SEMI-SUBMERSIBLE HEAVY-LIFT SHIPS IN OPERATION

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INTRODUCTION

Towing floating objects over the oceans has always been a risky business. Many accidents, ranging from minor damages to total losses have been recorded in history. Often the cause was identified as being failure of the towing connection [1]. The author's company, realizing this, entered the heavy lift market by introducing a semi-submersible barge with auxiliary propulsion, followed in the late 70's by fully self-propelled heavy-lift vessels.

The high risk of wet tows is clearly reflected in insurance premiums ranging from 1 to 7.5 percent of the cargo value. Premium rates obtainable for dry transports by self-propelled vessels are in the order of 0.20 percent, which is quite a dramatic difference, particularly considering the fact that the cargo values often amount to many tens of millions of dollars. To date, Wijsmuller Transport B.V. has dry transported over 135 jack-up and semi-submersible drilling rigs, see figure 1. It is therefore not surprising that their self-propelled semi-submersible heavy-lift ships of the Servant class are generally known as rig carriers.
But these versatile vessels can do more and offer a wide variety of capabilities. All kinds of cargoes such as floating drydocks, cranes, floating plants, jackets, modules, etc. have been transported world wide. The ships have also been used for salvage operations, either to lift a damaged vessel out of the water and transport it to the repair yard, or to function as a work platform from which diving and lifting operations were conducted.
Some of the Servant class ship capabilities are illustrated in this article, after the historical background on the origin of these vessels.

2. HISTORICAL BACKGROUND

For over a century, all kinds of dredging equipment, floating drydocks, drilling rigs, etc. have been towed across the world's oceans. Transit times were often long and there were the inherent dangers of towing an object that was not designed or built to be moved long distances across the water, see figure 2.

In the early 1960's, towage companies realized that if awkwardly shaped floating objects could be moved on a barge, this would have the significant advantage of being much faster and safer than the traditional 'wet' tow. At the end of the 60's, loading of floating cargo on board a cargo barge was effected. Thus, the 'dry tow' was born. Subsequently, specialized semi-submersible barges were built for this purpose. These barges all needed 'bottom reaction'; in the submerged condition the stern of the barge had to rest on the seabed.
In the fall of 1976, the author's company entered the heavy-lift market with their inhouse designed semi-submersible barge 'Ocean Servant 1'. One of the most innovative features of this vessel was the installation of buoyancy casings at the four corners, enabling the barge to submerge horizontally without the bottom reaction necessary for conventional barges. As a result, the water depth for submerging was not limited, the bottom did not need to be surveyed by divers, and during refloating and submerging the deck could be kept parallel to the keel of the cargo. Another new feature was that the Ocean Servant was equipped with two 500-hp omnidirectional propellers. With this auxiliary propulsion the barge could still be maneuvered if the tow line with the tug parted. But it was still a barge.
In 1979 the first self-propelled heavy-lift vessel was introduced, the Super Servant. The incorporation of the dual propulsion unit within the transport unit meant the elimination of the 'weak' towing connection, thus a substantial increase in reliability and safety. A total of three ships of this class were added to the fleet. These vessels can be submerged horizontally to a depth of 15 m, allowing 6.5 m of water over their deck. Ballasting and deballasting is done by pumps in combination with air compressors.
In 1983 the first of three Mighty Servants entered the fleet. These vessels belong to the most advanced class in which the know-how and experience of over one decade of heavy-lift shipping activities are incorporated. These vessels are similar in

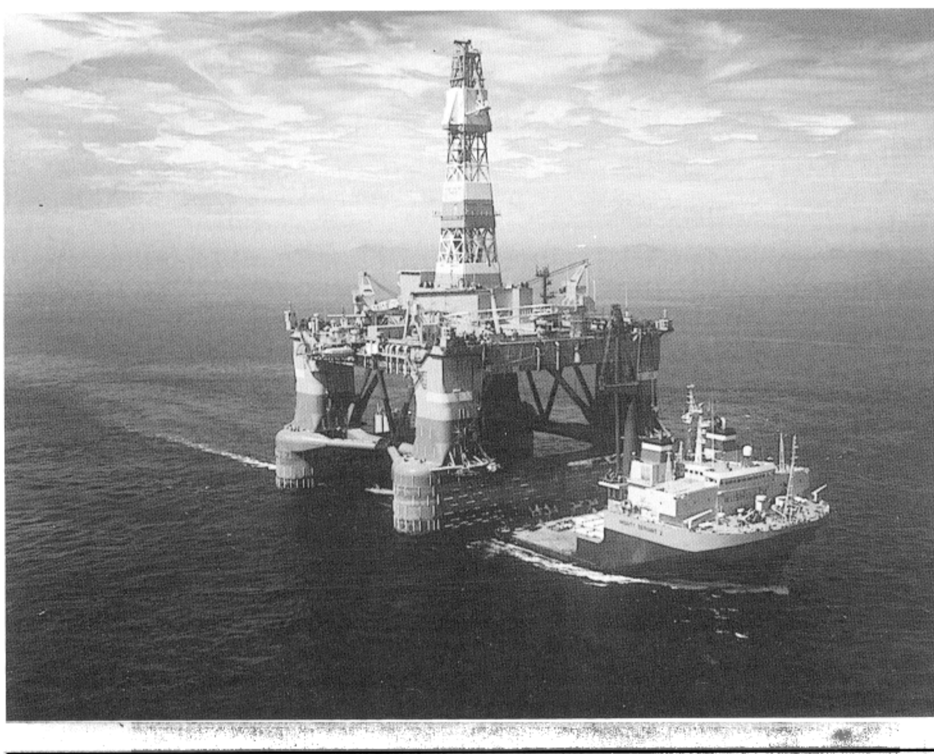

Fig. 1. Dry transport of the 19,000 T 'Ross' drilling rig.

concept to the Super Servant but larger, in order to be able to also transport the larger and heavier cargoes coming on the market. An important feature of these vessels is that the aft buoyancy casings are removable by running them forward on rails into recesses in the superstructure. In this way, an unobstructed clear deck space of up to 5600 m^2 can be created with the possibility of having an overhang of the cargo on three sides.
In April '85, Wijsmuller acquired the 'Dan Lifter' and 'Dan Mover' from Lauritzen Heavyweight Transport A/S. These heavy-lift ships, originally copied from the Super Servants, were renamed 'Super Servant 5' and 'Super Servant 6'.
In August of 1989, Heerema acquired a 75% share in the fleet of heavy-lift ships, as well as the operating company Wijsmuller Transport B.V.
As of April 1, 1990, Wijsmuller Transport B.V. has obtained the commercial and operational management contract for the 'Transshelf'. Wijsmuller Engineering B.V. was involved in the design of this Russian owned heavy-lift vessel.

3. THE CARGOES

Since the introduction of the first Super Servant eleven years ago, a variety of cargoes have been dry transported by the Servant class vessels. Starting with drilling rigs and dredging equipment, diversification soon increased the types of cargoes transported. Floating plants, pressure vessels, cranes, floating drydocks, jackets, modules, Navy vessels, to name but a few, clearly showing the flexibility of the vessels, which was an important design parameter.
In the conventional drilling rig market, a scale increase became noticeable. While the first jack-up rig dry transported weighed approximately 5,500 T, with legs of 85 meters in height, the largest jack-up transported 8 years later weighed no less than 21,500 T, with legs of 167 meters in height.

These developments in scale and diversification were made possible by the ever increasing engineering capabilities of the marine industry. Motion response computer programs became available and the author's company incorporated these in their inhouse developed dedicated suite of computer programs for dry transport computations [2]. Model tests were performed to tune the motion response program and to study the non-linear behavior of the vessels in the roll mode. Continuous feedback from the heavy-lift vessels resulted in a better insight in the environmental criteria.
To illustrate the capabilities and versatility of the self-propelled semi-submersible heavy-lift vessels of the Servant class, six

Fig. 2. 'Wet' tow of a jack-up drilling rig.

dry transports will be further discussed below.

Jack-ups 'Norbe 2' and 'Norbe 5'

In September 1988, two medium size jack-up drilling rigs needed to be mobilized from Salvador, Brazil to Bombay, India. The footings of both rigs were protruding no less than 4.5 meters below their hull bottoms. These footings consisted of 14 meter diameter cans with pyramid shaped tips underneath.
In case of a wet tow, these footings would result in a large drag, limiting the towing speed to 2 – 3 knots. Transit would take a minimum of 150 days. This exposure, in combination with the length of the jack-up legs of 90 and 125 meters, made the jack-up owner look for alternative solutions. The dry transport option turned out to be the safest and most economical option.
Before this transport could be effected, extensive engineering and preparations were required. The tips of the rig's stern legs were accommodated by four large recesses, cut in the deck of the 'Mighty Servant 3'. The stowage of the rigs was such that the bow legs were overhanging the sides of the ship. To provide support to the rig hulls, the cribbing arrangement was elevated 3.25 meters above the deck, by placing the softwooden cribbing blocks on steel T-bars, which in turn were welded onto 2.95 meter high steel pipes. A total of 284 of these pipes were required to transfer the loads from the rig hulls into the structural members of the ship's deck.
Installation of the recesses and the cribbing arrangement took 3 weeks after which the rigs were floated on. After loading, the aft legs were lowered slowly onto cribbing blocks in order to provide additional support for the dynamic loading. Seafastening was done by placing standard seafastenings around the aft footings of the rig, see figure 3. In order to ensure that the inertia loads on the rigs were transmitted to the footings, the legs were shimmed inside their guides.

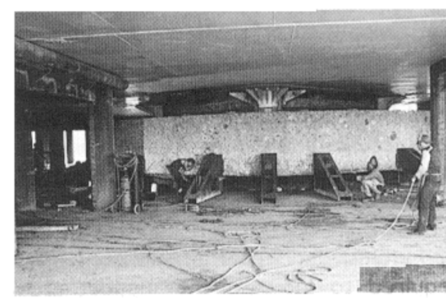

Fig. 3. Seafastenings around the jack-up's aft footings.

Fig. 4. 'Norbe 2' and 'Norbe 5' upon arrival in Bombay.

Upon approval of the seafastening by the Marine Warranty Surveyor, the ship departed for Bombay, via the Cape of Good Hope. Weather routing ensured that the most optimum route was followed and after 32 days the transport arrived safely in Bombay, see figure 4.
The offloading operation was the reverse of the loading operation and took place offshore were sufficient water depth was available. Seafastenings were cut and the

'Mighty Servant 3' submerged to its maximum draft at which moment the rigs were free floating with their footings just over the cribbing. Local tug boats towed the 'Norbe 2' and 'Norbe 5' clear from the ship and continued on to their drilling locations at Bombay High.

Tension Leg Wellhead Platform

In May 1989, the first TLWP (Tension Leg Wellhead Platform) was delivered in the U.S. Gulf by the 'Mighty Servant 3' [3]. This heavy lift ship departed Singapore only 41 days earlier after loading the TLWP by means of the float-on method. The dry transport of this platform broke new ground in various areas.

The TLWP is constructed from stiffened cylindrical shells. The truss deck is carried by four columns of 12.2 meters in diameter, 46.2 meters in height, spaced 42.67 meters apart (center to center). Pontoons, 7 meters in diameter, connect the four columns near the base. At the moment of load-out, the TLWP's displacement was 8,400 T with its center of gravity at 31.8 meters above its base. The draft measured 8.3 meters.

Given the relatively small footprints of the columns, in combination with the fact that these would mostly overhang the carrier's 40 meter wide deck, four sponsons were required to increase the support area. Small sponsons of 16 meters in length, 3.65 meters in width and 3 meters in height, were proposed. These sponsons remained above the waterline, and thus did not effect the known hydrodynamic properties of the carrier, see figure 5.

In order to ensure the adequacy of the ship's structure (including the proposed internal strengthening) and the sponson design, Lloyd's Register of Shipping performed a detailed structural analysis using their 3-D finite element program. 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. From this analysis, the following main conclusions were drawn:

1. The behavior of both the ship structure as well as the TLWP structure was satisfactory, with acceptable stress levels.
2. 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 capable of withstanding cribbing pressures well over 200 kg/cm^2.

After 10 days of preparations (installation of local internal strengthening and the four sponsons, laying out of the cribbing arrangement and installation of the positioning guides), the 'Mighty Servant 3' moved to the West Jurong anchorage where the TLWP was floated-on and seafastened, after which the heavy-lift ship departed Singapore to deliver the TLWP at Pascagoula, Mississippi, see figure 6.

During the transport, the experienced weather was in general favorable. The average transit speed was in the order of 12 knots, with a maximum recorded speed of 15.2 knots. The design extreme roll amplitude was 4.3 degrees and the design extreme pitch amplitude was 5.3 degrees. The observed extreme motions were all well within these design limits, leaving a safety margin in the order of 60%.

Upon arrival at Pascagoula, the seafastenings were cut and the 'Mighty Servant 3' was submerged to off-loading depth after which the TLWP was maneuvered off and towed away by three harbour tugs.

Challis Field SALRAM

The BHP Challis mooring system consists of a 121 meter tubular riser connected with an universal joint to a 34 by 34 meter gravity base structure. A 240,000 T dwt storage tanker is hooked up to the riser by means of a hinged yoke.

The riser/base structure, weighing over 4,500 T, was skidded onboard the 'Mighty Servant 2' at the Sembawang Shipyards, Singapore around mid August, 1989. To facilitate this operation, the ship's starboard buoyancy casing was moved forward thus creating an unobstructed cargo deck, see figure 7.

Skidding was effected by center-hole jacks controlled from two electro-hydraulic power packs. The vessel was ballasted continuously during the skidding operation to compensate for the increase of load to be carried, its corresponding heeling moment, as well as the change of tide. The speed of the skidding operation (average of 6 m/hr) dictated that the vessel needed to be maintained level (in an even heel/even keel condition) with the land side skid rails for a period of 2.5 hours.

After completion of the skidding operation, all skidding equipment was removed from the ship, and seafastening started, which consisted of securing the skid shoes to the deck, using standard Wijsmuller seafastenings and securing the riser and base to the skid shoes by means of welding shear plates in between. During seafastening, work on the base and riser continued

Fig. 5. Small sponsons were added to increase the deck area.

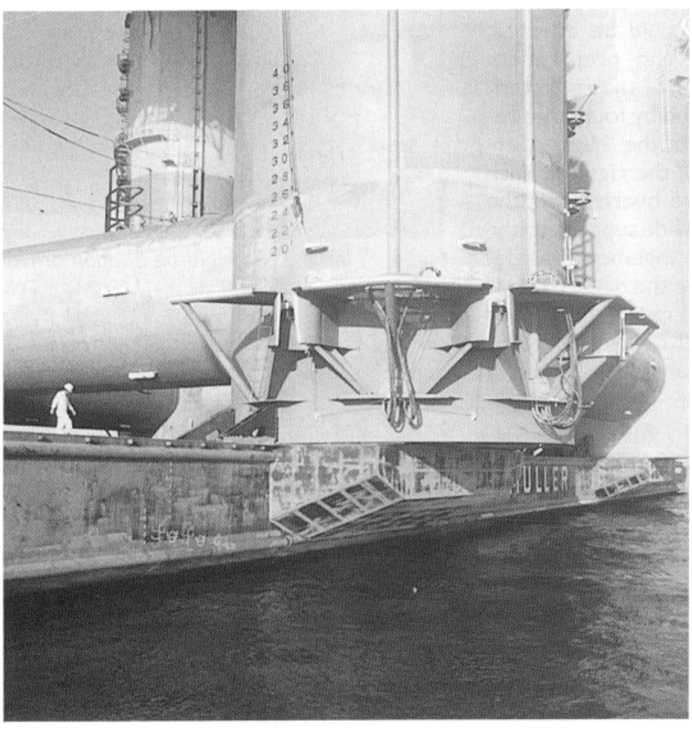

Fig. 6. TLWP enroute from Singapore to the U.S. Gulf.

Fig. 7. Skidding-on of the Challis Field SALRAM.

in order to get it finished. Guideposts were erected on the deck and the tugger wires were rigged. Upon completion, the 'Mighty Servant 2' departed Singapore, heading for Australia, see figure 8.
The transport to the offloading/installation

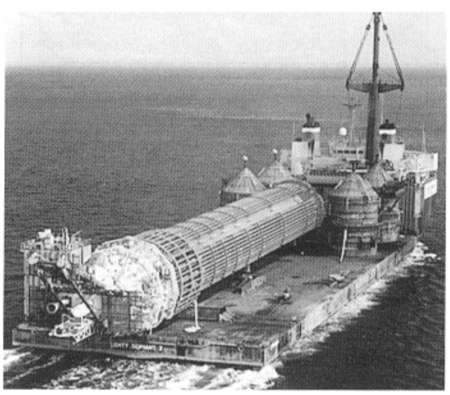

Fig. 8. Challis Field SALRAM enroute to the Timor Sea.

site in the Timor Sea, a sailing distance of 1600 nautical miles, took 6 days. During the voyage, the environmental conditions were calm and the monitored ship motions were well within the design limits, with roll angles not exceeding 3 degrees.
After removal of the seafastenings and final inspection of the riser, the 'Mighty Servant 2' submerged, in accordance to the model tests performed at Marin /4/, to a draft of 21.5 m, resulting in 9.5 m of water over deck. The riser/base structure thus had sufficient clearance and was floated off safely.

Fully erected Container Cranes
With the world-wide increase of containerization, the demand for container quay side cranes is still rising. These cranes can either be assembled on the terminal's quay after having been delivered 'knocked-down' i.e. in small pieces or they can be delivered 'fully erected' i.e. completely assembled. This of course has many advantages such as little disturbance of the terminal's activity, small number of expatriates required, short commissioning time, etc.
The author's company has delivered numerous fully erected container cranes to various terminals around the world. The most recent voyage being the delivery of two MGM post-Panamax ship toshore cranes from Venice, Italy to the Thames Estuary Terminal in England, last March.
The container cranes were rolled on board over the stern of the 'Super Servant 1'. The bogies were turned 90 degrees to effect this operation. With the bogies turned, it was possible to position seafastening boxes directly under the corners of the crane portals. These boxes were bolted to the cranes and consequently welded to the ship's deck. The crane booms were lowered in order to release the A-frame and, because of the extreme length of these post-Panamax booms, the forward boom was supported on the ship's forecastle deck. Internal strengthening, required for the voyage, was installed by the crane builder before loading of the cranes. Although severe weather was encountered during the crossing of the Bay of Biscay, the monitored motions were well within the predicted extremes. Figure 9 shows the transport two days before arrival at the Thames Estuary Terminal.

The roll-off operation was in principle the reverse of the loading operation. Seafastenings were removed and the booms were raised. A link beam provided the connection between the rails on deck of the 'Super Servant 1' and the temporary rails on the quay. Ballasting operations compensated for the crane movements and tide, keeping the ship level with the quay during the operation. Once in position, the cranes were jacked-up and the bogies were turned after which the cranes were lowered onto their permanent rails.

Damaged tanker 'Imperial Acadia'
A number of ships have been dry transported by the Servant class vessels. This included intact vessels in which cases the logistics of transporting a number of vessels in one go proved to be cost effective, as well as damaged vessels which were unfit for a wet tow. The demobilization of 3 wooden U.S. Navy minesweepers to Seattle from Bahrain by 'Super Servant 3' last

Fig. 9 Post-Panamax ship to shore container cranes in transit. (Photo: Fotoflite).

Fig. 10. Demobilization of 3 wooden U.S. Navy minesweepers.

April is a good example of the fist category, see figure 10.

The latter category is well illustrated by the dry transport of the 'Imperial Acadia'. During a severe storm in February of this year, this 135 meters long, Canadian tanker was slammed against the side of a dock on the French Miquelon Island. Consequently, the ship's starboard side was caved in 1.5 to 2 meters, from the bilge up to the main deck over almost its entire length. The structural integrity of the ship was reduced significantly and a wet tow to a yard in Halifax, some 400 miles distant, was considered too great a risk.

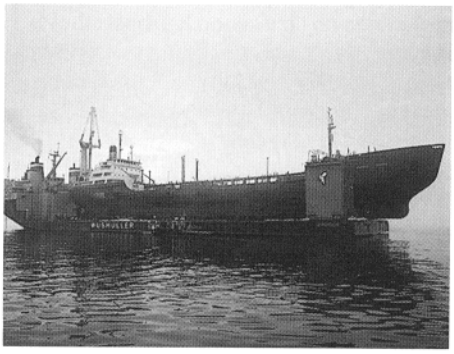

Fig. 11. Arrival of the 'Imperial Acadia' in Halifax.

Using the dry transport option, the tanker's hull was completely supported by the 'Mighty Servant 1', thus reducing the dynamic bending stresses to an absolute minimum. Prior to loading, the tanker was ballasted such that it no longer listed towards its damaged side. This ballasting increased the displacement to well over 8,000 T. The actual transport took less than 2 days and the 'Imperial Acadia' was safely delivered (see figure 11) to the Halifax shipyard, for repairs to the hull.

Floating drydock 'Karish'

Floating drydocks generally operate in sheltered waters and are therefore designed and built for still water conditions only. In case of an open water wet tow, the anticipated dynamic wave loading needs to be taken into account which may lead to substantial additional steel. In case of relocation of an older drydock, strengthening is often required. In spite of these precautions, such tows remain hazardous and not seldom they have ended in major damage or total losses.

During a dry transport, the floating dry dock is lifted out of the water and supported over all or most of its length, thus reducing the dynamic loading to an absolute minimum. This mode of transportation has been successfully applied to delivery of newbuilding drydocks as well as relocation of older drydocks.

One such relocation was only just completed last June, when the 'Transshelf' safely offloaded the 142 meter long 'Karish' drydock in Batangas, Philippines. This 7,500 T capacity drydock was loaded 25 days earlier in the Mediterranean. Before loading, minor preparations were required, such as removal of the forward apron (in order to reduce the overhang) and seafastening of the docking blocks and the wing wall cranes. Because of the dock's width of 30.7 meters, the port buoyancy casing of the 'Transshelf' was moved forward and the dock was loaded slightly skewed on the deck of the heavy-lift carrier.

Although the transport did meet some monsoon weather when crossing the Arabian Sea, the voyage was without incidents and the 'Karish' drydock arrived at its destination within schedule, see figure 12.

Before offloading, while the seafastenings were being cut, the new owner utilized the opportunity to grit blast and paint the under water part. When this 'drydocking' was finished, the heavy-lift ship submerged and the drydock was floated off.

With the delivery of the dock, the 'Transshelf' successfully completed its first voyage under its new management. All engineering and preparations were done in the IJmuiden head office, in accordance with the Wijsmuller Transport B.V. 'Standards for Self-Propelled Heavy-Lift Transports'. The loading and offloading operations were coordinated by a Wijsmuller superintendent.

4. CONCLUSIONS

The dry transports described above give some insight in the versatility and capabilities of the self-propelled semi-submersible heavy-lift vessels. The dual propulsion system, high transit speed, in combination with the possibility to avoid severe storms, makes the dry transport the safest option in comparison with tug/barge combinations or wet tows. This is clearly indicated by the differences in cargo insurance premiums.

Taking this insurance difference plus all other cost factors (transit time, riders, strenghtening, etc.) into account, dry transportation also often turns out to be the most cost effective option.

Each dry transport requires tailor made engineering. The inhouse developed suite of computer programs provides the transport engineers with a state of the art tool to quickly assess the feasibility of each transport. These programs are continuously updated. All engineering is done in accordance with the Wijsmuller Transport B.V. 'Standards for Self-Propelled Heavy-Lift Transports'.

With the heavy-lift market slowly improving, dry transports of a wide variety of cargoes will continue to be executed on a daily basis. Some of these will be run of the mill, others will be record breaking. But all of them will be spectacular in their own way.

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Fig. 12. 'Karish' drydock onboard the Russian owned 'Transshelf'.