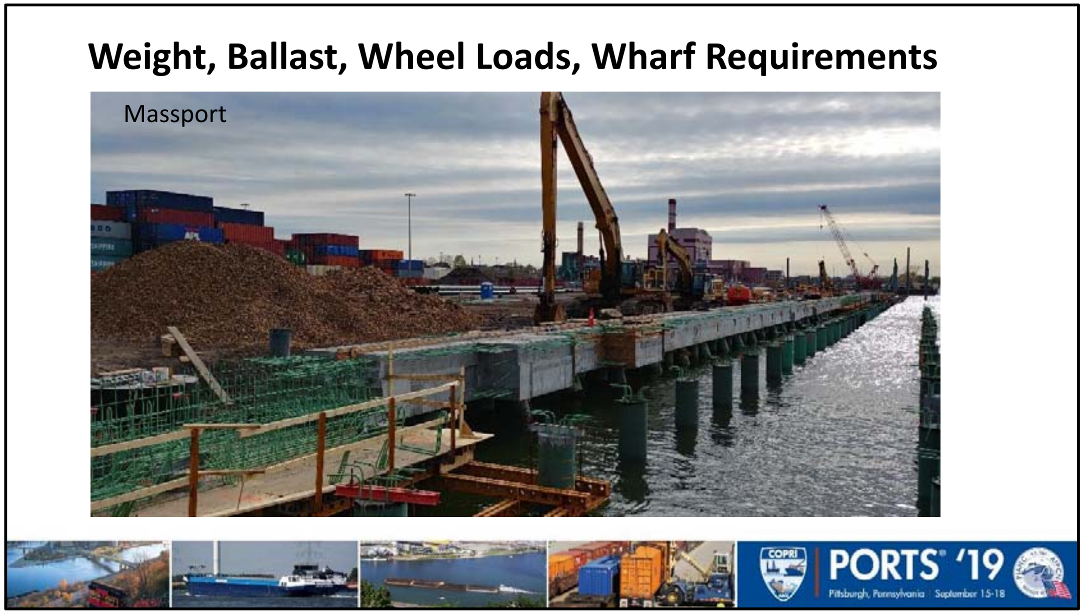
In the event of an emergency stop, the inertia forces may be as high as the steel-on-steel friction forces, which could overstress the crane frame or tip the crane.

Solutions considered:

Antilock brakes like a car—we are not aware that antilock brakes have been used on container cranes previously. This possible solution was not selected.

Variable torque brakes, where the torque on each brake is automatically adjusted for each different boom position. This solution was used at Massport.

Perform time history analysis to check the stresses and skidding. This solution was used at Port Everglades.

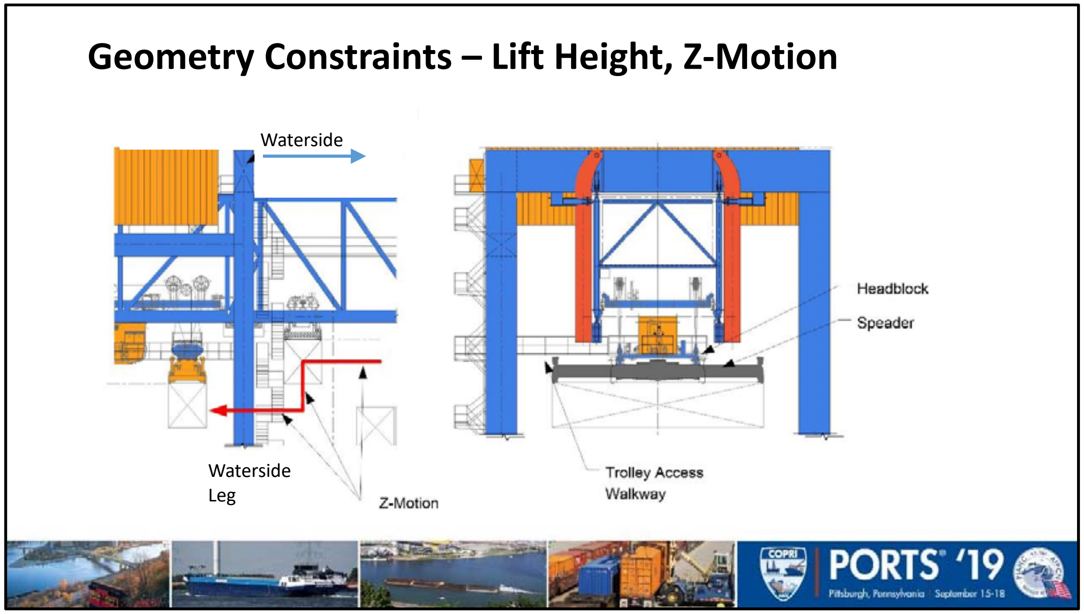


This is the Massport wharf.

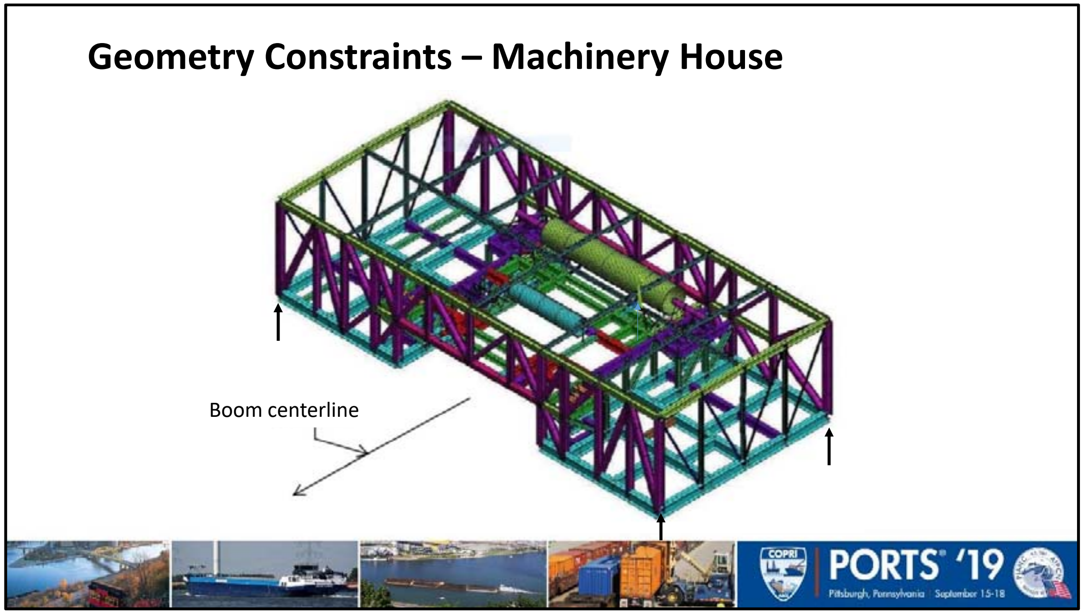
The waterside ballast at Massport is 500 tonne (550 ton). LPC wheel loads are significantly greater than a similar-sized conventional crane.

For wheel loads are so large that a typical ASCE 171-pound crane rail is typically inadequate, and DIN A150 rails might be required. Wheel loads, tie-down forces, and eccentric inertia forces are reduced when the rail span is increased.

Port Everglades opted to install new waterside and landside crane rails in their wharf to provide a 36.6 m (120 ft) gantry rail span versus 30.48 m (100 ft) span for existing Samsung LPCs.

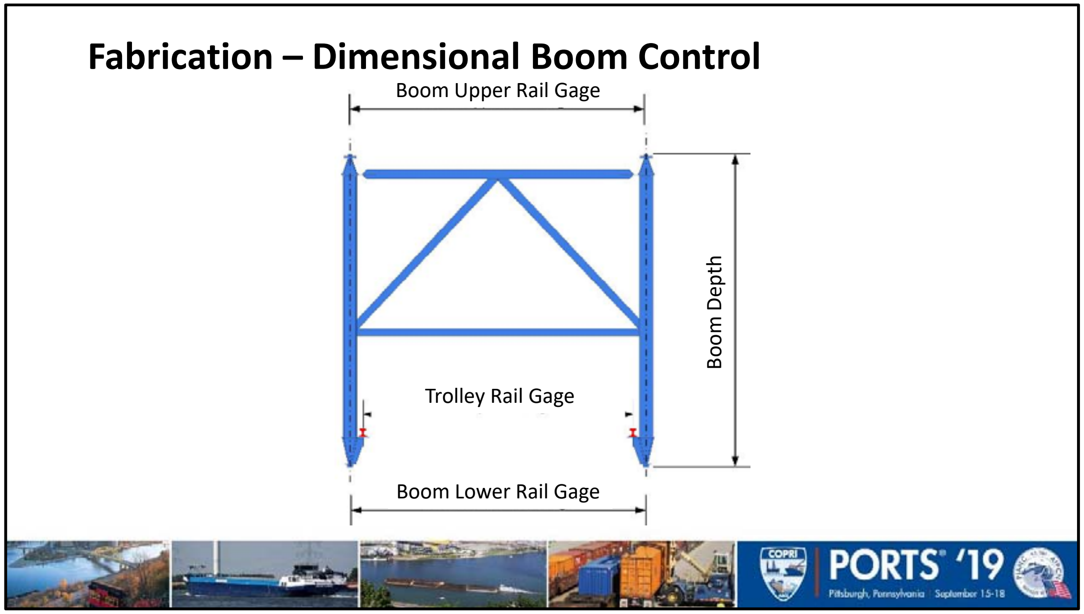


"Z-motion" maximizes the lift height. The trolley is designed such that the headblock and spreader (lift system) nest high into the trolley, gaining about 1 m (3 ft) of lift height, for removing the top row of containers, depending on the vessel and tide level. However, the lift system must be lowered to clear the waterside hangers, just waterside of the vessel.



The highest point of the crane is the roof of the machinery house for the main hoist and boom shuttling—minimizing height is important. The house straddles the boom and includes a higher-elevation center deck above the boom and two lower-elevation side decks. The multi-level deck needs trusses to keep it integral. Because the main hoist drum straddles the left and right decks, the frame size and stiffness is sized with consideration to keep the couplings from failing.

The AFC has a one level platform, so the walls and roof do not need to provide stiffness.



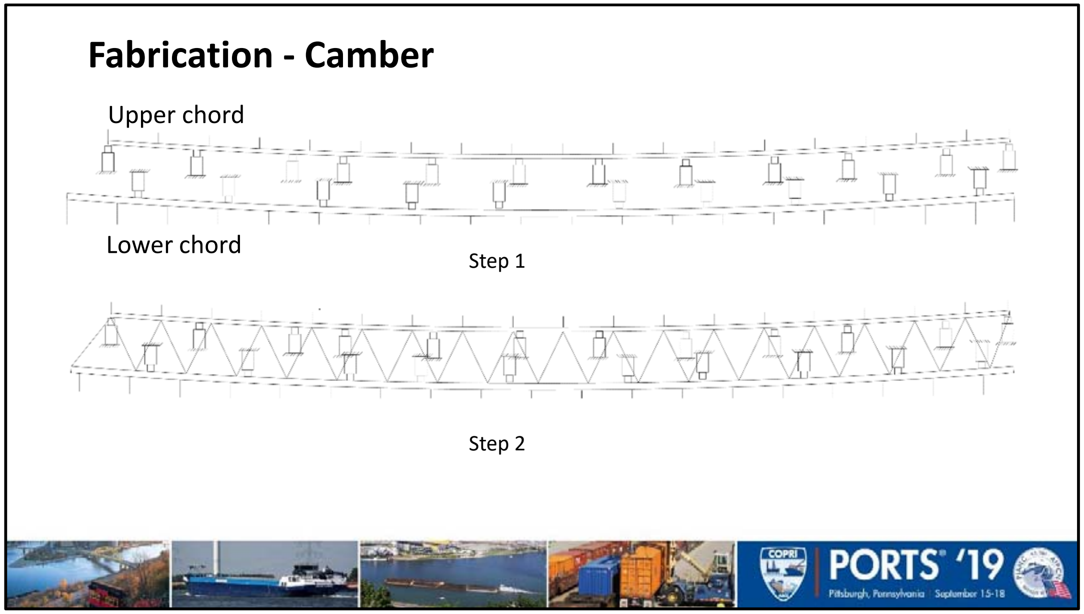
Fabricating a very large truss 120 m (400 ft) long is difficult, but a greater challenge is controlling the dimensions between the upper and lower chord rails, the out-to-out dimensions of the upper chords, and the dimensions between the trolley rail and the boom rails.

The boom fabrication requires careful measurements during numerous phases.

Fabrication - Dimensional Boom Control

PORTS '19 Pittsburgh, Pennsylvania September 15-18

This is an image of the Port Everglades boom during fabrication at ZPMC. Notice the person inside the white circle on the image to the left to get an idea of the size of the boom!



Boom camber is necessary but adds to fabrication complexity. The Sydney and Port Everglades boom upper and lower chords were initially fabricated straight. When the truss members were assembled on the shop floor, the straight chords were jacked to the proper camber shape, and the vertical and diagonal members were installed. The stresses imposed by the jacking are small. When the boom deflects due to operating loads, the stresses induced by the initial jacking are reduced. This method makes fabricating and assembling the truss much easier than fabricating the boom components in the cambered shapes.

Conclusion

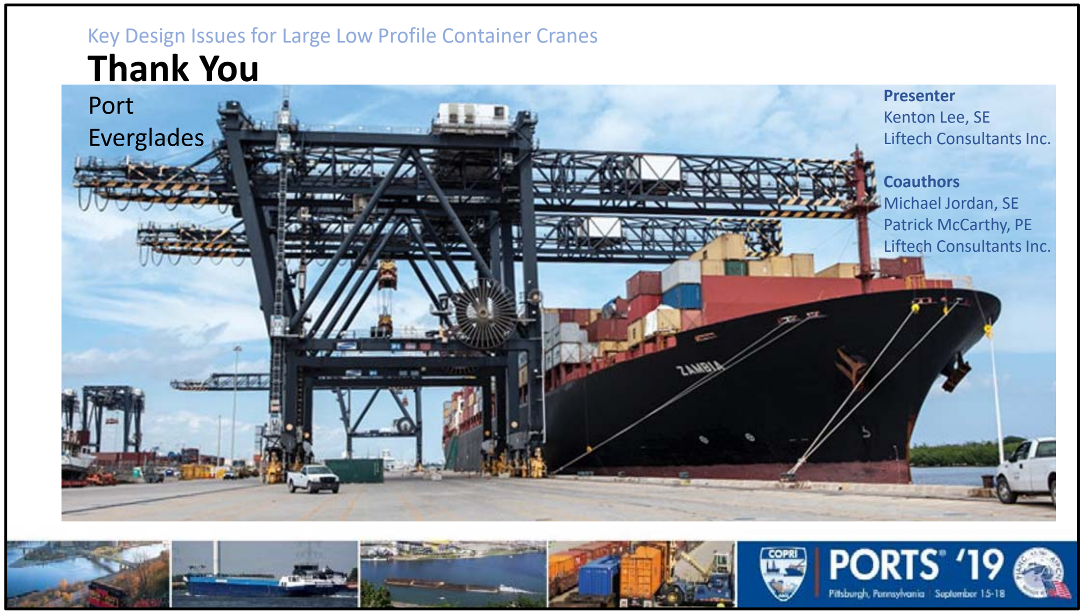
Container terminals near airports have significant height restrictions.

Cranes are getting bigger to service bigger ships all the time.

Large LPCs are necessary for these terminals to be competitive.

Large LPCs are much more complex than smaller LPCs or conventional cranes.

The latest generation LPCs contain many innovations that advance the state-of-the-art for crane design in the structural, mechanical, controls, and steel fabrication disciplines.



Thank you for your interest.

Co-authors Michael Jordan and Patrick McCarthy from Liftech also helped contribute to the paper and presentation.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