THE CONOCO JOLLIET TLWP TRANSPORT

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ABSTRACT

To date, the Conoco Jolliet TLWP structure is the only TLP to be dry transported as one complete unit. Most other TLPs presently in operation have been constructed near the installation site, often using large building blocks which were fabricated in remote (and competitive) yards. This paper discusses the engineering process that was followed to ensure a safe transport of the Jolliet TLWP. The support of the TLWP footings was optimized by providing sufficient bearing area without dragging large sponsons through the water. The actual transport is described.

INTRODUCTION

A typical Tension Leg Platform structure is not very suitable to be efficiently wet towed through the water. In accordance with Murphy's law however, in today's global economy the most cost effective shipyard is usually located far away from the final installation site, thus requiring some mode of transportation between the two. The Conoco Hutton TLP was constructed in Great Britain, with some of the major hull components subcontracted to a Far East yard. These components were transported by heavy lift ship. The Conoco Jolliet TLWP was constructed in Singapore and transported to the U.S. Gulf by heavy lift ship upon completion. The Norske Hydro Snorre TLP was constructed in Norway, with some of the major hull components subcontracted to an Italian yard. These components were transported by barges and heavy lift ships. The Shell Auger TLP hull was constructed in Italy and wet towed to the U.S. Gulf for mating with its deck after which the complete unit was installed in the Gulf. The Shell Mars TLP hull will also be constructed in Italy, but this time, the dry transport option of the hull is being considered.

This paper will concentrate on the 1989 dry transport of the Conoco Jolliet TLWP from Singapore to the U.S. Gulf. To date, this is still the only TLP to be dry transported as one complete unit, see figure 1 for a stowage plan. For more details, reference to Van Hoorn and Devoy (1990) is made.

THE TLWP

The Conoco Jolliet Green Canyon block 184 Tension Leg Wellhead Platform is a relative small structure. To minimize the platform's dimensions, most of the process equipment was installed on a conventional (shallow water) platform, removed from the TLWP (deep water) installation site.

The TLWP hull is constructed from stiffened cylindrical shells. The truss deck is carried by four columns of 12.2 m (40 ft) in diameter, 46.2 m (151.6 ft) in height, spaced 42.67 m (140 ft) apart (center to center). Cylindrical pontoons, 7 m (23 ft) in diameter, connect the four columns near the base.

At the moment of load-out, the TLWP's displacement was 8,400 T (18,520 Kips) with its center of gravity at 31.8 m (104.3 ft) above its base. The total draft measured 8.3 m 27.2 ft), leaving a freeboard on the pontoons of 1.2 m (4 ft).

TRANSPORT ENGINEERING

Engineering for the dry transport of the Jolliet Green Canyon TLWP started early 1988, about one year before the actual transport took place. This transport engineering consisted of:
- calculation of intact/damaged stability during transport;
- calculation of stability during on-loading/off-loading;
- determination of appropriate design environmental criteria;
- calculation of ship motions during the design storm;
- calculation of consequential extreme footprint loads;
- design of the optimum sponsons/internal strengthening;
- design of a suitable cribbing arrangement;

- calculation of the extreme transport forces;
- design of a suitable seafastening arrangement.

All methods/results were carefully checked and approved by all parties involved. Since the exact departure date was not known at the beginning of the engineering phase, the engineering process took on an iterative character.

STABILITY DURING TRANSIT

Both the heavy lift ship's initial stability and the statical stability were calculated. The loading condition was optimized so as to meet the stability requirement, without causing excessive roll motion.

The statical stability was calculated including the buoyancy contribution of the TLWP hull which was combined with the hull of the heavy lift ship to form one hydrostatic body for intact static stability calculations. Using this new hydrostatic body, the righting levers were calculated. The maximum righting lever equaled 1.61 m (5.3 ft) at 35 degrees. At 50 degrees, which was the downflooding angle of the heavy lift vessel, the righting lever was still 1.27 m (4.17 ft).

The calculated wind lever curve clearly showed the effect of the large TLWP deck area, which started to expose at larger angles of heel. The 1-min sustained beam wind of 57 knots resulted in a wind lever in upright condition of .26 m (.9 ft). At an angle of inclination of 40 degrees, the wind lever reached its maximum of .47 m (1.5 ft), after which it slowly decreased with increasing heel angles.

The first intercept of the wind lever curve with the righting lever curve occurred at 2.4 degrees. The area ratio equaled 3.10, well in excess of the ABS required minimum of 1.40.

The damaged stability of the heavy lift vessel loaded with the TLWP was checked for one-compartment damage in combination with a 50 knot wind. Flooding of the largest wing tank resulted in an equilibrium list of 5.3 degrees. A 50 knots wind increased this list to 7.7 degrees. The damaged stability area ratio was 1.57, still in excess of the ABS criterion.

STABILITY DURING LOADING

The stability during the loading of the TLWP was calculated in order to determine the most optimum deballast sequence. Over a large range of displacements, the stability was calculated for a range of trims by the stern. This calculation indicated a critical area where the stability was minimum. In this critical displacement range of 60,000 to 58,000 T (132,300 to 127,900 kips), just before the main deck breaks the water, the trim was to be at least 6 m (19.7 ft) in order to guarantee a positive stability (GM') of .5 m (1.6 ft). The deballast sequence was designed to slowly increase the trim from zero (moment of picking up load from the TLWP) to 6 m (19.7 ft) during the critical range, reducing to zero when reaching the departure draft.

The off-loading operation was the reverse of the loading operation.

DESIGN ENVIRONMENTAL CONDITIONS

It is clear that design wave heights/wind speeds are strongly dependent on the actual departure date. The initial selection of the design criteria was based on:
- transport via the Suez Canal must be possible all year round;
- unrestricted transport via the Cape of Good Hope must be possible with departure before May. After May, strict weather routing is to be applied.

Based on the above requirements, the following design environmental conditions were selected and approved:
- significant wave height = 8.51 m (27.9 ft)
- mean wave period = 9.2 - 12.5 s
- mean wind speed = 78 kn
- 1-min sust. wind speed = 93 kn

These criteria were used throughout the engineering phase, including the design of the sponsons and the cribbing arrangement. The final loading condition and seafastening arrangement were based on the environmental conditions for the actual route (via Suez) and departure date (April 15):
- significant wave height = 6.33 m (20.8 ft)
- mean wave period = 8.2 - 11.4 s
- mean wind speed = 47 kn
- 1-min sust. wind speed = 57 kn

SHIP MOTIONS

The behavior of the vessel was calculated using the SHIPMO computer program based on linear seakeeping theory. The motion responses were calculated for three headings: beam seas, bow quartering seas and head seas.

For specific points of interest (TLWP center of gravity, points on TLWP main deck level), linear accelerations were calculated in the three directions of the ship's axis. The linear point accelerations were composed from the linear ship accelerations, the angular ship accelerations and the earth-bound gravity acceleration, taking all relevant phase relationships into account.

The motion response results for the actual departure date are summarized as follows (all values are single extreme amplitudes):
- roll = 4.3 deg
- pitch = 5.3 deg
- transverse acc. at c.g. TLWP = .21 g
- longitudinal acc. at c.g. TLWP = .20 g
- transverse acc. at deck TLWP = .24 g
- longitudinal acc. at deck TLWP = .29 g

The predicted extreme lateral acceleration values on TLWP deck level were well within the process equipment's design limit of .4 g.

FOOTPRINT LOAD

Given the design accelerations/loads, the extreme footprint loads were predicted. The following assumptions were made:
- the TLWP behaves as a rigid body;
- loads which have no phase relationship are treated as being statistically independent.

The TLWP columns static footprint loads was 2,170 T. The total footprint loads, including all the dynamic components, was found

to be 3,822 T (8,426 kips) for the bow quartering wave heading. This all year departure load, increased with 5% for contingencies, was used for the design of the support arrangement.

SUPPORT AND CRIBBING DESIGN

Because of the dimensions and geometry of the TLWP columns, the "overlap" with the carrier's 40 m (131.2 ft) wide deck was insufficient. Sponsons were required to increase the support area.

A 100% support of all four columns would require substantial sponsons welded to the ship's hull, see figure 2. Such large sponsons would have some significant negative side effects, which were in conflict with the advantages of self-propelled dry transportation. It was estimated that four full depth sponsons would reduce the carrier's average transit speed from 12 knots to a slow 8 knots, thus increasing the exposure time by almost 50%.

Small sponsons, which would remain above the waterline, would however not effect the known hydrodynamic properties of the carrier. The selected sponsons measured 16 m (52.5 ft) in length, 3.65 m (12 ft) in width and 3 m (9.8 ft) in height. The ship including these sponsons supported approx. 70% of the total footing area.

In order to ensure the adequacy of the ship's structure (including the proposed internal strengthening) and the sponson design, a structural analysis was performed by Lloyd's Register of Shipping. A large section of the vessel was modelled. The lower part of one of the TLWP columns was added to this model as well as the cribbing interface. Both the static and the dynamic load cases were studied.

From this analysis, the following main conclusions were drawn:
• the behavior of both the ship structure as well as the TLWP structure was satisfactory, with acceptable stress levels;
• Because of the flexibility of the TLWP structure, the peak cribbing pressures found were well beyond the crushing limit of ordinary softwood.

The latter conclusion resulted in the development of special rubber cribbing blocks with a spring stiffness similar to that of softwood, but capable of withstanding cribbing pressures well over 200 kg/cm² (2,844 psi). Each rubber cribbing block measured 1,300 x 200 x 55 mm (51.2 x 7.9 x 2.2 inch). A 15 mm steel plate was built in just below the top surface. This plate guaranteed the stiffness of the top and thus avoiding digging in of the TLWP hard points, see figure 3. Tests confirmed this behavior.

For the final cribbing arrangement, Oregon Pine was selected for the areas where the maximum predicted cribbing pressures were less than 30 kg/cm² (427 psi). For all other areas the rubber blocks were used. The stiffness of the rubber was very similar to that of the softwood and the rubber behaved very well, even at extreme high pressures.

The lateral stiffness of the rubber blocks was of the same order of magnitude as the stiffness of the rubber seafastening fenders and the resulting lateral resistance was incorporated in the design of the final seafastening arrangement.

With a compatible behavior of the rubber compared with that of the soft wooden blocks, it was possible to design a hybrid cribbing arrangement with soft wooden blocks in the low pressure areas (up to 30 kg/cm² or 427 psi) and rubber blocks in the remaining (high pressure) areas (i.e. under the outer shell, pump room bulkhead and longitudinal bulkheads) thus combining the known behavior of the softwooden blocks with the pressure resistance of the rubber blocks. The area ratio between wood and rubber was approximately 1. The cribbing arrangement is given in figure 4.

SEAFASTENING ARRANGEMENT

The design extreme forces on the cargo in case the transport vessel meets its design extreme environmental conditions are a combination of inertia forces due to ship motions, wind forces and transverse gravity forces due to static wind heel.

The analysis, based on the actual departure date resulted in the following design extreme forces:
• transverse   =   2,149   T   (4,738   kips);
• longitudinal   =   1,767   T   (3,896   kips).

A suitable seafastening arrangement was designed to counteract these design extreme forces. The forces on the seafastenings arranged around the TLWP were determined basis the following assumptions:
• the flexibility of the TLWP is small compared to that of the rubber seafastening fenders;
• the lateral stiffness of only 80% of the rubber cribbing blocks is taken into account, assuming 20% of the blocks do not contribute;
• as a combined softwooden/rubber cribbing is used, no friction reduction of the wood is taken into account.

The final seafastening arrangement consisted of 6 seafastening brackets (outfitted with rubber fenders) per column, in a semi-circle around the inside. Each of these seafastening was positioned against a bulkhead or stiffener.

The total lateral resistance of the rubber cribbing blocks was in the order of 1,150 T (2,535 kips). The remaining load was taken by the seafastenings. Per seafastening, this load ranged from 68 to 208 T (150 to 460 kips).

THE DRY TRANSPORT

Before the TLWP load-out, the following preparations were made onboard the heavy-lift vessel:
• installation of local internal strengthening;
• installation of the four sponsons;
• laying out of the cribbing arrangement;
• installation of the positioning guides.

In the meantime, the TLWP was prepared for its voyage i.e. all loose items onboard the TLWP were secured.

Load-out started at daybreak on April 14, 1989 with favorable weather conditions. The heavy-lift ship submerged to its loading draft of 21 m (69 ft) i.e. 9 m (29.5 ft) of water over the main deck, while the TLWP was unmoored from the yard and towed to the loading location. In order to facilitate the connection of tug boats and winch wires, each pontoon was outfitted with two sets of double bollards.

Around noon, the TLWP arrived and was slowly maneuvered over the main deck of the submerged heavy-lift vessel and positioned by winches against the guides. The heavy-lift vessel

commenced deballasting until the TLWP started to rest on its cribbing.

A diving survey indicated that the TLWP was exact in position and deballasting continued in accordance with the prepared deballasting schedule. During this deballasting, a small list to starboard was maintained to limit any free surface effect. The minimum stability range was crossed without a moment of instability, due to the large trim by stern, see figure 5.

Early evening, the main deck emerged and the 24 seafastenings were positioned. Welding started around midnight, after reaching the departure condition, and finished before dawn the next morning. Figure 6 shows the port forward column resting on the deck/sponson with the seafastenings in place.

Around mid morning of that same day, while the weather conditions started to rapidly deteriorate, the heavy-lift ship departed Singapore to deliver the TLWP to Pascagoula, Mississippi.

During the transport, the experienced weather was in general favorable with a maximum wind speed of 35 knots (Red Sea, head on) which slowed the ship down to 9.4 knots. The maximum observed wave height was in the order of 3 m (10 ft). The average transit speed was in the order of 12 knots, with a maximum recorded speed of 15.2 knots.

Onboard observations indicated that the transport never encountered its design sea state as predicted for the transport and the TLWP motions and accelerations remained well within the design limits. This is typical for this type of transport (Van Hoorn, 1991). The rubber cribbing blocks and rubber seafastening fenders were reported to show some dynamic compression resulting from the motions and deflections of the carrier.

After the 41 day transit, the transport arrived at Pascagoula. The off-loading of the TLWP from the transport vessel was conducted on May 28, 1989 near the Ingalls Shipyard. The transport vessel was submerged to off-loading depth. By mid morning, the TLWP was afloat and maneuvered off the transport vessel. Under tow of three harbor tugs, the TLWP was moved to Hamm Industries Shipyard where it was safely moored with a spacer barge placed between the TLWP hull and the dock.

CONCLUSIONS

The dry transportation of the first complete TLP structure required a significant engineering effort to ensure a safe transit from Singapore to the U.S. Gulf.

The unique characteristics of the TLWP structure posed some interesting problems, which required novel solutions. The support area of the ship was increased by adding small sponsons to the side and special rubber blocks were developed to absorb the high cribbing pressures. Extensive finite element calculations were performed to check the TLWP structure as well as the ship structure.

The transport went exceptionally well and actual experienced weather conditions and resulting ship motions were well within the design extremes. With roll and pitch motions being negligible 75% of the transit time, fatigue damage was limited to the absolute minimum.

The reduced sponsons, combined with the purpose designed

rubber cribbing, worked out well. By not altering the underwater body of the heavy lift ship, its motion characteristics were not effected. Furthermore, the heavy lift ship was able to maintain an average speed of 12 knots over the 12,000 mile voyage.

A dry transport by heavy lift ship can be a cost effective solution for moving TLP structures from their construction yard to the installation site. Shell is presently considering a dry transport for the MARS TLP hull from Italy to the U.S. Gulf. Smaller TLPs, such as the Micro TLPs proposed by Hunter (1994) can be transported as complete units, possibly in sets of two.

REFERENCES

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Van Hoorn, F., 1991, "Design Criteria for Self-Propelled Heavy Lift Transports - and how Theory correlates with Reality", *The Second Offshore Symposium on Design Criteria and Codes*, Houston.
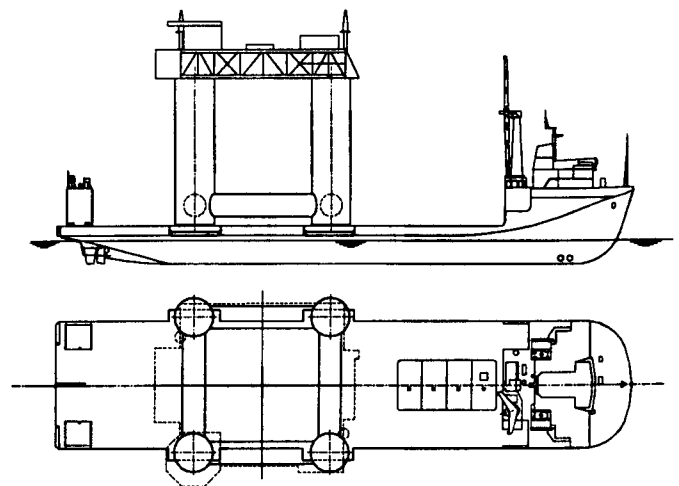
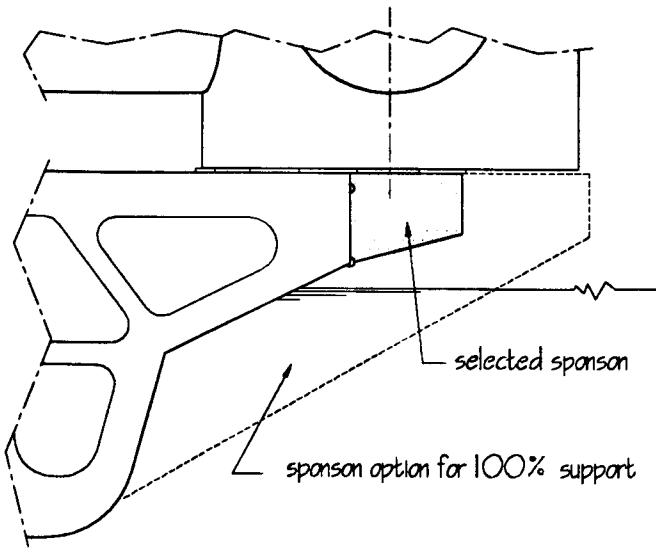**Figure 1**   Stowage arrangement TLP on heavy lift ship

selected sponson

sponson option for 100% support

Figure 2   Cross sections of sponsons considered for support of the columns

bulkhead

bottom plate

steel plate

solid rubber   steel plated rubber
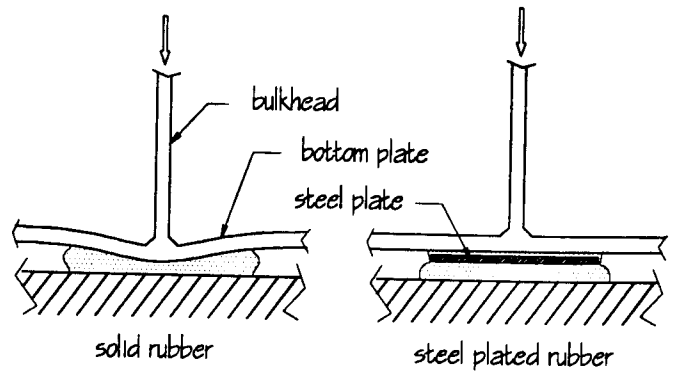
Figure 3   Effect of steel plate in rubber cribbing block

1335

deck edge

3650

rubber block

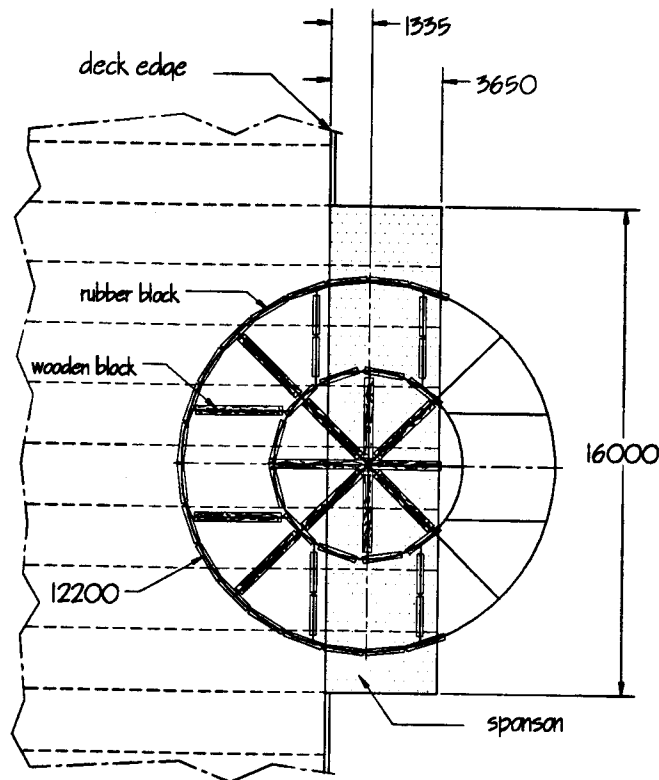wooden block

16000

12200

sponson

Figure 4   Hybrid cribbing arrangement consisting of rubber and softwooden blocks

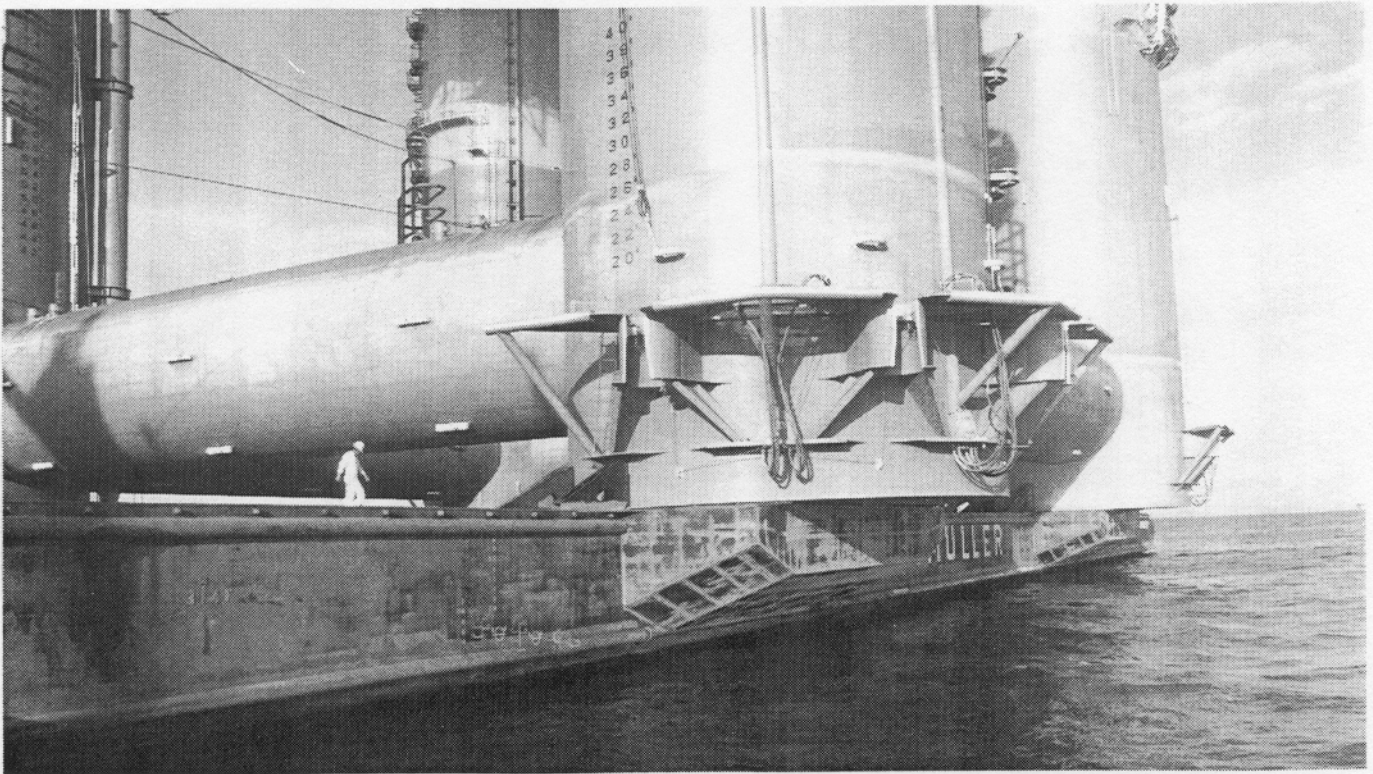**Figure 5**　　　　　TLP lifted out of water with substantial trim by stern

Figure 6　　　　　View of overhanging column, support sponson and seafastenings