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DOCKSIDE CONTAINER CRANES

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ABSTRACT

Technical information for the state-of-the-art container cranes is presented. Characteristic data, geometry, speeds, productivity, cost, load control, and rail reactions are included for Panamax and post-panamax shore side container cranes. Recommendations are made for the design of the wharf supporting structure for cranes. Minimum gantry rail loads are given. And the methods of wharf analysis and design considerations are discussed.

INTRODUCTION

Container traffic is expected to grow between 5 and 8 percent per year or even more. Post-panamax ships with 16 containers abeam and 4800 TEU are operating. Six thousand TEU ships with 18 containers abeam are planned. Large feeder ports will load and unload the entire ship's cargo at one berthing.

Post-panamax cranes service these large ships. They are bigger, 172 feet of outreach. They are heavier. They are more sophisticated, with powerful on board computers, fiber optics controls and communications, and electronic load control. They require more power.

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Many new concepts are being explored. New super cranes will be capable of 50 to 70 moves per hour. Yard equipment is improving, so the capability of the high productivity cranes can be used.

The new cranes require new design criteria for crane girder strength and for wharf geometry.

This paper discusses five types of containers cranes, the characteristics of the state-of-the-art post-panamax container crane, and recommends design criteria for the design of new wharf structures supporting the cranes.

CONVENTIONAL CRANES

The conventional and modified A-frame crane with a single trolley and one operator is the work horse of the industry. The Paceco cranes are the archetype. The gage is 50’ to 100’. If required for aircraft clearance, articulated boom and low profile cranes are used. Current production is 20 to 35 containers an hour depending on the yard operation work rules and the characteristics of the cranes. Containers can be handled in either a single cycle mode or a double cycle mode.

Most new cranes are conventional, with 50’ backreach, 100’ gage, and 145’ to 160’ outreach to service 16 wide post-panamax ships. Some cranes on order have 172’ outreach and can service 18 wide ships. Even if 18 wide capacity is not needed, the extended outreach improves production since the trolley does not go into the slow down zone at the end of the boom.

In the United States most trolleys are fleet through: the main hoist is on the frame and the ropes fleet through the trolley. This reduces the trolley weight but complicates the main hoist reeving. In Europe, many cranes have the main hoist on the trolley. This significantly increases the trolley weight but simplifies the reeving. For extreme outreach cranes, the hoist-on-trolley scheme is often most appropriate. Operators and manufacturers are debating which is better. It’s undecided, but expect more hoist on trolley cranes. Even though some crane components are heavier, the overall weight of the crane is not increased significantly.

The new, large post-panamax cranes are as productive as the Panamax cranes, since the new cranes are faster and have better anti-sway load control than the old small cranes. This is remarkable.

New conventional A-frame cranes cost 5 to 7 million dollars and take 14 to 24 months to deliver. Articulated boom cranes cost a little more. Low profile cranes cost a lot more, 50% more. Many cranes are shipped fully erected, tested, and nearly ready for operation. This increases cost but reduces disruption at the wharf.

DUAL HOIST SINGLE TROLLEY CRANES

Dual hoist cranes are conventional cranes with a second hoist added over the wharf. This increases productivity by about 50%, increases initial cost by 30% to 50%, adds one more operator, and increases operating costs. These costs are justified if more productivity is needed and it is impractical to add more cranes over the ship.

During unloading, the trolley picks the container from the ship and delivers it to a shuttle at the portal beam elevation. The shuttle moves landward under the second hoist. The second hoist, operated by the second operator, picks the container and sets it on a chassis. Vice versa for loading. Containers can only be handled in the single cycle mode.

The Baltimore Sumitomo cranes at Seagirt Marine Terminal and the ECT Nelcon cranes at Delta Terminal in Rotterdam are the archetypes.

DUAL HOIST ELEVATING PLATFORM CRANES

Dual hoist elevating platform cranes are dual hoist single trolley cranes except the shuttle runway elevates to the ideal elevation. The Virginia Intentional Terminals NIT Kone cranes are the only cranes of this type. They cost more than dual hoist platform cranes and produce more.

The operator's cab is not on the trolley, but on a separate runway next to trolley runway. This improves operator comfort and productivity.

DUAL HOIST ELEVATING GIRDER CRANE

The dual hoist elevating girder crane is a new idea with a patent applied for by Mr. C. Davis Rudolf III and Mr. Anthony Simkus of VIT. The crane is a conventional crane except the entire trolley runway elevates. The boom and trolley girders can be set to the ideal elevation for each vessel and load. Containers can be handled in both single cycle and dual cycle modes.

The dual hoist elevating girder crane is still being developed. Two manufacturers are investigating the feasibility of building the crane. The crane is expected to be appropriate for ports that service a wide variety of vessels ranging from post-panamax container ships to barges.

DUAL HOSTS AND DUAL TROLLEY CRANES

Paceco has conceived of a new crane that can truly be called a supercrane. It will produce twice as many moves as a conventional crane. But at what cost?

The crane is a conventional crane with one trolley runway, except that it has two trolleys and a shuttle that operate on the runway and a chassis guide system that operates at the portal tie. At least two operators will be required. The trolleys park over the container stack on the ship. The chassis guide parks under the shore trolley. For unloading, the ship trolley picks a container from the ship, lifting the container full height to get above the shuttle. The shuttle, which must be wide enough to clear the longest container, moves under the ship trolley and travels to the shore trolley. The shore trolley picks the container and when clear, lowers the container into the chassis guide and onto the chassis. For loading, the cycle is reversed. Containers can only be handled in the single cycle mode.

GEOMETRIC CRITERIA

Figure 1 shows a typical cross section of a wharf servicing C10 post-panamax ships. Notice the boom does not need to be fully raised to clear the ship. Normally the boom is stowed partially raised.

The unusually large 25’-8” set back provides for a ship service lane.

THE STATE-OF-THE-ART POST-PANAMAX CONTAINER CRANE

Typical characteristics of the state-of-the-art conventional and dual hoist single trolley post-panamax container crane are shown in Table 1.

MAIN HOIST REEVING AND LOAD CONTROL

Electronic load control, with a four-fall trolley is the state-of-the-art. Electronics system are smooth and operator friendly. They will adapt to automation. The hydraulic six-fall systems are no longer needed.

List, trim, and skew control (±3°) use hydraulic systems which also provide snag protection. Snag protection absorbs the kinetic energy of the moving machinery when the empty spreader snags.

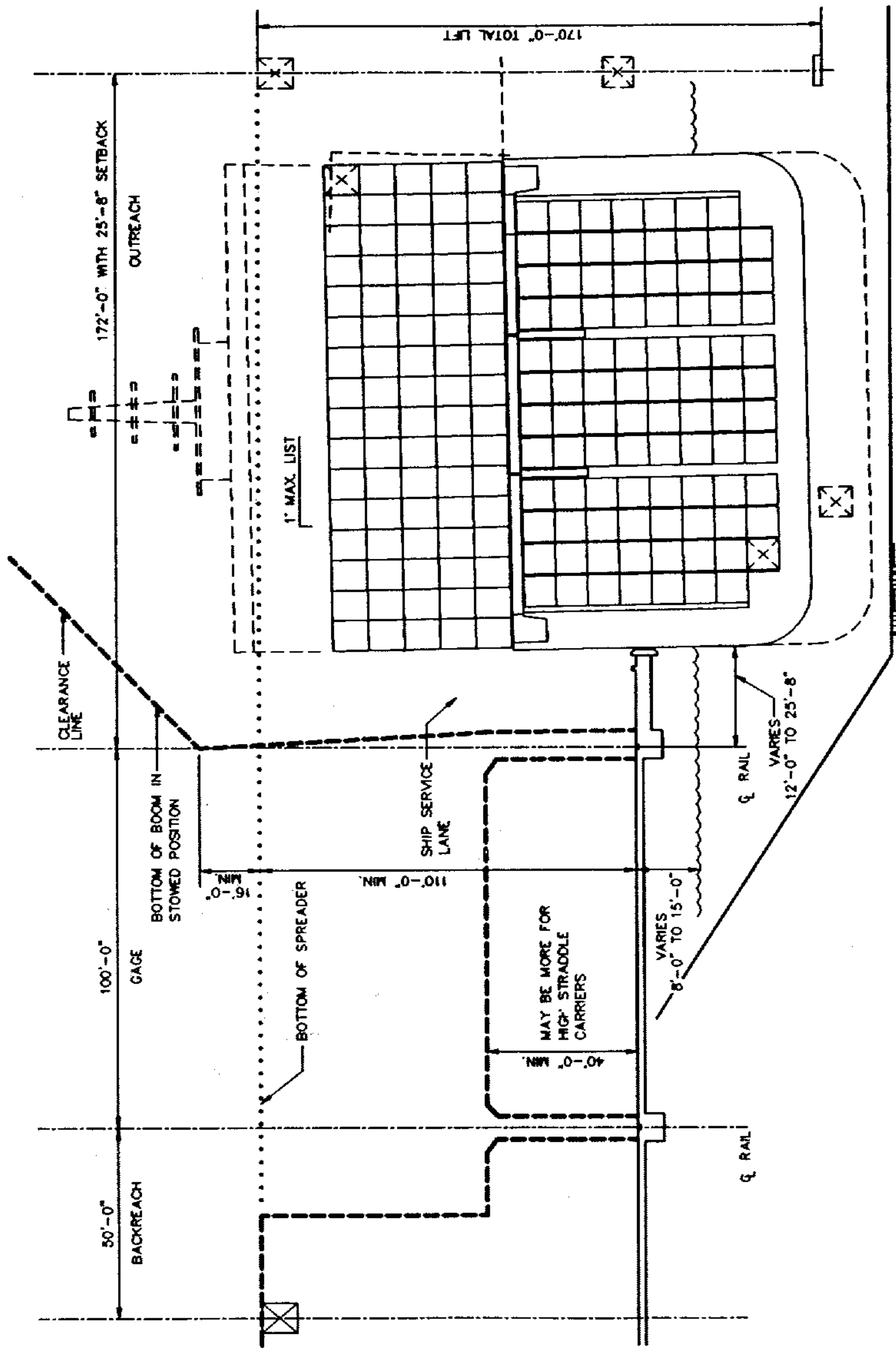

Figure 1: Geometric Criteria

SHORE POWER

Shore power is supplied either through a collector system or a cable. The cable is coiled on the crane on a cable reel and is usually fed to a Panzerbelt trench in the wharf. Which is better, a collector system or a cable?

In most cases the cable reel is better, according to Mr. Harold Scates, Electrical/Mechanical Engineering Manager, Port of Oakland. Initial cost is lower. Less space is needed in the wharf. A fiber optics cable can be included in the power cable. If a crane is relocated, the cable is easier to adapt.

Capacity:	Two 20' containers at 50 long tons or one 48' container at 40 long tons.		
Size:			
Gantry rail gage:	100'	Clear under portal:	40'
Clear between legs:	60'	Out to out bumpers:	88'-6"
Lift under the rails:	110'	Outreach from waterside rail with 13' set back:	165'
Total main hoist lift:	170'		
Speeds:	ft./min.		ft./min.
Hoisting with rated load:	200	Lowering with rated load:	230
Hoisting with empty spreader:	430	Lower with empty spreader:	430
Trolley travel:	800	Gantry travel:	150
Boom hoist time:	Min.		
Time to raise or lower.	3		

Table 1: Characteristics of the State-of-the-Art Post-panamax Container Crane

WHARF DESIGN CRITERIA

In 1994 a study was made for the Port of Oakland to determine the applied rail loads for 28 container cranes and the strength of the supporting wharves. The cranes represent a good sample of existing Panamax and post-panamax cranes. Concomitant with the study was the development of design criteria for the design of new wharves.

The study is consistent with *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 meet the intent of the code. Load combinations and factors are shown in Table 2. Typically, the ratio of the combined unfactored or working loads to the operating factored loads is 1.45.

BASIC LOADS	OPERATING CASES		STOWED CASES	
	Ship loading	Gantry travel	Wind	Earthquake
Crane loads:				
Dead load	1.40	1.40	1.05	1.05
Trolley load	1.40	1.40	1.05	1.05
Lift system	1.40	1.40	1.05	1.05
Hook load	1.70	1.70		
Impact	0.85			
Trolley lateral	1.40			
Gantry lateral		1.40		
Stowed wind			1.30	
Stowed earthquake				1.43
Wharf loads:				
Dead load	1.40	1.40	1.05	1.05
Superimposed live load	1.70	1.70	1.28	1.28
Soil load	1.70	1.70	1.28	1.28

Notes:
Wind is stowed wind acting in the most adverse direction, "angled wind."
Operating wind is not included in the ACI combinations. So it is not included here.
Impact is reduced since the value at the gantry rail is much less than the value at the trolley rail.
If tiedowns are required during stowed wind, the factored tiedown force should be 0.9 times (DL+TL) plus 1.3 times stowed wind or 1.4 times stowed EQ.
All loads causing and combined with overloads have a load factor of 1.0.

Table 2: Load Combinations and Factors

Applied factored loads for the existing cranes are tabulated in Table 3.

Manufacturer Years	Factored Rail Load kips/ft × feet spread		Crane Description
	Land side	Water side	
Paceco 1965-69	21×30	26×30	Panamax A-frame Trussed boom 50' gage 40 long ton
KSEC 1986	27×36	36×36	Post-panamax A-frame Articulated twin plate girder booms 100' gage 50 long ton
Paceco 1977 Raised 1990	24×30	30×40	Panamax 100' A-frame gage Trussed boom 40 long ton. "SL-7"
Krupp 1980	30×18	27×27	Panamax 100' A-frame Monogirder 40 long ton
Hitachi 1980 Raised 1993	31×29	33×29	Panamax 100' gage A-frame Articulated twin plate girder boom.
Paceco 1968 Raised 1993	35×30	30×40	Panamax 100' gage Low profile.
Paceco 1990	20×38	36×38	Post-panamax 100' gage A-frame Twin girder boom
Kocks 1988	30×40	47×40	Post-panamax Low Profile 96' gage 50 long ton
Kocks 1988	35×40	52×40	Post-panamax Dual hoist Low Profile 96' gage 50 long ton
Mitsubishi 1988	33×42	30×42	Post-panamax A-frame Articulated plate girder boom 100' gage 50 long ton
Mitsubishi 1988	39×42	37×42	Post-panamax Dual hoist A-frame Articulated plate girder boom 100' gage 50 long ton
Paceco 1993	31×42	36×42	Post-panamax A-frame Articulated plate girder boom 100' gage 50 long ton
Notice the increased rail load due to the dual hoist is 5 to 7 kips/ft. The increased load because of articulated booms is small. The load per foot was calculated by dividing the corner loads by the length over which the wheels spread the load.			

Table 3: Factored Loads from Existing Cranes

RECOMMENDED DESIGN CRITERIA FOR NEW CRANE RUNWAYS

The strength of the girder should be determined using ACI 318. Prestressed concrete piles should be designed using Section 4.7.6 of the *PCI Design Handbook, 4th edition,* with modifications for pile slenderness.

For girders on piles, the stiffness of the piles and soil should be included. For girders on spread footings, the beam on elastic foundation method should be used. The girders may be modeled with cracked section properties, since the girder moments will crack the section.

The effective span length is greater than the pile spacing, since the curvature does not reverse between piles. Consequently the girder need not be designed as a deep beam. See Figure 3. The applied loads should be multiplied by the load factors tabulated in Table 2. The minimum recommended factored loads on the landside and waterside rails are shown on Table 4.

Based on the wheel rail interface, the theoretical working load limit for a 175 ASCE rail is 57 kips/ft. if the gantry wheels are spaced at 1.1 times their diameter. The factored load limit is 83 kips/ft., much more than is expected.

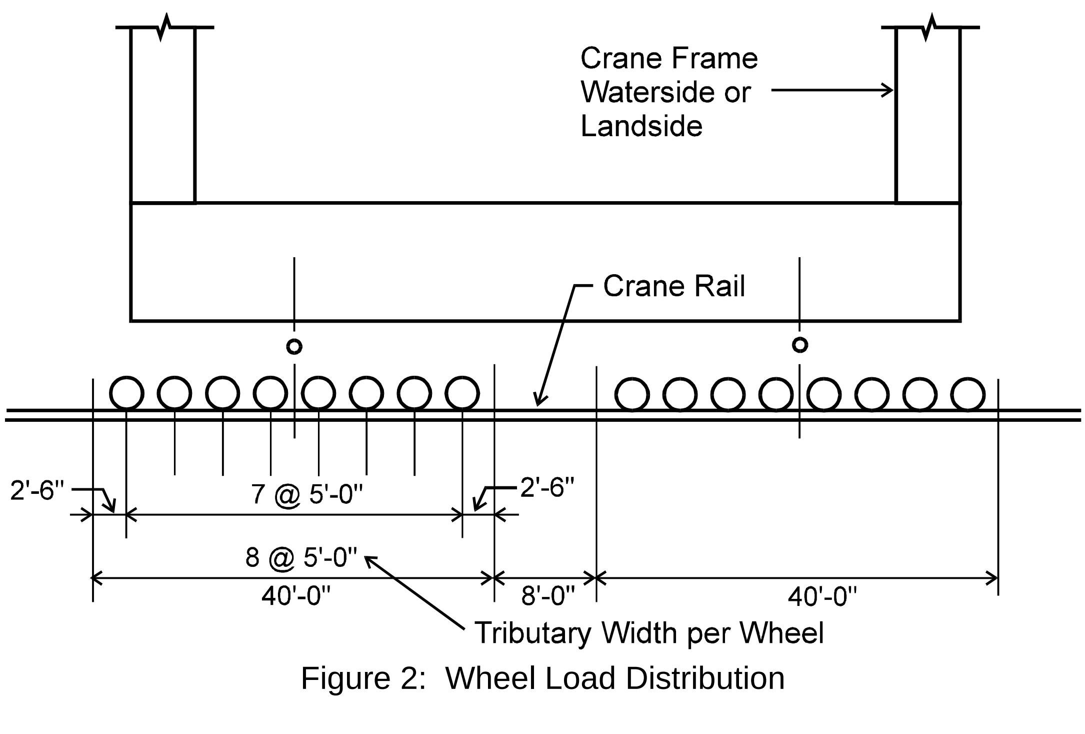

Figure 2: Wheel Load Distribution

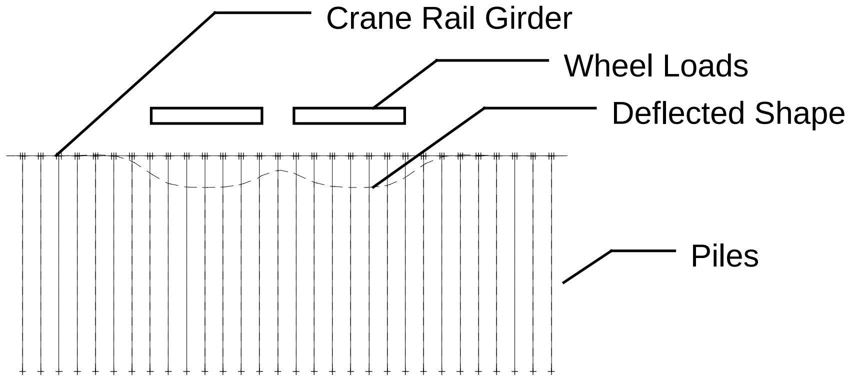

Figure 3: Girder - Deflected Shape

FACTORED LOAD	KIPS/ FT.	COMMENTS
Vertical	55.0	See Figure 2 for wheel load distribution.
Horizontal		
⊥ to Rail	2.5	The total load on a rail should be the distributed load times the effective length used for the vertical load.
‖ to Rail	3.0	

Table 4: Recommend Minimum Factored Rail Loads

The superimposed surface load should be held away from the rail 6'-0" each way.

Occasionally the ship's bulbous bow strikes the girder piles. An economic study should be made to determine the incremental cost to design the girder with one pile missing and with two piles missing. In many cases a three dimensional analysis of the girders including the adjacent wharf structure will reduce the seriousness of missing piles. The appropriate missing pile criteria should be determined after the study. If no provision is made for missing plies, an analysis should be made to determine the allowable factored load with one and two piles missing.

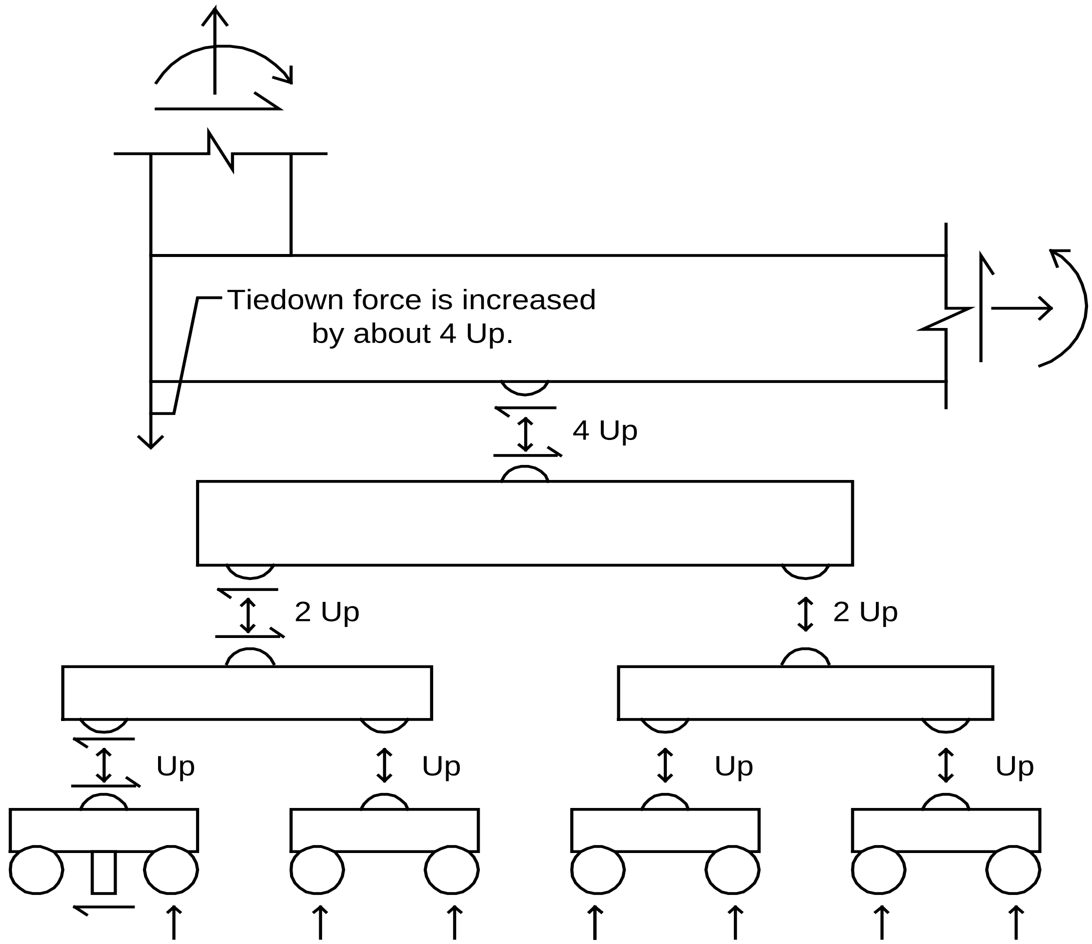

Figure 4: Prying Action for Stowage Pin on Equalizer System

WATCH OUT FOR PRYING!

Of all the container cranes that have been totally destroyed because of a failure, most, over 30, have been victims of storm wind loads. And in every case of storm wind failure, the failure has not been in the crane structure per se but in the tie down system. Why?

Typically there are two errors: The embedded hardware is not robust and the effect of prying is not included. To correct the first error, the designer should imagine the failure mode of the embedded hardware. Many designs fail by opening and releasing the pin, a very brittle failure. To correct the second error, the designer should be sure the tie down force includes prying.

Prying occurs when the stowage shear pin that transfers the horizontal wind load to the wharf is on the equalizer system. The crane manufacturer usually neglects this.

Even if the manufacturer reports that no tie downs are needed there still may be a problem. Figure 4 shows the loads and load path for the effects of the horizontal force tending to rotate the equalizer system. If the shear pin is on the main equalizer beam the problem is still there. If the shear pin is on the sill beam, there is no prying.

CONCLUSIONS

The marine container industry continues to expand. New, more productive cranes are needed. Some super cranes will double productivity.

Data for extant and near future container cranes is given.

New wharves must be designed to carry the new cranes and allow for uninterrupted use of the quay. One approach is to provide a ship's service lane.

Shore power will be by cable reel to save space, allow for relocation, and provide fiber optics communication.

The recommended design of new wharves uses load factor methods. Load factors are given for the crane and wharf loads. The effect of damage from a ship should be considered