THE IMPACT OF JUMBO CRANES ON WHARVES

Catherine A. Morris, MS, ASCE Member, Principal and Structural Engineer,
Liftech Consultants Inc., 3666 Grand Ave., Oakland, CA 94610, USA,
cmorris@jwdliftech.com
Patrick W. McCarthy, MS, Structural Designer,
Liftech Consultants Inc., 3666 Grand Ave., Oakland, CA 94610, USA,
pmccarthy@jwdliftech.com

Introduction

Jumbo: a very large specimen of its kind.

Worldwide container traffic continues to grow faster than the worldwide economy. Increased traffic means increased ship size and terminal throughput. Ship size and production demands lead to bigger and faster cranes: cranes capable of serving 22-wide ships and lifting 65 metric tons under spreader and 100 metric tons under hook. These new jumbo cranes are imposing greater loads on the wharf structure, loads that wharf designers are just now beginning to realize.

The jumbo cranes are big: 65-m outreach, 37-m lift height, increased wind area, and increased weight and inertia forces. Their designs are affected by trolley type, maintenance needs, automation, and trolley and hoist speeds. Even their power requirements are changing. These factors result in heavier wheel loads, greater stowage and tie-down forces, and increased collision bumper loads, creating the need for stronger wharves.

Even though the overall wharf design doesn't change much for these cranes, the designer needs to look at the capacities of the rail girders, the stowage devices, and the collision bumper. Stowage pin sockets and tie-down brackets are key elements in the wharf that often get overlooked. More cranes are damaged from the failure of the connection in the wharf during high winds than from the failure of the crane itself.

This paper presents current design issues for jumbo cranes and discusses how they effect wharves.

Jumbo Cranes

The size of container cranes has more than doubled since the first container cranes were built in the late 1950s. The Matson container cranes built by PACECO in 1959 were designed to lift 22.7-t boxes 15.6 m over the rails with an outreach of 23.8 m. The latest container cranes, such as the ones shown in Figure 1, lift 65-t boxes 36 m over the rails with an outreach of 65 m. The new cranes are taller and heavier than any before – up to 75 m high and weighing 1300 t.

Typical size characteristics of state-of-the-art, conventional, single-trolley, post-Panamax container cranes are shown in Table 1.

Figure 1: These cranes manufactured by ZPMC in China were the largest in the world when they were delivered to the Port of Oakland in October, 2000.

Crane Configuration

The typical configuration of a post-Panamax crane, the modified A-frame developed for PACECO in the 1970s, has remained, with only minor modifications, the most efficient configuration. See Figure 2. Often, height restrictions require changing the modified A-frame by using an articulated boom, or by using an alternate configuration, such as the low-profile crane. The articulated boom does not significantly effect the loads to the wharf, but the low-profile crane has significantly higher wheel loads and tie-down forces. The operating wheel loads are approximately 30-50% higher, and though the stowed wheel loads are lower at the waterside, they can be twice as high at the landside.

Wind Load

In many locations, the storm wind load condition controls the design of the crane legs and sill beams. Extra steel, not needed for operating conditions, is required to strengthen the crane for infrequent high wind loads, adding weight to the crane and possibly increasing the size of overall sections, which, in turn, increases the wind area. The result is an increase in crane wheel loads and tie-down forces.

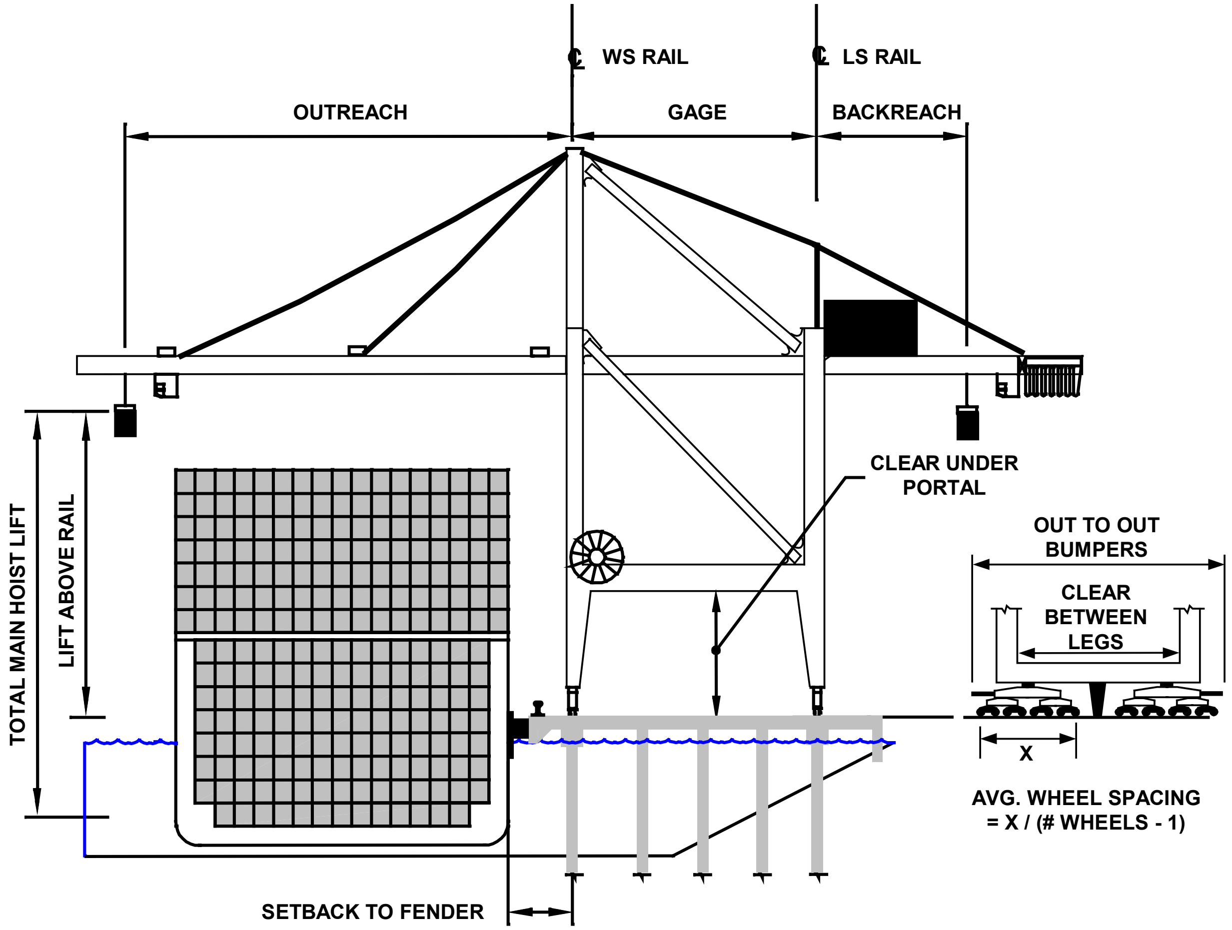

Figure 2: Standard Modified A-Frame Crane Geometry

	16-Wide	18-Wide	20-Wide	22-Wide
Gantry rail gage (m)	30.5	30.5	30.5	30.5
Clear between legs (m)	18.3	18.3	18.3	18.3
Lift above rails (m)	34	34	36	36+
Total main hoist lift (m)	50	52	54	60+
Clear under portal (m)	12	12-15	15	12-18
Out-to-out bumpers (m)	27	24-27	24-27	24-27
Outreach from waterside rail with 4-m setback (m)	45-47	50-52	56	60-65

Table 1: Size Characteristics of State-of-the-Art, Post-Panamax Container Cranes.

Wind tunnel testing of a scale model is often worthwhile. A properly conducted wind tunnel test can more accurately determine forces for different wind regions, as well as identify potential wind-induced vibration problems. Use of code-estimated wind force factors typically results in very conservative loads.

Trolley Selection

The selection of a crane's trolley type is significant for the structure, as well as for the wheel loads. The trolley can be rope towed or machinery type. The trolley selection should be based on the needs at a particular location, as well as the preference of the owner and operators.

With a rope-towed trolley system, the trolley drive, main hoist, and boom hoist drums and machinery are located in the machinery house, fixed on the crane frame. Trolley and main hoist ropes run from the machinery house to the end of the trolley girder, through the trolley, and to the tip of the boom. This arrangement allows the trolley to be shallow and lightweight, permitting greater lift height and smaller loads on the crane structure and wharf.

A machinery trolley has the trolley and main hoist machinery on board. With most of the machinery on the trolley, the machinery house on the frame is much smaller, containing only the boom hoist. No trolley drive ropes are required, and the main hoist ropes are shorter than for a rope-towed trolley.

For the structural design, weight is the main difference between the two types of trolleys. The weight of the rope-towed trolley is approximately one-third that of a machinery trolley. Most dramatically, the heavier machinery trolley increases fatigue damage on a similar crane with a rope-towed trolley by a factor of 5 to 1. Table 2 gives an example of the effect of trolley type on the structure. The operating wheel loads for a machinery trolley crane are typically 10-20% higher than for a rope-towed trolley crane.

	Rope-Towed Trolley	Machinery Trolley
Trolley weight, (t) (with electronic anti-sway)	23	65
Moving load, (t) Trolley + spreader + headblock + 50.8-t (50-LT) container + impact	110	160
Moving load for fatigue damage (t)	70	115
Relative fatigue damage	1.0	4.63
Total crane weight (t) 30.5-m gage, post-Panamax	1050	1200

Table 2: Effect of Trolley Type on Structure

The main disadvantage of the machinery trolley is the increase in crane weight and wheel loads on the wharf. Some wharves are not strong enough to support the latest jumbo cranes with a machinery trolley.

Wharves for Jumbo Cranes

The basic wharf design philosophy applies to any crane size, but as the cranes get larger, looking at the key components that connect these two large structures becomes even more important. Loads from the jumbo cranes vary with the trolley type and the location of the crane, i.e. the wind region. Table 3 shows typical jumbo crane loads for each trolley type and for three wind regions: the U.S. West Coast, U.S. East Coast, and U.S. high-wind regions, such as the tip of Florida.

Typically, crane and wharf designers work separately, often without knowledge of what the other is doing. This can lead to inconsistent designs of the components that connect the two, which may lead to component failures.

The primary connecting components are crane runways, tie-downs, stowage pins and sockets, collision end stops, and power connections.

		US West Coast (Low Wind)		US East Coast (Moderate)		US High-Wind Regions (High Wind)	
		RT	MT	RT	MT	RT	MT
Wheel Loads *(ton/wheel)*							
Operating	LS	80	85	85	90	90	95
	WS	110	125	115	130	120	135
Stowed	LS	80	80	100	100	140	140
	WS	110	90	150	140	220	200
Maximum Tie-Down Load *(ton/corner)*		N/A	N/A	300	250	800	700
Maximum Stowage Pin Load *(ton/side)*		130	100	250	200	350	300

Note:

- All loads are based on a hypothetical crane with a 60-m outreach, 15-m backreach, 30.5-m gage, 50.8-t rated load (50 LT), and 23-t and 65-t for rope-towed and machinery trolleys loads, respectively.
- See Table 4 for applicable load combinations.
- Loads are approximate and only reflect the order-of-magnitude variations between the different crane types and wind regions. Wheel loads vary considerably from crane to crane, depending on manufacturer, location of machinery house, and other miscellaneous factors.

Table 3: Typical Jumbo Crane Loads

Crane Runways

The method for calculating crane wheel loads must be consistent with the design code for the wharf. A concrete wharf should be designed to the *Building Code Requirements for Reinforced Concrete, ACI-318*. Most of the crane loads are identifiable within the ACI definitions. Factors for loads that are not defined should meet the intent of the code. Load combinations and factors are shown in Table 4. Typically, the ratio of the combined, operating, factored loads to the unfactored (or working) loads is 1.45.

	Comb	Operating	Overload	*Stowed
Load Name	Name	OP1	OL1	S1
Crane Loads:				
Dead Load	DL	1.4	1.0	1.05
Trolley Load	TL	1.4	1.0	1.05
Lifting System	LS	1.4		1.05
Lifted Load	LL	1.7		
Impact	IMP	.85		
Operating Wind	OWL	1.3	1.0	
Stall Torque	STL		1.0	
Stowed Wind	SWLU			1.3
Wharf Loads:				
Dead Load	WDL	1.4	1.0	1.05
Superimposed Live Load	WLL	1.7	1.0	1.28
Soil Load	SOIL	1.7	1.0	1.28

EXAMPLE: OP1 is 1.4 x WDL + 1.7 x WLL + 1.7 x SOIL + 1.4 x DL + 1.4 x TL + 1.4 x LS + 1.7 x LL + 0.85 x IMP + 1.3 x OWL.

*Stowed: The boom is up, the trolley and lifting system are in the stowed position and tie-downs, if any, are in place.
Wind is acting in the most adverse direction, “angled wind.”
Impact is reduced, since the value at the gantry rail is much less than the value at the trolley rail.
If tie-downs are required during stowed wind, the factored tie-down force should be calculated based on a combination of 0.9 x (DL+TL) + (1.3 x SWLU or 1.4 x stowed EQ) applied to the crane.
All loads causing and combined with overloads have a load factor of 1.0.

Table 4: Load Combinations

Other design issues the wharf designer should consider are the interaction with the soil, the effective span between piles, the spacing of the piles, and the effect of impact loads such as a ship hitting the piles. In the last case, an economic study should be made to determine the incremental cost to design the girder with one and two piles missing. Since it is not uncommon for one pile to be damaged, it is often economical to design the wharf for one missing pile.

Tie-downs

Of all the container cranes destroyed because of a failure, most have been victims of storm wind loads. In every failure due to storm wind, the failure origin has not been in the crane, but in the tie-down/stowage pin system.

Most often, there are two main design errors: the embedded hardware is not designed properly, and/or the stowage pin prying effect is not included. To correct the first error, the designer should account for all possible embedded hardware failure modes. For example, many designs fail by simply opening and releasing the pin. In this case, the plates in the wharf are too flexible, and the bending of the plates cause the two vertical plates to move farther apart, allowing a short pin to come loose. To correct the second error, the designer should be sure the tie-down force includes prying. Prying only occurs if the stowage pin is on the equalizer system.

The design load for tie-downs is often miscalculated. Very often, the crane is designed using an allowable strength approach. While this results in a practical design for the crane, it often produces unconservative loads for uplift. The loads for uplift should be calculated with a factored load approach using factors such as the ACI recommended combination of 0.9 times the dead load plus 1.3 times the storm wind load. Using these factors, the steel hardware of the tie-downs can be designed to 90% of its strength, and the turnbuckle can be designed to a factor of safety of 2.5.

Collision Loads

The purpose of the collision end stop on a wharf is to keep the crane from running off the end. Trying to keep a runaway crane on a wharf during the most adverse condition is impractical. A practical design load for the end stop is for the force required to tip the crane.

Many times a large, expensive bumper is added to the end stop. A bumper must be designed for a specific speed and force of impact for the energy dissipation system to work. As it is almost impossible to predict this, the bumpers are unlikely to be able to absorb the energy of the actual condition.

Power

Power is fed to the cranes typically by bus bars or cables, either of which are located in a trench to the waterside of the waterside crane rail. The bus bar system requires a larger trench and an arm attached to each crane to feed the power to the crane. The cable system requires a smaller trench and a cable reel on the crane. The trench for the cable system must be large enough to hold cable from all of the cranes being fed by the system.

While either power system works for jumbo cranes, it is important to identify both present and future needs, since modification of the system at a later date can be costly. The two most likely scenarios effecting the future needs are adding cranes and extending the wharf. Adding cranes in the bus bar system requires no additional work, but if more cranes are added in the cable system, the designer should plan for enough room in the cable trench. Building a larger trench at the time of the wharf construction has only a small effect on the cost of the wharf. However, modifying the trench at a later date is often not economically practical. For both systems, the main power system must be sufficient to handle the load of all the cranes without a voltage drop.

Adapting the wharf for an increased length in either system merely requires extending the trench. However, if the existing cranes are designed for a shorter wharf and are later required to travel to the extension, the crane cable reel may need modification or replacement to accommodate enough cable for the full travel distance. Replacing a cable reel and cable is costly.

Many wharves are now being built with a traffic lane waterside of the waterside rail. Embedding the bus bar system in the wharf requires a large trench. If traffic is required to cross the trench, the trench must be configured so that the covers can take the traffic weight. Trenches designed for the typical wharf, with no traffic lane to the waterside, often have covers more than 700 mm wide, as shown in Figure 3a. This allows access to the trench for maintenance at all locations. However, designing a large cover that can be lifted by the crane travel and that can accommodate a heavy traffic load is impractical. Limiting the width of the trench opening with a more traditional Panzerbelt cover will facilitate traffic. Figure 3b shows one possible arrangement. For this case, manholes must be provided at intervals to provide access to the trench for maintenance.

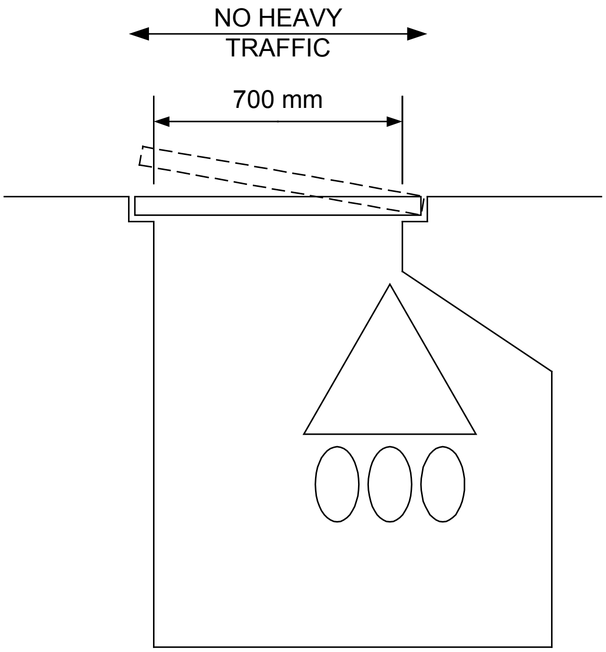

Figure 3a: Traditional Bus Bar Trench

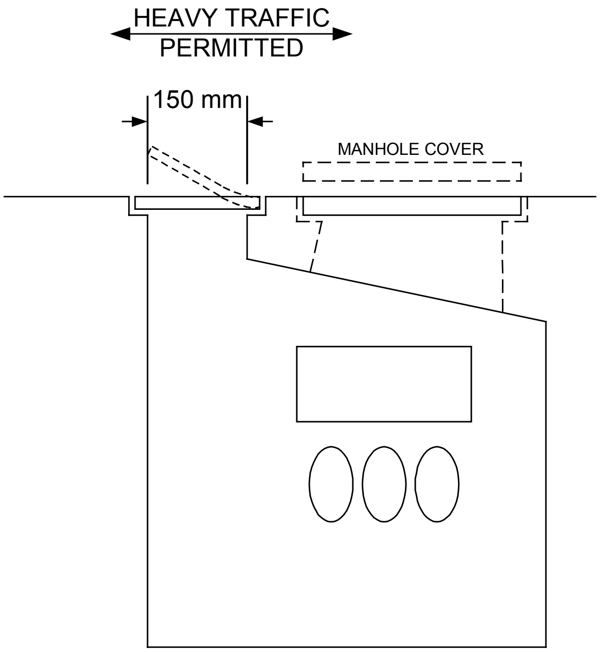

Figure 3b: Alternate Bus Bar Trench

Conclusion

To keep pace with crane size increases and associated load increases, wharves need to be designed, and/or reassessed, paying special attention to critical crane-to-wharf interface elements, namely crane runway beams, tie-down and stowage connections, collision bumpers, and power trenches.