Key Design Issues for Large Low Profile Container Cranes

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ABSTRACT

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 long and has a massive 7 m deep truss.

This paper discusses key design issues and solutions for projects in Australia, Florida, and Massachusetts. Issues include crane and component weights, geometry constraints, wheel loads, skidding, and fabrication challenges.

INTRODUCTION

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 have been around since the 1970s. However, the latest generation LPCs are significantly larger, to service today's ultra-large container vessels. They are heavy and complex and present a myriad of new challenges for crane and wharf designers.

This paper discusses key design issues and solutions for projects in (1) Sydney International Container Terminals Pty Ltd, Sydney, Australia, (2) Broward County Port Everglades Department (PED), Fort Lauderdale, Florida, and (3) Massachusetts Port Authority (Massport), Boston, Massachusetts. Issues include crane and component weights, geometry constraints, wheel loads, and skidding. The paper also presents selected design features and fabrication challenges particular to LPCs.

LOW PROFILE CRANES VERSUS CONVENTIONAL CRANES

LPCs differ significantly from conventional A-frame cranes (AFCs). 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. See Figures 1 and 2 for AFC and LPC crane operating positions, and Figure 3 for the LPC in the retracted position.

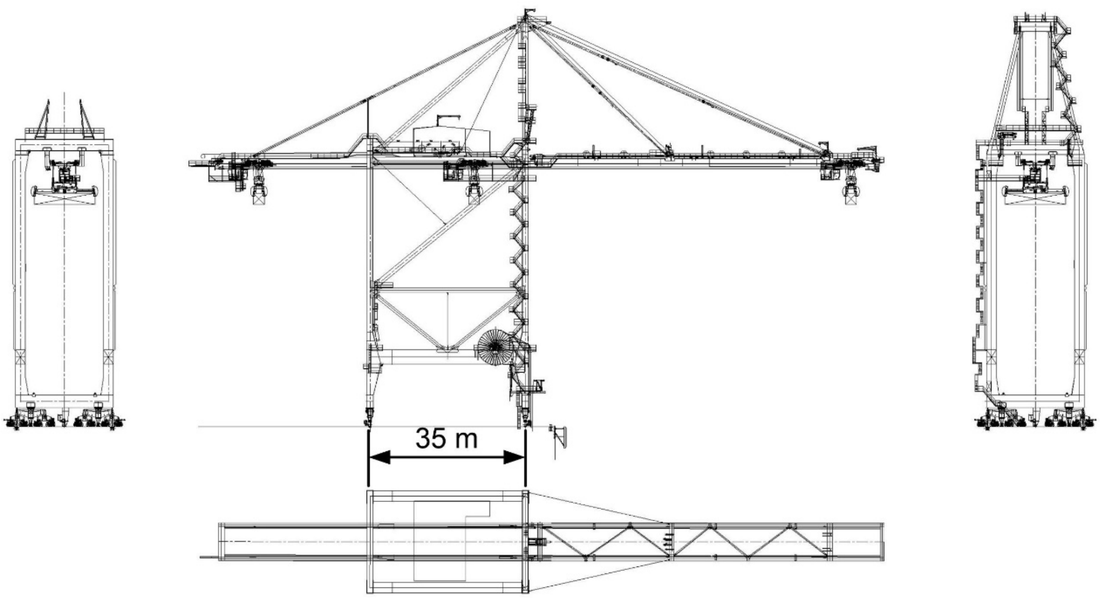

Figure 1. Latest generation conventional A-frame crane (AFC)

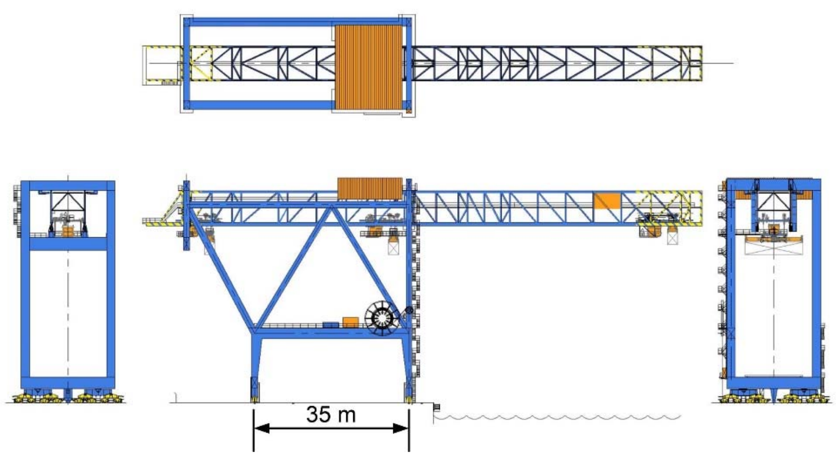

Figure 2. Latest generation low profile crane (LPC)

LATEST GENERATION LOW PROFILE CRANE SIZE

The outreach and lift height of LPCs have increased significantly to service larger vessels. See Table 1 for a comparison of the dimensions between older and newer LPCs and a recent 25-wide AFC. Notice that LPCs are still smaller than the largest AFCs due to vertical clearance and wharf wheel load constraints.

Table 1. Dimensional Comparison of Older and Newer LPCs and a Recent AFC

Crane		Year Commissioned	Rail Span (m)	Outreach (m)	Lift Height above rail (m)	Maximum Height (m)
Older Generation LPCs						
1	Massport Kocks LPC	1988	29.3	45.7	30.5	40
2	Massport Paceco LPC	1995	29.3	45.7	30.8	44
3	PED Samsung LPC	1992	30.5	44.3	32.4	46
New Generation LPCs						
4	Sydney LPC	2013	35.0	50.0	34.0	48
5	PED ZPMC LPC	Est. 2020	36.6	62.5	40.5	53
6	Massport ZPMC LPC	Est. 2021	29.3	61.6	30.5	44
7	Massport ZPMC LPC	Est. 2021	29.3	61.6	49.7	63
New Generation AFC, for Reference						
8	Recent 25-wide AFC	Est. 2019	35.0	73.0	53.0	138

The PED ZPMC LPC (PED 2020 LPC) is the latest and largest LPC to date and is currently being fabricated. The crane is suitable for operating over a 15,000 TEU (twenty-foot equivalent unit container) vessel, with 22 containers abeam and a maximum stack height of seven high-cube containers or four high-cube plus four standard-cube containers above deck, with an average vessel draft of 12.5 m. The Massport LPCs are expected to be completed about a year after the PED 2020 LPCs.

COMPONENT AND CRANE WEIGHT CHALLENGES

Boom Weight

Recent LPC truss booms are approximately 7 m deep, 8 m wide, and 130 m long. The boom weighs over 520 t, which is approximately 25% of the crane's total weight. Due to the heavy LPC boom weight, the crane center of gravity shifts from waterside to landside significantly when moving the boom from the outreach to retracted position. The AFC boom is lighter (about 200 t for crane 8 in Table 1) and rotates up for stowage. Thus, stowing the AFC boom does not shift the crane center of gravity from waterside to landside nearly as much as an LPC. *(1 Metric tonne (t) = 1,000 kg = 2.2 kip = 2,204 lb)*

The boom weight and center of gravity shift are critical to wharf wheel loads, crane stability, frame weight, and LPC movement control, and can be the critical factors in deciding if an LPC can be placed on an existing wharf without strengthening.

Boom Camber and Deflection

Modern LPC booms are so long that the boom vertical deflections due to dead load and trolley moving load significantly reduce the lift height. Large boom camber is necessary. The camber for crane 5 in Table 1 is 700 mm at the boom tip. One problem due to camber is that when the boom is retracted, the boom bows upward and can intrude into the clearance envelope (Figure 3).

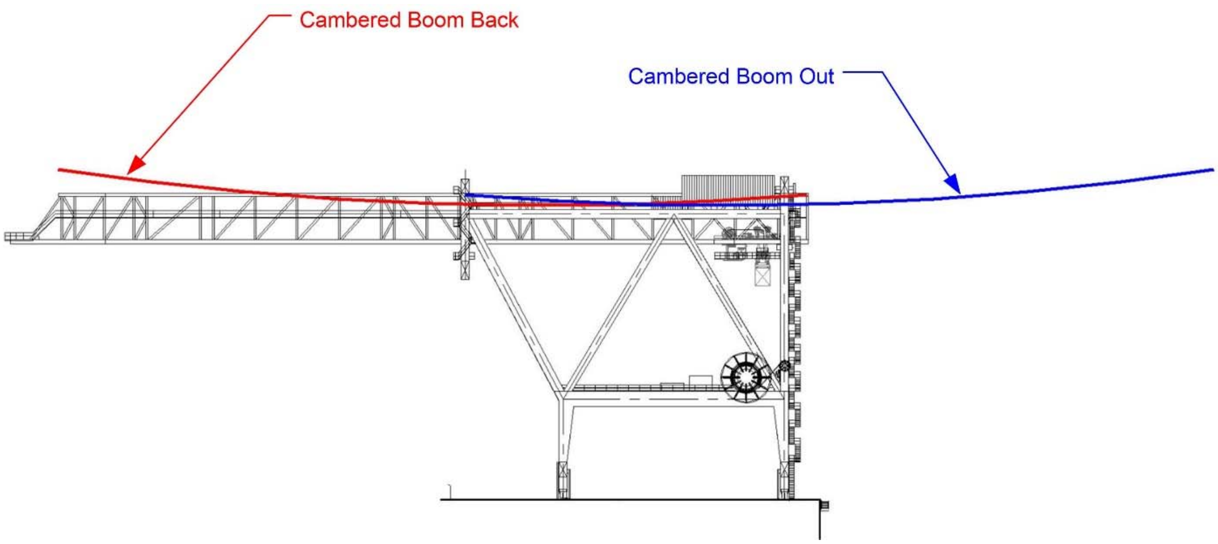

Figure 3. Boom camber (*camber is not shown to scale*)

Boom Depth

The LPC overall height, including camber effects, is limited by the aircraft clearance envelope imposed by local agencies (e.g., the FAA in the US). The limitation is often a line with a high point near the outreach, sloping slightly downward toward the landside. To maximize the container lift height, the boom depth, machinery house height, and boom camber need to be reduced. However, the boom needs to be stiff to control deflections and needs to be as light as practicable to control the crane weight and wheel loads. This presents an iterative design challenge. For the PED 2020 LPC, a 7.3 m boom depth was selected to best meet the various constraints. For comparison, the PED 1992 LPC had a 6.7 m boom depth.

Boom Support Spacing

The boom support spacing (Figure 4) is also a significant variable affecting the boom weight.

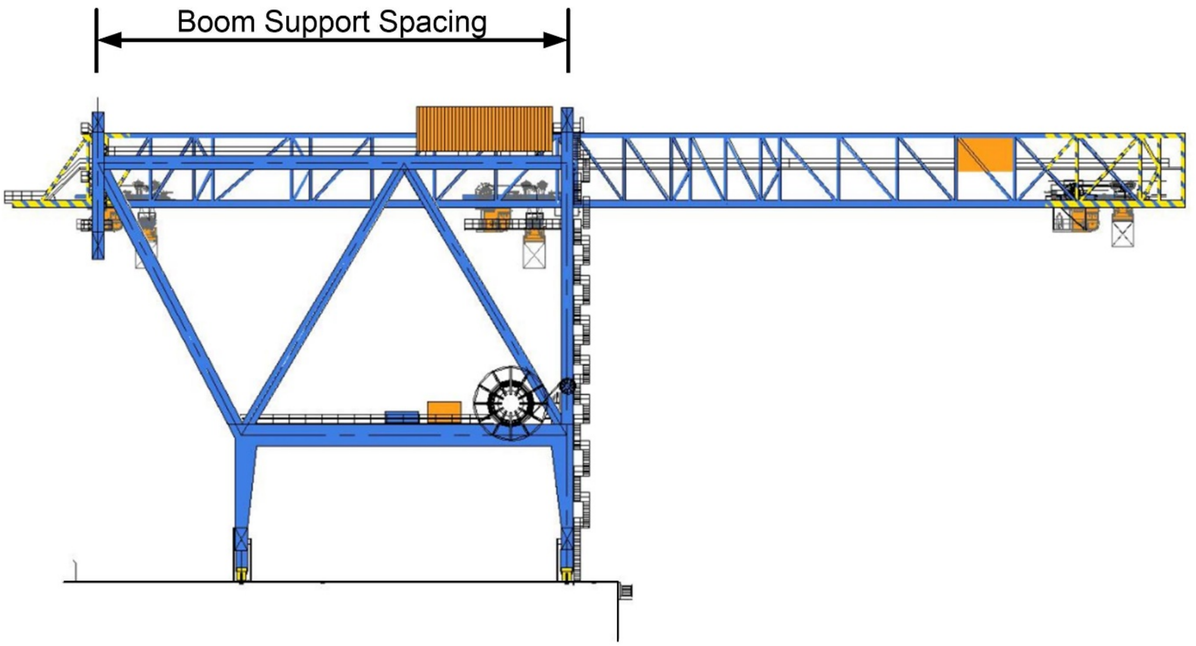

Figure 4. Boom support spacing

The boom support spacing affects the boom reactions on the boom supports. This in turn affects the boom member sizes, the support reactions, the boom rails, the boom hangers on the waterside, the O-frame on the landside, and the boom hold-down wheels. An increased boom support spacing will reduce the support reactions, minimize the size of the components listed above, and reduce the weight of the frame and the boom. A sweep-back frame design was introduced about twenty-five years ago, that inclines the landside legs to make the boom support spacing greater. The LPCs prior to that have vertical landside legs, so the boom support distance was the same or nearly the same as the LPC rail span.

Boom Fixed Positions

Some older, smaller LPCs have only two positions where it is locked in place for container operations and stowage—fully out or fully retracted. The PED 2020 LPC boom travels approximately 61 m from full backreach to full outreach and has four fixed positions (Figure 5).

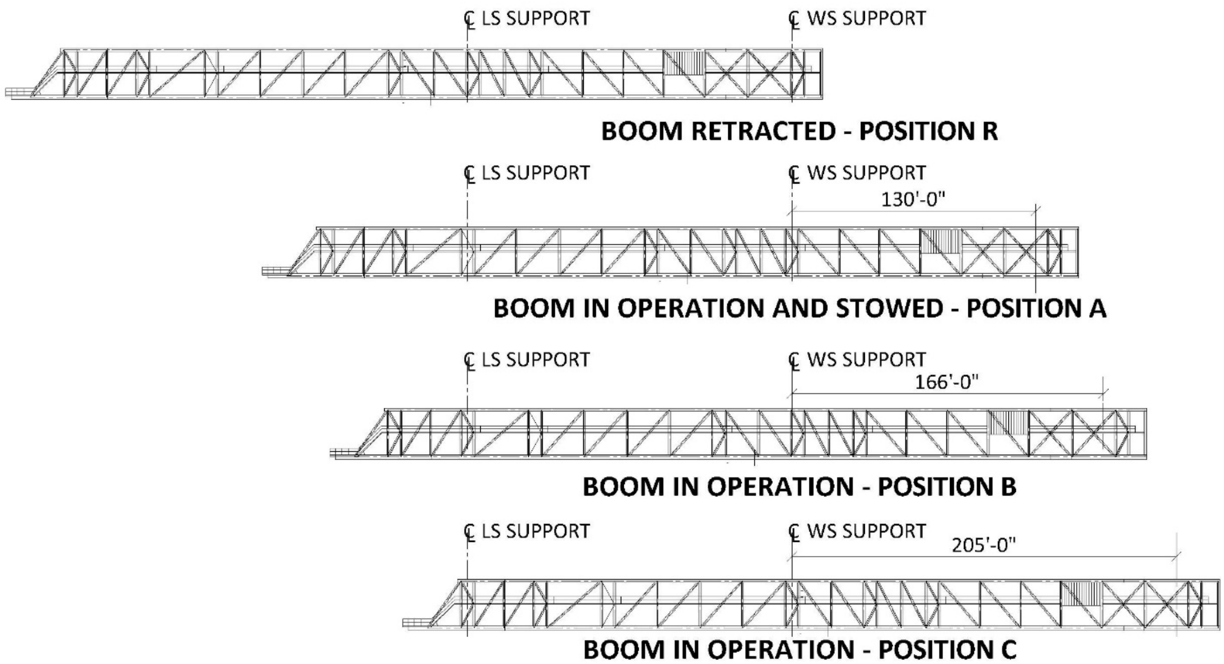

Figure 5. Boom positions

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.

Boom Supports

Boom Waterside Supports

Specially shaped waterside hangers are used for smooth and structurally reliable boom travel (Figure 6). 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.

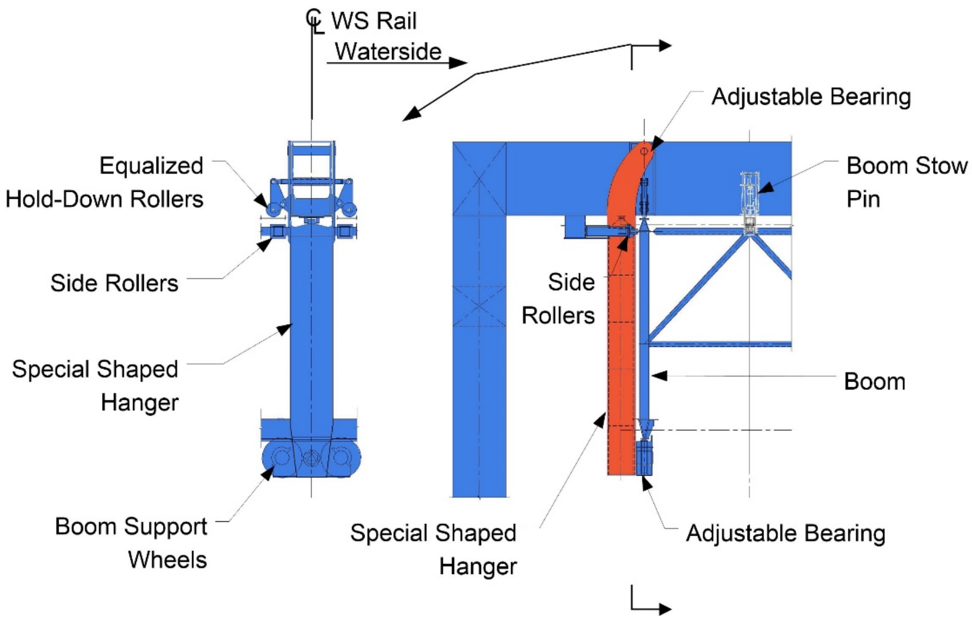

Figure 6. Boom waterside hangers

Boom Landside Supports

The PED 2020 LPC has equalized support wheels at the bottom of the landside O-frame similar to those on the waterside hangers. The wheel positions are adjustable to compensate for construction tolerances. Preloaded equalized hold-down rollers are provided at the top. The preload keeps the wheels in contact with the boom upper rail, even when the boom is at the full backreach position. See Figure 7.

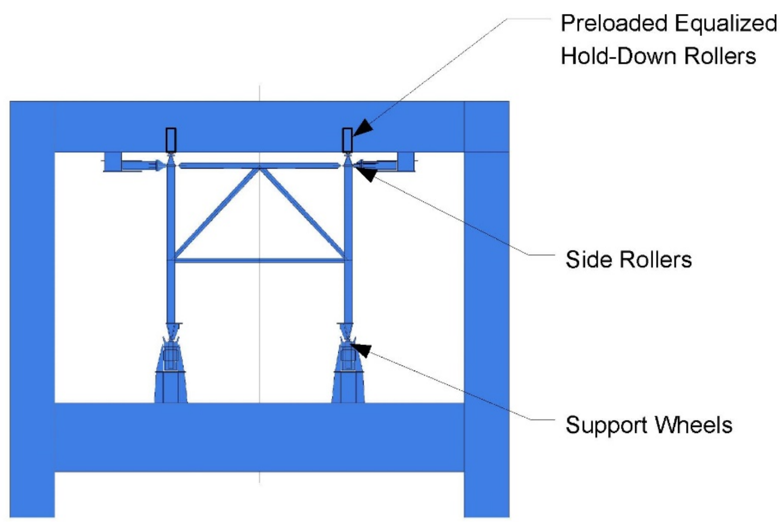

Figure 7. Boom landside supports

In the earlier PED Samsung cranes, specially shaped hangers similar to the boom waterside hangers were used for both the landside and waterside supports. The use of an O-frame in the PED 2020 LPC (Figure 7) is much simpler than the waterside hangers. A lighter boom support beam can be used, which is especially advantageous when the allowable air clearance decreases toward the landside, such as for PED.

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.

A common problem of earlier LPCs is that there is a gap between the boom and the landside hold-down rollers and support wheels, causing the boom to rock vertically during boom shuttling and during some trolley operations depending on the boom position. This caused an impact load every time the boom rocked, causing unnecessary wear and noise. The preloaded hold-down roller design eliminates the problem.

ECCENTRIC INERTIA FORCES

As described above, the LPC center of gravity shifts significantly from landside to waterside when the boom is moved between retracted and outreach positions. When traveling along the wharf, with the boom out or retracted, eccentric inertia lateral and vertical forces tend to twist the crane. When the boom is retracted, the waterside wheel load is small, causing the waterside wheels to skid, and vice versa when the boom is out. Also, during an emergency stop, the inertia forces may be as high as the steel-on-steel friction forces. This force could be enough to overstress the crane frame or tip the crane. For the PED 2020 LPC, non-linear dynamic analysis was performed to simulate the braking phenomenon. The problem is more significant in the Massport LPC than the PED 2020 LPC, since the rail spans are 29.0 m and 36.6 m respectively.

A solution to the skidding problem is to use antilock brakes and a UPS to prevent the brakes from losing power during a power outage. Antilock brakes, to our knowledge, have not been used in container cranes previously. Another solution would be to use variable torque brakes, where the torque on each brake is automatically adjusted for each different boom position.

WEIGHT, BALLAST, WHEEL LOADS, WHARF REQUIREMENTS

The PED 2020 LPCs are expected to weigh 2,000 t, but depending on rail span and other factors, modern LPCs may weigh as much as 2,500 t. A similar size and capacity AFC weighs approximately 1,500 t. LPC wheel loads for the same lift capacity, outreach, and lift height are significantly higher than a similar-sized conventional crane due to the heavier LPC boom.

The horizontal location of the crane center of gravity is extreme—near the landside rail when the boom is retracted and near the waterside rail when the boom is fully out. Because of the extreme boom positions, as much as 500 t of ballast is required to keep the crane stable in the latest LPCs. Ballast is usually concrete in the crane sill beam and legs. However, there is insufficient volume inside the sill beam and legs to accommodate typical concrete ballast, so high-density concrete ballast containing steel punchings is used.

Wheel loads for the latest generation LPCs are so large that a typical ACSE 171-pound crane rail is inadequate, and DIN A150 rails are required.

The wheel loads, tie-down forces, and eccentric inertia forces described above are reduced when the rail span is increased. Accordingly, PED opted to install new waterside and landside crane rails in their wharf to provide a 36.6 m span, while their existing rails and smaller Samsung LPCs are 30 m span.

GEOMETRY CONSTRAINTS

Lift Height

The clear distance under the raised spreader, the lift height, should be maximized to service the largest ship possible. For the PED 2020 LPC, a Z-motion (Figure 8) is used to maximize the lift height. The trolley is specially designed such that the headblock and spreader (lift system) can nest high into the trolley, gaining about 1 m of lift height, which might be needed 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. Special trolley and lift system motions allow for this operation.

Even with these features, the PED 2020 LPC cannot service the design vessel with more than eight containers on deck. The vessel has capacity to carry up to ten containers on deck, so special vessel planning will be required.

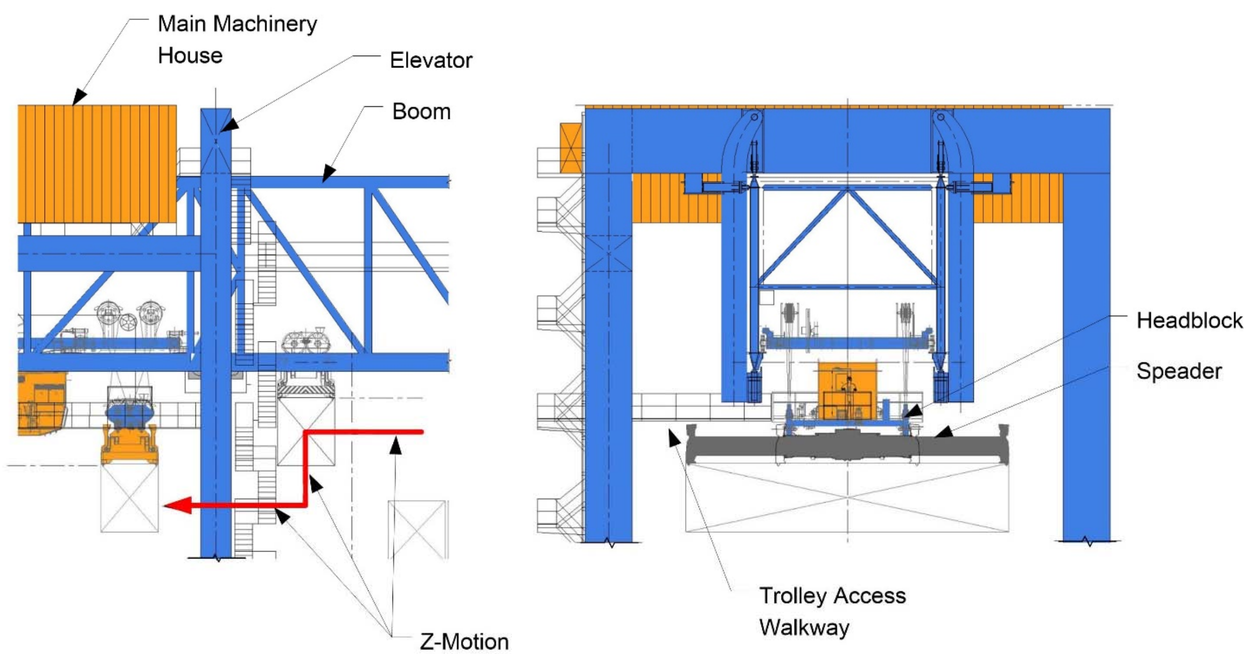

Figure 8. Z-motion sketch

Machinery House

Since the highest point of the crane is the machinery house roof, and the machinery house height affects the boom depth, minimizing the machinery house 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 short house and the multi-level deck create unique challenges for arranging the main hoist, boom drive, service cranes, and electrical components.

The main hoist drum is located in the higher-level deck with drive motors on both side decks. If the side decks were to move relative to one another, they could cause movement larger than the drum couplings could tolerate, leading to coupling failure. To mitigate this potential problem, trusses were used along the machinery house walls and underneath the drum supports to stiffen the structure and reduce relative movement between the left and right decks. See Figure 9 (ZPMC 2018).

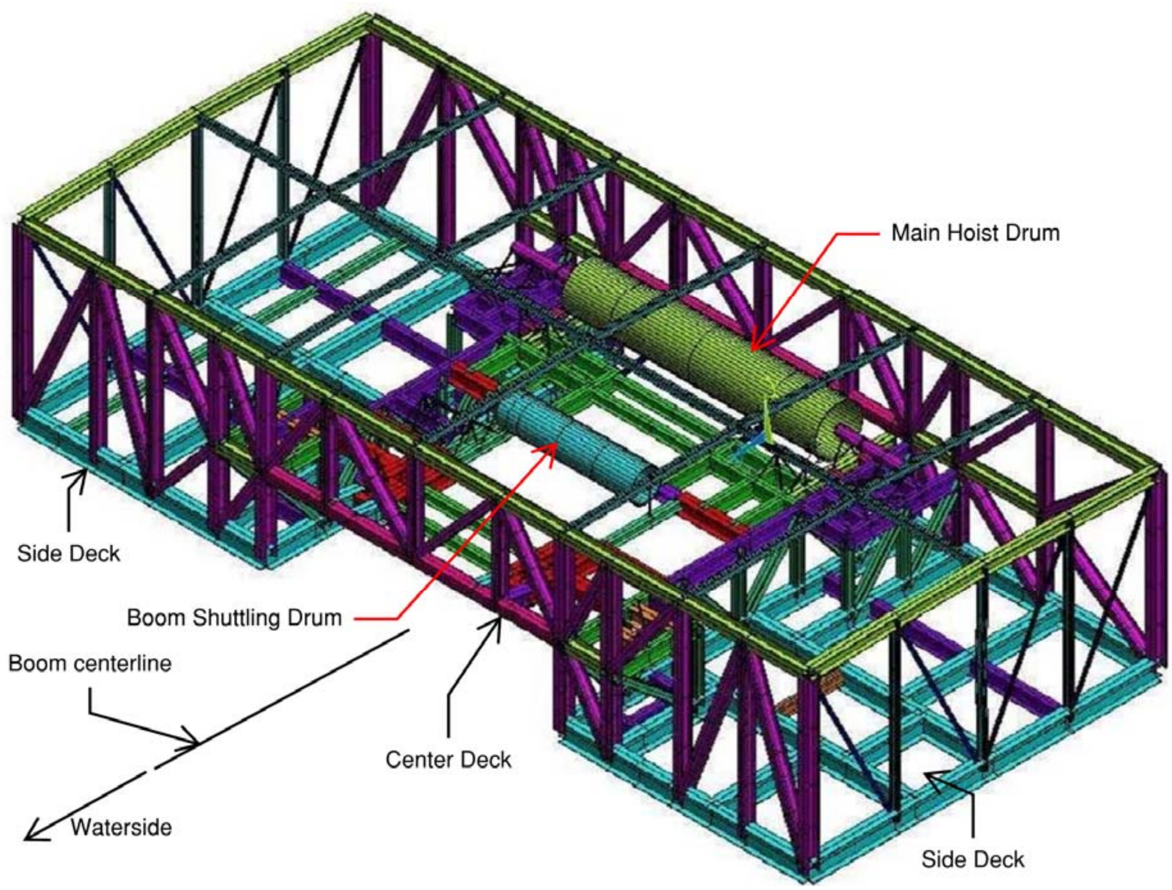

Figure 9. Machinery house framing

In an AFC, the components inside the house can be removed using a service crane and hatches in the machinery deck. For many LPCs, the house roof height is so low that a service crane cannot be located inside the house to access all components, so some components must be lifted by a land-based truck crane through the roof.

Unlike a conventional AFC house, the low clearance of the LPC house and the multi-level decks require the drives and electrical panels be located on opposite sides of the house. The low clearance and multi-level decks make running medium voltage wiring from the electrical panels to the drives difficult. For the PED 2020 LPC, the wires were run down into the right horizontal beam, into the legs, across the boom support beams, and out into the left horizontal beam.

FABRICATION CHALLENGES

Another challenging aspect of LPCs is the boom fabrication. Fabricating a very large truss is difficult, but a greater challenge is controlling the dimensions between the upper and lower chord rails, and the out-to-out dimensions of the upper chords, as well as the dimensions between the trolley rail and the boom rails (Figure 10). The boom fabrication requires careful measurements during numerous phases.

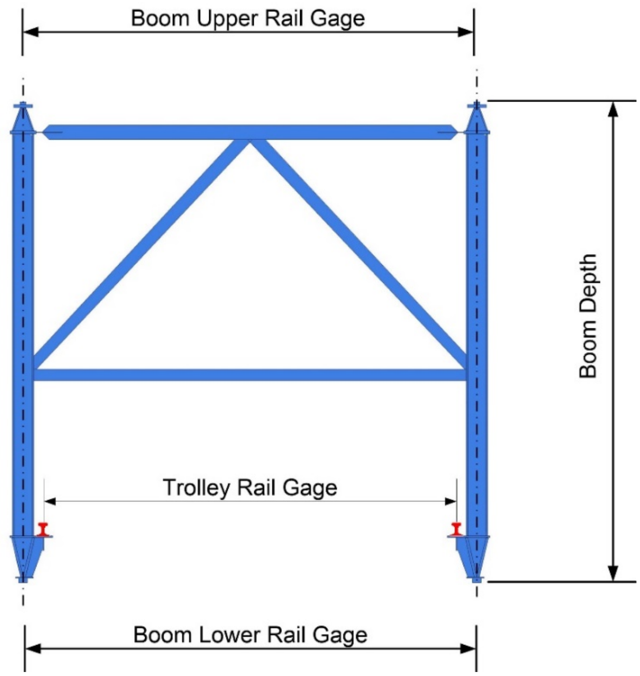

Figure 10. Dimensional control for boom

Boom camber is necessary but adds to fabrication complexity. The Sydney and PED 2020 LPC 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 trying to fabricate the boom components in the cambered shapes.

CONCLUSION

Numerous container terminals have significant height restrictions caused by proximity to airports. Low profile container cranes are vital to these terminals. Large LPCs are necessary for these terminals to compete with nearby terminals not affected by airports. LPCs servicing large ships present a myriad of challenges that are not present in 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 as described in this paper. The various LPC challenges required multi-country coordination with the entire design team of structural, mechanical, electrical, and controls engineers, and the fabrication team.

REFERENCES

ZPMC (Shanghai Zhenhua Heavy Industries Co., Ltd.). 2018. "PED Low Profile 3 STS Cranes, Machinery Deck Stiffness Calculation, Version No.:3," ZPMC report, August 23, 2018, used for Figure 9.