

Megacranes: Holding Sway

Larger models of container crane are susceptible to the problem of excessive frame sway in the trolley travel direction. Michael A. Jordan, PE of US-based Liftech Consultants quantifies the problem and offers a solution

If a mouse grows to be as large as an elephant, could it stand up? No. Why not? Both have bones, and the bones are of similar materials. But, volume, and therefore weight, varies as the cube of the length while area varies as the square of the length. So stress, which is weight divided by area, varies linearly with length. So the proportions of elephants are different than the proportions of a mouse. So much for giant insect movies. A giant spider would simply collapse. Such are the laws of similitude.

Similitude also affects dynamic behavior. A mouse is quicker than an elephant. What does this have to do with megacranes? A great deal.

Dynamic Behavior

The dynamic behavior of a large crane is different than that of a smaller crane. If the dynamic properties of the crane structure are unintentionally tuned to the dynamic properties of the moving masses, unfortunate responses can occur and have occurred. Productivity has been seriously limited due to excessive vibrations, and millions of dollars have been spent to remedy resonance problems.

One of the dynamic problems of large container cranes is addressed here: the problem of excessive frame sway in the trolley travel direction. This problem can be avoided for a small cost when the crane is being designed. Fixing it after the crane is built is expensive.

High production requires accurate and rapid positioning of the hanging load. Sophisticated and effective electronic systems are here. But all of the systems control the motion of the load relative to the trolley. If the platform supporting the trolley, the crane structure, is moving relative to the quay, the benefit of the electronic load control system is lost. This has happened. Although a stiffer crane is always better, the best way to avoid the sway problem is to limit the period of the first mode of structural vibration in the direction of trolley travel. The figures help to explain why.

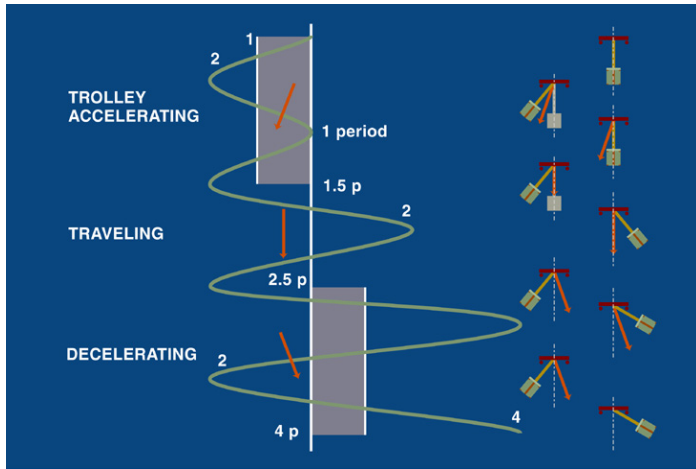


Figure 1: Worst Control

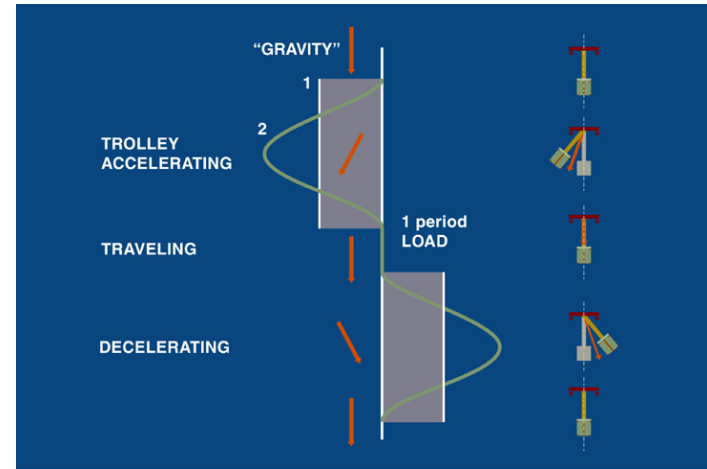


Figure 2: Best Control

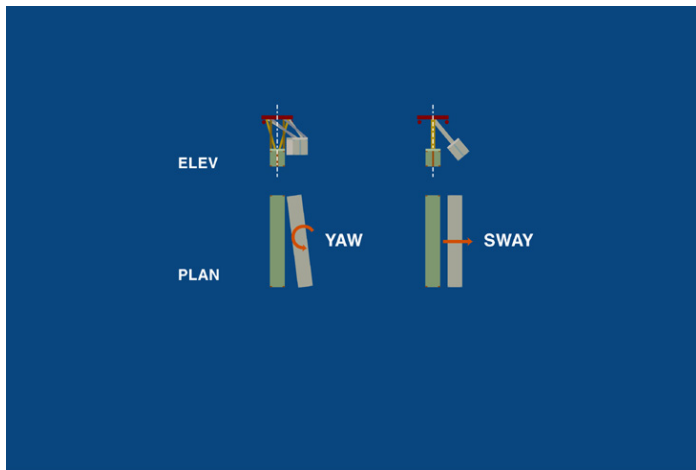


Figure 3: Sway and Yaw

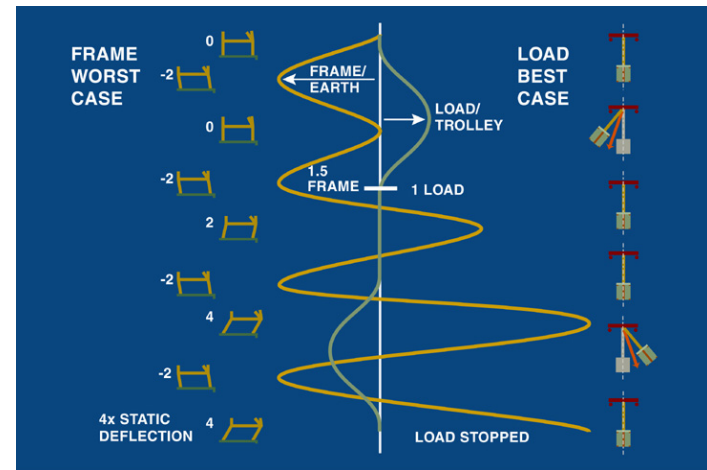


Figure 4: Trolley Frame Interaction

Trolley-Frame Interaction

First, consider a trolley, with vertical or nearly vertical falls, moving on a stationary platform. The hanging load has a natural period of vibration that depends only on the length of the falls. If the trolley accelerates for a time equal to the period of the hanging load, or a multiple of that period, and then travels at a constant speed, the load will at first swing behind the trolley and then, once the trolley is traveling at a constant speed, hang directly below the trolley. The load will not swing relative to the trolley. If the reverse occurs when the trolley stops, the load will at first swing ahead of the trolley and stop directly under the trolley. This is ideal load control. You can see this phenomena, if you watch a well-controlled container crane operation from the side. This applies whether a computer or a human is controlling the trolley motion.

Next, consider the least ideal control, the worst case. You will probably never see this, but the concept is necessary to understand the interaction between the frame and the trolley. The trolley accelerates for a time equal to one and one half times the period of the hanging load, and the reverse occurs when the trolley stops. The load first swings behind to trolley, comes under the trolley, and then swings behind the trolley. Just when the load is at the maximum swing, acceleration stops. As the trolley travels at a constant speed, the load swings. Then, just when the load is at maximum distance behind the trolley, the trolley decelerates. When the trolley stops, the load is swinging violently. The magnitude of the swing has been increased by a factor of four.

So, for one case the load is perfectly controlled, and in the other case, the load is perfectly excited. Of course, the worst case never occurs intentionally. But, in effect, the worst case can, and sometimes does, occur accidentally. Sometimes the most ideal pattern of forces to trolley is the least ideal pattern of forces for the frame. This is shown in the figure combining frame and trolley motions.

The initial frame displacement can be magnified by four, each time the trolley stops and starts. Since the trolley stops and starts every thirty seconds, for a productive crane, the magnifications from each cycle are additive. The resulting sway may be eight to ten times the initial sway. If you are on the crane, you will want to hold on.

When structural resonance occurs, there is no way to control the load effectively without either slowing the operation or modifying the structure.

Other Questions

Why use vertical falls? The phenomena that makes vertical falls desirable is also the phenomena that makes them undesirable. The period of load swing for vertical falls depends only on the length of the falls. If the load is eccentric there will be no yaw. If the falls are inclined enough to control sway, and the load is eccentric, the period at one end of the load will not match that at the other end and the load will yaw. Since trolley motion can control sway but not yaw, the operation will need to wait for the load to stop rotating. This slows production. Vertical falls are needed for the trolley to rapidly stop the load.

What about damping and other effects? Damping is important. The reduction in sway due to damping depends on the number of swing cycles. When the period is longer, the number of cycles between trolley moves is less, and the cumulative effect to the exciting forces is greater. Damping helps but is not the answer. Other effects are present, but those mentioned here are the essential ones.

Why now? Why hasn't this been a problem on smaller cranes? Remember the mouse and the elephant. Similitude.

The Solution

The solution is to limit the period in the trolley travel direction and to limit the deflection due to trolley acceleration. The Liftech specification requires the period to be 1.5 seconds or less – shorter is better. The deflection due to a static force of ten percent of the moving load, including the hanging load, in the trolley travel direction is limited to 15 mm – stiffer is better.

The criteria are easily met by using larger legs and portal tie beams. The benefits in operational terms are readily apparent.

Michael A. Jordan