Crane Loads—Triple E Class and Beyond

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ABSTRACT

Given the rapid growth of container ship sizes and the cranes that service them, what type of crane and loads should a new wharf be designed for? Recently, crane loads on wharves have exceeded wharf capacities sooner than expected. For instance, some wharves designed within the last 15 to 20 years are having their design capacities approached by recent cranes designed for Triple E ships.

Future cranes will continue to get bigger and require larger wharf capacity. A variety of possible crane designs and their impact on crane loads on the wharf are discussed, including the following:

- Increasing the outreach and lift height beyond Triple E size cranes
- Multiple trolleys
- Triple or quad twin lift
- Unconventional crane systems

Wharf strengthening is expensive from direct costs to upgrade the wharf and indirect costs from restricted wharf usage and interruptions to operations. This paper discusses historical crane load increases and possible future crane designs.

INTRODUCTION

Container ship sizes and the size of the cranes that service them are continually growing. This makes it difficult to determine appropriate crane girder design loads, since the wharf is typically designed for at least 50 years.

An understanding of traditional approaches and potential future cranes and upgrades and their impact on crane loads will help the wharf designer understand appropriate design loads. This will help the owner avoid premature wharf strengthening, which is expensive both in direct upgrade costs and in the indirect costs of operation interruptions.This paper discusses these issues and provides expected increases to crane wheel loads due to selected cranes and crane systems. The loads presented are approximate, depend on the assumed solution, and should not be used for design.

HISTORICAL APPROACH TO CRANE LOADS FOR WHARF DESIGN

Traditionally, wharf designers have estimated the largest ship expected to service the wharf during the wharf design life and then estimated a size of a crane to service the ship. Estimated loads for that crane were then increased 10% to 20% to obtain a design load. The increase was intended as an allowance for variations in crane design, such as for the center of gravity location, weight, larger wind area, etc., and for minor crane modifications. Historically, this method has worked well, but recently has resulted in crane loads that exceed the wharf design loads sooner than expected.

An example of this is the relatively recent wharf designs at the Port of Oakland. Several wharves built around 15 years ago during the Wharf Embankment and Strengthening Program 2000 now have girder capacities near the capacities required for current cranes for Triple E size ships. Considering the cost of strengthening and typical design lives of 50+ years, approaching the design loads in 15 years is unexpected.

SHIP AND CRANE SIZES AND YARD PRODUCTIVITY

Ship Size Growth

In 1980, the average ship size was 1,000 twenty foot equivalent units (TEU) and the largest was 3,500 TEU. In 2014, globally the average ship size was 3,500 TEU and the largest was 18,500 TEU. Figure 1 shows that according to the U.S. Department of Transportation, the average ship calling at U.S. ports increased in size an average of 4% per year between 2002 and 2014. Currently, the largest ship being ordered has a capacity of 20,000 TEU.

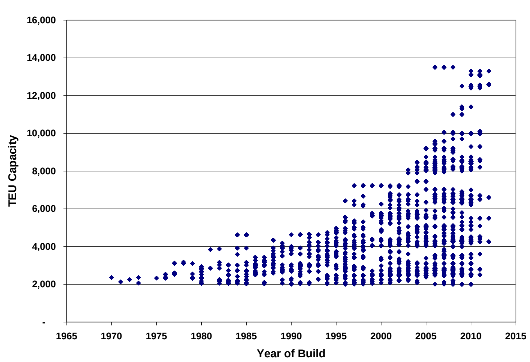

Figure 1. Ship sizes 1970 to 2013.

Productivity Demands

Ship volume has grown faster than ship length and the number of cranes that can service the ship. Yard productivity, which used to be the primary bottleneck in the terminal, has been improving recently due to automation and other technology.

As a result, there is a recent stronger need for increased crane productivity. This has resulted in a variety of crane design changes. Features such as tandem 40 lifts and dual trolleys are becoming more common, and different crane systems altogether are becoming more probable. This adds an additional complication to determining design crane loads beyond the geometry demands.

Crane Loads

Wheel loads have increased significantly over time, particularly with the introduction of tandem 40 lift cranes and dual trolley cranes. For instance, adding a shore side trolley and hoist will have a significant impact on landside wheel loads. Similarly, increasing the trolley weight and rated load for a tandem lift crane will have a significant increase to the overall crane weight and, in particular, waterside girder loads.

Choosing crane loads for girder design now requires many more considerations than 15 years ago. The next section presents some of the more significant considerations.

CRANE FEATURES AND IMPACT ON CRANE LOADS

This section presents the changes in service wheel loads for a variety of features relative to a "base crane" design. See Table 1 at the end of this section for a summary of the changes in the operating wheel loads due to the crane features discussed below. The loads presented are for the particular conditions presented. Wheel loads for a particular crane design will differ and require calculation.

The first two alternative cranes, "lift height increase" and "outreach increase," could either be new cranes or a modification of the base crane—the expected wharf loading would be similar in either case.

The other alternative cranes considered would need to be new cranes. For instance, increasing the strength of the trolley girder and boom for a dual hoist tandem crane is probably not practical.

Prior to designing crane girders for triple tandem, quad tandem, two main trolley, or other types of cranes not currently used, studies should be performed to estimate when the cranes may become viable and be reasonable to design for. Unconventional cranes or crane systems similar to those discussed in this paper also need significant research and development prior to use.

Base Crane

The largest crane that many ports and operators are currently planning and designing for is a crane to service Triple E Class ships. This is the base crane used in this paper as a comparison for other potential features. The base crane has a single hoist with 65 LT capacity under the spreader, 30.48 m (100 ft) rail gage, 70 m (230 ft) outreach, 22 m (72 ft) backreach, 50 m (164 ft) lift height, and is designed for little or no damage in a larger earthquake.

> *Note regarding units:*
> *Metric tonne (t) = 1,000 kg is used for reporting wharf loading (2,204 lb)*
> *Long ton (LT) = 1,016 kg is used for rated loads (2,240 lb)*

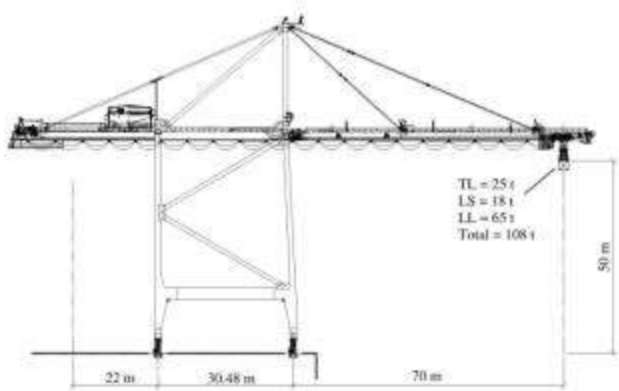

Figure 2. Base crane used in this paper.

Lift Height Increase

Increasing the lift height 10 m permits stacking three containers higher on the ship and some sea level rise. Operating wheel loads including impact loads and operating wind load increase by 4 tonne/wheel landside and waterside. Stowage loads are affected due to the increased wind loading and more significantly the increased overturning, particularly in high wind locations. Recently, this modification has been the most common among crane structural changes, due to ships stacking containers higher on deck.

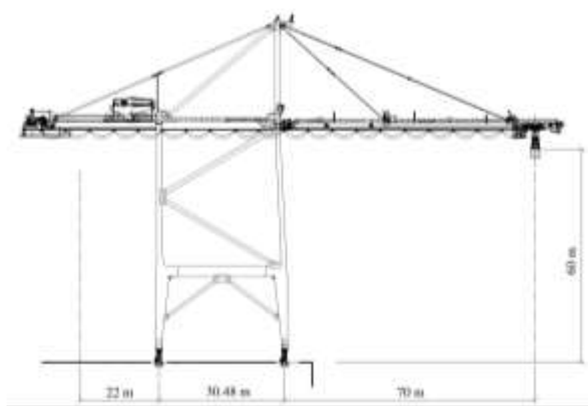

Figure 3. Lift height increase of 10 m.

Outreach Increase

Increasing the outreach by 10 m allows for nearly four additional container rows on a ship. Operating wheel loads decrease by 5 tonne/wheel at landside and increase 10 tonne/wheel waterside. Given the trend of increasing ship width, it is probable that future cranes will have larger outreaches and that existing cranes will be extended. Waterside operating wheel loads increase due to the added boom weight, increased trolley travel, and increased boom wind load.

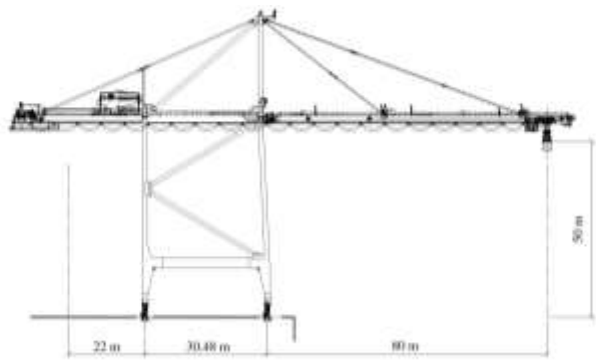

Figure 4. Outreach increase of 10 m.

Tandem Lift

Dual hoist and single hoist tandem lift cranes offer the opportunity of loading two 40 ft (or four 20 ft) containers in a single trolley cycle. Operating wheel loads increase 28 t/wheel and 36 t/wheel landside and waterside, respectively, for a dual hoist tandem lift crane.

Wheel load increases are primarily due to the increased moving load consisting of the trolley, lift system, and lifted loads. Secondary increases are from the increased weight of the crane structure.

The rail gage is often increased to accommodate the dual truck lanes that are advantageous for operations. A wider gage improves stability about the gantry rail axis, limiting or avoiding the need for operating ballast and reducing wheel loads. Figure 5 and Table 1 do not include the effects of a wider gage.

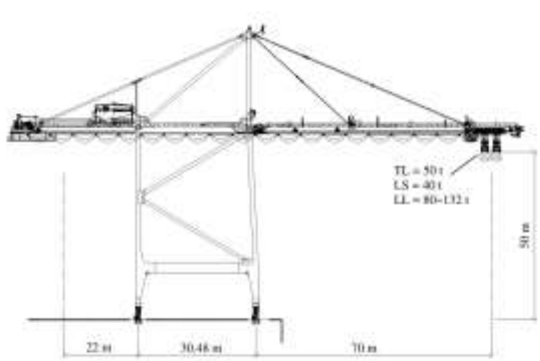

Figure 5. Dual hoist tandem lift.

Shore Trolley and Hoist

Shore hoist systems are used to increase crane productivity, primarily for terminals with automated yards. The primary hoist sets the container on a container stacking platform for inter-box cone removal. The shore hoist transports the container to the yard for automated guided vehicles or other yard transport systems.

As expected, adding a shore hoist will affect the landside wheel loads more significantly than the waterside wheel loads. Operating wheel loads increase 54 t/wheel and 32 t/wheel landside and waterside, respectively.

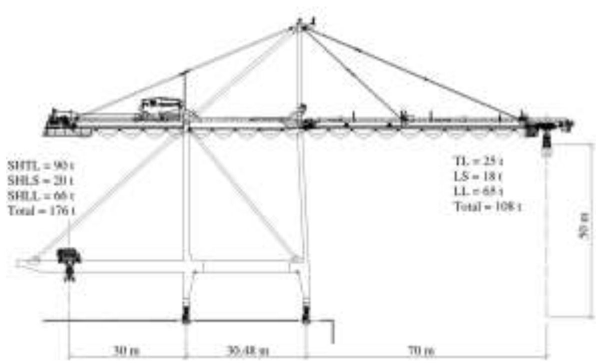

Figure 6. Shore trolley and hoist.

Triple and Quad Twin Lift

Typical container cranes are capable of lifting two 20 ft containers simultaneously—a "twin-twenty" lift. One crane is now capable of lifting six, fully loaded 20 ft containers simultaneously, as shown in Figure 7.

Operating wheel loads increase 30 t/wheel and 46 t/wheel landside and waterside, respectively, for a triple lift. Similarly, operating wheel loads increase 38 t/wheel and 63 t/wheel landside and waterside, respectively, for a quad lift.

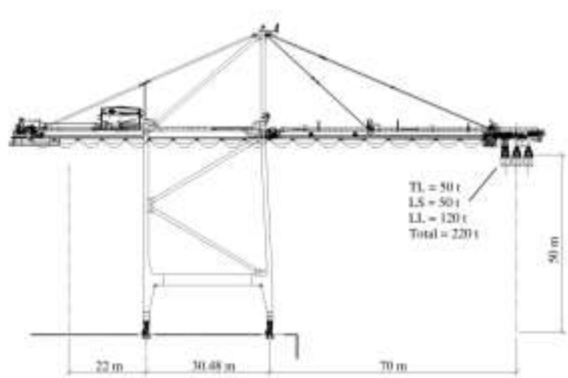

Figure 7. Main hoist triple tandem (six twenties) lift.

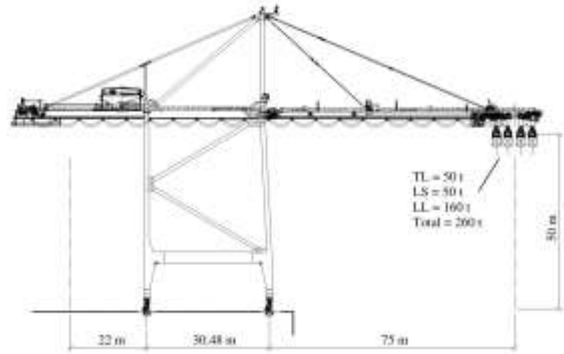

Figure 8. Main hoist quad tandem (eight twenties) lift.

The capability to effectively handle six to eight containers at a time with the main hoist could significantly increase productivity. Major challenges include attaching to multiple containers in a single lift, coordinating vehicle placement and traffic to unload the containers simultaneously, and designing the crane boom and trolley for possible large container loads.

Wheel load increases are primarily due to the increased moving load and resulting overturning moment, and secondarily due to the additional weight of the stronger crane structure.

ZPMC supplied dual hoist, triple tandem cranes to a Chinese domestic terminal. We understand the triple 40 feature is no longer used because of operational limitations.

Lifting multiple containers beyond a tandem 40 ft lift is currently not effective but its time may come.

Two Main Trolleys and One Shore Trolley

Operating wheel loads increase 116 t/wheel and 84 t/wheel at the landside and waterside, respectively, primarily due to the large moving loads caused by the multiple heavy trolleys. The trolleys contain the hoist and travelling machinery. A relatively large 40 m wheel gage is used for stability and to limit wheel loads. Larger gages may be beneficial.

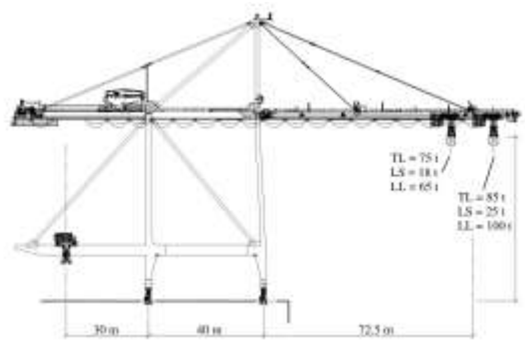

Figure 9. Two main trolleys and one shore trolley.

Summary

A summary of the base crane and the effect of the crane features considered in this paper beyond the base crane are provided in Table 1.

Table 1: Summary of Service Wheel Loads.

	Landside Wheel Load tonne/wheel		Waterside Wheel Load tonne/wheel	
	Total	Change from Base Crane	Total	Change from Base Crane
Base Crane	66	0	91	0
Increased Lift Height	70	4	95	4
Increased Outreach	61	-5	101	10
Dual Hoist Tandem Lift	94	28	127	36
Shore Trolley	120	54	123	32
Triple Lift	96	30	137	46
Quad Lift	104	38	154	63
Two Main Trolleys and One Shore Trolley	182	116	175	84

UNCONVENTIONAL CRANE SYSTEMS

Unconventional crane systems will vary greatly. See Figures 10 and 11 and refer to Liftech's paper, "Concept High Productivity STS Cranes," also included in ASCE Ports 2016.

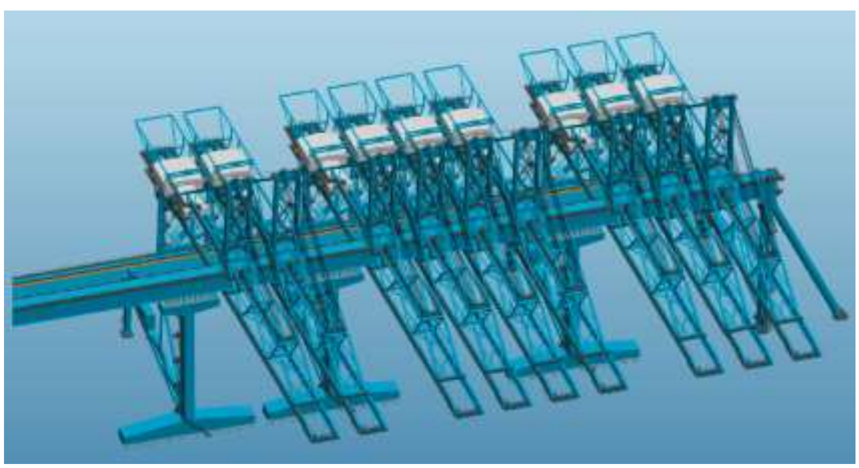

Figure 10. APMT FastNet system.

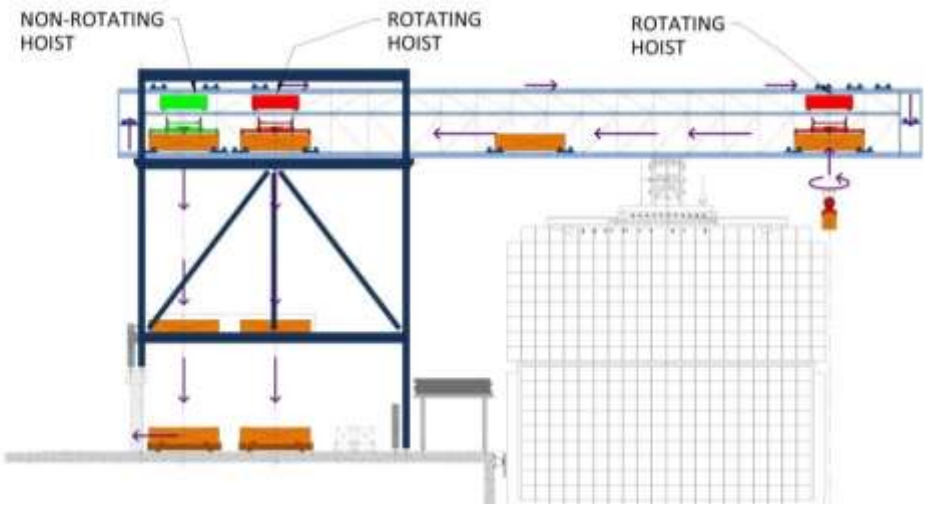

Figure 11. Liftech conveyor Supercrane.

A general description of an unconventional crane system from a World Port Development article published in May 2013:

Sometime during the next ten years, a system capable of servicing adjacent hatches will be implemented. The system will be innovative and have the following features:

> *Adjacent hatches will be serviced by STS cranes.*
>
> *The system will be fully automated. The operators will not be on the crane.*
>
> *Traffic lanes for ship utility and personnel transfer vehicles will be provided waterside of the structure's waterside leg.*
>
> *Some means of handling special and oversized loads will be provided outside the restricted automated yard.*
>
> *Hatch covers will be stowed near the waterside of the wharf, either waterside or landside of the waterside rail.*
>
> *Deconing platforms will be on the crane. The cones will be removed automatically or manually.*
>
> *The wharf waterside girders will carry anywhere from 150% to 175% of the customary loads from today's jumbo cranes.*
>
> *The wharf landside girders will be elevated to eliminate the gantry tunnel.*
>
> *Containers in the yard will be handled by either AGVs or automated shuttle carriers.*

The loads from these systems will likely be larger than conventional systems presented in this paper. It is not economic to design a wharf for these types of crane systems unless stakeholders are reasonably certain they will be used.

Considering the 50+ year wharf design life, it is worth considering the possibility of an unconventional system; and although it may not be practical to provide that capacity, it may be practical to design to facilitate the future modifications for such a system, such as providing space for a larger gage landside girder with utility placement.

CONCLUSION

It is important to select appropriate crane loads for the wharf design to help avoid expensive future wharf strengthening. The conventional method of selecting design loads may not be appropriate considering the current variety of crane features and systems. Stakeholders are encouraged to consider the variety of potential crane features and possible systems in addition to the expected crane size when choosing design loads. Designers are encouraged to incorporate the ability to modify capacity, such as providing space for larger gage landside girders, and to consider opportunities to obtain larger capacities than specified at little cost, e.g., driving piles slightly farther if significantly increased capacity can be had at little additional cost.

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