DRY TRANSPORTATION OF LARGE SEMI-SUBMERSIBLE UNITS

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SUMMARY
Dry transportation of semi-submersible drilling units has become common practice in recent years. The paper reviews the merits of this mode of transportation and the technical problems which have to be overcome in the engineering of the transport.

1. INTRODUCTION

Although heavy cargoes have been dry-towed since the early sixties, the first semi-submersible drilling rig was not dry-transported until 1983. Transportation by selfpropelled heavy lift vessels means:

- reduced transit time, thus a reduction of downtime and speed-ups of revenues,
- possibility to avoid stormy areas,
- reduced motion response, hence reduced inertia forces on the cargo,
- manoeuvrability in all circumstances,
- increased safety, hence reduced insurance premium.

Dry transportation of semi-submersible drilling units poses many technical challenges on the transporter [1]. Standard analytical methods may not be accurate enough to meet all of them in an adequate way. In this respect model tests have proven to be an acceptable means to generate data on motions, slamming, hydrodynamic loads, etc. which can be used for the design of cribbings and seafastenings.

Because of the large overhang of the rig floaters and the fact that often the outer columns are situated outside the carrier's deck edges, much attention must be paid to the strength of the floaters, overall as well as local. Since the nett supporting area is relatively small in relation to the weight of the rig, also the carrier strength must be carefully checked to avoid any structural member to become overstressed. A finite element model is used, incorporating both rig and ship, as well as the cribbing in order to determine their mutual influence on the load distribution. The shape and density of the cribbing layers can be optimized in this way to avoid local areas of high stress. Full scale measurements support the value of this method.

2. BACKGROUND

Traditionally, the semi-submersible drilling rigs were towed by large ocean going tugs. The transit speed was low, often in the order of 2-4 knots. Sometimes this could be improved by having the rig's propulsion assisting the tug. This is not always economical especially if the rig's propulsion system was designed for station keeping.

In the mean time, jack-up drilling rigs with their awkward hull shapes and fragile legs were dry-towed on barges since the early seventies, and dry-transported by selfpropelled heavy lift vessels since 1979, the year of the introduction of the "SUPER SERVANT 1". Not until 1983, however, the first semi-submersible drilling rig was dry-transported. Wijsmuller transported its first semi-submersible rig in the following year, and successfully increased its market share since, see Table 1.

Table 1
Semi-submersible rigs dry-transported by Wijsmuller to date

Date	Name	Weight (t)	From	To
6/84	Benreoch	17200	N. Zealand	Spain
1/85	Sedco 601	7000	Spain	U.S. Golf
7/86	ROSS	19200	Japan	Norway
10/86	Shelf-6	12800	Finland	Shakalin
10/86	Bowdrill 2	17000	Canada	China

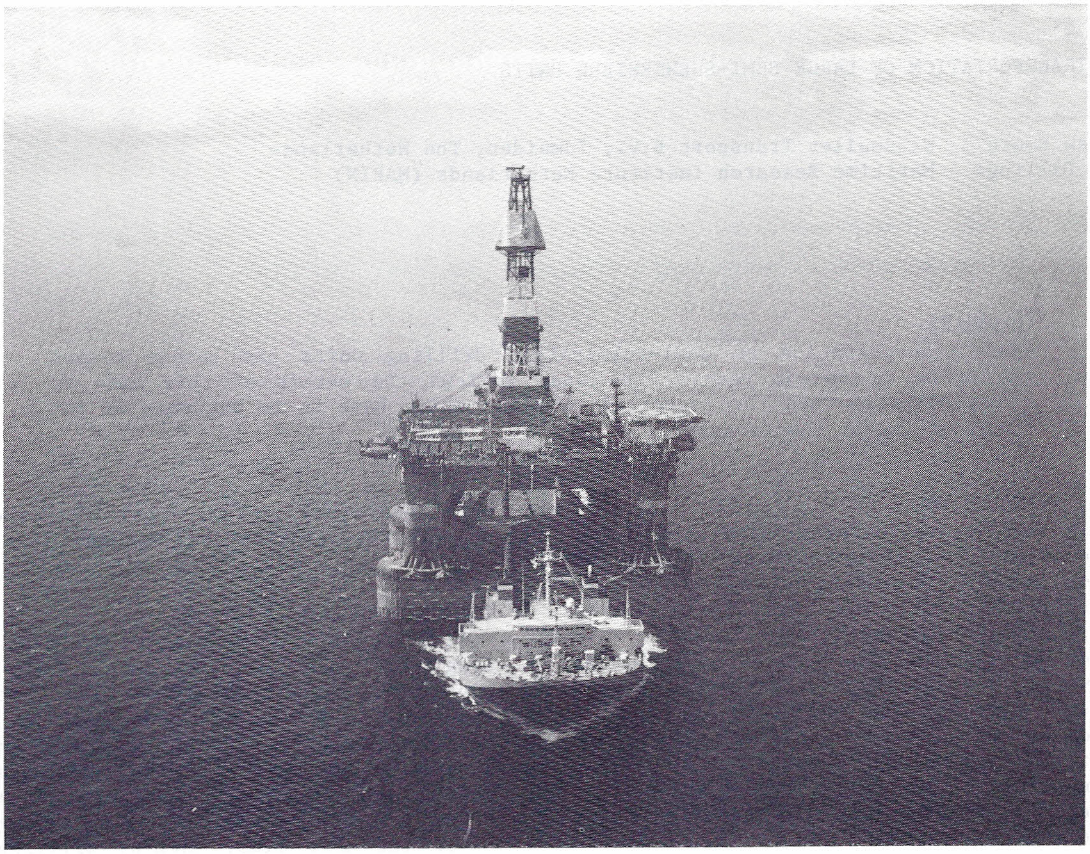


Fig. 1. ROSS semi-submersible drilling rig transported by "MIGHTY SERVANT 2" from Japan to Norway

Because of the great spacing of the rig floaters, all rigs were loaded athwartships on the carrier. In this way maximum support area is achieved while keeping the overhang at a minimum (diagonally positioning of the rig will increase the support area but also the overhang). Furthermore, the rig's strength members more or less coincide with the carrier's strength members.

Fig. 2 illustrates the overhang of the various rig floaters. It is obvious that an ocean transport of this type of cargo can only be done after extensive feasibility studies.

3. TRANSPORT ENGINEERING

3.1 Introduction

Before a heavy lift transport can be realized a substantial engineering effort is required to ensure its feasibility and safety. Depending on The type of cargo special attention must be paid to specific areas [1]. In case of large semi-submersibles, loaded athwartships on deck, these areas are:

- design environmental conditions,
- motion responses,
- slamming,
- floater strength,
- deck strength carrier,
- cribbing design
- seafastening arrangement.

Dynamical stability is in general no problem, given sufficient initial stability, because of the buoyancy contribution of the overhanging floaters, see Fig. 3. The ABS 1.40 ratio is often easily met.

3.2 Design environmental conditions

The ship motions are induced by the waves which can only be predicted by using existing wave data. The resulting design sea state is often a point of discussion between the various parties involved. Wijsmuller just recently established a new method for determining the long-term design sea state.

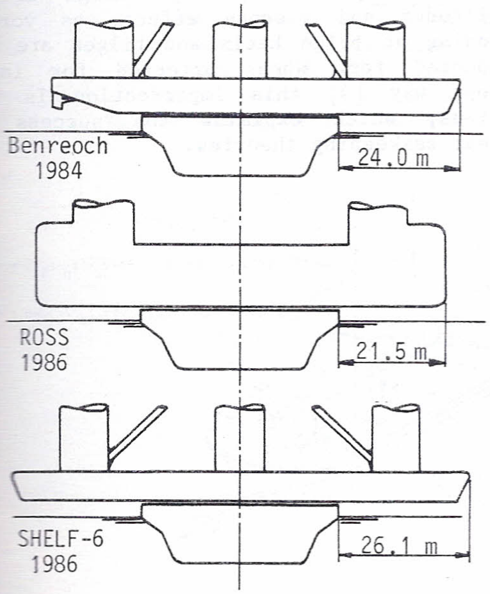


Fig. 2. Typical cross-sections showing the overhang of various semi-submersible drilling rigs

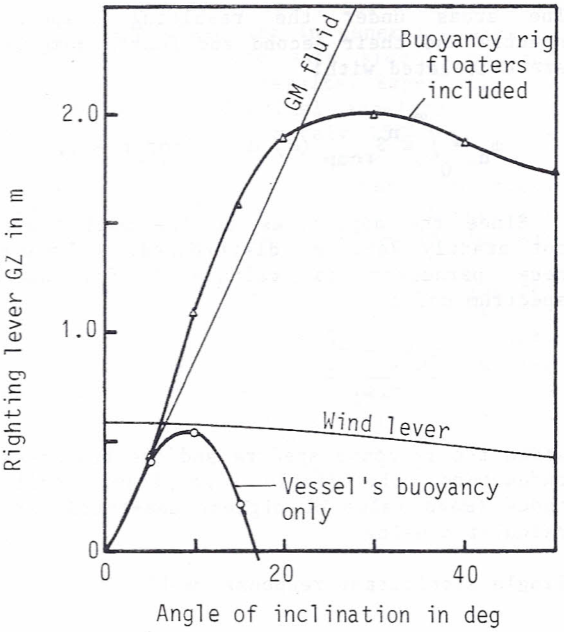


Fig. 3. Influence of floaters on dynamical stability

It is based on the "Global Wave Statistics" as compiled and edited by British Maritime Technology Ltd. [2]. The data are presented in terms of probability distributions of wave heights, periods and directions for the global selection of 104 sea areas. An analysis technique has been used to derive reliable statistics of wave period by an analytical modelling of the joint probability distribution of heights and periods, thus avoiding any use of visual observations of wave period, which are known to be very misleading. From the above long-term wave statistics, short-term design sea states are derived, a probability of exceedance of 5% is used to establish the wave height.

The long-term prediction of the design wind speed is based on the "U.S. Navy Marine Climate Atlas of the World" (Volume IX, World-Wide Means and Standard Deviations) as prepared by the Naval Oceanography Command Detachment [3].

The design wind speed is used for the stability check and wind load calculation. The design sea states are used for the motion response calculation.

3.3 Motion responses

The behaviour of the vessel was calculated by MARIN with the aid of their computer program SHIPMO based on linear seakeeping theory. Within the scope of such a theory the problem of determining the wave induced motions can be separated in the problem of determining the wave induced forces in waves (vessel fixed in space) and determining the unit motion response reaction forces (in calm water). The wave induced forces, together with the reaction forces and the inertia and geometric characteristics of the vessel, result, when applying Newton's law, in the motion response. The computer program used for determining the induced wave and reaction forces is based on two-dimensional strip theory. An important feature of the program is the incorporation of forward speed effects. The surge motion is neglected. In order to "tune" the calculations, model tests were performed. The motion responses were calculated for beam, bow quartering and head seas.

The motion responses in irregular waves are calculated by multiplying the squared response functions with a uni-directional (long-crested seas) Pierson-Moskowitz wave spectrum, given by the following formula:

$$S_\zeta(\omega) = A\omega^{-5}\,e^{-B\omega^{-4}}$$

where $A = 172.8\ (H_{sig})^2 (T_m)^{-4}$

$B = 691\ (T_m)^{-4}$

The areas under the resulting response spectra and their second and fourth moments are calculated with:

$$m_n = \int_0^{\infty} \omega^n S_{resp}(\omega)\, d\omega \qquad \text{for } n = 2,4$$

Since the amplitudes of the motion are not exactly Rayleigh distributed, a broadness parameter is calculated for each spectrum using:

$$\varepsilon^2 = \frac{m_0 m_4 - m_2^2}{m_0 m_4}$$

Given the response spectra and the broadness parameters, the single significant amplitudes (mean value of highest one-third) are calculated using:

Single significant response amplitude =

$$2\sqrt{m_0}\ CF$$

in which CF = correction factor to take the broadness into account

$$= \sqrt{(1 - \varepsilon^2)}$$

The extreme values of a random process are depending on the number of observations or, more meaningful, depending on the duration of the process being stationary. This stationary period is taken as six hours, analogous to the design sea state calculations. Given the response spectra, the most probable single extreme amplitudes are calculated :

Single extreme response amplitude =

$$\sqrt{m_0}\ \sqrt{2 \ln \left(\frac{(60)^2 T}{2\pi} \sqrt{\frac{m_2}{m_0}}\right)}$$

in which T = stationary storm period
= six hours.

For up to five different points, fixed to the vessel, linear accelerations can be calculated in the three directions of the ship's axis. The linear point accelerations are composed of the linear ship accelerations, the angular ship accelerations and the earth-bound acceleration of gravity. For the formulas, see Fig. 4.

Conventional linear motion theory assumes small motion amplitudes and an irrotational and ideal fluid medium. This means that a number of phenomena, e.g. large motion amplitudes and viscous effects as vortex shedding at bilge keels and bilges are not accounted for. When corrected for in a proper way [4] this imperfection is not serious, which explains the success of linear seakeeping theories.

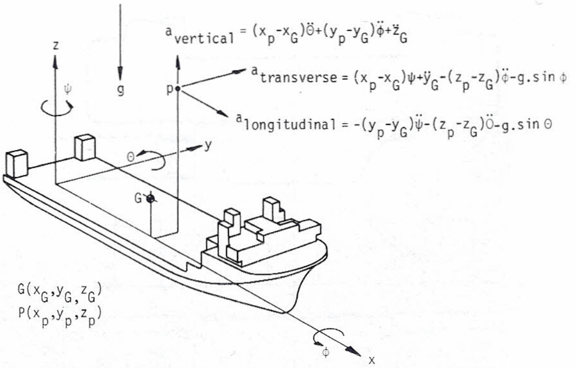


Fig. 4. Tri-axial point acceleration

3.4 Model tests

For the experiments use was made of a 1 to 40 scale model of the "Mighty Servant 2". The rigs were represented by light weight floaters and steel weights, see Fig. 5. The connection between the floaters and the ship model consisted of a six component force transducer for recording the hydrodynamic loads acting on the floaters.

All tests were performed in the Seakeeping Laboratory of MARIN. They were performed in long-crested irregular waves in order to get an impression of the statistical properties of the hydrodynamic loads. Measurements comprised the loads acting on the floaters, the various motion and acceleration levels and the impact pressures under the floaters. The inertia loads acting on the rig were calculated (in the time domain) from the recorded acceleration levels. The total loads were obtained by adding the hydrodynamic and inertia components.

The tests showed that the overhanging floaters affect both the wave induced roll excitation and the restoring roll moment in a very non-linear way. The total loads acting on the rig in beam seas exceed the loads in head seas by more than a factor of two indicating that beam seas represent a very unfavourable wave direction.

3.5 Model test results versus prediction

In order to check the validity of the motion response prediction (ignoring the effect of overhang), a comparison is made with the model test results. The comparison is made for the following design sea state:

$$H_{sig} = 8.5\ \text{m};\ T_m = 10.5\ \text{s}$$

For the comparison of the single extreme amplitudes in beam, bow quartering and head seas, see Table 2. It shows that the angular ship motions are significantly underestimated, because of the long natural roll period and the fact that the additional roll excitation induced by the pontoons is not taken into account, see Fig. 6.

Fortunately, the angular motions are not design parameters. For calculation of inertia loads, the tri-axial point accelerations are used and these are in general overestimated (hence "on the safe side") compared with the model test results. Especially the vertical and longitudinal accelerations in head seas are approximately 150% off. This can be explained to some extent by the difference in forward speed (zero for model tests, 6 knots for prediction) and the fact that surge motions are neglected in the calculations.

The measured and predicted forces for the design sea state are given in Table 3. The measured forces include all hydrostatic forces and their phase relationships. The measured values given in Table 3 are the single extreme amplitudes, corrected for a 6 hour storm period. Some of these loads are strongly asymmetric, due to the influence of the hydrodynamic loads, see also Table 4.

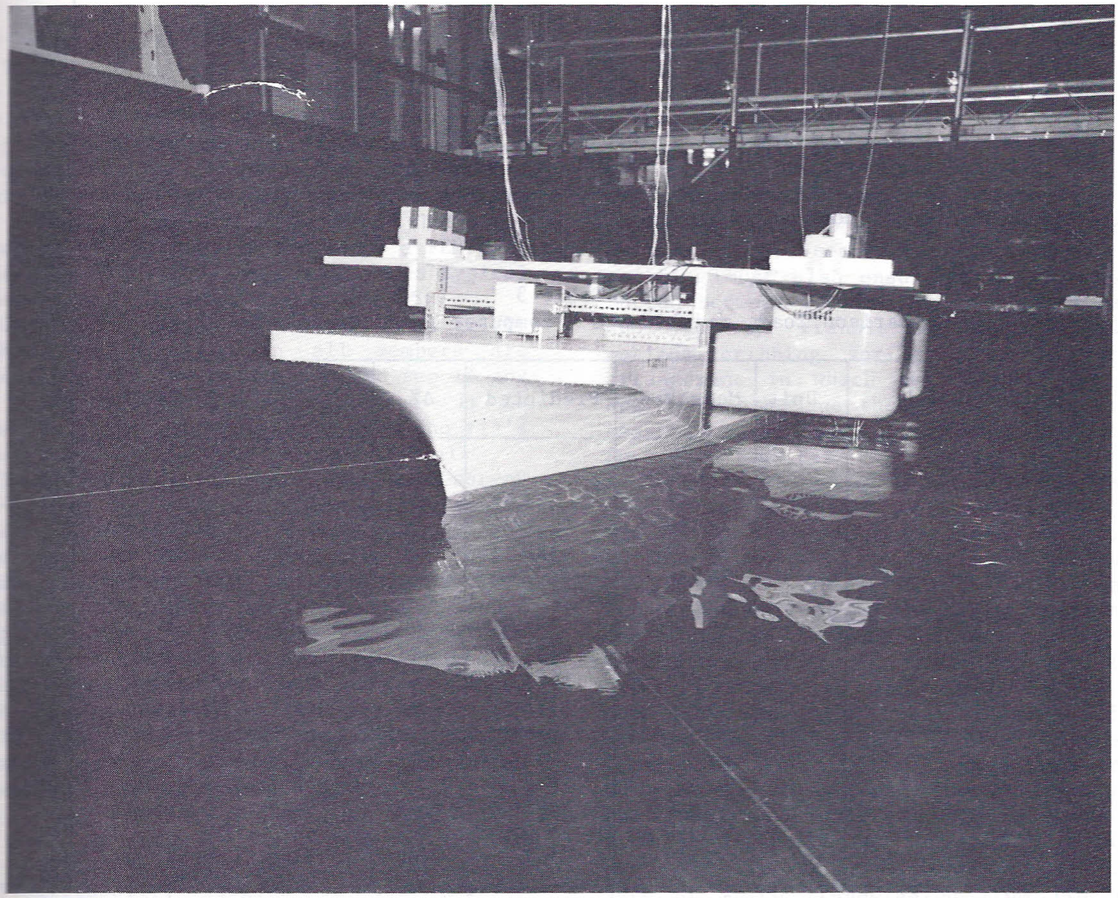


Fig. 5. Model in head seas

Table 2
Comparison motions model tests - computer prediction "ROSS" rig

Heading, mode	Unit	Measured*	Predicted	Δ%	Design value	Remarks
BEAM SEAS						
Roll	deg	4.6	0.4	-91	no	
Pitch	deg	1.9	0.4	-79	no	
Vertical acceleration	g	0.318	0.229	-28	yes	Underest.
Longitudinal acceleration	g	0.012	0.012	0	no	
Transverse acceleration	g	0.207	0.192	-7	yes	Underest.
BOW QUARTERING SEAS						
Roll	deg	3.3	0.2	-94	no	
Pitch	deg	6.5	7.2	+11	no	
Vertical acceleration	g	0.183	0.227	+24	yes	Overest.
Longitudinal acceleration	g	0.106	0.207	+95	yes	Overest.
Transverse acceleration	g	0.131	0.088	-33	yes	Underest.
HEAD SEAS						
Roll	deg	5.6	0.0		no	
Pitch	deg	6.8	8.1	+19	no	
Vertical acceleration	g	0.076	0.197	+159	yes	Overest.
Longitudinal acceleration	g	0.095	0.235	+147	yes	Overest.
Transverse acceleration	g	0.107	0.000		no	

*Corrected for 6 hour storm period

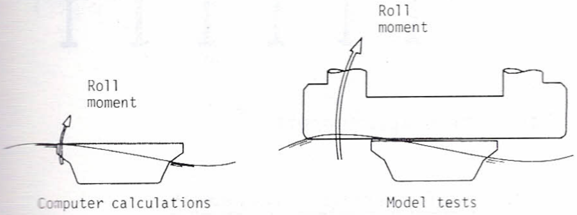
Table 3
Comparison loads model tests - computer prediction "ROSS" rig

Heading, mode	Unit	Measured*	Predicted	Δ%	Design value	Remarks
BEAM SEAS**						
F_x total	t	268	228	-15	no	
F_y total	t	6183	4251	-31	yes	Underest.
F_z total	t	6172	4351	-30	yes	Underest.
BOW QUARTERING SEAS						
F_x total	t	2050	3933	+91	yes	Overest.
F_y total	t	4317	1672	-61	yes	Underest.
F_z total	t	4026	4313	+7	yes	Overest.
HEAD SEAS						
F_x total	t	1848	4465	+142	yes	Overest.
F_y total	t	3994	0		no	
F_z total	t	1795	3743	+108	yes	Overest.

* Corrected for 6 hour storm period
** Including 6.6 deg static wind heel

Table 4
Transverse loads on semi-submersible in beam seas

F_y total	Unit	Maximum starboard	Maximum port side	Double maximum
Measured	t	2228	6183	8411
Predicted	t	4153	4153	8306



Computer calculations

Model tests

Fig. 6. Comparison of roll moments: computations and model tests

3.6 Strength rig/ship

The strength of the cargo is in general the responsibility of the cargo owner but the strength cannot be checked without the ship characteristics and vice versa. Close co-operations between both the cargo owner's engineers and the transportation engineers is essential. In order to study both the strength of the rig and the ship, a FEM (Finite Element Method) beam model of a typical cross-section is made, see Fig. 7 [5].

Once all design loads have been established the stresses in all members are calculated and checks are made to see if any of these members are overstressed. It is clear that the interaction between the rig's floater and ship's main deck is crucial.

The cribbing wood is modelled as a set of non-linear springs. By changing the stiffness and/or the length of the springs, the load transfer can be controlled and optimized, resulting in the lowest possible stresses in critical spots of the floater/ship structure. Of course, the resulting stresses from the 2-D analysis must be combined with stresses from other sources, such as the longitudinal bending moment in still water and in waves. The optimum set of cribbing springs must be translated into an effective cribbing arrangement.

3.7 Cribbing arrangement

Traditionally, cargoes on board heavy lift vessels are placed on wooden cribbing blocks which serve the purpose of absorbing any unevenness between the bottom of the cargo and the ship's deck. In case of transporting large semi-submersible rigs, the cribbing must also ensure even load distribution between floater and deck. This can be achieved by translating the calculated optimum cribbing springs into a cribbing arrangement in which the height (i.e. the spring length) and the density (i.e. stiffness) is varied over the width of the ship's deck, see Fig. 8.

In critical cases, a sandwich cribbing is used (two or more layers cross-wise combined). The crossings can then be designed so that the wood starts to deform excessively just before the floater of the rig and/or supporting structure become overstressed. The increased load is then absorbed by the surrounding supports, see Fig. 9. If a crossing starts to deform excessively this does not mean that it collapses and looses its load bearing capacity. After the deformation the transferred load will increase only little, in spite of large compression. The results of the cribbing analysis are strongly influenced by the properties of the proposed cribbing wood. Especially the pressure at which transmission from linear to non-linear behaviour takes place is an important parameter.

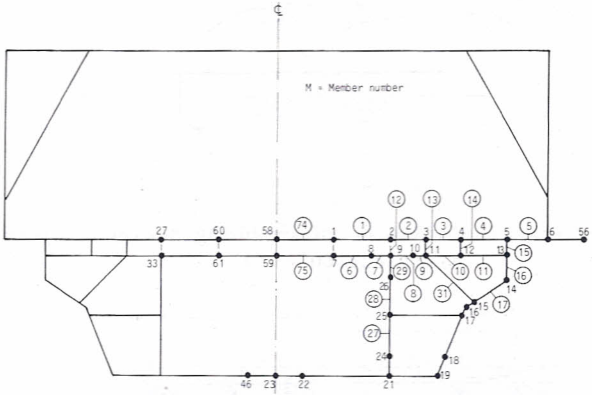


Fig. 7. 2-D FEM of transverse section of forward floater

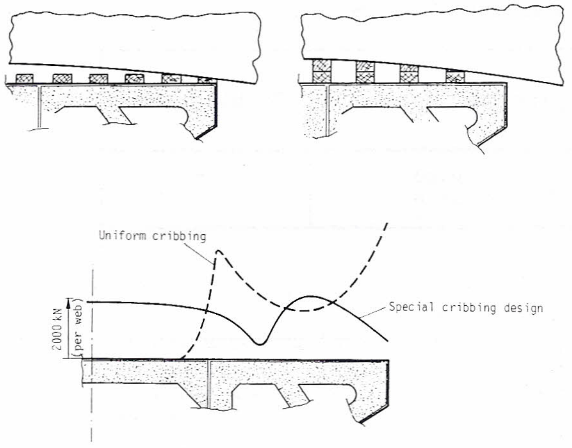


Fig. 8. Influence of cribbing design on load distribution

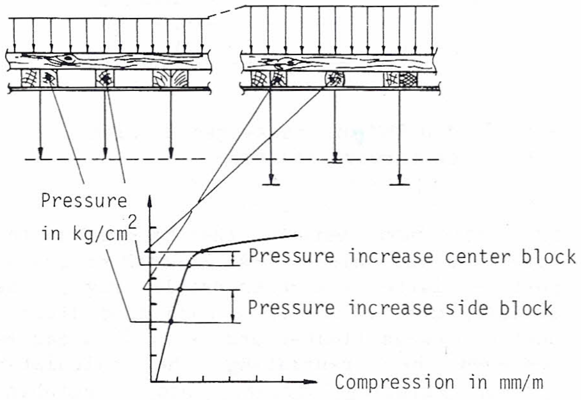


Fig. 9. Principle of limiting maximum load by excessive deformation of cribbing crossing

Because of the large bilge radius of some semi-submersible rigs the effective supporting area is insufficient to absorb all the loads. In such cases, a solution can be found in increasing the supporting area by including the bilges, supported with custom shaped cribbing blocks, see Fig. 10. Without these supports bottom of the floaters and webstructure may suffer from large transverse stresses. The bilge supports may increase the supporting area as much as 30%.

Measurements on the full scale behaviour of the cribbing arrangement of the "Shelf-6" during the transport from Finland to Shakalin were made. The method used and results obtained will be discussed in Section 4.3.

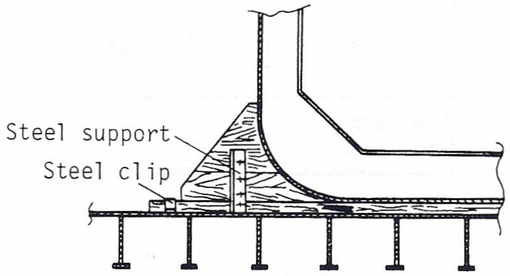


Fig. 10. Bilge support

3.8. Seafastening arrangement

In order to prevent the cargo from shifting, it has to be secured to the ship's deck. This is done by placing steel brackets (so-called seafastenings) against strong points of the cargo and weld these seafastenings to the main deck, see Fig. 11.

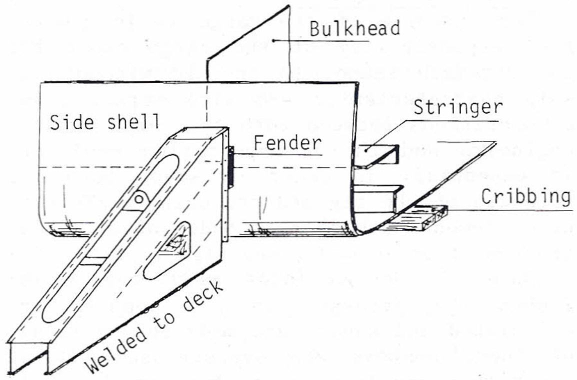


Fig. 11. Seafastenings secured against strong point cargo

Relative motion between cargo and seafastening is still possible, thus allowing for differences in flexibility. Because the floaters of a semi-submersible rig provide no supports for the transverse seafastenings, so-called strong boxes are necessary. In some cases these strong boxes are designed and constructed so that they also act as load spreading devices again to increase the supporting area of the floaters. For a typical strong box, see Fig. 12.

The loads acting on the cargo are:
- inertia loads due to ship motions,
- wind load,

- gravity loads due to wind heel and angular ship motions,
- hydrodynamic loads (slamming, submerging).

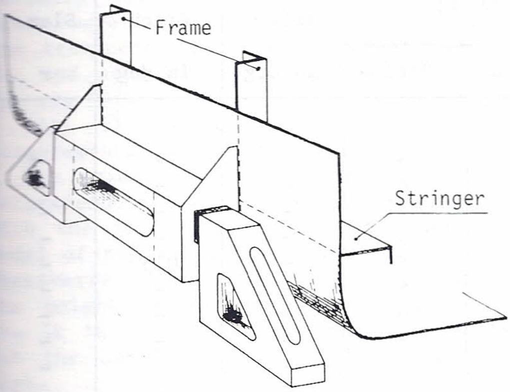


Fig. 12. Typical strong box

In case of little or no overhang and the lack of model test results, the extreme loads on the cargo are calculated from the inertia loads (including the static part due to angular motions) and the wind load (including static part due to wind heel), assuming statistical independency. Since ship motions and wind fluctuations can be considered to be independent events, the probability that the extremes of both events occur simultaneously, is small. Assuming all extreme loads to be in phase would lead to conservative results. This is also clearly illustrated with the model test results.

Aforementioned loads on the cargo are counteracted by:
- friction between cargo and cribbing wood,
- seafastenings,
- hydrodynamic loads.

The latter are often 180 degrees out of phase with the inertia loads, i.e. loads due to roll motions.

The friction between wood and steel is in the order of 30-50%. Barnacles, rust, etc. will even increase this percentage.

Wijsmuller Transport B.V. incorporates 15% of friction in its standard seafastening calculations.

Both the statistical independency of the loads and the deduction of friction forces from the total seafastening loads, are often a point of discussion between the transportation engineer and the warranty surveyors. The latter, representing the insurance companies, tend to be more conservative, resulting in superposition of all extreme loads and no reduction for friction. It must be noted that the transport company has the same goal, namely to provide a safe transport. Examples hereof are given in the following chapter.

4. THE TRANSPORTS

4.1 Introduction

Once all engineering is finalized and the numbers confirm the feasibility, the actual transport can be effected.

Before load-out, the cribbing arrangement is laid out and secured onto the main deck. The guide posts are positioned and welded to the deck and the seafastenings are prepared, as well as the strong boxes (if not already in place).

The load-out will take place within a suitable weather window, with the submerged vessel preferably weathervaning behind one bow anchor. The semi-submersible rig is slowly approaching, under control of 3 or 4 highly manoeuverable harbour tugs. Once over the deck, the rig will be hooked up to the ship's tugger wires which will accurately position the rig against the guide posts, thus ensuring an exact position over the cribbing arrangement. The ship then starts deballasting and lifts the rig out of the water after which the seafastening commences.

4.2 Observations during the transports

Upon completion of the seafastening the ship will depart. All navigational aspects of the transit are left to the responsibility of the master. He has at his disposal weather facsimile, telex and radio equipment which enables him to gather all available weather information for the anticipated route. Sometimes additional weather routeing is required by the warranty surveyor. This may be helpful in remote areas where less weather information is readily available. With the available weather information the master decides on the optimum course and speed to ensure motions to stay within the critical limits.

For the recorded wind/sea states and corresponding motions and slams during transportation of the "ROSS" rig from Japan to Norway, see Table 5.

Table 5 indicates that the environmental conditions were mild throughout the complete voyage (maximum wave height 4.0 m) and as a result, the ship hardly moved at all. Only little slamming against the overhanging pontoon was observed around July 9.

Recordings of the other dry transports of semi-submersibles show similar numbers; mild sea states, little motions, no reports of slamming. Stormy areas including typhoon areas were successfully avoided.

Table 5
Record of "ROSS" transportation

Date	Speed in kn	Wind speed in kn	Sea		Swell		Roll	Pitch	Slam
			Height	Period	Height	Period	in deg	in deg	-
23/6	Departure Hiroshima								
24/6	11.5	10	0.5	1	-	-	-	-	-*
25/6	10.5	10	1.0	3	2.0	6	-	-	-
26/6	12.9	13	0.3	1	-	-	-	-	-
27/6	12.5	8	0.5	2	1.0	5	-	-	-
28/6	11.8	7	0.5	1	1.0	5	-	0.5	-
29/6	12.5	6	0.5	1	1.0	6	-	-	-
30/6	12.0	10	0.5	2	1.5	6	-	-	-
1/7	9.8	20	1.0	3	2.5	8	-	-	-
2/7	10.0	22	1.0	3	3.0	7	-	-	-
3/7	11.0	10	0.5	1	1.5	4	-	-	-
4/7	Bunker stop Singapore								
5/7	12.0	10	-	-	-	-	-	-	-
6/7	14.9	10	-	-	-	-	-	-	-
7/7	12.3	6	0.5	2	-	-	-	-	-
8/7	10.0	15	1.0	3	3.5	-	-	0.5	-
9/7	9.0	20	1.5	2	4.0	8	-	1.5	Slight
10/7	10.0	20	1.5	3	3.5	7	-	0.5	-
11/7	11.0	12	0.5	2	2.5	7	-	0.5	-
12/7	11.0	10	0.5	1	2.5	7	-	0.5	-
13/7	12.6	5	0.5	2	2.0	7	-	-	-
14/7	12.8	10	0.5	1	2.0	8	-	0.5	-
15/7	12.5	10	0.5	2	1.5	8	-	0.5	-
16/7	12.5	16	1.5	2	1.5	5	-	0.5	-
17/7	12.5	20	1.5	3	2.0	7	-	0.5	-
18/7	14.5	20	2.0	4	2.5	7	-	0.5	-
19/7	15.5	34	2.0	4	3.5	8	-	0.5	-
20/7	12.0	15	0.5	3	2.0	7	-	-	-
21/7	9.0	10	0.5	-	-	-	-	-	-
22/7	1.0	12	0.5	2	-	-	-	-	-
23/7	8.5	20	1.5	3	1.5	6	-	-	-
24/7	12.5	5	-	-	-	-	-	-	-
25/7	7.0	18	0.5	2	0.5	4	-	-	-
26/7	Suez Canal passage								
27/7	Suez Canal passage								
28/7	Suez Canal passage								
29/7	Suez Canal passage								
30/7	12.5	10	0.5	3	-	-	-	-	-
31/7	13.0	-	-	-	-	-	-	-	-
1/8	13.0	5	-	-	-	-	-	-	-
2/8	13.3	10	0.5	3	-	-	-	-	-
3/8	12.5	5	-	-	-	-	-	-	-
4/8	10.5	20	1.0	3	1.5	6	-	-	-
5/8	12.5	10	0.5	3	-	-	-	0.5	-
6/8	12.0	10	0.5	2	1.5	10	-	-	-
7/8	11.3	6	0.5	2	2.5	10	-	1.0	-
8/8	13.0	-	-	-	-	-	-	-	-
9/8	13.0	-	-	-	-	-	-	-	-
10/8	13.0	-	-	-	-	-	-	-	-
11/8	Arrival Sandefjord								

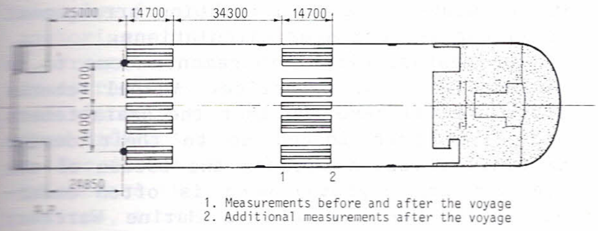
* - Indicates nihil

4.3 Compression measurements on cribbing

The cribbing arrangement of the "Shelf-6" transport from Finland to Shakalin was visually studied and some simple measurements were taken during several stages of the transport, i.e. before and after load-out and after arrival, before unloading of the rig [6].

Fig. 13 indicates the location of the measurements under forward floater.

The transverse shape of the cribbing was determined by Wijsmuller Engineering B.V. with the aid of a 2-D finite element beam model of rig and ship. Before load-out, this transverse shape was checked by measuring the height at various locations, see Fig. 14. It is clear that the shape is correct, but the complete cribbing is a little too high.



1. Measurements before and after the voyage
2. Additional measurements after the voyage

Fig. 13. Loacation of measurements

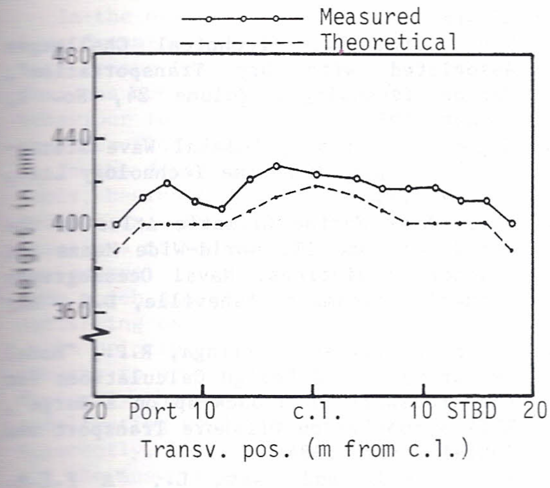


Fig. 14. Cribbing height before load-out

After load-out, the distance between the deck and the floater bottom was measured again at the same locations. The results are given in Fig. 15.

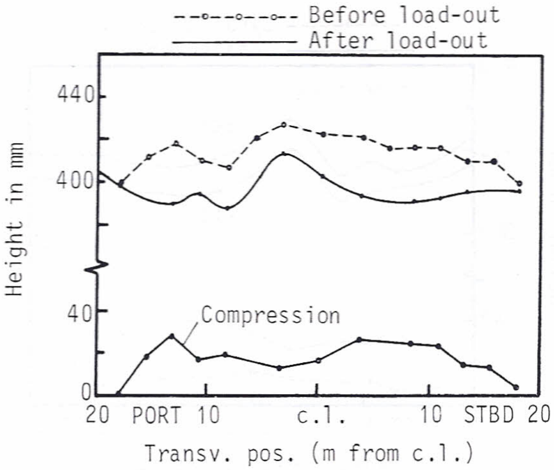


Fig. 15. Cribbing height before and after load-out

As is shown the resulting compression is fairly uniform with the exception of the outside blocks. This is in accordance with the intentions to have the centre blocks absorb most of the static load and have the outside blocks absorb the dynamic loads (due to roll, sway and wind forces on the rig).

The cribbing height was again measured 53 days later, prior to the unloading of the rig. During the time span of the transport the rig settled itself a little deeper in the cribbing as a result of its dead weight and some dynamic loading, see Fig. 16.

Fig. 16 shows that the plastic compression due to dynamic loads is relatively uniform along the width of the deck. The fact that the outside blocks are not more deformed than the centre blocks can be explained by the lack of rolling during the transport. The maximum roll angle observed was in the order of 1.0 degree. The uniform deformation is caused by the heave and pitch motion experienced en route. The maximum observed pitch angle was 3.4 degrees, when the transport was going through the tail of typhoon "ELLEN" (swell of 4.5 metres).

The measurements as discribed above are not very accurate and were hampered by imperfections on the ship's deck and marine growth on the floater of the rig. However, the measurements do indicate the behaviour of the shaped cribbing which is in line with its design helping to avoid high loads at the deck edges.

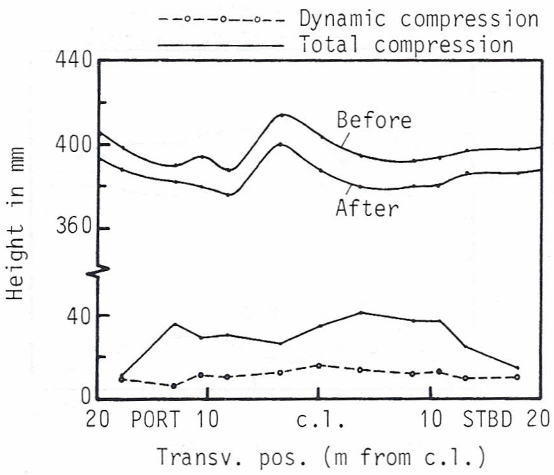


Fig. 16. Permanent compression during transport

4.4 Seafastenings

Seafastenings are always visually observed during and after the transport. In general, they are never loaded to their design loads, indicating:

- actual experienced environmental conditions are less severe then the predicted design conditions;
- friction between the cribbing wood and the cargo counteracts the inertia loads to a large extent.

The latter was clearly proven during the final phase of the "Shelf-6" transport. After removal of all seafastenings, the weather suddenly started to deteriorate fast and wind picked up, exceeding Beaufort 10. Waves started to grow to 6 metres. It was then decided to leave the scheduled unloading area and try to find some shelter close to the southern point of Shakalin Island. The rig was standing loose on deck, only kept in place by friction, for two days before it was safely unloaded.

The actual loads on seafastenings need to be measured systematically over a large period of time. A full scale measurement project is presently being studied.

5. CONCLUSIONS

After dry transportation of five large semi-submersibles over a total distance of 52000 miles, complemented with the information from model tests, Wijsmuller Transport B.V. gained valuable experience and know-how in this field.

The model tests were concentrated on the effect of the large overhang caused by the athwartships orientation of the semi-submersible units on the deck of the carrier. The floaters caused non-linear effects in the ship motions and suffered from slamming, especially in beam seas. In practice, however, slamming against the floaters (overhanging up to 26 metres each side) could be minimized by the master by carefully routeing the ship around stormy areas and selecting optimum course and speed in case of increasing sea states.

Using a 2-D finite element analysis, both the strength of the carrier and the rig's floater can be checked, including their interaction. This interaction can be controlled by changing the cribbing design. The shaped cribbing results in a decrease of peak loads near the deck edges. Full scale measurements on such a cribbing arrangement confirmed the computer calculations.

The seafastening arrangement seems to be over-designed in practice. Visual checks after arrival revealed that the seafasteners had never been loaded up to their design maximum. Friction between the bottom of the rig and the cribbing wood is often underestimated and, as a rule Marine Warranty Surveyors do not allow for any reduction of seafastening loads due to friction. Full scale measurements are recommended.

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