Megacranes: holding sway – boom motions

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ABSTRACT

Over time, vessel size and container weights have increased. While the size, mass, and strength of the crane structure have also increased, the stiffness of the crane structure has not increased proportionally. The crane response to trolley and gantry accelerations has changed.

Several years ago, operators reported undesirable crane deflections in the trolley travel direction during operation. Liftech responded by developing crane stiffness requirements in the trolley travel direction to limit the crane deflection, and the problem was solved [1].

Within the last year, a similar problem has emerged. Some operators reported unacceptable boom vibration in the gantry travel direction.

This paper discusses the factors affecting lateral boom vibration, what vibrations are acceptable, and provides recommendations to reduce lateral boom vibrations.

Factors affecting boom vibration

The primary factors affecting boom vibration are the magnitude of gantry acceleration, the duration of gantry acceleration, low structural damping, and the stiffness of the crane structure. Other factors, such as the mass and the geometry of the crane structure, are difficult to change and will not be discussed.

Gantry acceleration magnitude

Different gantry accelerations are used during operations. The gantry motors normally accelerate the wheels a maximum of 0.010 to 0.014g as the operator requires. During an emergency stop, the wheel motors and wheel brakes are used to decelerate the crane approximately 0.10g in less than a second. Some cranes also have an inching control originally intended to facilitate stowage pin engagement. This control provides 5% of the rated power to the gantry motors, resulting in very small gantry accelerations.

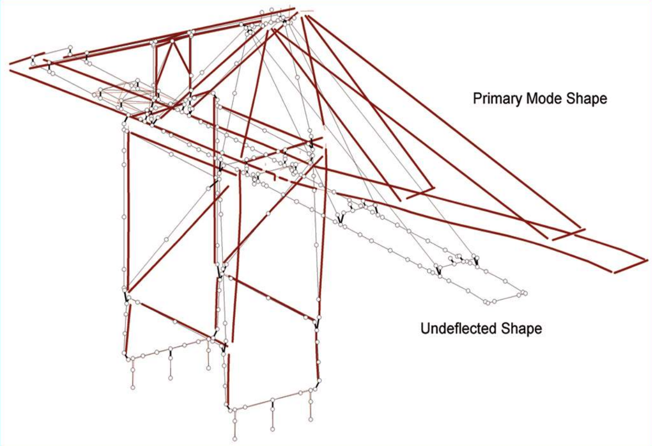


Figure 1. Primary Container Crane Mode Shape.

For a given acceleration duration, the resulting deflection magnitude is proportional to the gantry acceleration. Therefore, the easiest way to reduce the magnitude of the deflections in the crane caused by gantry accelerations is to reduce the gantry acceleration. Reducing the magnitude of the acceleration is practical for both normal accelerations and emergency stop accelerations. Changing the normal acceleration does not significantly affect the time to move the crane. Significant changes to the emergency stop acceleration will not significantly affect the crane's stopping distance. The crane may stop in 2' instead of 1'.

Gantry acceleration duration

When gantrying long distances, a crane is accelerated to full speed. Based on calculations and measurements, if the acceleration duration is a multiple of the primary crane period, the boom response will be greatly reduced because when the acceleration ends there is no relative deflection between the upper works of the crane and the sill, resulting in no vibration of the upper works. This is the best case. (See Figure 2).

In contrast, the largest response occurs when the crane gantry acceleration ends halfway through a cycle of vibration, i.e. at a half period. When this occurs, the relative deflection between the

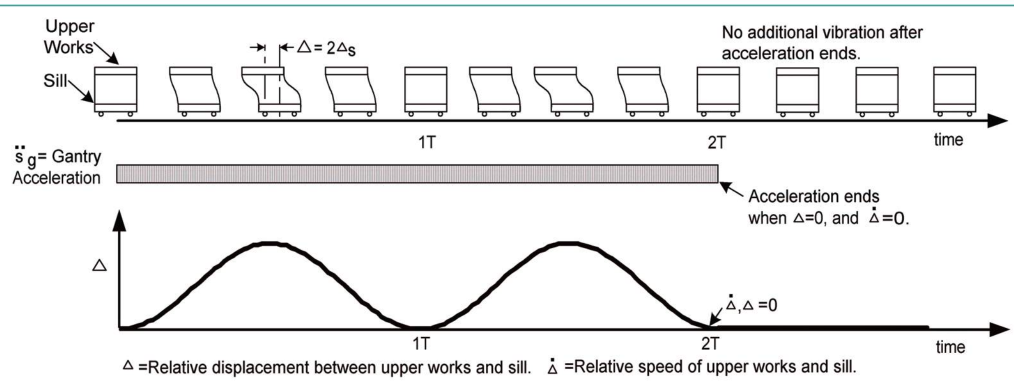


Figure 2. Smallest response – acceleration time is a multiple of crane period, nT.

upper works and the sill beam is maximum and the vibration continues. (See Figure 3).

The effect of the acceleration duration was measured during recent testing on the Port of Oakland Berths 55-59 cranes. (See Figure 4).

The effect of acceleration duration on travel time is small. If the gantry acceleration is changed from four to eight seconds and the maximum gantry speed is 46 meters per minute, it takes at most an additional two seconds to gantry any distance.

Damping and compounding effects

The damping in a structure affects how quickly vibrations attenuate. Without significant damping, the vibration caused by a loading will continue for many cycles of vibration. If the time between loadings or excitations is short relative to the attenuation rate, the deflection from consecutive loadings can compound, resulting in deflections much larger than those caused by a single acceleration.

When gantrying short distances such as between container rows or when aligning a particular row, the operator may gantry the crane multiple times relatively quickly. This could result in the compounding of vibrations.

To understand what attenuation typically occurs, the measured damping in the Oakland cranes is approximately 1% of the critical damping. At 1% damping, the vibration half-life is 11 cycles. With a period of four seconds, it takes 44 seconds for the initial deflection to decrease 50%, and 88 seconds to decrease 75%. During operations, it is impractical for an operator to wait for the vibration to attenuate.

Although possible, it is impractical to add dampers to the crane. A mass damper requires the addition of significant weight either at the end of the boom or at the landside end of the trolley girder. Active dampers require significant energy and costs. All damping systems require significant maintenance.

Since compounding is most probable during alignment, and because alignment requires gantrying short distances, it is practical to gantry at a reduced acceleration. Compounding will still occur, but because the acceleration magnitude is greatly reduced, the combined vibration does not result in significant deflections.

On the Port of Oakland Berths 55-59 cranes, where a reduced power inching control is commonly used by the operators, the maximum root mean squared boom tip acceleration measured during 2 hours of operations was 0.055g and the average 0.011g. See Figure 5.

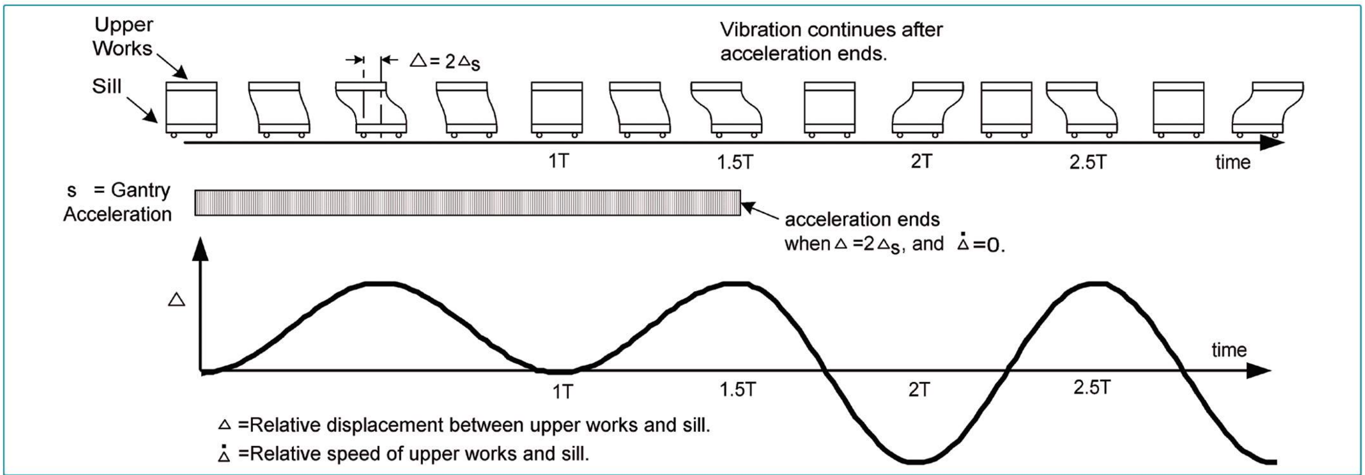


Figure 3. Greatest response – acceleration ends at a half period, (n +0.5)T.

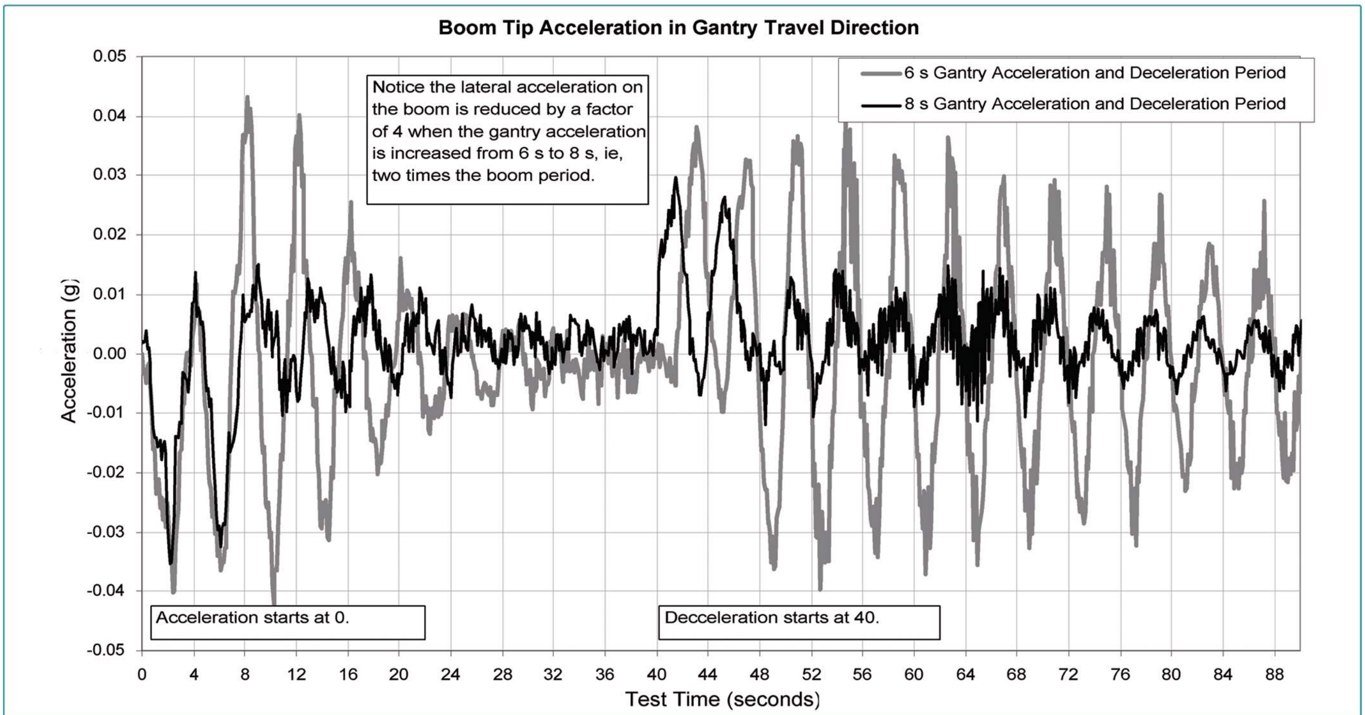
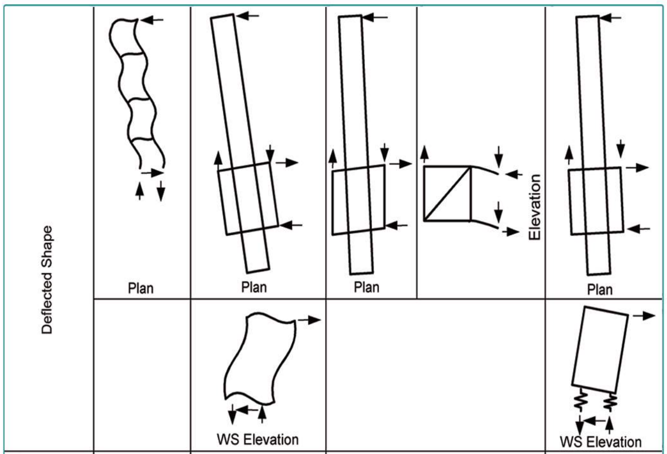


Figure 4. Measured crane response for acceleration times of 1.5 and 2 times the boom period.



Component	Boom Frame	O-Frame	Portal Frame	Gantry System
Stiffness / Boom Frame Stiffness	1.0	3.2	9.6	20
Portion of 100 cm Tip Deflection	68 cm	22 cm	7 cm	3 cm

Table 1. Approximate relative stiffnesses affecting boom tip deflection.

Structural stiffness

The stiffness of the structure affects the deflection magnitude and the vibration frequency. By increasing the stiffness of the crane structure, the deflection will decrease and the vibration frequency will increase. Increasing the frequency increases the attenuation rate and further reduces the affects of compounding.

The stiffnesses of the boom frame, the O-frame, the portal frame, and the gantry system contribute to the lateral deflection of the boom. The relative stiffnesses and the proportion of the boom tip deflection due each component are shown in Table 1.

As shown in Table 1, additional portal frame and gantry system stiffening will not significantly reduce the boom deflection. It is more effective to stiffen the boom frame and O-frame.

Several stiffening options were recently investigated for existing Port of Felixstowe cranes. Three of these options and their affect on the boom tip deflection and period are shown in Table 2.

It is impractical to significantly stiffen the O-frame because of clearance envelopes. Since boom flexing is the greatest contributor to boom tip deflection, adding braces to the boom frame provides a high reduction in this deflection.

TABLE 3. HUMAN PERCEPTIBILITY THRESHOLD

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

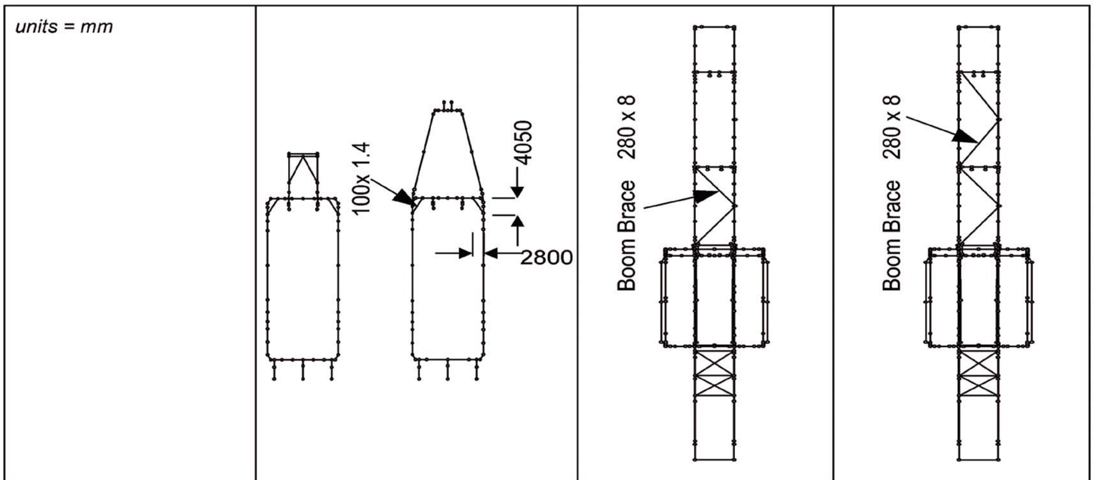
Data combined from various sources. There is scatter by a factor of up to two on the values given.

Vibration acceptance

Vibration acceptability depends on the frequency, magnitude, and duration of the vibration. The perceptibility thresholds for humans are provided in Table 3 above. Note that the primary crane structure frequency, approximately 0.25 hertz, is lower than the frequency range provided in the table. We are assuming the thresholds are similar for lower frequency vibrations.

The magnitude, duration, and frequency of vibration that affect human proficiency compared to the measured vibrations on the Port of Oakland's Berths 55-59 cranes during normal operation are provided in Figure 5. Note that these cranes have a reduced power inching control for crane alignment.

Assuming that the lower frequency vibrations guidelines are comparable to the guidelines provided above, the vibrations that occur during normal operation will most of the time be "clearly perceptible", and during gantrying events will range from "clearly perceptible" to "unpleasant." However, the vibrations should not impair an operator's proficiency.



Stiffening Option	O-Frame Stiffening	Boom Stiffening One Panel	Boom Stiffening Two Panels
Lateral Boom Tip Deflection / Unstiffened Deflection from 5% Inertia Loading with Trolley at Outreach	0.94	0.64	0.53
Primary Crane Period	4.0 s	3.3 s	3.1 s

Table 2. Stiffening Options and the Effect on Response – Port of Felixstowe Crane.

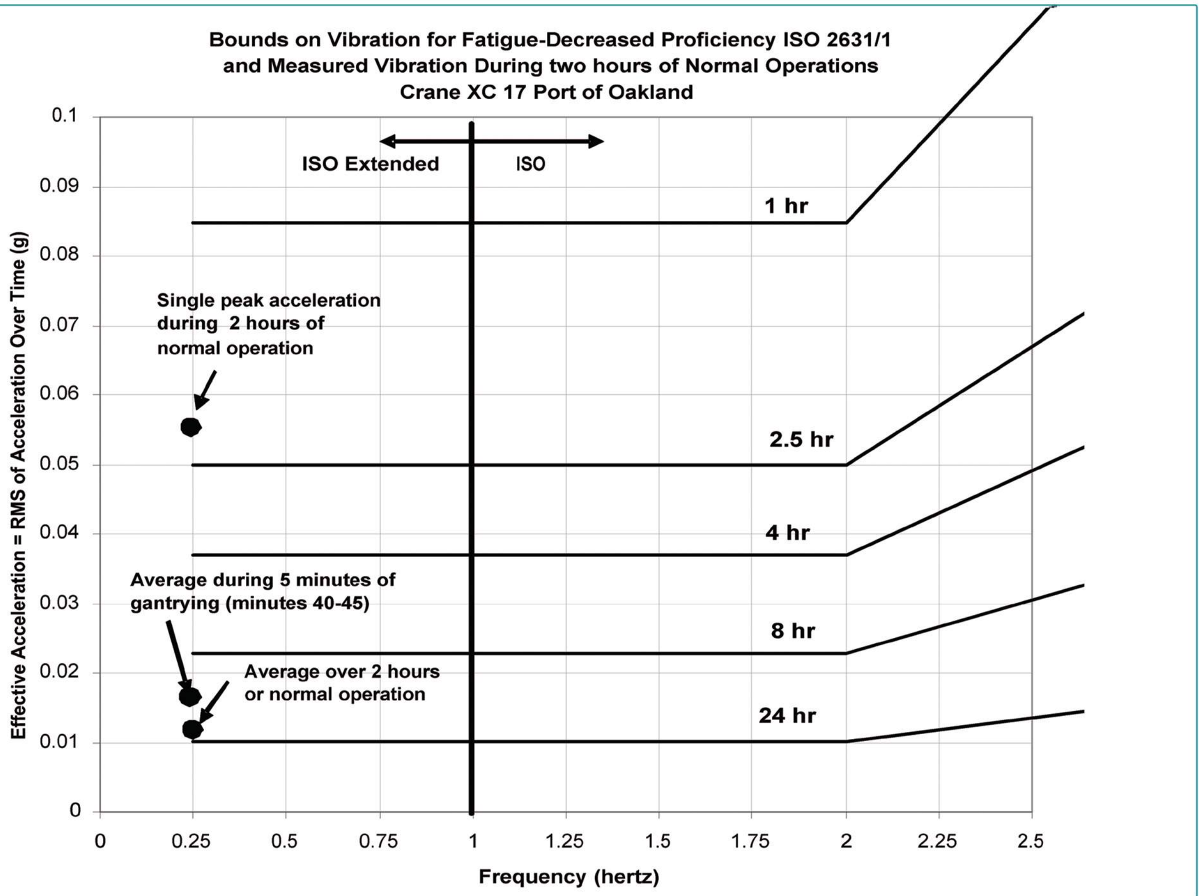


Figure 5. Measured boom tip vibration at Port of Oakland versus bounds on vibration for fatigue decreased proficiency – ISO 2631/1.

As expected, the vibration resulting from an emergency stop will be "intolerable" to most operators.

Conclusion and recommendations

Factors affecting boom vibration that are practical to modify include the acceleration magnitude, the acceleration duration, and the stiffness of the crane structure.

To reduce lateral boom vibrations, we recommend the following.

Set the gantry acceleration duration to twice the primary crane period. This will reduce the acceleration magnitude without significantly affecting the gantry times and will reduce the response of the crane structure when the crane is gantried to full speed. The primary crane period can be measured by measuring the average period over five to ten cycles after emergency stopping the crane when gantrying at full speed.

When traveling short distances, such as when aligning the spreader over a ship's hold, provide a lower gantry power setting so the gantry acceleration is approximately 5% of normal. This will reduce the deflection magnitude when compounding is most probable.

If necessary, decrease the emergency stop deceleration by modifying the control system so that the caliper brakes are not all set simultaneously. We recommend setting portions of the caliper brakes sequentially so that the maximum boom tip lateral acceleration is reduced to approximately 0.20g. This will slightly increase the stopping time and distance.

If the modifications above do not reduce the boom vibration to an acceptable level, add bracing to the boom. This will reduce the boom deflection and increase its vibration frequency.

REFERENCES

[1] http://liftech.net/LiftechPublications/megacranes.pdf.

[2] Table I.1 Vibration Problems in Structures: Practical Guidelines, by Hugo Backman et al, Birkhauser, 1995.

ABOUT THE AUTHOR

Erik Soderberg is experienced in the design, review, and modification of a variety of structures including container cranes, wharves, buildings, heavy lift equipment, and various rigging structures. He is also an experienced field engineer involved in the repair of damaged structures ranging from container cranes and bulk loaders to hydraulic excavators. His field skills include an understanding of heat straightening techniques and the ability to develop repair procedures on site.

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