Presented at Container Efficiency Conference
World Trade Center, Singapore
March 1996

DOCKSIDE CONTAINER CRANE DESIGN FOR THE 21ST CENTURY

ARUN K. BHIMANI, S.E.
President
Liftech Consultants Inc.

CATHERINE A. MORRIS, S.E.
Principal
Liftech Consultants Inc.

SHUJI KARASUDA
Asst Mgr., Electric & Control Designing Section
Mitsubishi Heavy Industries

INTRODUCTION

With the introduction of larger than post-Panamax ships, the megaships, orders for dockside megacranes to service these ships are increasing. The larger cranes require improved construction and operational sophistication to supplement the economies of the megaships. Although the sheer size of the cranes required to service the big ships produce some challenges, the biggest challenge to the engineer is to increase productivity.

This paper looks at two design approaches to achieve the desired performance for megacrane projects. One approach is to specify an extremely rigid structure and electronic load control system to control the load. A second approach is to specify strength requirements for the crane structure and electronic load control system to control the load and accommodate the crane deflections. American President Lines used this approach when they ordered twelve machinery-on-trolley cranes for their new Los Angeles hub facility.

BIG SHIPS - BIG CRANES

The arrangement of a megacrane is shown in figure 1. The key dimensions for both the rigid structure approach and the load control approach, as well as for a typical post-Panamax crane, are summarized in Table 1 below.

DESCRIPTION	MEGACRANES		TYPICAL POST PANAMAX
	RIGID STRUCTURE APPROACH	LOAD CONTROL APPROACH (APL)	
Outreach from WS Rail	55 m	52.4 m	45 m
Lift Height from WS Rail	35 m	33.5 m	30-34 m
Backreach from LS Rail	21 m	15.2 m	15 m
Total Height (Boom Down)	75 m	73 m	55-60 m
Total Weight, including Trolley and Lift System	1200 - 1300 t	1156 t	850-950 t

Table 1 - Key Crane Dimensions

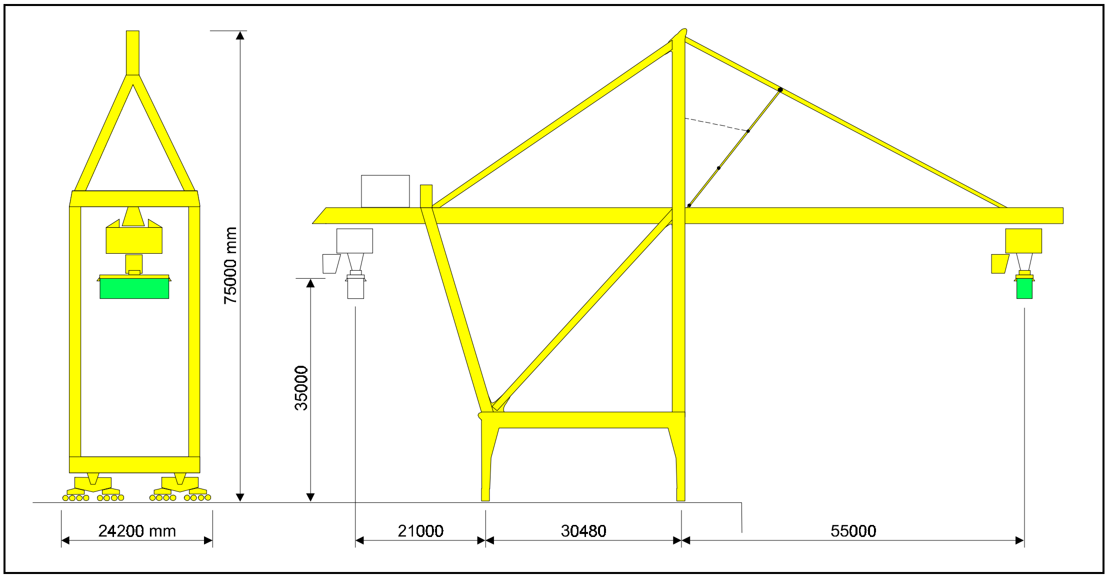


Figure 1
Rigid Structure Megacrane
by MHI

The result of the increased crane size is a heavier structure, increased wheel loads, and increased trolley travel distance. Since many of these new cranes are on new wharves, the increase in weight and wheel loads is usually not a problem. Still, the designer must look at ways to reduce the wheel loads whenever possible. Some factors to consider are the location of the machinery house and the overall structural configuration.

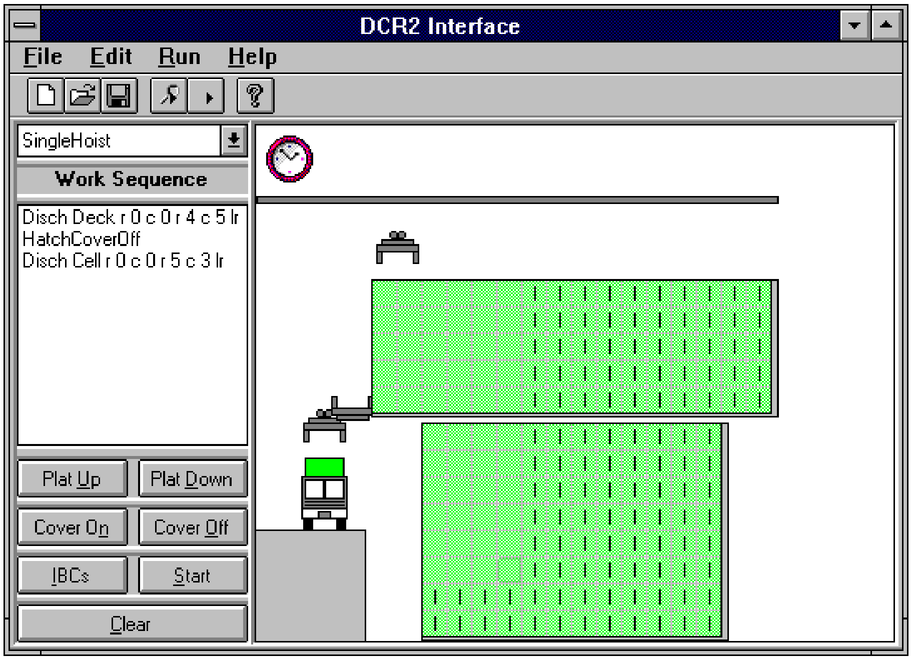
A factor in a decision to use machinery trolleys is the increased travel distance of the megacranes. The use of a machinery trolley substantially reduces the amount of rope, simplifies the reeving, and eliminates the need for catenary trolleys, although it also increases the weight and wheel loads.

INCREASING PRODUCTIVITY

To increase productivity, the cycle time to move containers on and off the ship must be decreased. Each step in the cycle must be analyzed to determine possible ways to increase speed, how much increased can be attained, and the cost and effect of the increased speed to the total crane system. The most efficient solution to the problem balances the cost and practicality of each action in the cycle.

Increasing Speeds and Accelerations

Increased trolley and hoist speeds and accelerations are obvious targets for increased efficiency. Today's machinery is much faster than earlier models, but there is a limit to speed before the effects on the total crane system become adverse, and the cost becomes too high. Engineers and equipment suppliers can determine the practical limits of the machinery, and simulation programs, such as Liftech's Cranesim, can help determine the optimum design speeds and accelerations. See figure 2.



SingleHoist

Disch Deck r 0 c 0 r 4 c 5 lr
HatchCoverOff
Disch Cell r 0 c 0 r 5 c 3 lr

Figure 2
Liftech's Cranesim

Increasing Load Control and Decreasing Dwell Times

One of the major contributions to the cycle time is the time it takes to pick and set a container. This time is primarily affected by mechanical load control and operator skill. By adding automation to the system, the load control can be increased, and the dwell time decreased. Systems can be added to automate the trolley motion between the shipside and chassis lanes, including automatic landing and pick-up of containers.

CREATING AN EFFICIENT DESIGN

The Missing Ingredient

For years the design team members - the mechanical engineer, the structural engineer, and the electrical engineer - have worked together to produce economic designs that meet operational demands and can be efficiently fabricated and erected. This worked because the crane components were mechanical, structural, and electrical. But now a new parameter has been added, *automation*.

We have not addressed this new parameter. The automation engineer specifies the requirements for an acceptable platform. The mechanical, structural, and electrical engineers try to meet these requirements. So far, we have worked without the automation engineer on the team.

The crane is not only part of the terminal system, but is also a system in its own right. The optimum design requires balance. The cost and benefits of each alternative should be considered in concert. We need the automation engineer on the design team from the start.

Machinery Trolleys

The decision to use a machinery trolley or a rope-towed trolley requires careful consideration of many factors including productivity, reliability, maintenance, necessary spare parts including ropes, operator preferences, manufacturers' preferences, weight and wharf loading, and cost. Although a complete discussion of machinery vs. rope-towed trolley is beyond the scope of this paper, some of the features may make the machinery trolley a better choice for automated cranes. Because there is no stretch of trolley tow ropes and the hoist ropes are much shorter, the machinery trolley provides better load control.

Structural Design for Automation

For automation to operate correctly, the location of all of the components in the system must be known. For fixed objects, this is an easy task. For moving objects, such as the crane structure flexing with the movement of the trolley, the task becomes more difficult.

One approach is to require a very stiff structure to limit crane deflections. A stiff structure helps with load control and provides an easier ride for the operator, but a heavier structure is required. A detailed structural design process is required to minimize the weight and optimize the geometry and sections. APL has chosen to account for the crane movement in the load control system design, and not specify deflection limits. While the logic for APL's automation will be more complex than for a deflection controlled crane, the weight and wheel loads of the APL crane will be about seven percent lighter.

Frame Stiffness

The rigid structure approach example used in this paper provides deflection limits in all three directions at the outreach. The deflections and the major members that contribute to those deflections are tabulated in Table 2 below.

DIRECTION	CALCULATED DEFLECTION	CONTRIBUTING EFFECTS OF MEMBERS
Perpendicular to Gantry Rails	4 mm	Stretch of the Backstay Bending of the Portal Frame
Vertical	128 mm	Elongation of the Forestay Stretch of the Backstay
Parallel to Gantry Rails	49 mm	Rotational Stiffness of the Crane Stiffness of the Boom

Table 2 - Deflection Requirements for a Rigid Crane

The frame design is optimized by choosing an overall geometry considering both the deflections and fabrication cost. Individual members are then examined to determine their contribution to each of the three deflections. Those sections of individual members that contribute the most to the overall stiffness are then increased.

Most of the optimization is structurally straightforward, but the forestay requires a second look to evaluate its contribution to the vertical deflection.

Optimizing the Forestay Design

The elongation of the forestay, or any axial loaded flexible linked beam, is derived from three sources: elastic elongation, linkage straightening, and curvature reduction. See figure 3. The elastic elongation is simply the stretch of the member due to the applied tension. The linkage straightening is caused by the reduction in sag when an axial load is applied to a linked beam. The curvature reduction is caused by the beam bending between the links. The curved shape of a beam with no bending stiffness, like a cable, is a catenary.

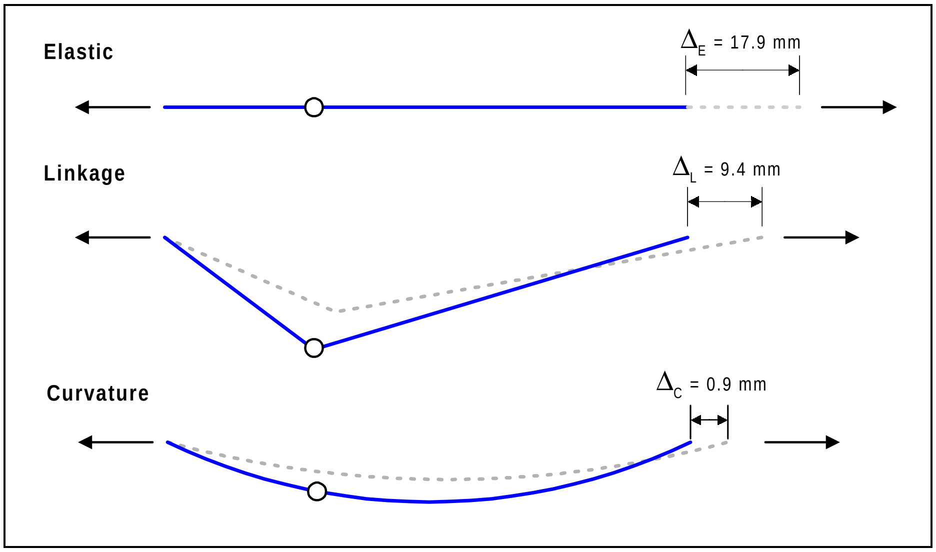


Figure 3
Forestay Elongation

The natural reaction to decreasing elongation is to increase the forestay's area. As shown in figure 4, this only works to a point. The elastic elongation decreases as the forestay area is increased, as one expects, but the elongation due to linkage and curvature increases. Imagine holding a linked beam with one end in each hand. If there is a 5 kg weight hanging from the link, and the tension in the beam increases, the sag will decrease. If there is a 0.5 kg weight, and the tension increases by the same amount, the sag will also decrease, but because the sag of the first system is considerable more than the second, the difference in the lengthening is greater.

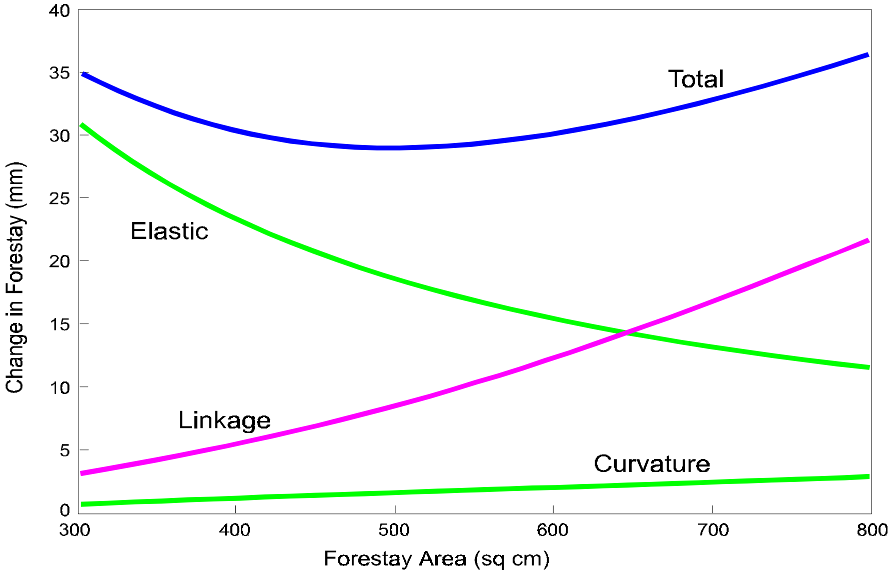
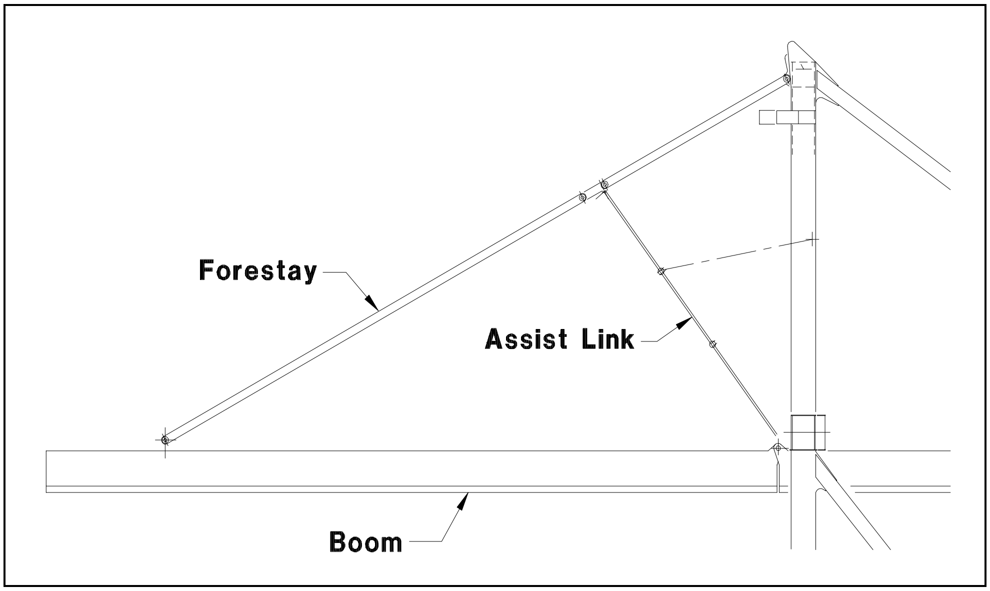


Figure 4
Forestay Length Change vs. Forestay Area
without Assist Link

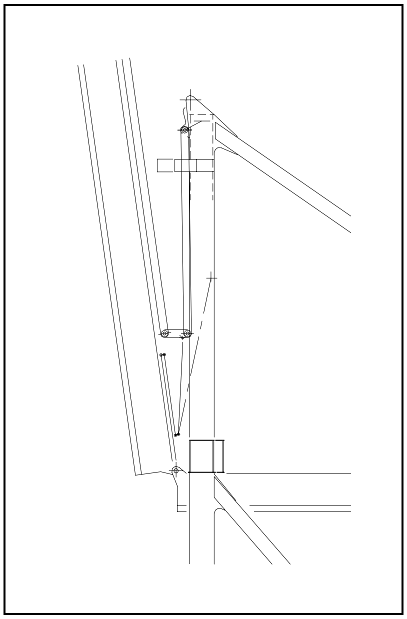
Assist Link (MHI Patent Pending)

As figures 3 and 4 show, a considerable part of the total elongation of the forestay is due to the linkage and curvature. If these two components were eliminated or controlled, then the elongation would be significantly reduced. The assist link, as shown in figures 5, 6 and 7 can do just this. Figure 7 neglects the effect of the elastic deformation of the assist link. A large deflection analysis has shown a 20 mm decrease in vertical deflection due to the addition of the assist link.



MHI patent pending

Figure 5
Assist Link, Boom Down



MHI patent pending

Figure 6
Assist Link, Boom Stowed

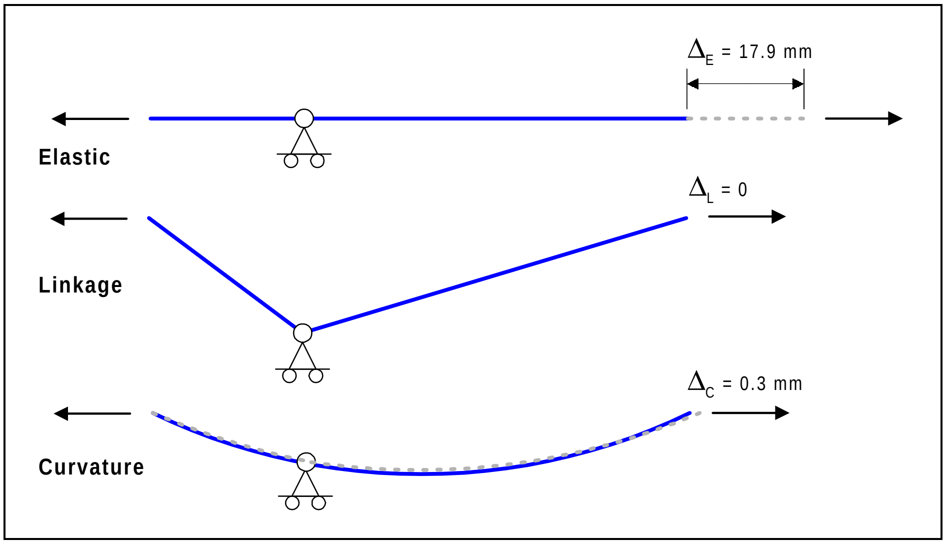


Figure 7
Forestay Elongation including Assist Link

MAKING MEGACRANES WORK

To meet dockside requirements for more efficient terminals and to serve the increasing demands of megaships, the owners and designers must carefully balance the mechanical, structural, electrical, and *automation* systems.

The new megacranes must allow for increased automation, while maintaining a cost effective structural design. Failure to reach the balance between the systems may result in a less productive and more expensive crane. Success will be achieved when we all work together.