CONTAINER CRANE TRANSPORT OPTIONS: SELF-PROPELLED SHIP VERSUS TOWED BARGE

F. van Hoorn, Argonautics Marine Engineering, USA

SUMMARY

Container cranes are rarely assembled on the terminal quays anymore. These days, new cranes are delivered fully-erect, complete, and in operational condition. In today's world economy, these fully-erect container cranes are routinely shipped across the oceans. New cranes are transported from manufacturers to terminals, typically on heavy-lift ships either owned by the manufacturer or by specialized shipping companies. Older cranes, often removed from the quay to make space for newer, bigger cranes, are relocated between ports and typically transported by cargo barges. Although the towed barge option is less expensive from a day rate point of view, additional expenses, such as the heavier seafastenings, higher cargo insurance premium, longer transit time, etc. need to be included in the cost trade-off analysis. Some recent container crane transports on ships and barges are discussed in detail and issues such as design criteria, stowage options, seafastening, etc. are addressed.

Figure 1: Heavy-lift ship Swan *departing Xiamen, China, with 2 new container cranes for delivery to Mundra, India*

1. INTRODUCTION

New container cranes are on order for delivery to many ports around the world. With quay space a valuable commodity, the cranes are no longer assembled on the destination quay, but are delivered to the quay fully-erect, complete, and in (near) operational condition. As a result, fully-erect container cranes are now routinely transported across the oceans. Most are new cranes, transported from their manufacturer to the ports of destination on heavy-lift ships either owned by the crane manufacturer or by specialized shipping companies. Older cranes are relocated within port limits as well as between ports. These older cranes, often removed from the quay to make space for new (bigger and faster) cranes, are typically transported by cargo barge. Exceptions are the local delivery of new cranes to a port close to the crane manufacturer by towed barges (within a 300 – 1,000 mile radius) and relocation of older cranes to other continents by ships. Although the towed barge option is less expensive from a day rate point of view, additional expenses, such as the heavier seafastenings, higher cargo insurance premium, longer transit time, etc. need to be included in the cost trade-off analysis. The Jones Act limits the transportation options for crane relocations between US ports.

2. HISTORY

Today, a maritime port is synonymous to rows and rows of container cranes, loading and unloading containers on and off large container ships. Worldwide container trade is growing at a 9.5% annual rate. It is expected that up to 90% of all liner freight is shipped in containers by 2010. Starting with the first special designed and built PACECO A-frame container crane in Alameda, CA, in 1959, container cranes have spread across the ports of the world in record pace [1]. Initially, these cranes were built on the quay from locally fabricated small components, delivered by trucks. This took a long time and valuable quay space. Building could be sped up by having the crane delivered “knocked down” i.e. in large building blocks that needed to be assembled on site, but the biggest time and quay space savings are achieved when the container cranes are delivered “fully-erect”, in working condition. This also allows the manufacturers to fully complete and test the cranes in their own yards, under optimum quality control conditions and with all required specialized labor at hand.

Although most container cranes are very similar, they are seldom identical. Crane manufacturers have their own basic designs, or license a specific design. Depending on each individual client’s specific requirements, these designs are custom adapted. And over time, the size keeps increasing to keep up with larger and heavier containers and larger (post-Panamax) container ships. Container ships with a capacity of 10,000 TEU and a beam of 45.6 m have entered service, and ships with capacities of up to 15,000 TEU are on the drawing boards. To speed up loading and discharging of these ever larger ships, cranes with twin hoists and dual trolleys and an outreach of 25 containers (61 m) have been developed. Bigger and faster is the trend.

New container cranes are being delivered to new terminals. Existing terminals are being upgraded, adding new cranes or changing out older cranes with new cranes. Obsolete container cranes are often sold for a nominal price, subject that they are removed from the dock within a short time frame.

Dockwise Shipping started transporting fully-erect container cranes in 1984 and has since delivered over 650 container cranes for a variety of crane manufacturers worldwide. Since 1995, crane manufacturer ZPMC has delivered over 500 container cranes using their own fleet, which has grown to 9 vessels over this time period. Since the early seventies, hundreds of new and old cranes have been transported by cargo barges. Occasionally, a container crane is shipped using a project cargo ship.

3. STOWAGE OPTIONS

The way a container crane is stowed on the vessel or barge depends on a large number of factors. Some of these are a function of the crane itself or of the vessel or barge. Others are dictated by the loading or offloading location, loading or offloading method, or the voyage itself, which may impose certain physical restrictions, such as:

- Panama Canal, with its 32.3 m width, and 62.5 m air draft restriction;
- Suez Canal, with its 68 m air draft restriction;
- Bridges and power cables between the manufacture location and the destination terminal.

If a crane transport has to go under a bridge or power cables, the air draft can be a design limit for the stowage configuration of the crane on deck, unless modifications to the crane(s) can be made prior to passing the bridge, for example lowering the boom or APEX after the sea voyage and before going under the bridge at the destination port.

Figure 2: Dock Express 11 *arriving at Freeport, Bahamas, with 3 container cranes with lowered superstructures*

Stowing multiple cranes onto a barge or vessel with a limited free deck space, often results in a transverse (athwart ships) stowage, see figure 1. The width of a crane is typically limited to a maximum distance between the gantry bumpers (which can be removed, if the total width is too much) of 88.5 ft to permit two cranes to work side-by-side on alternate hatches. Even with its boom up, its length is much greater, given the crane’s backreach. So unless the cranes can be nested (with their superstructures temporary secured at different elevations, see figure 2), a transport of 3 cranes typically shows the cranes stowed transversely. These days, the typical crane rail spacing is 30 m or 100 ft, which fits well transversely on a Panamax size ship with a beam of 32.2 m. When a project cargo ship is used and the crane is lifted on and off using the ship's own gear, the container crane is typically stowed transversely, as rotating it with the ship's cranes is difficult if not impossible.

A transverse stowage is often more favorable for the crane structure as the largest (roll) forces are acting in the strong direction of the crane. The crane structure is designed to lift heavy containers at the tip of its boom, resulting in a bracing in each of its side planes. To allow for the container to be passed through, the water and land side portals however are wide open, which makes the crane less rigid in the side to side direction. Smaller reinforcements are required in the water and land side portals if they are subjected to the lesser pitch motions.

A transverse stowage may be required if the crane is to be loaded or offloaded at a river terminal with strong currents. A perpendicular "stern to" or Mediterranean mooring at a high current quay is not safe and should be avoided.

Figure 3: Dock Express 10 *arriving at Laem Chabang, Thailand, with 2 new container cranes with booms down*

Stowing a crane with the boom up allows for securing of the boom to the APEX. With the boom down, securing the boom is more complicated as this may require pipe bracings or tension rods back to the trolley girder support beam. With 2 cranes stowed longitudinally, the boom of the aft crane may have to be slightly raised to clear the forward crane, see figure 3. Boom "down" typically refers to the crane boom being horizontal, in its working position. Occasionally, a crane is transported with its boom rotated all the way down, with its boom tip resting on the deck, on a special support. This option requires an additional set of (lower) boom hinges and longer boom hoisting wires, or a separate lowering winch. The forestays need to be disconnected from the boom and properly secured.

With a crane stowed on deck with its boom horizontal, the stability will be greater and the barge or ship will be stiffer (shorter natural roll period), resulting in higher lateral accelerations. But because the crane's center of gravity is lower, the net increase may be small. The total inertia force on the horizontal boom is likely smaller as its center of gravity is much lower compared to the boom up condition. Also the total wind area is smaller and the center of effort lower, which combined with the increased stability results in a smaller wind angle of loll.

4. LOADING AND OFFLOADING

Loading and offloading of container cranes can be achieved in a number of different ways, depending on the location, crane size, destination, manufacturer, availability of contractor's equipment, etc. Typical loading methods are:

- Rolling the crane on using its own (rotated) bogies;
- Rolling the crane on using multi-wheel trailers, dollies, or jack bogies;
- Skidding the crane on using skid shoes sliding over skid tracks;
- Forklifting the crane using the ship or barge outriggers to pick up the crane and skid it on board;
- Lifting the crane on, using a large floating crane or sheerleg.

Each of these methods has its own advantages and disadvantages. Rolling a crane on its own bogies requires little additional equipment, other than mobile rail sections to roll over and means to move and stop the crane. However, it typically requires the bogies to be made turn-able and the crane needs to have jack points for supporting the jacks required to lift the crane for rotating of the bogies. The supporting quay will also have to be suitable to accommodate these same jack loads in a relatively small footprint area.

To roll a crane on using multi-wheel trailers requires a support frame that transfers the lifting loads into the crane structure, see figure 4. For dollies or skid shoes, smaller support attachments can be fitted to both sides of the sill beams. Propulsion can be provided by winches, hydraulic push-pull units, or large trucks. The land and water side need to be connected so as not to deform the legs. Care should be taken to minimize any pushing loads going into the mooring wires. A break and retrieval system is to be provided if at all possible.

Figure 4: Crane loaded on barge with multi-wheel trailers

To forklift a crane, skid brackets are required on the outside of the crane legs. These brackets hold the skid pads that slide over the ship mounted skid rails. The leg's outer dimensions are to be within the maximum allowable for the ship hold. The crane bogies are to be turn-able or removable, and its auxiliary bogies shimmed, so the wheels stay more or less level after pick-up. The quay heights and tidal conditions at both the loading and offloading locations are to be such that a safe forklifting operation can be executed at either end.

Except for the forklift and lift-on methods, all other loading methods require a careful ballasting of the vessel or barge during the actual operation for the deck to maintain level with the quay during the load transfer. Portable pumps (electric submersible pumps, or self-priming diesel pumps) are installed if the barge does not have its own internal ballast system. The effect of tide has to be incorporated in the ballast procedures. The loading progress, ship/barge movement, and tide all have to be continuously monitored and corrections need to be made as necessary. Generally the loading operation will be stop-and-go, allowing for the tide and the ballasting to catch up.

In order to load a crane sideways onto a barge, the barge needs to have (some) separate wing tanks. Some cargo barges have only water tight bulkheads in the transverse direction (i.e. ballast tanks are full width) and therefore unable to compensate for any heeling moment caused by load coming onto its side. In such a case, either the barge has to be modified (closing openings in longitudinal non-watertight bulkheads), replaced, or a longitudinal loading over the stern has to be adopted.

Quay height, edge to rail distance, quay slope, power trench location, tide data, fender particulars, bollard particulars and locations, curb details, local wind, wave, and current data, etc. are all to be considered when making loading and offloading procedures. Water depth restrictions at the manufacturer's yard need to be considered.

Loading operations are typically done during favorable weather conditions. Before the operation starts, local weather forecasts are studied to see if there is a safe window. Some operations cannot be stopped or reversed once started. Adverse conditions can be dealt with as long as the relative movements between the vessel and the quay are limited (safe limits vary with the method and system used), and the mooring wires are not being overstressed. The GO or NO GO decision is often made in small committee, which include the captain, superintendent, surveyor, contractor, terminal representative, and client.

If possible, passing shipping traffic is notified of the operation and requested to proceed at dead slow speed when going by. At working terminals, container ships often arrive or depart during slack tide, which is also the best time for this type of operation.

Offloading the crane is often the reverse operation, if conditions at the discharge locations allow for this. If not, an alternative offloading method has to be used, resulting in for instance a roll-on/skid-off operation, or a lift-on/roll-off operation.

Container terminals typically have deep water at the quays, allowing for the biggest ship to moor alongside. Timing of the delivery of new cranes to a terminal can be critical. In case of a brand new terminal, the infrastructure has to be in place in order to be able to receive the cranes. In case of existing working terminals, an opening in the container ship arrival schedule needs to be found (or created) to allow for the discharge of the new cranes, with minimum disruption of the terminal activities. If the terminal has a specific strengthened section of quay that is needed for the offloading, this will further limit the flexibility.

5. DESIGN CRITERIA FOR THE TRANSPORT

The design criteria for the transportation of container cranes by ship or barge depend mostly on the route and time of year [2]. Using risk based criteria, a slow towed barge with a long exposure window will see a higher design wave height compared to a faster ship based transport over the same route. Note that the often used "10-year return period" does not take this exposure time into account unless some arbitrary reduction is applied to take a reduced exposure into account. A ship also has a better chance to avoid stormy areas and has the ability to control its wave heading in adverse conditions. A barge can be over a kilometer behind its tug, allowing for little, if any, heading control. The design environmental criteria and associated design motions and accelerations are very project specific, and no general criteria can be presented here. To illustrate the magnitude and to compare the two transport options, in table 1 some past examples are given:

- Barge tows (relocation of old cranes):
    - 1 Old crane from Honolulu, Hawaii to Portland, Oregon, on the *Z Big 1* in 2003, see figure 5;

Figure 5: Barge Z Big 1 *departing Honolulu with 1 old crane transversely stowed on deck*

- 3 Old cranes from Long Beach, California, to Seattle, Washington, on the *Western Carrier* in 2005, see figure 6.

Figure 6: Barge Western Carrier *departing Long Beach with 3 old cranes transversely stowed on deck*

- Ship transports (delivery of new Post-Panamax cranes):
  - 2 New cranes from Oita, Japan to Laem Chabang, Thailand, on the *Dock Express 10* in 2004, see figure 3;
  - 2 New cranes from Xiamen, China, to Mundra, India, on the *Swan* in 2004, see figure 1.

The vessel motions translate into accelerations on the crane structure. Point accelerations can be calculated for any point of interest, including the proper phase relationships between the various modes of freedom. For a stiff barge or ship, with a short natural roll period, the sway and roll are typically in phase, resulting in an increase of transverse accelerations with elevation. The virtual point of rotation is below the vessel, resulting in a metronome type motion, see figure 7, left hand side. In case of a long natural roll period, the sway and roll can be out of phase, resulting in a decrease of transverse accelerations with elevation. The virtual point of rotation is above the crane and the vessel makes more of a pendulum type motion, see figure 7, right hand side.

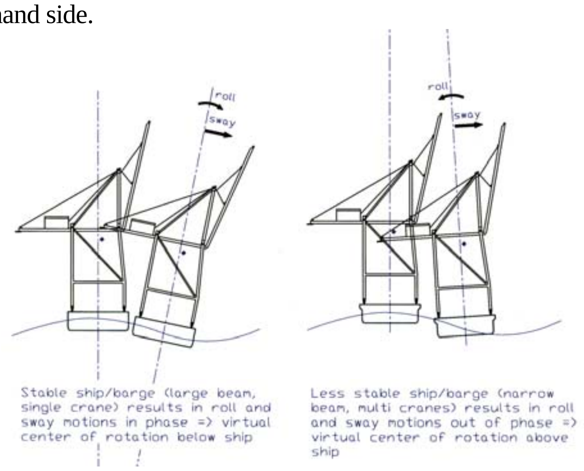

Figure 7: Effect of stability (stiffness) on phase relationship between sway and roll

6. STABILITY AND EFFECT OF BALLAST

From table 1 it can be noticed that the barge transports show significant more initial stability (higher GM values). The loaded barges typically sail without any ballast, unless some is needed to increase the draft or trim the barge by the stern to improve its directional stability. For a large cargo barge, container cranes are a relatively light cargo and the draft of the loaded barge may be insufficient to avoid slamming against the bottom. A good target draft is between 35 and 65 percent of the barge depth. Even including the free surface effect and its reduction on stability, adding ballast to the barge rarely improves its roll motion behavior. A lighter barge behaves more favorable as far as rolling and transverse accelerations (which are often dominant for the seafastening design) are concerned,.

For the ships ballast is used to ensure their propellers are well submersed as well as to optimize their loading condition. Using high ballast tanks, the stability can be fine-tuned and the ship's natural roll period can be increased, away from the typical range of wave periods. The ship transports with much smaller GMs still have a limited wind angle of loll as their total mass is relatively large. In addition, they have the ability to actively counter ballast any steady wind list, which is common practice.

The intact statical stability for the manned ships is to be in excess of 36 deg. For the unmanned barges, this minimum range varies with class, jurisdiction, etc. Generally, the area under the righting moment curve to the second intercept of the righting arm and wind overturning moment curves or the downflooding angle, whichever is less, should not be less than 40 percent in excess of the area under the wind overturning moment curve to the same limiting angle (1.4 rule).

7. SEAFASTENING AND REINFORCEMENTS

In order to assure the safe transportation of a container crane, it needs to be secured to the deck and internally reinforced. The crane structure by itself is typically not strong enough to accommodate the worst case inertia forces it may be subject to during the voyage. Additional bracings may be required to stiffen the large open portals. These can be steel pipe bracings, able to take tension and compression loads, or simple tension rods, such as Williams rods or Dywidag bars, which are easy to re-use. Many crane manufacturers have developed inhouse systems for use on their new cranes to be delivered. Often the components are sized such that they can be shipped back to the yard in standard containers and re-used on the next shipment. For older cranes, transportation bracings are often custom designed and fabricated, and scrapped after use. Most reinforcements can only be installed shortly before loading, as it interferes with the testing or operating of the crane. If the time schedule is tight, reinforcements are installed after loading, simultaneously with the installation of the seafastenings.

After loading, the container crane is supported under its wheels by rails or flat bars. Stoppers welded on either side of the outer bogie wheels prevent rolling. Before the voyage can commence, the crane has to be secured to the deck of the carrier. Heavy cargoes are typically only restricted against lateral movement to allow for some relative movement between the cargo and the carrier, but in case of container cranes, uplift is almost always predicted for the design conditions and the crane corners are rigidly connected to the vessel deck, using pipe seafastenings, see figure 8. For the *Dock Express* class vessels, Dockwise has developed their so-called Uplink™ system to pin the crane skid brackets to the vessel's skid rail, thus preventing any corner uplift.

Figure 8: Pipe bracings fix crane corners to the deck

During the transport, the barge and ship hulls will flex some in seaways. The spacing between the crane legs is typically small enough to not be significantly affected by this deflection of the carrier. However, if the boom tip of a longitudinal stowed crane is supported, this support must allow for some relative motion. Greased steel or Teflon sliding plates work well.

All seafastenings are to be designed such that there is a clear load path and high stress areas are avoided. Brackets need to be supported by strong points inside the crane structure and under the barge/ship deck. In case of high local point loads, adequate load spreading has to be provided. Full welding of the seafastenings should not commence until the barge or ship has been ballasted to its final departure condition, to avoid any major changes in the still water hogging or sagging condition after installation of the seafastening. All seafastening welds are to be at least visually checked and the throat heights measured and compared with the construction drawings. Non-destructive testing, such as magnetic particle inspection, ultrasonic, or dye penetrant, is recommended for critical and/or high stress welds.

Container cranes operate in cycles (trolley loaded with containers going back and forth) and outside in an exposed environment. They are therefore subject to fatigue damage over time. The structural strength of older cranes can locally be reduced due to fatigue damage. Part of the function of the seafastenings is to minimize any additional fatigue damage during the transport. Fatigue damage can be further reduced by selecting a transportation option that offers the highest transit speed (fewer oscillations) and the lowest accelerations (smaller excitations).

Unless used for securing of small items and packages, stretchable securings, such as wire ropes, can only be used on manned ships, where the crew can check the wire tension on a daily basis and adjust where necessary. Bolted connections require securing of all bolts and nuts to assure they do not come loose during the voyage. Any shackles and turnbuckles also need to be secured so that they cannot get unscrewed.

8. INTERNAL SEAFASTENING

During the transport, the crane will move back and forth tens of thousands of times. Any play will allow for a small movement, which may become larger over time, thus increasing the mass inertia, until a critical point is reached, resulting in failure. Internal seafastenings are applied in order to limit any movement and prevent (heavy) items to gain momentum and break or cause damage. Some items that need particular attention:

- The trolley is to be secured to the trolley girder using welded stoppers. Some relative movement is to be allowed; stoppers are to be welded to the girder only. Equipment and controller chair inside the control cab are to be secured;
- The headblock with spreader is preferably lowered onto the deck and secured there. Or it can be lowered to sill beam level and secured with cross wires to the two portals and to the deck;
- The trolley festoon cable needs to be secured. Any play in the festoon support rollers has to be eliminated by bundling the festoon cable at the end as much as possible. If the cable does not contain any fiber optics, the cable can be pulled onto the aft festoon platform and secured there. In case there are fiber optics inside the festoon cable, sharp bends are to be avoided in the securing process;
- The cable reel is to be secured to avoid any large sideways movements as well as un-spooling;
- Flood lights are to be secured;
- The boom hinges are to be shimmed to minimize any side-to-side play. The shims are to be secured after insertion to avoid that they work themselves out during the voyage;

- The forestays need to be shimmed inside the forestay guides to minimize any movement of the forestays;
- Large tubular diagonals are to be protected against vortex-induced vibrations due to wind. This can be done by wrapping a large diameter nylon mooring rope around the pipe, or by running a tensioned steel wire down from about the middle of the pipe to a strong anchor point;
- The winch drums are to be secured. The various trolley, boom control, and hoisting cables are to be bundled and pulled away from any sharp edges to avoid chafing. At areas where contact is inevitable, a rubber protection sleeve is to be secured around the cable, or a wooden or Teflon block is to be inserted;
- The auxiliary hoist inside the machinery house is to be secured in all directions. The main girder is to be secured against its end stoppers. The trolley is to be secured to the girder and the hook is to be secured to a strong point;
- The electrical cabinets are to be secured to the machinery room walls, if not already. Its doors are to be locked and secured. Any drawers, desk chairs, spare parts, etc, are to be secured in place, using wire rope or cable ties;
- The elevator and its cabling are to be secured to the elevator track;
- Exposed hydraulic cylinder pistons, subject to green water, are to be wrapped or coated in heavy grease or other protective coating;
- Wrapping electrical items with plastic can be counterproductive. Without adequate drainage, spray or rain water can collect inside the bag, immersing the equipment;
- Bolted seafastening connections are to be provided with bolt and nut securings or self locking nuts.

For new cranes, any loose items and debris accumulated on the crane structure during the construction is to be removed before loading. During loading and the voyage, items falling from the crane are a hazard to the crew on deck. Scaffolding remaining in place during the voyage is to be thoroughly secured.

Safe access to the cranes has to be provided. The main access stairs are often removed for loading as they interfere with the load-out and/or seafastening. Temporary access ladders are to be provided to allow access to the crane during the final preparations on a barge and for regular inspections during the voyage on a ship.

9. INSPECTIONS DURING THE VOYAGE

In case the cranes are transported by towed barge, the inspections are limited to frequent checks of the overall condition through a set of binoculars. With the barge trailing the tug at a distance in excess of 1 km, no details will be visible. Barge roll motions can only be estimated.

During a ship based transport, the cranes can be inspected daily from top to bottom, weather permitting, and provided that safe access is available. The seafastenings between the cranes and the deck are inspected for cracks or other signs of high stresses. The crew typically climbs into the cranes to look at the various internal seafastenings and reinforcements, and to listen for any unusual noises. Minor repairs and fixes (re-inserting of shim plates for instance) can be made before it is too late. The ship motions are monitored and recorded. In adverse weather conditions, the speed and heading of the ship can be optimized to minimize the accelerations on the crane and not exceed the design values.

10. ROUTING

Although clients are often in a hurry to have their cranes delivered, the voyage is typically plotted along the most favorable route, which may not necessarily be the shortest. Crossings of the Atlantic or the Pacific are often done following a southerly route, rather than the shorter northern great circle route. Cargo safety is of primary concern and areas with severe weather are avoided if at all possible. Once underway, daily weather forecasts will assist the captain to plot his course and make changes where needed. In case of very restrictive design criteria, active weather routing by a specialized weather routing service will further help the captain in plotting the best possible route [3]. The weather routing service needs to be well informed about the design limits and needs to be provided with feedback from the ship to be able to verify their past predictions.

11. FEEDBACK FROM THE TRANSPORTS

The past example crane transports as listed in table 1 were all successfully executed. The Portland crane was included in this comparison because it was instrumented to monitor the accelerations experienced during the tow. A triaxial accelerometer was mounted on the crane structure and the accelerations were logged at a frequency of once every 3 seconds, for a total of 351,239 data points. The plot of the accelerations is given in figure 9.

Together with the captain’s weather log, a comparison could be made between predicted crane accelerations and actually experienced accelerations, and the following conclusions were drawn:

- The highest transverse (x-axis) acceleration of .48 g was recorded on October 3. At this time the captain reported 25 knot winds and 8 ft (2.4 m) waves coming in from the beam (~ Beaufort 6). Recalculated barge accelerations for this observed wave height shows that the theoretical extreme transverse acceleration at the sensor location in a 2.4 m beam seas equals .51 g, very close to the measured value of .48 g;
- At the time of highest transverse accelerations,

longitudinal accelerations (y-axis) of about .1 g are measured, indicating the waves were not long crested;

- The observed wave height was about 35% of the design significant wave height for this tow;
- The observed wind speed was about 70% of the design wind speed for this tow;
- The highest recorded transverse acceleration at the sensor location was about 33% of the design transverse acceleration at this location;
- The highest recorded longitudinal acceleration at the sensor location was about 65% of the design longitudinal acceleration at this location;
- The highest recorded vertical acceleration (z-axis) at the sensor location was about 87% of the design vertical acceleration at this location;
- Vibration in the crane due to wave slamming against the barge bow could have distorted the peak values for the longitudinal and vertical accelerations.

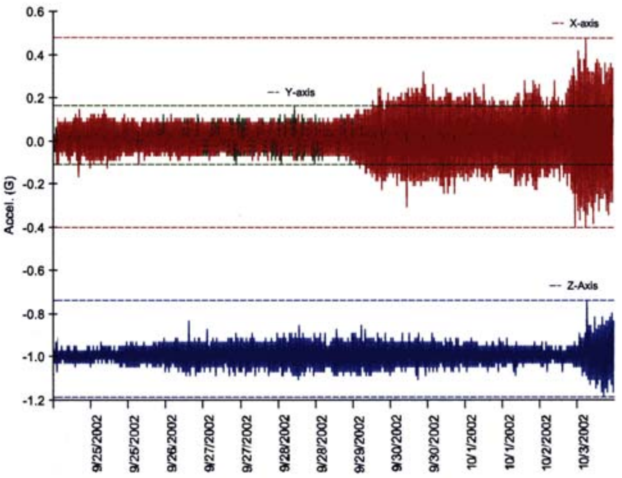

Figure 9: Plot of accelerations recorded during the tow to Portland (x = transverse, y = longitudinal, z = vertical)

Although July is generally the most favorable month, the tow of the 3 cranes from Long Beach to Seattle was hampered by severe head winds, with gusts at one time exceeding 40 knots - pushing the tow temporarily backwards with a speed of almost 3 knots. Including a deviation to San Francisco to await better weather and to re-fuel, the tow took 16 days, almost twice as long as anticipated. The combined wind and swell waves were between 1.2 and 2.7 m most of the route, at one point increasing to 3.6 m, still well within the design limit of 5.4 m. The cargo barge reportedly rode the waves well with slow rolls up to 8 deg and both external and internal crane seafastenings and reinforcements worked satisfactory.

In spite of crossing the South China Sea during typhoon season, the 2 new cranes to Laem Chabang experienced good weather, resulting in negligible ship motions. Occasionally however, heavy wind gusts pushed the vessel over a few degrees, which was quickly corrected by the crew with appropriate counter ballasting.

The 2 new container cranes to Mundra experienced very little motions during their 13 days in transit. The captain reported negligible pitching and rolling and a maximum wind list of .5 deg. Some small loose items in the machinery house of one of the cranes, such as a half full water bottle standing on a ledge, were found to be in the exact same position upon arrival in India, confirming the gentle ride.

12. COSTS, QUOTES, AND CONTRACTS

The cost for transporting one or more container cranes will depend on a large number of variables, such as market conditions, barge/vessel availability, location, auxiliary equipment required for loading and offloading, sea bracings, etc.

When comparing the towed barge option versus the self-propelled vessel option, the following factors need to be considered:

- Cargo insurance premium for transportation by self-propelled ship is generally only a fraction of that for transportation by barge;
- A lower day rate of the barge is attractive, especially if loading and/or offloading takes a long time, or is subject to potentially long delays;
- During the transit, the higher speed of the self-propelled ship can partly offset its higher day rate;
- The transport schedule affects the fabrication and delivery schedule. A faster transport can result in a later departure, leaving more time at the factory, or an earlier arrival, leaving more time for commissioning;
- Mobilization and demobilization costs for the marine equipment and all specialized loading and offloading equipment;
- Material, fabrication, installation, and removal of the seafastening and crane reinforcement are largely dependent on the design accelerations which generally favors the self-propelled ship;
- Rental cost of the auxiliary equipment for loading and offloading, such as mobile cranes, forklifts, man lifts, welding machines, etc., including all consumables, qualified operators, etc.;
- Operational marine costs for tug boats, pilots, line handlers, longshore labor, dock fees, agents, etc.;
- Travel expenses and board and lodging for supervisors, representatives, surveyors, etc.

Oftentimes it will be difficult to compare the cost directly as the options considered can be vastly different in concept and detail. A crane move by cargo barge whereby the crane has to be loaded by skidding is very different from a move by heavy-lift ship whereby the crane is forklifted from the quay. Crane transportation quotes are to be carefully compared as to what is and what is not included in the price quoted.

During the transportation contract negotiations, the scope of work concerning the crane loading operation, internal reinforcements, seafastening to the deck, and offloading operation is to be spelled out in great detail and responsibilities clearly assigned to the parties involved in the loading, transportation, and offloading of the crane(s).

If old cranes need to be relocated between two US ports, the Jones Act will be an issue and a US flagged ship or barge may have to be used.

13. CONCLUSIONS

For the transportation of new and old fully-erect container cranes, both towed barges and self-propelled ships offer viable solutions. Both options are safe and have proven track records. Proper engineering, crane preparation and reinforcements, seafastening, warranty survey, and prudent seamanship will ensure a safe arrival of the cranes at their final destination.

When comparing the barge option with the ship option, expenses, such as the heavier seafastenings, higher cargo insurance premium, longer transit time, etc. need to be included in addition to the day rate. Oftentimes, each option has its own specific scope of work, making a direct comparison difficult.

Every container crane transport is unique, with many variables. Each loading, stowage, and seafastening option has its own specific details and requirements that need to be identified and understood at an early stage of the transportation planning. Limitations of the loading and offloading locations, barge or ship to be chartered, equipment to be used, etc. are to be incorporated in the transportation procedures.

Design environmental criteria are to be carefully and appropriately selected for the crane transport, based on route, season, and anticipated transit speed. Over conservative criteria generate excessive seafastening and internal reinforcement requirements, while overly liberal criteria increase the risk for damage or loss. Active weather routing can be used to minimize the risk for encountering severe conditions.

For a barge tow, the tug size is to be carefully selected, depending on barge size and shape, total crane wind area, tow route, and season. The slower transit speed makes towed barge transport more vulnerable to heavy weather exposure and associated delays. The heading control of the barge is limited.

The Jones Act, restricting the use of foreign flag vessels, needs to be considered when moving cranes within or between US ports.

A detailed warranty survey of the crane, its internal reinforcements, and seafastenings to the deck minimizes the chances for damage or loss during the transport. For older cranes, a general condition survey to flag any weak areas is recommended.

Practical hands-on field experience with numerous crane transports combined with a thorough theoretical knowledge of the barge/ship motions and resulting forces on the crane structure is invaluable when evaluating the risks of container crane transports.

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16. AUTHOR’S BIOGRAPHY

Frank van Hoorn is the President of Argonautics Marine Engineering, providing consulting services related to marine heavy-lift transportation. He received his Masters degree in Naval Architecture from the Delft University of Technology in the Netherlands in 1983. He then joined Wijsmuller Engineering, working on the design of workboats and harbor tugs, and assisted Wijsmuller Transport with the more complex heavy-lift transports. He transferred to Wijsmuller Transport in 1985 to focus entirely on heavy-lift transportation. In 1992 he moved to California and founded Argonautics Marine Engineering, servicing clients worldwide. Over the last 20+ years, he has been frequently involved in container crane transports, on the engineering side, as well as in the field, during loading, seafastening, and offloading operations, or for cargo or marine warranty surveys. Member of SNAME and ASNE.

Table 1: Comparison of some typical old and new container crane transports by towed barges and self-propelled ships

	1 old crane to Portland	**3 old cranes to Seattle**	**2 new cranes to Laem Chabang**	**2 new cranes to Mundra**
Barge / Ship	*Z Big 1*	*Western Carrier*	*Dock Express 10*	*Swan*
Dimensions L x B x D (m)	122 x 30.3 x 7.6	91.4 x 25.6 x 5.8	159 x 32.3 x 7.0	180 x 32.2 x 13.3
Loading / Offloading	roll-on/off	roll-on/off	forklift-on/off	roll-on/skid-off
Stowage orientation	transverse	transverse	longitudinal	transverse
Boom configuration	down	down	down	up
Crane weight (t)	1 x 790	3 x 660	2 x 1,030	2 x 1,450
Crane VCG above rails (m)	25.6	23.5	35.1	39.4
Displacement (t)	4,700	3,800	13,600	29,100
GM' (m)	51.5	14.5	1.6	1.6
Natural roll period (s)	6.5	11.5	30.5	34.4
Sailing distance (nmiles)	2,330	1,260	2,510	4,410
Departure month	September	July	July	November
Anticipated / Actual average speed (kn)	7.0 / 7.5	6.0 / 3.6	12.0 / 12.1	12.0 / 13.8
Actual transit time (days)	13	16*	9	13
Design significant wave height (m)	6.9	5.4	6.0	7.8
Design 1-min sustained wind speed (kn)	36.0	34.0	31.0	38.6
Design extreme roll amplitude (deg)	26.2	20.5	1.7	.6
Design extreme pitch amplitude (deg)	8.0	7.8	9.1	7.4
Design extreme transverse acc. (g)	1.09	.55	.22	.24**
Design extreme longitudinal acc. (g)	.21	.17	.37	.27
Design extreme vertical acc. (g)	.31	.31	.41	.31
Notes	*) Including deviation to San Francisco to await better weather and re-fuel. **) Design transverse accelerations were increased to .50 g by the Marine Warranty Surveyor.