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A FEW FACTS ABOUT JUMBO CRANES

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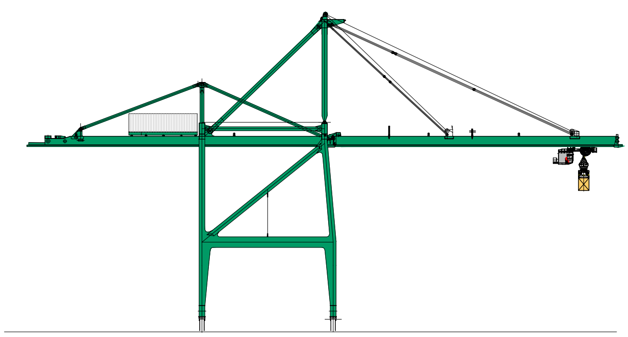
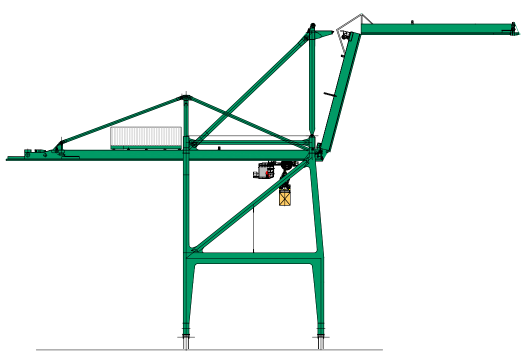
INTRODUCTION

Jumbo Cranes—cranes with outreaches of 60 meters or more, lifts above the crane rail of 46 meters, and capacities of 60, 80, 100, and 120 tons—are already built or being built. Why? Increased traffic and the economy of size. Larger vessels can deliver more for less, so terminals must deliver more.

Of the many issues created by these cranes, five are discussed in this paper: configuration, size and weight, stability, operator comfort, and a recent concern, visual impact.

CONFIGURATIONS

Table 1: Typical Container Crane Arrangements and Components

Configuration		*Comments*
Conventional A-frame		Simple with a proven track record. Lowest cost. Lowest wheel loads.
Articulated		Applicable when there is a height limit. A slight cost increase.

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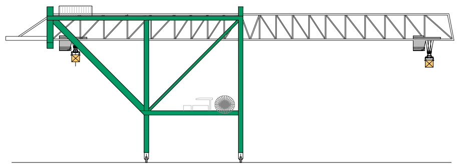
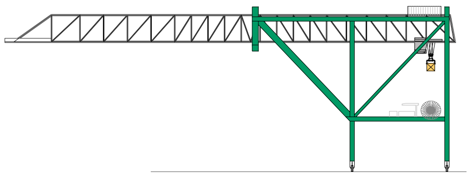
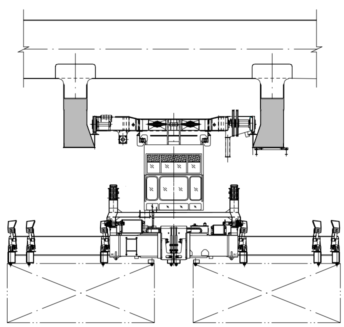
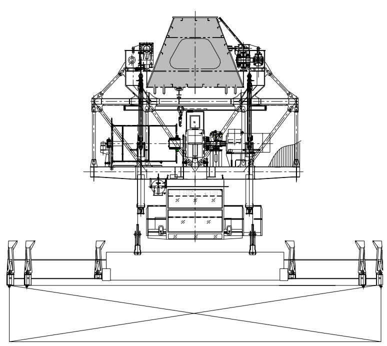
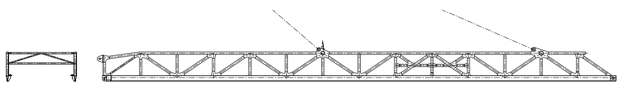
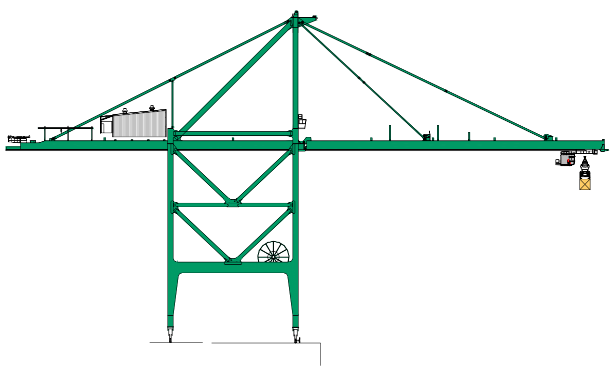
Configuration		Comments
Low Profile	 	Minimum height used near airports and possibly for reduced visual impact. Higher costs and wheel loads.
Twin Girder / Rope Trolley		Used for both rope and machinery trolleys, usually rope trolleys. Rope driven is lightest. If self driven, it is a little heavier. Requires long ropes, catenary trolleys or continuous rope supports. Please refer to our website for detailed comparisons of machinery and rope trolleys[1].
Monogirder / Machinery Trolley		Like twin booms, used for both styles of trolley. This boom is lighter than the twin boom.

[1] http://www.liftech.net/LiftechPublications/machtrly.pdf
http://www.liftech.net/LiftechPublications/mot.pdf

Configuration		*Comments*
Box Beams	 Liftech Standard for many years.  Liftech Design Noell Design	Simple with only a few details controlled by structural fatigue. The twin box sections were invented by Liftech for Paceco in the 1960's. The trapezoidal section was developed by Liftech for Paceco, MHI, and ZPMC. The rectangular section is Noell's standard.
Trusses	ZPMC-VPA-Liftech 	Lighter than box beams but with many details controlled by fatigue. The latest design allows access to all the details that may develop cracks.
Single Hoist		Simple and most common. Only one operator is needed. The single hoist crane production, i.e. moves/hour is usually limited by the production on the wharf.
Dual Hoist		Requires two independent hoist system and usually two operators. Used in the USA in Norfolk and Baltimore. The results were disappointing because the yard limited production and two operators increased costs. The pictured cranes in Hamburg, Germany are new and take advantage of the latest controls and automation. Only one operator.

Configuration		*Comments*
Twin Twenties		Twin twenties handled by the spreader. The only significant design change is to the spreader.
Tandem Forties Tandem Twin Twenties		Tandem containers are handled by one head block and two spreader. The spreaders can handle 40's or twin 20's. Jumbo cranes with tandem spreaders are currently being designed. ZPMC will supply a tandem 40's crane with two independent head blocks and spreaders to the Port of Dubai. See Figure 2.

The rope trolley is common. The machinery trolley is less common. The following sketch shows a typical machinery trolley.

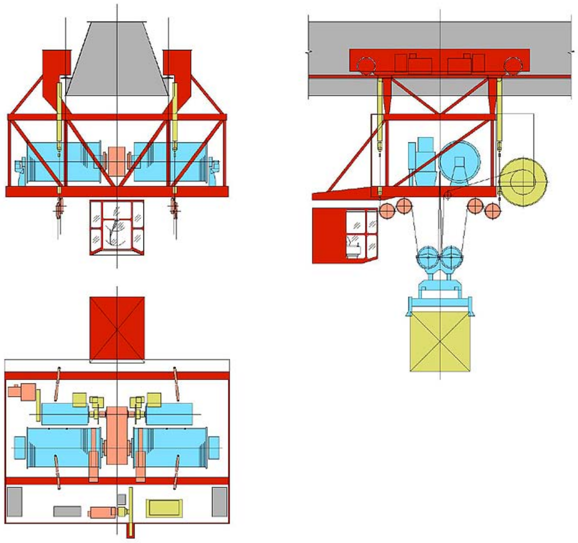


Figure 1: Typical Machinery Trolley

ZPMC Dubai Tandem 40 Crane

The dimensions of the Dubai crane are typical for the current issue of jumbo cranes.

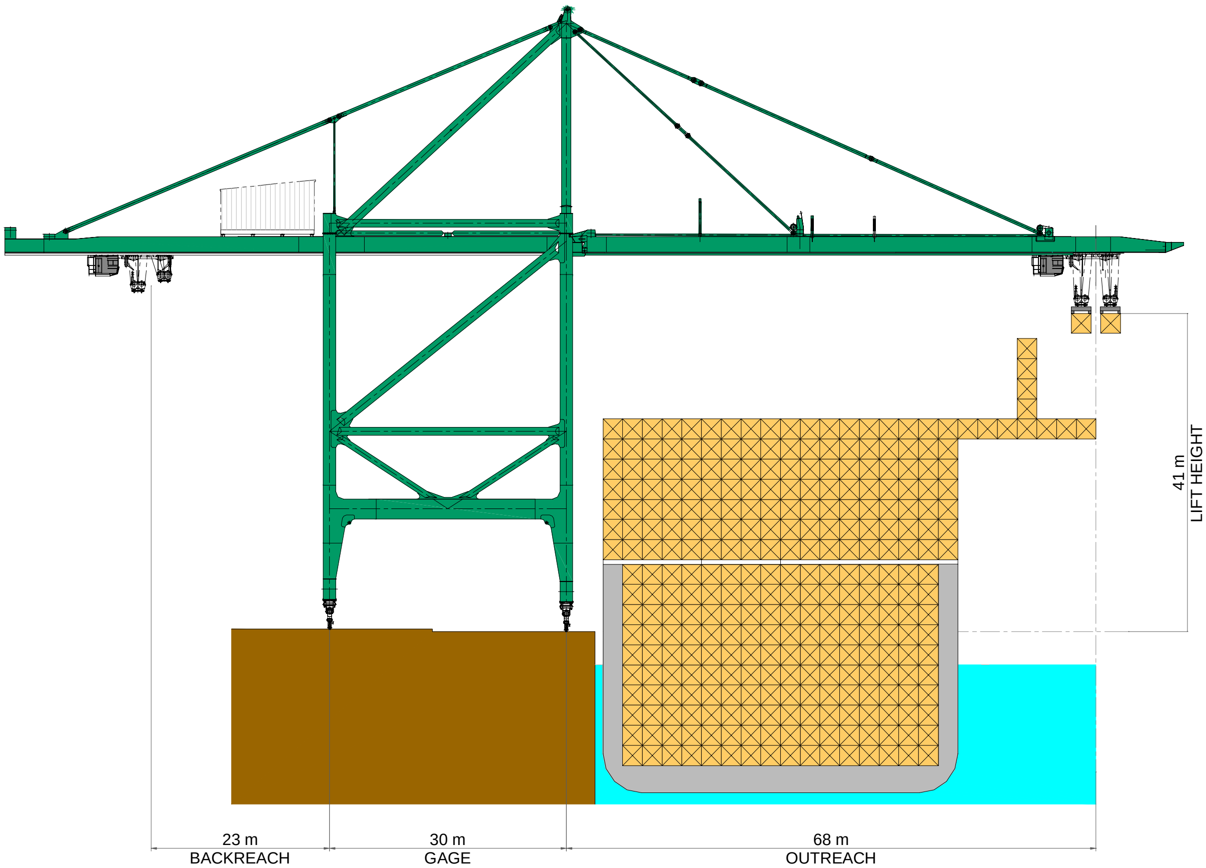


Figure 2: ZPMC Dubai Tandem 40 Crane

Typical Jumbo Crane Particulars

Some recent large crane data is shown in Table 2.

Table 2: Recent Jumbo Cranes

Manufacturer	Delivered Date	Location	Description	Girder Type	Machinery or Rope Trolley	Rated Load Under Spreader (t)	Lifted Load Under Cargo Beam (t)	Main Hoist w/ Load (mpm)	Trolley Speed (mpm)	Waterside Outreach (m)	Gage (m)	Backreach (m)	Lift Height Above Rail (m)	Crane Weight (t)	Trolley Weight (t)	Lift System Weight (t)	Design Duty Cycles (millions)
ZPMC	2004	Dubai	A-frame	Twin box	RT	80.0	100.0	90	250	68	30.48	23	41.0	1440	46.0	35	3.0
IMPSA	Design		A-frame	Twin box	RT	81.5	89.6	90	240	63	30.48	24	41.0	1165	40.0	30	4.0
ZPMC	2004	VPA	A-frame	Twin box	RT	66.2	80.0	90	244	71	30.48	23	40.0	1590	35.0	21	2.0
ZPMC	2003	YICT	A-frame	Twin box	RT	61.1	70.0	70	240	65	30.00	22	42.2	1440	26.8	18	4.0
Liftech Concept	Design	POLA	Low Profile	Twin box	RT	61.1	100.0	75	244	62	30.48	23	36.6/ 42.8	1850	37.0	18	4.0
Noell	2001	POLA-Pier 400	A-frame	Single box	MT	61.1	84.0	90	240	64	30.48	23	40/ 47.5	1280	74.4	17	2.0

STABILITY

Historically dockside container cranes have not had stability problems except during hurricane winds or collisions. Hurricane winds have caused dramatic catastrophes. For example, the recent Pusan cranes collapsed due to failure of the tie-down systems during Typhoon Maemi.

Figure 3: Collapsed Pusan Cranes

Establishing appropriate stability criteria for operating conditions is problematic. Outreach-to-gage ratios are typically 2 to 1 and in a few cases nearly 3 to 1, so unexpected loads at the maximum outreach position must be considered.

One approach is to use the same load factors that are used for buildings; e.g. 1.4 times all the tipping moments and 0.9 for all the righting moments. These factors are suitable for buildings that may be overloaded due to excessive dead loads or variable loads. These factors require excessive ballast and are, therefore, unworkable for jumbo cranes.

We are unaware of a container crane tipping during operations or testing. A ship unloader in Louisiana did tip during testing. The cause to this accident was gross underestimation of both the boom weight and the trolley weight. Although the unloader errors were extreme, we found that the measured weights of container cranes and trolleys are often an estimation error of as much as 20%. Usually, if the weight is underestimated, the entire crane is heavy—both the righting moments and tipping moments are heavy. So only the rail reactions are increased and stability is not a problem, although the potential problem is there.

Typical operating stability combinations are shown in Table 3.

Table 3: Operating Stability Combinations

Loads Case	*1*	*2*	*3*	*4*	*5*	*6*
Dead Load[1]	1.00	1.00	1.00	1.00	1.00	1.00
Trolley Load[1]	1.00	1.00	1.00	1.00	1.00	1.00
Lifting System[1]	1.00	1.00		1.00	1.00	1.00
Lifted Load	1.50	1.00		1.00		1.00
Trolley Load Lateral	1.00	1.00				
Gantry Load Lateral[2]		1.50			1.50	
Operating Wind Load	1.00		1.0	1.0		1.50
Stall Torque Load			1.15			
Collision Load				1.15		
Number of Legs Allowed to Lift Off[3]	1	1	1	1	0	0

1. These loads must be verified by measurements with an error of less than 3%.

2. The minimum lateral acceleration for this calculation must be at least 5% g, providing 7.5% factored g.

3. One leg allowed to lift off means one leg may lift off while the other three legs remain in contact with the gantry rail. Zero legs allowed to lift off means no legs may lift. All wheels shall remain in contact with the gantry rail.

Stability blocks

For Jumbo Cranes, the distance between the main equalizer pins is reduced so nearly the entire distance from bumper to bumper is filled with wheels. This not only reduces the wheel loads but also reduces the stability. Liftech developed the concept of stability blocks.

Stability blocks are supports, in effect outriggers, between the sill beam and the sub-equalizer that increase the stability arm and increase the righting moment. Under normal conditions there is a 10 mm gap between the support on the sill and the block on the sub-equalizer. If the crane tends to tip in the gantry travel direction, the gap is closed and the stability base is increased. The vertical reaction is moved from the equalizer pin to the outermost sub-equalizer. The result is significantly more stability and significantly less ballast.

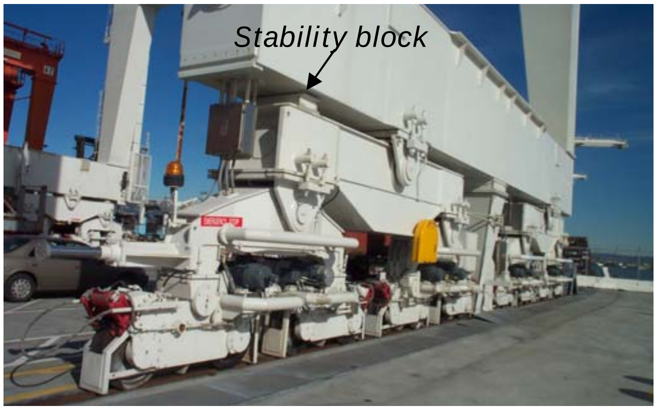


Figure 4: Stability Block

OPERATOR COMFORT

Big Is Slower

Just as an elephant moves slowly compared to a mouse, large structures vibrate more slowly than small structures. The increased motions of jumbo cranes affect operator comfort.

The Latest Problem: Sway in the Gantry Travel Direction

The latest motion problem is sway in the gantry travel direction. The earlier problem of sway in the trolley travel direction has been controlled by limiting the modal period in the trolley travel direction to 1.5 seconds.

Sway in the gantry travel direction has been a problem for some large cranes. It is impractical to limit the period to a low enough value to control gantry sway. A more sophisticated solution is needed. Liftech developed a solution and verified the solution during field tests on an operating jumbo crane.

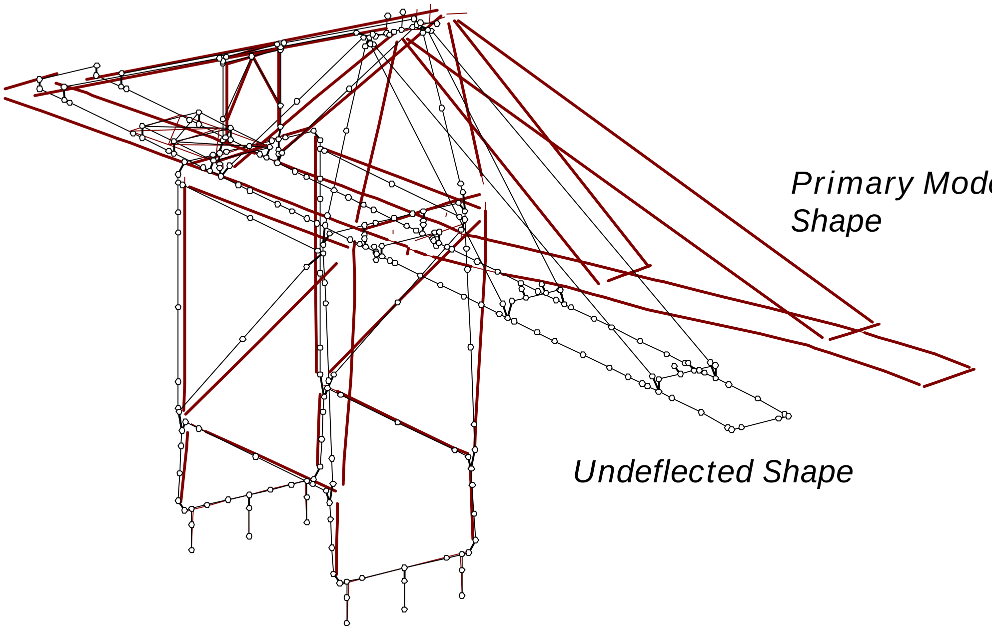


Figure 5: Response to Gantry Acceleration

The Liftech Study

Two motions are important: motions in the trolley travel direction and motions in the gantry travel direction. The motions in the trolley travel direction usually affect production but not comfort. Those in the gantry direction affect both. Motions in the trolley travel direction can be controlled by limiting the maximum natural period of the crane in this direction to 1.5 seconds. This is practical and achieved on most cranes being built now. The motions in the gantry travel direction are more difficult to evaluate and to control.

To further complicate matters, operator comfort depends on the operator's opinion. For identical cranes, some operators are comfortable and some are not. If the operator thinks he is uncomfortable, he is, and his concerns must be addressed.

Liftech studied the problem both analytically and experimentally. Our findings verify the comfort levels conform to the acceptance criteria in ISO 2631/1 and generally accepted human threshold perceptibility standard. These criteria are shown in Table 4. Data from the properly tuned Oakland cranes is shown in Figure 6.

Table 4: Human Perceptibility Threshold, Table I.1 Vibration Problems in Structures: Practical Guidelines, by Hugo Backman et al, Birkhauser, 1995

Description	*Frequency Range 1 to 10 Hz Peak Acceleration (g)*
Just Perceptible	0.004
Clearly Perceptible	0.010
Disturbing / Unpleasant	0.056
Intolerable	0.18
Data combined from various sources. There is scatter by a factor of up to two on the values given.	

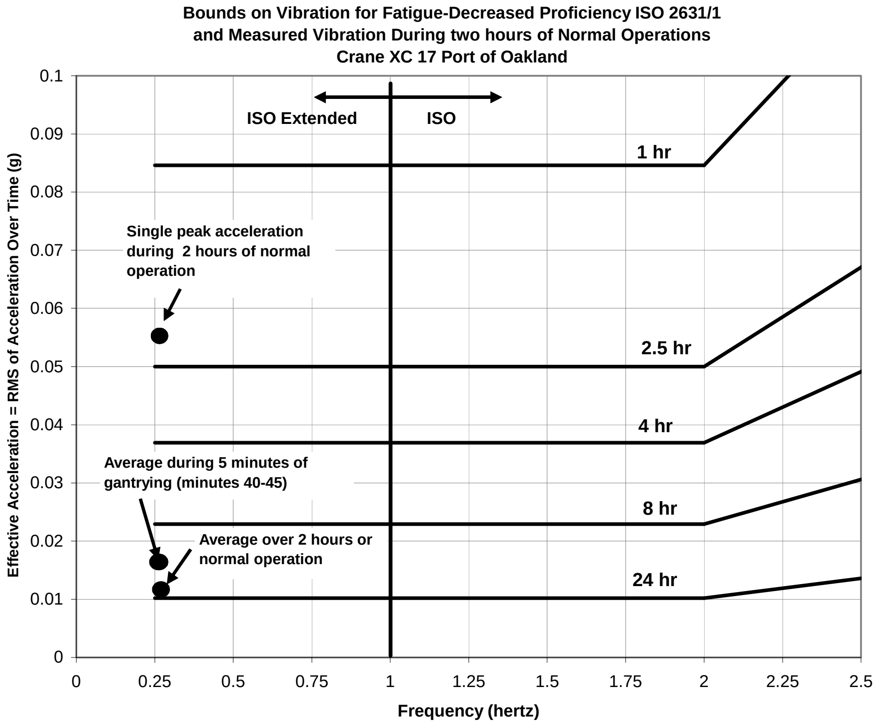


Figure 6: Measured Boom Tip Vibration at Port of Oakland versus Bounds on Vibration for Fatigue Decreased Proficiency—ISO 2631/1

The primary exciters of motion in the gantry travel direction are both the magnitude of the acceleration at the rails and the duration of the acceleration. The response depends on the structural stiffness and the structural modes and periods of vibration.

The structural stiffness may be increased by increasing member sizes and, in twin girder booms, using horizontal bracing. But structural changes, within practical limits, are not enough. A much more effective way to control motions is to control the duration of gantry acceleration. The duration of gantry acceleration should be a multiple of the structural period. The worst case occurs when the acceleration duration is a multiple of one and one half times the structural period. This explains why the problem is more noticeable on jumbo cranes. For years the specified acceleration duration was 6 seconds and the period to the crane was about 3 seconds, a favorable relationship. Now jumbo cranes have periods of about 4 seconds and the acceleration duration is still specified at 6 seconds, the most unfavorable relationship. An eight second duration is much more desirable.

Figure 7 shows the response of a well-tuned gantry drive, and Figure 8 shows the response of a poorly-tuned drive. Figure 9 shows the field measurement of one crane for both a well-tuned drive and a poorly-tuned drive.

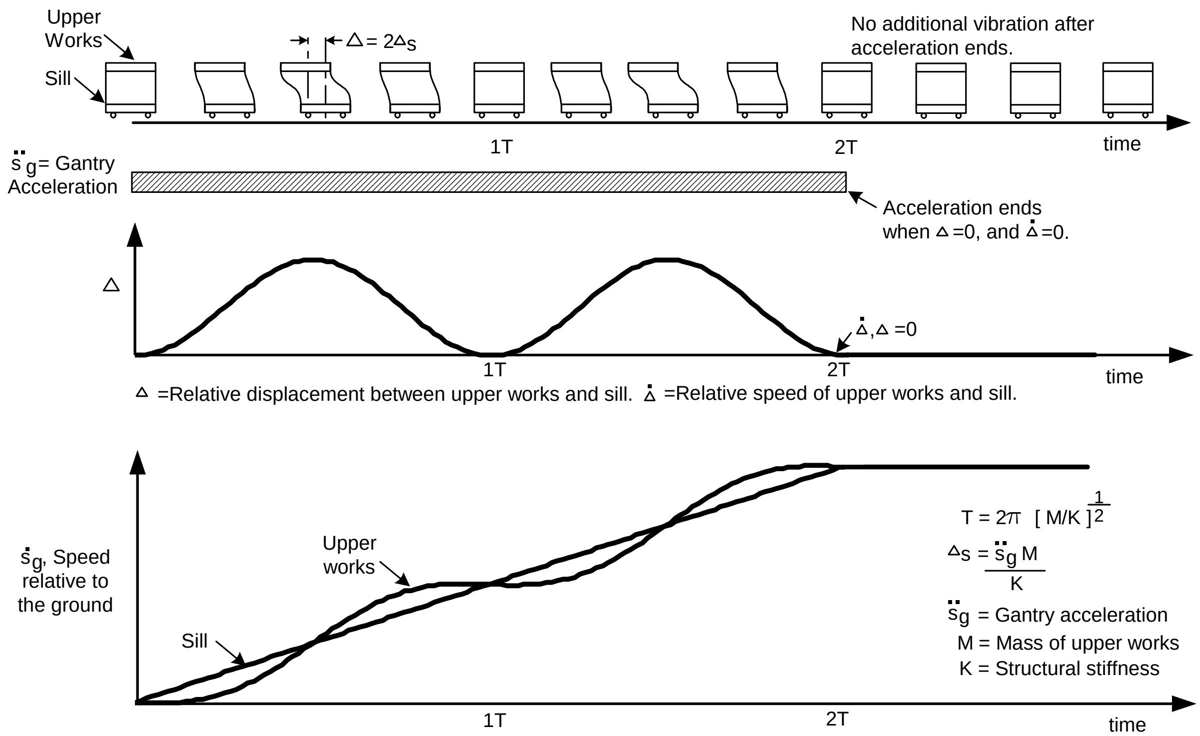


Figure 7: Smallest Response—Acceleration Time is a Multiple of Crane Period, nT

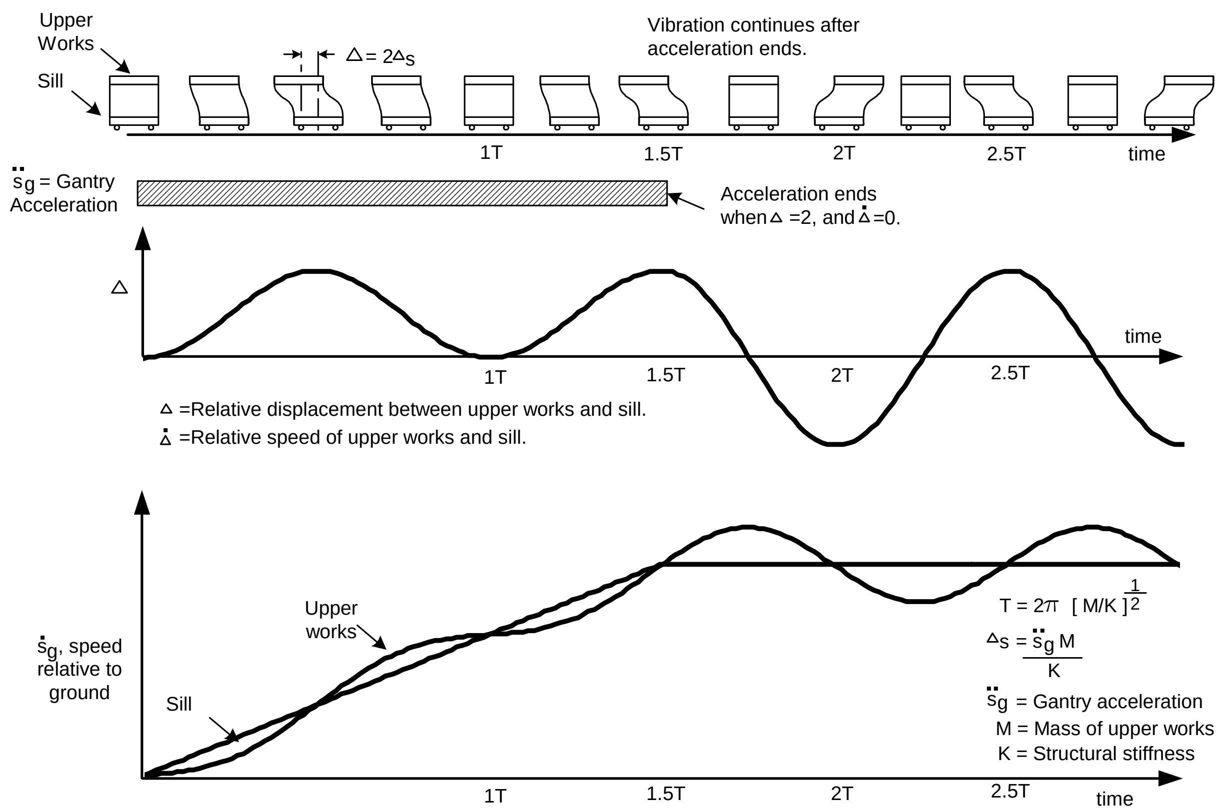


Figure 8: Greatest Response—Acceleration Ends at a Half Period, (n +0.5)T

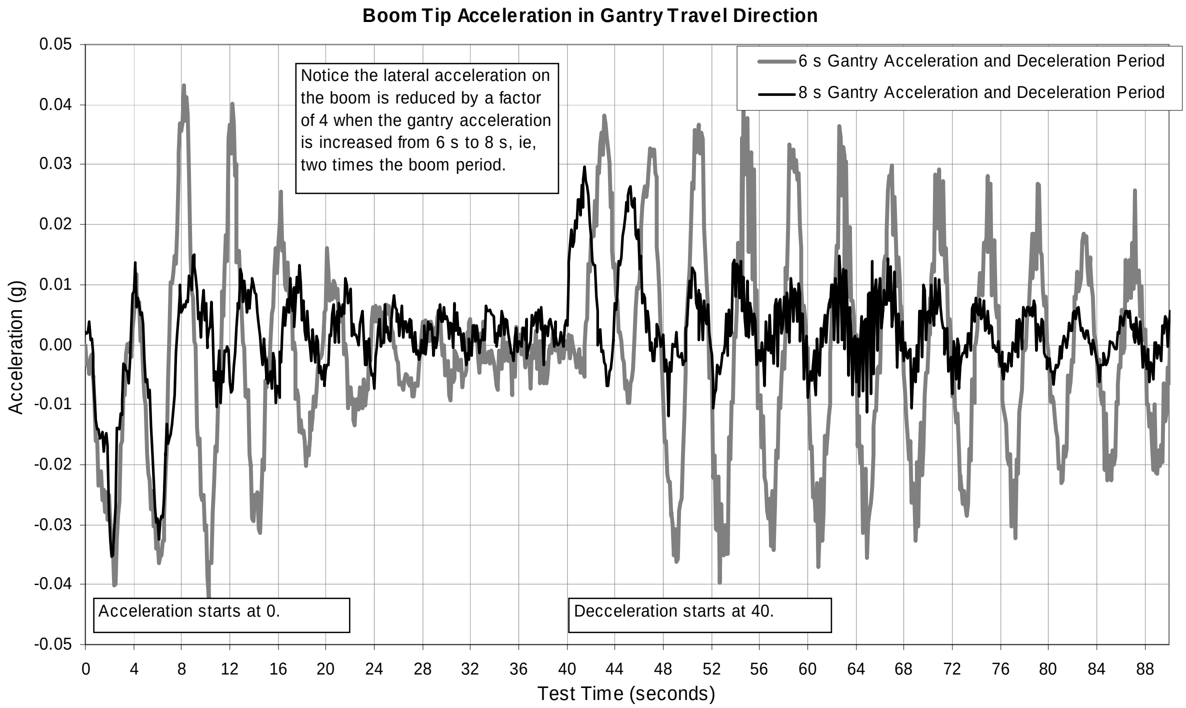


Figure 9 : Measured Crane Response for Acceleration Times of 1.5 and 2 Times the Boom Period

Notice that the appropriate tuning for gantry acceleration is out of phase for the appropriate tuning to trolley acceleration. Both issues are discussed in detail on our website[2].

Recommendations

The gantry acceleration duration should be a multiple of the structural period. Fine acceleration control, "inching motion," should be available to the operator for fine positioning to avoid delays while servicing the vessel.

VISUAL IMPACT

Jumbo cranes tower above the wharves and may dominate the skyline at the waterfront. In Los Angeles, the new China Shipping Terminal cranes block the local residents' view of the Vincent Thomas Bridge. The Port is addressing people's concerns, in hopes of improving the residents' view. Meanwhile, the China Shipping cranes are ready to operate but cannot operate until the concerns of the people are satisfied.

One alternative to the A-frame cranes is the low profile cranes. Another alternative is the use of more subtle colors. Generally, lighter colors reduce the visual impact.

Studies are underway to determine what can be done to reduce the visual impact of the new jumbo cranes in the Port of Los Angeles. The following figures, taken from these studies, show the rendered images of the China Shipping Terminal and the nearby Evergreen Terminal[3].

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[2] http://www.liftech.net/LiftechPublications/holdingsway.pdf

Figure 10: Existing Cranes at the China Shipping Terminal, POLA

Figure 11: Rendered Low Profile Cranes at the China Shipping Terminal, POLA

Figure 12: Existing Cranes at the Evergreen Terminal, POLA

Figure 13: Rendered Low Profile Cranes at the Evergreen Terminal, POLA

Figure 14: 16-Wide Low Profile Crane at Port Everglades

Visual impact is a serious concern and may need to be addressed at other ports. Current technology allows the planners to create realistic images that help the community understand the visual impact of the cranes. Many find low profile cranes less obtrusive than A-frame cranes.

Low profile cranes cost more than A-frame cranes and create higher wheel loads. Moves per hour are not affected by the configuration.

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[3] Courtesy of JWD Group, and Jones and Stokes.

The Future

Whether you are buying a Panamax or jumbo crane, you should consider future. A critical component of the crane system is the wharf. Wharves should have viable lives of at least 50 years. In ports where jumbo vessels may have access someday, the wharves should be designed to support the largest crane needed to service those vessels.

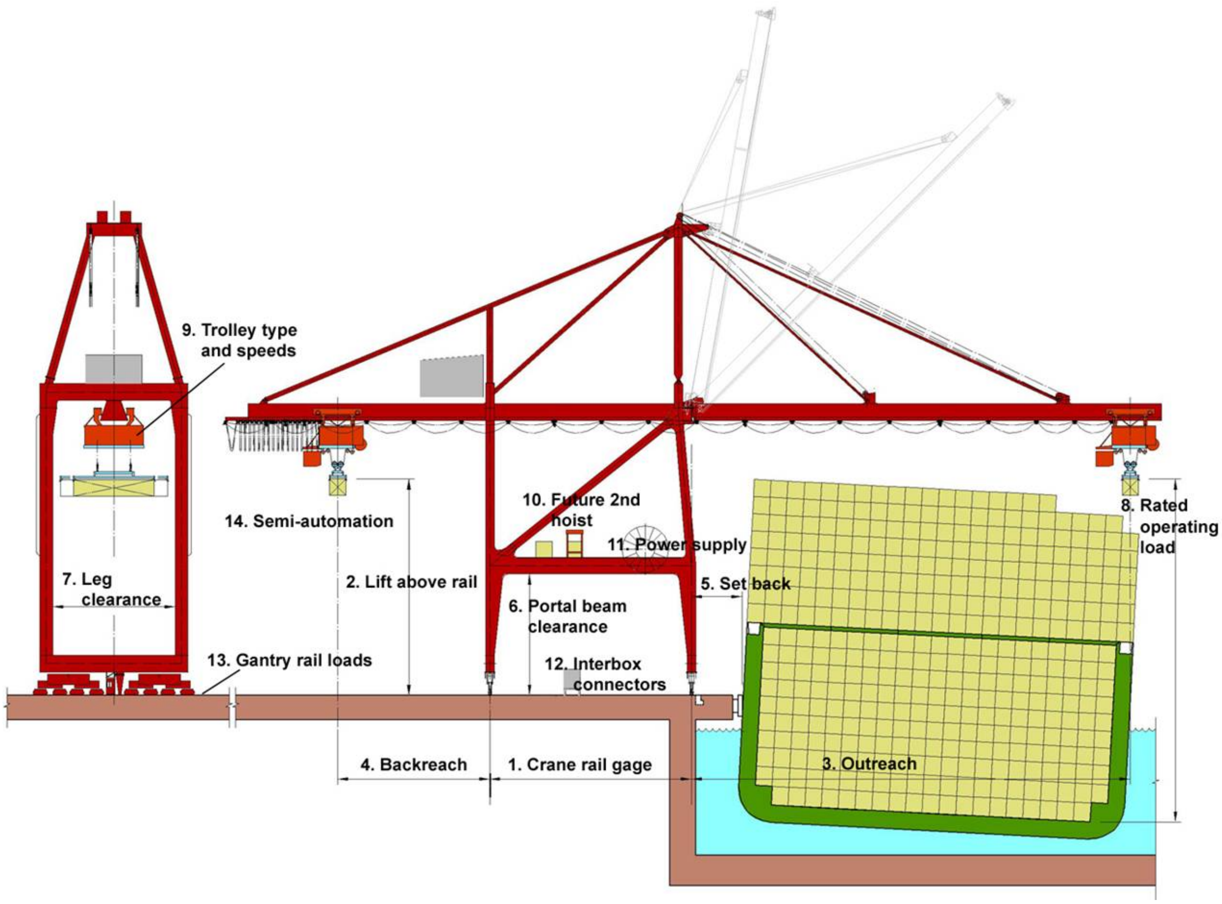

Figure 15: Design the Wharf for the Future Crane[4]

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[4] http://www.liftech.net/LiftechPublications/mj_futureproofcrane.pdf