FLOATING DRY DOCK ACCIDENTS INVOLVING TRANSVERSE BENDING FAILURE OF THE PONTOON

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SUMMARY

There have been three separate accidents involving transverse bending failures of dry dock pontoons within the last few years. All three accidents involved dry docks that had longitudinally framed pontoon decks and were operated in such a manner as to overload the pontoon deck plate's buckling strength. Pontoon decks that are stiffened longitudinally have steel plate panels that have their long axis parallel to the longitudinal axis of the dock and perpendicular to the line of transverse compressive stress in the plate when docking a ship. This orientation results in a panel that will buckle under a much lower stress than that of a similarly sized panel orientated transversely to the dock's axis.

All three failures occurred while lifting vessels well within the overall rated capacity of the docks. Each of the three accidents had different root causes that instigated the failures. This paper discusses the accidents, the reasons for the failure and how to prevent similar accidents from happening in the future.

1.0 INTRODUCTION

Up until recently, structural failures of floating dry dock pontoons due to excessive transverse bending stresses were thought to be relatively rare occurrences. There have been three accidents involving transverse bending failures of pontoons within the last few years however.

All three of these accidents involved floating dry docks that had longitudinally framed pontoon decks that buckled while the vessel was being lifted. Pontoon decks that are stiffened longitudinally have steel plate panels that have their long axis parallel to the longitudinal axis of the dock and perpendicular to the line of transverse compressive stress in the plate when docking a ship. See Figure 1. This orientation results in a panel that will buckle under a much lower stress than that of a similarly sized panel orientated transversely to the dock's axis. This is not a problem of course, if the dock is operated within its design limits which keeps the actual compressive stresses in the pontoon deck below the ultimate buckling stress of the panel. It can become a factor however once the design limits are exceeded or the plate experiences loss of metal thickness due to corrosion, since the factor of safety against buckling in a longitudinally framed plate is less than that for a similarly sized panel framed transversely.

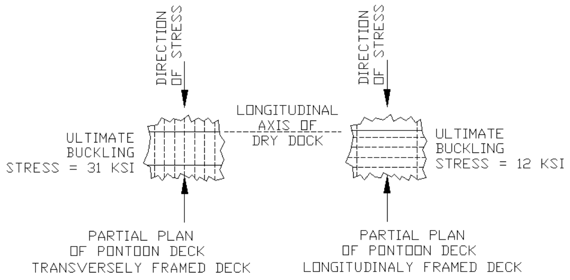

FIGURE 1
COMPARISON OF PANELS

Two of the accidents discussed here occurred while the docks were being deballasted in a manner that unknowingly magnified the compressive stress in the pontoon deck plates to a point which exceeded their buckling strength. The third accident was due to corrosion of the pontoon deck. A 40% loss of metal thickness drastically reduced the allowable buckling stress of the deck panels.

This paper discusses the accidents and the reasons for the failures. Names of the parties involved will not be mentioned.

2.0 CASE 1 - 18,000 TON FLOATING DOCK DOCKING SHORT, LOADED VESSEL

Case 1 involves an 18,000 metric ton capacity floating dock with length of pontoon equal to approximately 180 meters (600 feet). The crew was docking a loaded vessel that was estimated to weigh approximately 15,000 metric tons (well within the overall capacity of the dock). As the vessel was being brought out of the water (the vessel's keel was just emerging from the water), the pontoon deck suddenly buckled throughout the length of the dock. The crew stopped pumping, re-ballasted the dock and undocked the vessel. When the empty dock was pumped back up, it could be seen that the pontoon deck and transverse bulkheads had sustained massive damage due to buckling of the plating.

There were two main factors that contributed to the accident, the pontoon deck's strength and the method of deballasting the dry dock.

The strength of the pontoon deck was adequate for lifting vessels within the design limits. As mentioned above, the pontoon deck was stiffened longitudinally. This resulted in deck panels that could buckle if the design limits were exceeded however. Figure 1 shows the relative difference in stiffener orientation between longitudinally framed and transversely framed deck panels when resisting compression induced by transverse bending of the pontoon.

According to Reference 1, a panel framed longitudinally does not have as great a capacity to resist transverse buckling as a transversely framed panel of similar dimensions. A 600 mm x 2100 mm (2' x 7') panel with plate thickness of 12mm (½") has an ultimate buckling stress (stress in plate at time of failure) of 214,000 kPa (31,000 psi) if orientated transversely and 82,700 kPa (12,000 psi) if orientated longitudinally. This means the factor of safety before failure is less for a longitudinally framed pontoon than for a transversely framed pontoon.

The dock in question had a rated load capacity of 100 metric tons per meter (30 long tons per foot). This was based on the structural and buoyant capacity of the dry dock.

The 15,000 metric ton vessel had a keel bearing length of approximately 100 meters (330 feet). This resulted in an average loading on the keel blocks of 150 metric tons per meter (45.0 long tons per foot). This exceeded the per meter buoyant capacity of the dock.

During the docking, water was at first deballasted under the loaded blocks. Since the block loads exceeded the buoyant capacity however, the water in the tanks under the vessel approached their minimum levels and the vessel had yet to emerge from the water. Deballasting of the unloaded end tanks was increased to try to get the pontoon out of the water.

Pumping in this manner caused the dock to deflect longitudinally and increased the transverse bending moment on the pontoon. Unfortunately, the crew was not monitoring longitudinal deflections and there was no method of monitoring transverse stresses.

When a loaded tank is deballasted, the buoyancy created by removing water is offset by the weight of the vessel being lifted. The buoyancy is spread across the width of the pontoon but the vessel load is concentrated at the center (on the keel blocks). This creates a tendency of the pontoon to bend up around the keel block. See Figure 2. This puts the bottom plate in tension and the pontoon deck plate in compression. Typically, the pontoon is designed to resist the full buoyancy of the tank offset by an equal but opposite vessel load on the keel blocks. If the block load over a tank exceeds the buoyant capacity of that tank the excess load must be compensated by buoyancy from other areas of the dock. In this case, that additional buoyancy came from the unloaded tanks at each end of the dock. See Figure 3.

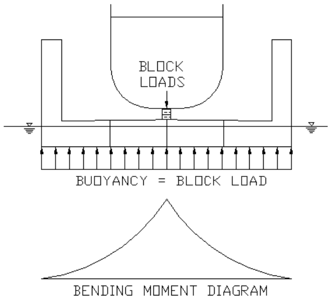

FIGURE 2

BENDING MOMENT DIAGRAM
BUOYANCY EQUALS LOAD

When an unloaded tank is deballasted there is no ship weight to offset the increased buoyancy. The pontoon in this area wants to rise out of the water but is held down by the vertical walls of the wings.

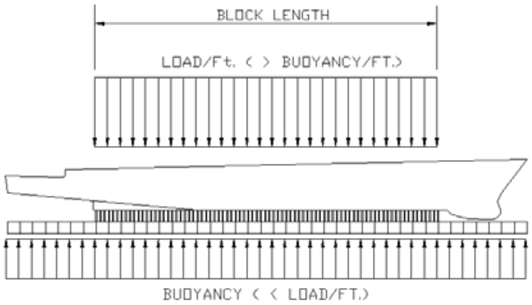

FIGURE 3

DISTRIBUTION OF BUOYANCY

The excessive buoyancy is transferred longitudinally down the wing walls as shear load to the area where the ship loads exceeds the local buoyancy. This shear load in the wing walls provides the additional force required to hold up the ship. This additional uplift force is located at the wing wall vertical shells and can greatly increase the transverse bending moment on the pontoon. This increase in moment causes an increase in the bending stresses in the top and bottom plates of the pontoon. See Figure 4.

This accident was caused by this phenomenon. As the vessel was being pumped up, the water in the loaded tanks was approaching minimum levels. The crew began to pump more out of the unloaded end tanks to attempt to get the pontoon deck out of the water. The additional buoyant force from the end tanks was transferred down the wings to the overloaded tanks.

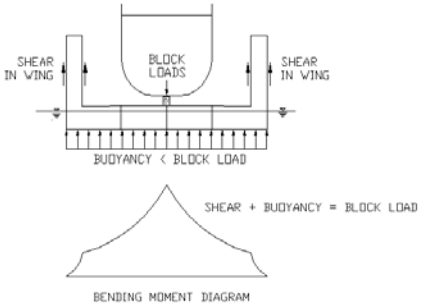

FIGURE 4
BENDING MOMENT DIAGRAM
BUOYANCY LESS THAN LOAD

This increased the transverse bending force on the pontoon to the point when the pontoon deck plate panels buckled (probably first in the area of the ship's knuckle). Once one area failed the remaining panels would have failed "domino" style. The dry dock was a total loss.

The accident could have been prevented if the vessel's load per meter on the blocks was calculated and compared to the dock's rated capacity. It would have been seen that the block load imposed by the vessel was 150 metric tons per meter (45.0 long tons per foot) versus a rated capacity of 100 metric tons per meter (30 long tons per foot). The vessel could have been lightened by unloading prior to docking or the shipyard could have refused to dock the ship.

3.0 CASE 2 - 14,200 TON FLOATING DOCK DOCKING NAVAL VESSEL

Case 2 involved a 14,200 metric ton (14,000 long ton) capacity floating dry dock which was docking a CG-47 Class Naval Vessel. The vessel weighed approximately 9,350 metric tons (9,200 long tons) at the time of docking. Before dry docking, block loading calculations were performed which showed the vessel's load per meter would exceed the dock's rated capacity if the standard keel block arrangement was used. See Figure 5. (These vessels have a very long fantail overhang aft of the last block that results in a high load per meter for a short distance on the aft blocks.)

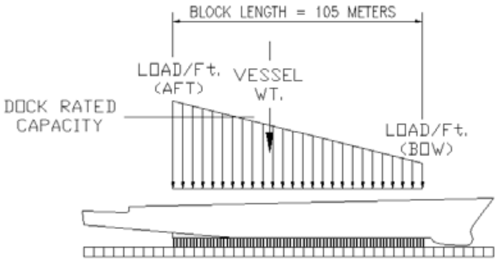

FIGURE 5
BLOCK LOADING WITH ORIGINAL KEEL BLOCK LENGTH

To reduce the load per meter, the shipyard added additional keel blocks along the fantail. This had the benefit of lengthening the effective keel line and reducing the eccentricity between vessel LCG and block centerline. The result of the longer block line was a reduction in the load per meter to an acceptable value. See Figure 6. A pumping plan was prepared based on this loading.

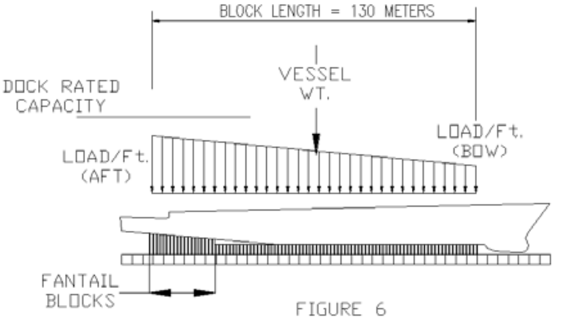

FIGURE 6
LOAD PER FOOT WITH FANTAIL BLOCKS ADDED

Experience with prior dockings had shown dimensional information on the fantail's shape was unreliable for building blocks to the exact height. It was decided to set the initial height of the fantail blocks 75 mm (3") too low. The ship would be landed on the "standard" keel line, lifted 2 feet and stopped. At that point the fantail blocks would be packed tight by divers and then the vessel lifted the rest of the way.

The vessel was landed and the dry dock dewatered according to the pumping plan. After the dock reached operating freeboard it was noticed that the pontoon deck plate had buckled for the entire length of the dock. Further investigation showed the upper portions of the transverse bulkheads were also buckled, the wing wall had tilted in towards dock center and the pontoon sides had deflected up. The pontoon required extensive rebuilding.

An investigation after the accident showed the accident occurred for the following reasons.

The keel block loading was calculated assuming that the combined "standard" keel blocks and the fantail blocks were a typical keel line in which a trapezoidal load configuration as shown in Figure 6 developed. The pumping plan was developed based on this loading. In actuality the vessel was landed on the "standard" keel blocks first and raised 2 feet. This had the effect of preloading the "standard" keel line with the higher loads near the aft knuckle before any load was imparted to the fantail blocks.

In addition to this, the fantail blocks were not wedged up tight against the hull as originally believed. Divers installed shims in the 75 mm (3") gap between the fantail blocks and hull but they left approximately 6mm (¼") gap between shims and the hull. Because of the gap between fantail blocks and hull, the fantail blocks took no load until the vessel was pumped high enough to squeeze the "standard" blocks and deflect the dry dock until the gap closed up.

This docking procedure resulted in an actual block loading that looked approximately like that shown in Figure 7.

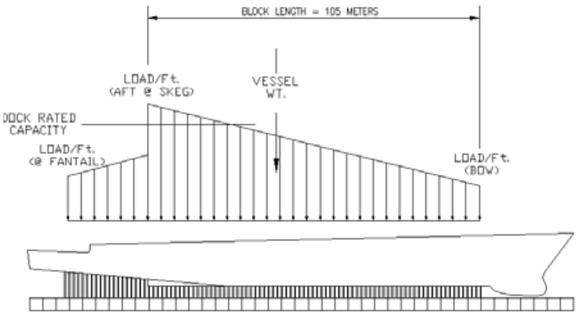

FIGURE 7

ACTUAL BLOCK LOAD

The load on the fantail blocks was much less than the pumping plan assumed and the load on the skeg area of the "standard blocks was much greater than the pumping plan assumed. This high load on the skeg area exceeded the design limit for the dock. This resulted in a situation very similar to the accident in example 1. The excess buoyancy under the fantail blocks was transmitted through shear in the wing walls to the overloaded skeg area. This increased the transverse bending moment causing the deck plate to buckle in that area. Other areas failed "domino style" once one area gave way.

4.0 CASE 3 - 53,400 TON CAPACITY DRY DOCK DOCKING 42,000 TON VESSEL

Case 3 involved a 53,400 metric ton (52,500 long ton) capacity floating dry dock which was docking a Military Sea Lift Command (MSC) class vessel. The vessel weighed approximately 42,000 metric tons (41,300 long tons) at the time of docking. Before the dry-docking, block loading calculations were performed which showed the vessel's maximum load per meter loading was 199.0 metric tons per meter (59.7 long tons per foot). This was less than the rated capacity of the dry dock of 206.7 metric tons per meter (62.0 long tons per foot).

The vessel was brought into dock and the dock properly de-ballasted to compensate for the calculated loads. Once the vessel was high and dry, localized buckling of the pontoon deck was observed.

An investigation into the incident revealed the pontoon deck had significant loss of metal thickness due to corrosion. Ultrasonic thickness measurements of the plate showed the original metal thickness had been reduced by 18 to 43 percent.

Using the methods employed by Reference 1 it can be shown that a 40% loss of metal thickness in the pontoon deck results a reduction of allowable buckling stress of approximately 70% for the plate panels of the pontoon deck. This reduction in allowable stress coupled with the reduced area of the pontoon deck results in a reduction in allowable transverse bending moment of about 75%.

Figure 8 shows the allowable transverse bending moment for transverse frames of the pontoon for the original design condition and for the dock with 40% wasted of the pontoon deck as described in Reference 2. Superimposed on the chart is the actual bending moment induced by drydocking the vessel. It can be seen from Figure 8 that the dry dock had sufficient strength to dry dock the vessel in the original condition but was significantly lacking in strength once the pontoon deck had corroded.

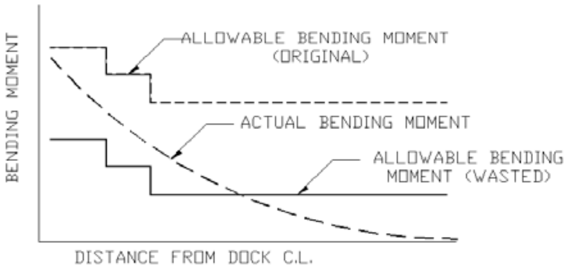

FIGURE 8

TRANSVERSE BENDING MOMENTS

5.0 EFFECTS OF PLATE PANEL ORIENTATION

Pontoon decks that are stiffened longitudinally have steel plate panels that have their long axis parallel to the longitudinal axis of the dock and perpendicular to the line of transverse compressive stress in the plate when docking a ship. This orientation results in a panel that will buckle under a much lower stress than that of a similarly sized panel orientated transversely to the dock's axis. All three of the docks involved in the accidents described above were longitudinally framed. Although it cannot be proved that the accidents would not have occurred had the pontoon decks been constructed with transverse stiffening, it can be shown that transverse stiffening would have made the pontoon decks much less likely to buckle.

5.1 CASE 1

The dock involved with Case 1 had pontoon deck panels 600 mm x 2000 mm x 12 mm thick in the areas that buckled. Condition of the dock was good so corrosion was not a factor.

Table 1 shows the critical buckling stress of this panel depending on its orientation to the direction of stress. Calculated critical buckling stress is based on the methods used in Reference 1.

TABLE 1
CRITICAL BUCKLING STRESS
600 x 2000 x 12mm

STRESS ALONG LONG EDGE	82,000 kPa 11,900 psi
STRESS ALONG SHORT EDGE	218,500 kPa 31,700 psi

The pontoon was designed with longitudinal stiffening. This orientated the compressive stress due to transverse bending along the long axis of the panel resulting in a critical buckling stress of 82,000 kPa (11,900 psi). Had the pontoon been constructed with the same panels but orientated transversely to the dock's longitudinal axis the compressive stress would have been along the short axis and the critical buckling stress would have been 218,500 kPa (31,700 psi), or 266% higher. Failure of the pontoon by buckling of the deck would have been much less likely.

5.2 CASE 2

The dock involved with Case 2 had pontoon deck panels 610 mm x 4000 mm x 8.5 mm thick in the areas that buckled. Condition of the dock was good so corrosion was not a factor.

Table 2 shows the critical buckling stress of this panel depending on its orientation to the direction of stress. Calculated critical buckling stress is based on the methods used in Reference 1.

TABLE 2
CRITICAL BUCKLING STRESS
610 x 4000 x 8.5 mm

STRESS ALONG LONG EDGE	37,200 kPa 5,400 psi
STRESS ALONG SHORT EDGE	149,000 kPa 21,600 psi

Again the pontoon was designed with longitudinal stiffening. This orientated the compressive stress due to transverse bending along the long axis of the panel resulting in a critical buckling stress of 37,000 kPa (5,400 psi). Had the pontoon been constructed with the same panels but orientated transversely to the dock's longitudinal axis the compressive stress would have been along the short axis and the critical buckling stress would have been 149,000 kPa (21,600 psi), or 400% higher. After the accident analyses of the stresses in the pontoon deck at the time of the failure showed the deck would not have buckled had the pontoon deck plating been stiffened transversely.

5.3 CASE 3

The dock involved with Case 3 had pontoon deck panels 815 mm x 5000 mm x 19 mm thick in the areas that buckled. After the accident it was noted that corrosion had caused a 40% reduction in plate thickness in many areas of where the deck had buckled.

Table 3 shows the critical buckling stress of this panel depending on its orientation to the direction of stress for both the original design and assuming 40% reduction in thickness. Calculated critical buckling stress is based on the methods used in Reference 1.

TABLE 3
CRITICAL BUCKLING STRESS
815 x 5000 x 19 mm

	No Corr.	40% Corr.
STRESS ALONG LONG EDGE	102,000 kPa 14,800 psi	37,200kPa 5,400 psi
STRESS ALONG SHORT EDGE	233,000 kPa 33,800 psi	149,000kPa 21,600 psi

The pontoon was designed with longitudinal stiffening. This orientated the compressive stress due to transverse bending along the long axis of the panel resulting in an original critical buckling stress of 102,000 kPa (14,800 psi). The actual critical buckling stress at the time of the accident however was 37,200 kPa (5,400 psi) due to the 40% corrosion. Had the pontoon been constructed with the same panels but orientated transversely to the dock's longitudinal axis the compressive stress would have been along the short axis and the critical buckling stress even of the corroded panel would have been higher than the critical buckling stress of the non-corroded longitudinally orientated panel. Failure of the deck due to buckling would not have occurred.

5.4 OTHER CONSIDERATIONS REGARDING PANEL ORIENTATION

In many instances a plate panel will dish in (permanently deflect down) between the stiffeners. The dishing can be caused by hydrostatic pressure on the deck when the dock is submerged or vehicle wheel loads from machinery running on the deck. The dishing always occurs across the short span of the panel.

For a panel with compression along its long edge, any dishing of the plate will reduce the critical buckling stress of that plate from the theoretical values established for flat plates. Due to the eccentricity of the load path the plate tends to buckle at a lower stress than that of a flat plate. See Figure 9.

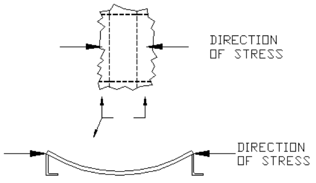

FIGURE 9
EFFECTS OFF PANEL DISHING
LONGITUDINAL PANEL

For a panel with compression along its short edge, any dishing of the plate will increase its radius of gyration and thus tends to increase the critical buckling stress of that plate from the theoretical values. (This is some times referred to as the "corrugated box" effect.) This theoretical increase in stress from the flat plate values is generally not used in design but can help prevent buckling failure should the panel become overloaded. See Figure 10.

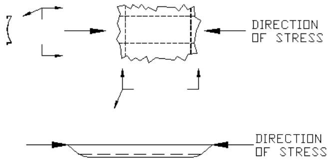

FIGURE 10
EFFECTS OFF PANEL DISHING
TRANSVERSE PANEL

6.0 CONCLUSIONS

All three accidents discussed in this paper involved floating dry docks that had longitudinally framed pontoon decks that buckled while the vessel was being lifted. Each case had a different reason the stresses in the pontoon deck exceeded the critical buckling stress of the deck panels causing collapse. In all three cases however, the critical buckling strength of the deck would have been greatly increase and the accident may have been avoided if the pontoon deck been constructed with transversely stiffened panels of the same dimensions .

Future designers of floating docks should carefully consider the critical buckling stress of the pontoon deck when selecting a framing arrangement.

Obviously, the plate panel orientation of existing docks cannot be changed. There are procedures that the dock operators can follow to minimize the chances of overstressing the pontoon deck however.

The accident described in Case 1 could have been easily avoided if the load per meter (load per foot) the vessel imposed on the blocks was calculated prior to docking. This would have shown that the load per meter capacity of the dock was greatly exceeded. Steps could have been taken to lighten the ship, lengthen the block line or refuse the docking. It is important to realize that dry docks have other limitations besides their overall lift capacity. Load per meter capacities, stability limitations and local loading limits must not be exceeded in order to insure a safe docking.

The accident described in Case 2 was more difficult to foresee. The load per meter (load per foot) was calculated based on certain assumptions. A detailed pumping plan was developed and followed. Unfortunately, some deviations from the assumptions used for calculations had a greater effect on actual loading than anticipated. Also, seemingly minor details in the docking procedures had a significant effect on the results. If the fantail blocks had been wedged tight at the time the shims were installed they would have taken a greater percentage of the vessel's weight and relieved the overloaded skeg area – probably preventing the collapse.

The accident described in Case 3 could have been avoided if the condition of the dock was routinely monitored and the effects of the deterioration on critical buckling stress was realized. This would require developing corrosion criteria for all structural elements of the dock that delineates the amount of corrosion that is acceptable before allowable stresses are exceeded under normal design conditions.

For dry docks constructed with longitudinally stiffened pontoon decks the following actions can be taken to help reduce the chance of buckling failure of the deck:

- Develop corrosion criteria that establishes the amount of corrosion allowed before repair is required.
- Perform periodic inspections of the dock structure and replace items that do not meet the corrosion criteria.
- Periodically inspect the pontoon deck for excessive dishing of the plate between stiffeners.
- Establish an overall lift capacity and maximum load per meter rating for the dry dock.
- Always calculate vessel block loads and never dock a vessel with a load per meter that exceeds the dock's rated maximum load per meter.
- Develop a pumping plan that minimizes longitudinal and transverse bending stresses.

7.0 REFERENCES

1. Naval Sea Systems Command, “DDS 100-4 - Strength of Structural Members”, Department of the Navy, Design data Sheet, 1982.

2. LCDR Scott A. Davis, “Failure Analysis and Lessons Learned From The Floating Dry Docking Of USNS WATSON (T-AKR 310)”, SUPSHIP, Portsmouth, Virginia, 2002.

8.0 AUTHOR’S BIOGRAPHY

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