Wharf Upgrade Considerations for Large Low Profile Cranes

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ABSTRACT

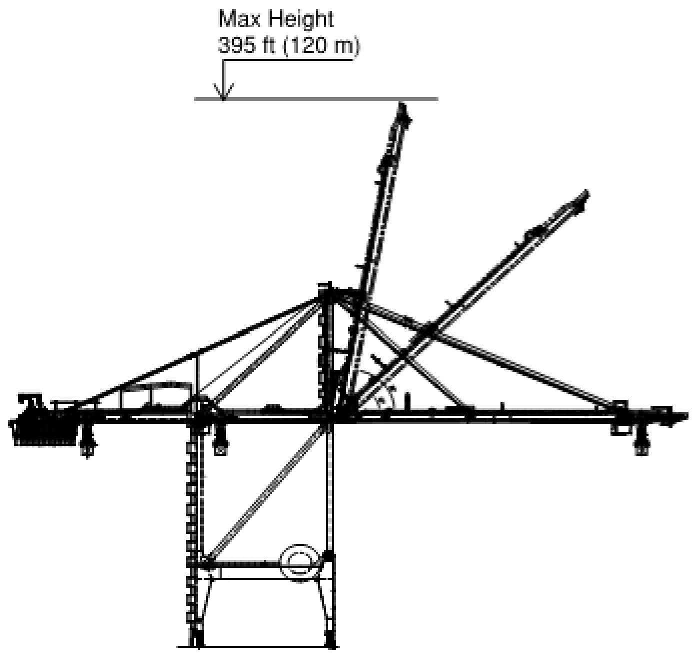
There are seaports with severe aircraft clearance limits that need to accommodate ever-increasing ship sizes. A low profile container crane with a boom that shuttles in and out is sometimes required to meet these demands. However, low profile cranes to service current generation container vessels present unique design challenges for the cranes and infrastructure. A low profile crane has extreme changes in center of gravity due to the heavy shuttling boom, which results in very large wheel loads on the wharf.

This paper presents key considerations for the infrastructure supporting large low profile cranes, including large crane girder and pile capacities, electrical demands, and construction challenges associated with the project, such as phased construction and daily coordination to avoid interruptions to the operations. The focus will be on the Broward County Port Everglades Department new crane girder and wharf upgrade project, which covers about 1 mi (1.6 km) of waterfront.

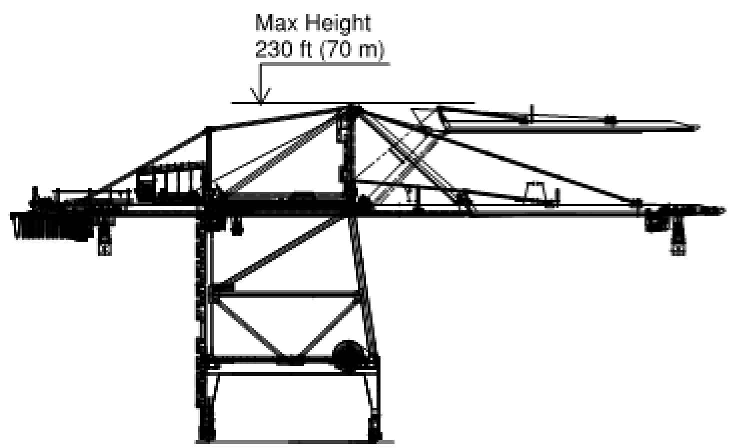
INTRODUCTION

Some marine container terminals are situated adjacent to airports and military airfields. In the United States, flight paths at the airports are controlled by the Federal Aviation Authority (FAA). The FAA, and similar agencies outside of the USA, place height restrictions for structures located in the flight paths. Ship-to-shore (STS) cranes and other structures at these terminals, if located near the flight path, are subject to the height restrictions. Such terminals in the USA are at Port Everglades (PED) near Fort Lauderdale Airport in Florida, Massachusetts Port Authority (Massport) near Boston Logan Airport in Massachusetts, and parts of New York/New Jersey marine terminals near Newark Liberty International Airport in New Jersey. Major container terminals worldwide are equipped with STS cranes suitable for serving current generation ultra-large container vessels up to 23 containers across the beam and up to 10 containers on the main deck. Conventional STS cranes, called A-frame cranes (AFCs), that serve this size vessel often do not meet the height restrictions near airfields, so a different type of crane with a lower overall height must be used instead. Figure 1 (ZPMC 2005, 2009, 2018) shows typical heights of a current generation A-frame STS crane, an articulated boom crane, and a low profile crane (LPC) for servicing a 22-wide ship. AFCs are tallest, at about 400 ft (120 m), followed by articulated boom cranes, and then LPCs.

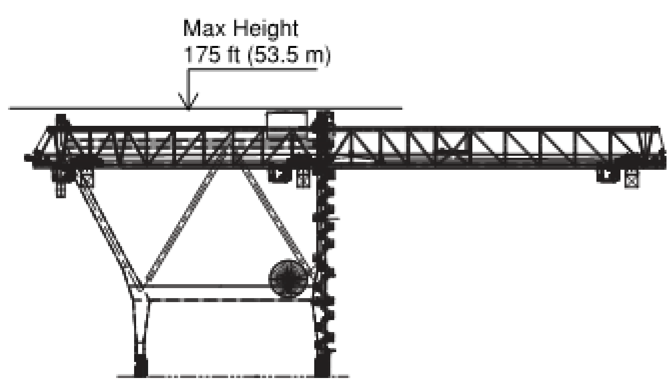
A-frame Crane



Articulated Boom Crane



Low Profile Crane



Lift height above rail: 133 ft (40.5 m)
Outreach: 205 ft (62.5 m)

Figure 1. Ship-to-shore crane types

The AFC is the most common type of STS crane. The boom is designed to rotate up to allow vessels to berth or for the crane to traverse along the berth without encroaching on the shipping channel. The tip of the rotated boom is the highest point of the crane. The articulated boom crane is similar to the AFC, except the boom folds as it rotates up or down, significantly reducing the crane height compared to the AFC. The apex beam and/or the outer segment of the boom is the highest point of the articulated boom crane. LPC boom, made of deep truss work, shuttles in and out as opposed to rotating up and down. The boom shuttles to extend out over the vessel for ship loading operations. It retracts to allow ships to berth, the crane to traverse the berth, or to secure the crane for high wind conditions, as shown in Figure 2 (ZPMC 2018).

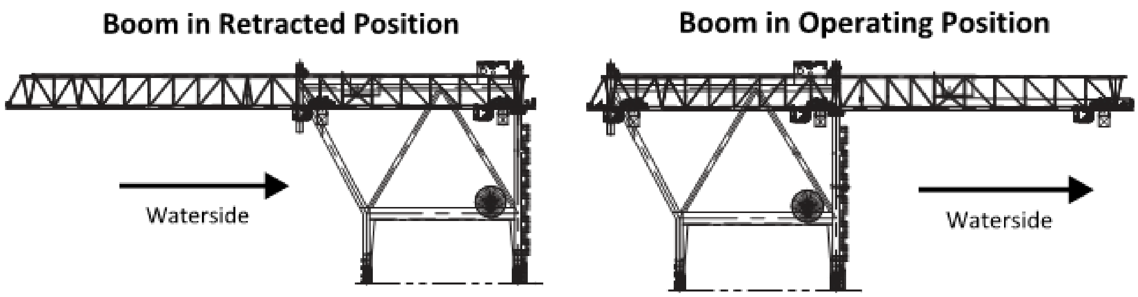


Figure 2. Low profile crane boom positions

LOW PROFILE CRANE CHALLENGES

LPCs are the heaviest, most complex, and most expensive STS cranes. The heavy, shuttling boom results in a significantly heavier crane and larger wheel loads. The AFC boom is supported by multiple stays anchored to the apex of the cranes, which fold when the boom is raised to clear the vessel. This reduces the weight of the boom and crane frame. LPCs were designed to maximize the container lift height for a crane overall height restriction. LPCs have truss booms that cantilever over the vessel from the crane frames for loading and unloading (boom extended) and cantilever over the container terminal to clear the vessel and for traversing the berth (boom retracted).

Boom weight is a significant part of the total crane weight. Consequently, the center of gravity of the LPC with the boom fully extended is close to the waterside rail, and the center of gravity with the boom fully retracted is close to the landside rail. The center of gravity of an AFC with the boom in the horizontal position or fully raised is closer to the middle of the two rails. Proximity of the center of gravity of LPCs to one of the rails results in a large amount of ballast required for crane stability and to provide sufficient downward load at the “light” corners when driving or braking the crane, especially for smaller crane rail spans.

CRANE LOADS ON WHARF

The PED ZPMC LPCs, being manufactured by ZPMC of China, are expected to weigh about 4,400 kip (2,000 t), but depending on rail span and other factors, modern LPCs may weigh as much as 5,500 kip (2,500 t). Ballast at both sides of the crane is a significant part of the weight and can be as large as 770 kip (350 t) on one side. A comparable size and capacity AFC weighs approximately 3,300 kip (1,500 t). *(1 Metric tonne (t) = 1,000 kg = 2.2 kip = 2,204 lb)*

LPC wheel loads are disproportionately higher than for a similar size and capacity AFC due to the heavier boom and bigger shift in center of gravity of the crane when the boom is in various positions. The larger loads from LPCs affect the design of several elements of the wharf, including the crane rail, rail girders, piles, crane stop, and crane stowage hardware.

Table 1 shows a sample comparison of the crane loads, assuming similar stowed wind parameters, lift height, and 22-wide outreach. The tie-down loads for LPCs depend on the stowed position of the boom. The LPC loads are based on the new PED crane geometry and weights. At PED, the boom is planned to be stowed nearly centered about the crane rails, but at other terminals, the boom is likely to be stowed fully retracted, so the LPC stowed crane wheel loads and tie-down loads could differ significantly at other terminals.

Table 1. Approximate Wharf Loads

	Typical AFC				**PED Low Profile Crane**			
	Service		Factored		Service		Factored	
	LS	WS	LS	WS	LS	WS	LS	WS
Operating Wheel Loads, kip/ft (t/m)	37 (55)	44 (65)	44 (65)	54 (80)	56 (84)	51 (76)	69 (102)	64 (95)
Stowed Wheel Loads, kip/ft (t/m)	54 (81)	52 (77)	75 (112)	75 (112)	78 (116)	54 (80)	105 (156)	74 (110)
Tie-down Loads, kip/corner (t/corner)	-	-	412 (187)	1090 (495)	-	-	529 (240)	397 (180)

Notes:

Dead Load: Typical AFC = 3,300 kip (1,500 t)
PED LPC = 4,400 kip (2,000 t)

Operating: Dead Load + Moving Load + Gantry Inertia Load

Stowed: Dead Load + Trolley + Lift System + Stowed Wind

LS is landside; WS is waterside.

CASE STUDY: NEW LOW PROFILE CRANES AND INFRASTRUCTURE FOR PORT EVERGLADES, FLORIDA

As of fiscal year 2017, Port Everglades ranked first in Florida and tenth in the USA in container cargo throughput. A total of nearly 1,080,000 TEU (twenty-foot equivalent unit containers) was handled during the fiscal year with fifteen percent of all USA/Latin American trade moves through the port. The Southport area of Port Everglades, where the turning notch and crane infrastructure project is located, handled 90% of the total PED container traffic. To reach this level of activity, the existing cranes and berths are being operated at near full capacity in Southport. Due to the anticipated increases in demand for containerized cargo in the south Florida area, PED determined that additional berths and higher capacity gantry cranes were required to remain competitive and service new-Panamax and larger vessels. This would include upgrading the existing gantry cranes, acquiring new, larger LPCs, and constructing new crane infrastructure at some of the new berths. However, construction of these additional facilities would have to occur with minimal impact to the tenants' operations.

Existing Port Facility and Cranes

The existing terminal consists of approximately 3,700 ft (1,130 m) of L-shaped container wharf with seven LPCs. Berths 31–33 with a total length of 2,800 ft (850 m) are aligned approximately north-south. Berth 30 with an approximate length of 900 ft (275 m) is aligned east-west, as shown in Figure 3.

Figure 3. Existing facility aerial photograph (*Google Maps*)

The existing LPCs have an overall height of 151 ft (46 m) above ground and have a rated 40 long ton (41 t) capacity under the spreader. Three of the seven cranes are capable of traversing around the corner from Berth 30 to Berth 31.

Although main power to the terminal is 13.2 kV, the existing cranes operate on 4,160 V power via step-down transformers and switchgear located in a switchgear building. The 4,160 V power is supplied by underground medium voltage cables from the switchgear building to the cable vaults located along the waterside edges of Berths 30–33. The individual cranes pick up the power through cables that spool onto and from the cranes as they traverse the wharf. The existing electrical infrastructure has inadequate capacity to support the new cranes, so upgrades were required as part of the proposed project.

The typical wharf structure has a sheet pile retaining wall at the waterside with tie rods connected to sheet pile anchor walls at the back. The 100 ft (30.48 m) span crane rails are supported on isolated concrete girders with auger piles, and the waterside rail is set back 9 ft (2.7 m) from the wharf face. Battered steel piles are installed at fender locations. See Figure 4 (Williams et al 1990).

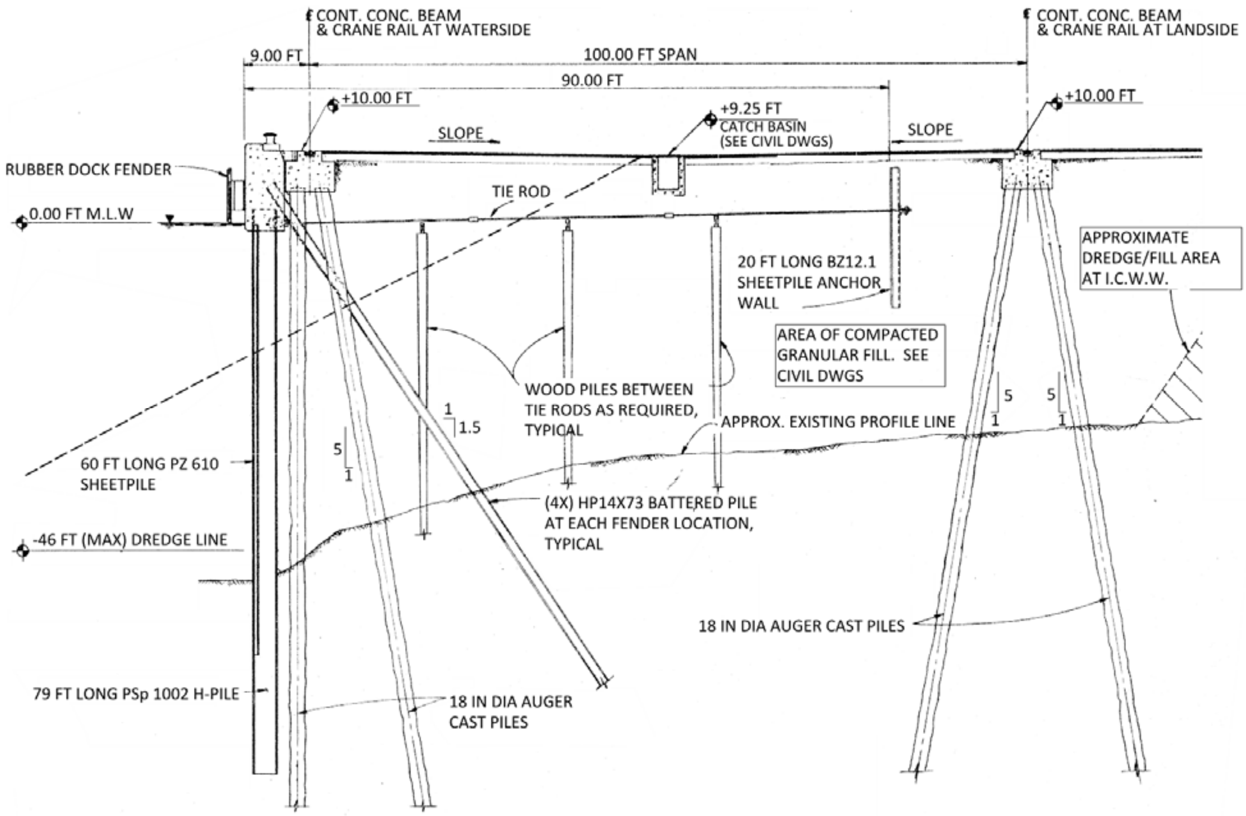


Figure 4. Existing wharf section

New Low Profile Cranes and Wharf Girders

The FAA is in the process of approving an aviation clearance of 175 ft (53.3 m) above ground level for Berths 30–33, which would allow the port to deploy LPCs suitable to serve current generation vessels. The port ordered three new LPCs for operating at Berths 31 and 32 and has an option for ordering two additional cranes for Berth 30. The new LPCs are suitable for operating 15,000 TEU vessels with 22 containers abeam, a maximum stack height of seven high-cube containers or four high-cube and four standard-cube containers above deck, and an average draft of 41 ft (12.5 m). The cranes will have a separate set of rails with a 120 ft (36.6 m) span and 65 LT (66 t) capacity under the spreader. Berthing a light vessel at high tide may require reduced trolley speed and loading of the top tier containers from outermost to the innermost. The new cranes will be supplied with 13.2 kV power as part of the electrical upgrades.

The existing 100 ft span crane girders and rails did not have sufficient capacity to support loads from the new cranes. Upgrading the capacity of the existing crane girders would require installing additional auger piles through the girders or on either side of the girders. This scheme would prevent the existing cranes from travelling past the construction activities. Shutting down parts of the berths would risk losing some tenants and hence, was not an option.

In consultation with port management, it was decided to construct new 120 ft (36.6 m) span crane girders to support the new cranes. See Figure 5 (Liftech 2016). The new waterside crane girders are set 10 ft (3 m) landside of the existing waterside crane girders, and the new landside crane girders are set 30 ft (9.1 m) landside of the existing landside crane girders, which permits existing cranes to travel past the construction areas. The new auger piles to support the girders are located to clear the existing sheet pile tie rods and battered piles. Although this arrangement increases the boom cantilever past the waterside rail, the larger 120 ft (36.6 m) rail span helps with crane stability and reducing the loads on the crane girders.

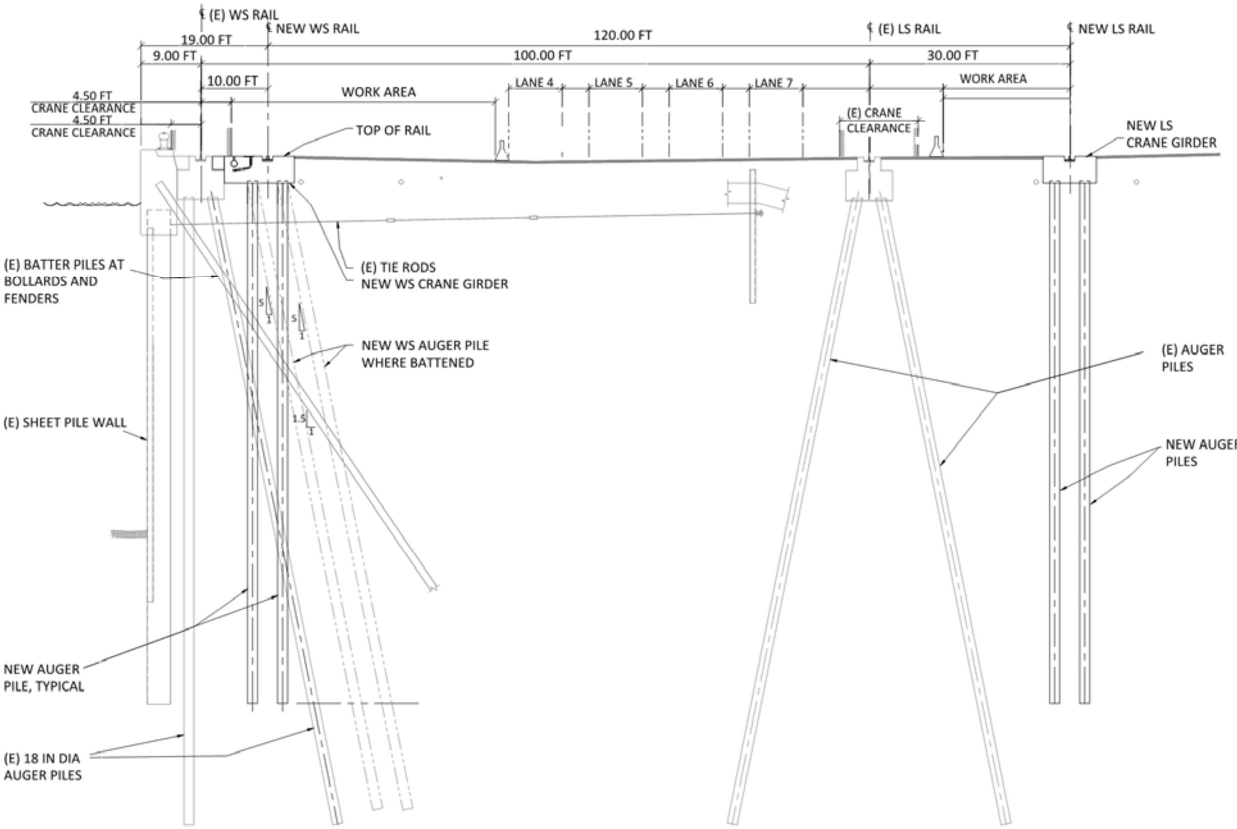


Figure 5. Modified wharf section

Infrastructure Improvement Phasing

Improvements consist of:

> Crane Rail Project—upgrading the existing Berths 30–33 for new cranes and extending Berth 30 by 1,500 ft (460 m)
>
> Turning Notch Project—constructing new berths including new wharf for a Berth 30 extension

The author's team was awarded the design and construction observation contract for all crane and crane rail infrastructure related work, but a team headed by Louis Berger was awarded the contract to design the adjacent marine facilities including bulkheads, anchor walls and tie rods, turning notch dredging, and civil and electrical work related to the construction of the turning notch extension and berths.

To accommodate the need to maintain port operations throughout the project schedule, construction activities for the crane rail project are broken into three phases.

Phase 1 – Berths 31 and 32

Phase 1 consists of constructing new crane rail girders at the existing Berths 31 and 32, as well as a new switchgear building to handle the higher voltage requirements of the new cranes. To provide power to the new switchgear building and support the 13.2 kV required to operate the new cranes, the local electric utility, Florida Power & Light, will construct a new substation on a remote parcel of port property. Additionally, approximately 7,000 linear feet (2100 m) of concrete-encased duct bank will be constructed such that power will be available prior to arrival of the cranes.

The new cranes will be fed with 13.2 kV power, thereby eliminating the need for yard transformers to step down the voltage from 13.2 kV to 4,160 V. Existing cranes will continue to operate on 4,160 V. New duct banks will be built to carry the 13.2 kV power from the switchgear building to the cranes.

Cable channels and vaults for six new gantry crane cables will be constructed along the crane girders.

Phase 2 - Berth 30 Extension

Phase 2 consists of constructing approximately 1,500 ft (460 m) of 100-ft (30.5-m) span rail girders and 300 ft (90 m) of 120 ft (36.6 m) span rail girders designed by the author's team concurrent with construction of bulkhead and dredging of the new berths designed by Louis Berger. The Berth 30 extension is planned for berthing two container vessels along the north face of the facility. During this phase, minimal impacts to port tenant operations are anticipated, as these areas were previously vacated by the tenants during Phase 1 in preparation of this work. Although the Phase 2 construction of the crane rails is anticipated to be substantially complete before the construction of the bulkhead and dredging is completed, the contractor is required to wait until all work on the turning notch extension is complete and the new berths are ready for port tenant use before proceeding with the Phase 3 crane rail construction. The hiatus in crane rail construction has the potential to exceed a year.

New duct banks are constructed to route medium voltage cables from the switchgear building to the crane cable vaults at the Berth 30 extension. The crane cables are planned to be routed from the switchgear building to the berth in conduit installed with directional boring through the tenant container storage yard.

Phase 3 – Berth 30

Upon completion of Phase 2 and transferring port operations from the existing Berth 30 to the newly constructed Berth 30 extension, the contractor will be allowed to proceed to Phase 3, which consists of constructing the 120 ft (36.6 m) span crane rail girders at existing Berth 30 and complete repaving of the Southport dock aprons.

New stowage positions for new cranes, including tie-down and stowage pin hardware, will be installed on Berth 30.

At the time of submitting this paper, Phase 1 construction is approximately 50% complete and is expected to be completed by early 2020. Phase 2 is scheduled to start in 2020, after completion of Phase 1. Phase 3 is scheduled to start by early 2022 and be completed by mid-2023.

Crane Logistics

The three new cranes are scheduled to arrive at the port in September 2020. Approximately 500 ft (150 m) of crane girders at the north end of Berth 30 construction is scheduled to be completed in time for the new cranes to be offloaded and commissioned. After the new cranes are operational, the port plans to move two of the five existing cranes at Berths 31–32, to the Berth 30 Extension.

Construction Challenges and Solutions

There was a recognized potential for construction conflicts with two design teams preparing plans for proposed work in the same Berth 30 extension area. To help mitigate anticipated problems, the port required extensive coordination between the two design teams starting early in the design process. In addition, during the design phase, the port acquired the services of a Construction Manager at Risk who provided review and comments starting with 60% plan submittals to reduce potential for construction conflicts. The construction manager was also given the construction contracts for both design teams.

During the preliminary design concept stage, the existing crane rail girders were analyzed for their ability to handle the larger cranes required to service post-Panamax ships. The existing girders were found to have insufficient capacity to support increased loads. As described herein, the first concepts considered upgrading the existing girders, but construction would be too disruptive for existing crane operations. To allow for acceptable operations of the existing cranes, the decision was made to construct new crane rails for use by the new, larger LPCs. This decision also allowed the new cranes to have a 120 ft (36.6 m) rail span instead of the existing crane 100 ft (30.5 m) span. As a result, the existing cranes remained available to work in all areas that were not active construction zones.

The port worked with the tenants and agreed to dedicate one 300 ft (91 m) long segment at a time to allow construction of the new crane girders within each segment. The contractor first installed all the auger piles for the crane girders, 18 in (457 mm) and 24 in (610 mm) diameter, and the switchgear building, 18 in (457 mm), and then constructed the crane girders in 300 ft (91 m) segments while the terminal operations continued at the berths.

The requirement to perform the construction work in three phases allowed port tenants to adjust their operations as needed to continue providing container services for their clients with only minor inconveniences.

Upon the start of the Phase 1 construction, it became apparent that despite all the planning and reviews during design, not all potential disruptions to operations were accounted for. Among the first activities on the project schedule was installing auger cast test piles. The design plans located the test piles in areas away from the existing crane rails to allow for the existing cranes to move freely. Although the design described that the drill rig could interfere with the crane boom, the amount of crane movement disruptions due to the height of the drill rig required to install the piles was not anticipated until work was under way. Realizing that this would be recurring throughout Phase 1 construction, the port solicited input from the port tenants. As a result, weekly coordination meetings for port tenants to communicate their planned operations to the construction manager were held. Attendees included port staff, port tenants, the construction manager, and the engineer, who in turn helped coordinate construction activities to minimize impact as much as possible. In addition, the construction manager was requested to communicate with the harbormaster office daily to determine any changes to ship schedules and adjust as necessary to allow for movement of the existing cranes as needed.

CONCLUSION

When a port decides to upgrade their STS container cranes, sometimes the proximity of an airfield to a container terminal can limit the type of crane to a low profile crane. LPCs have much higher load demands on the wharf structures than conventional AFCs, and it is likely that the existing infrastructure will not be able to support them, requiring new infrastructure. A recent example of this is Port Everglades, which purchased three new LPCs suitable for operating 15,000 TEU vessels with 22 containers abeam. To accommodate the new LPCs, and allow the existing cranes to operate without interruptions, the port is building a new system of crane girders and rails parallel to their existing crane girders and new electrical infrastructure to service the new cranes. In addition to design challenges, there were many challenges in the construction of the new infrastructure. Careful construction phasing and coordination with the port tenants was implemented to reduce interruptions to daily operations. By facilitating continuous communication between all the Southport stakeholders, Port Everglades has been able to proceed with the construction of this large-scale project with manageable inconvenience to port operations.

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