ASSESSMENT OF THE DAMAGE STABILITY OF A HEAVY LIFT SHIP TRANSPORTING A MODU

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ABSTRACT

In the case of self-propelled semi-submersible heavy lift ships, the conventional stability requirements are no longer applicable. Considering the MIGHTY SERVANT class of vessels as ships of a novel kind, the damage stability criteria are adapted and presented in this paper, In order to examine the validity of these new criteria, the dry transportation of a jack-up respectively semi-submersible drilling rig are checked with regard to damage stability. It is shown that in both cases the new criteria are easily met.

1 INTRODUCTION

Transportation of floating heavy and bulky objects over sea was first effected by simply connecting a tugboat and (wet) tow them across the oceans.
This method was improved by the introduction of submersible barges which were designed to be towed, resulting in improved transit speed. The latest improvement was made by the introduction of the semi-submersible self-propelled heavy lift vessels. These vessels are unique in design and cannot be regarded as a simple barge or a conventional cargo ship. Rules of statutory and regulating authorities lag behind. To illustrate this, damage stability requirements with respect to load line rules were studied and found to be unacceptable for these type of vessels.

Safety is increased by addition of buoyant deck cargo. However this is not taken into account when calculating the load line for these vessels. After several discussions between Dutch Shipping Inspection, Lloyd's Register of Shipping and the author's company, this aspect was recognized and as such the existing rules were adapted.

Applications of the new set of requirements for dry transportation of large mobile offshore drilling units are shown in this paper.

MIGHTY SERVANT 3 en route from the Far East to the North Sea, transporting the largest jack-up rig built to date.

2 DAMAGE STABILITY REQUIREMENTS

2.1 Introduction

Heavy lift ships are designed to carry cargoes on their main deck. Often these are loaded by means of floating on, i.e. the carrier submerges, the cargo is floated over the submerged deck and positioned, after which the carrier starts deballasting and the cargo is lifted out of the water, see figure 2.1.

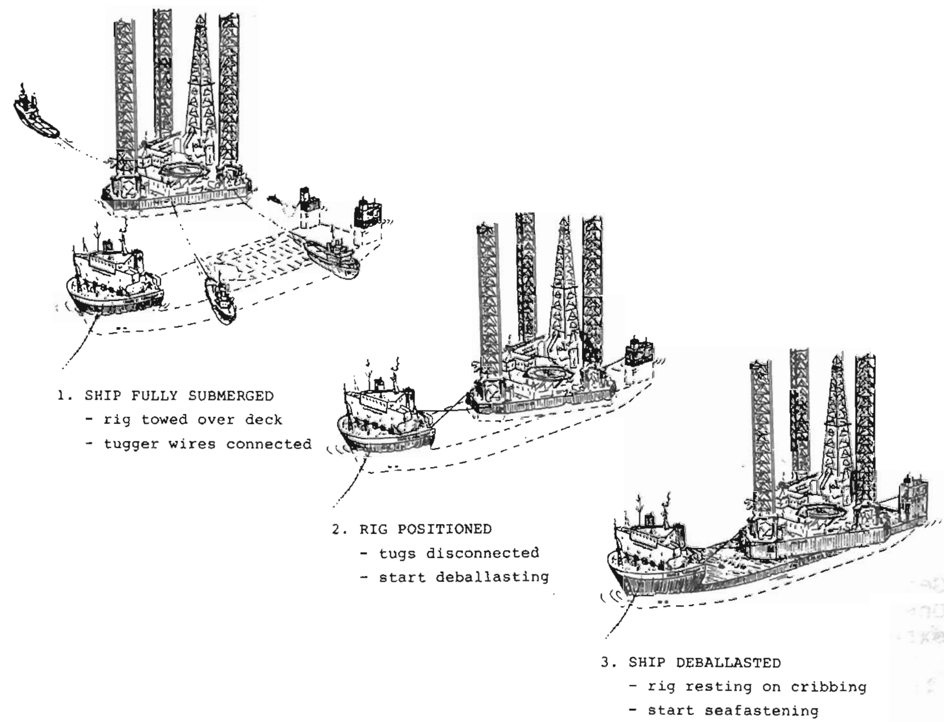


Figure 2.1 Float-on operation.

Subsequently, the cargo is secured by seafastenings which are placed around it and welded to the deck, see figure 2.2.

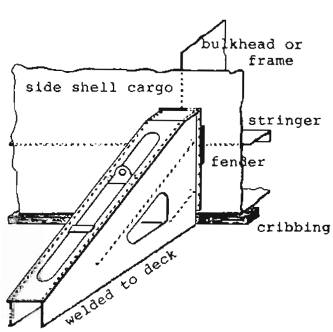


Figure 2.2 Standard seafastening.

After seafastening, both carrier and cargo can be considered as one combined unit. As such, the buoyancy of the cargo is included in the dynamic stability calculations. Without this cargo buoyancy, countless heavy lift transports executed in the past would not have been possible since the dynamic stability of the carrier alone did not meet the intact stability requirements. (See figure 2.3).

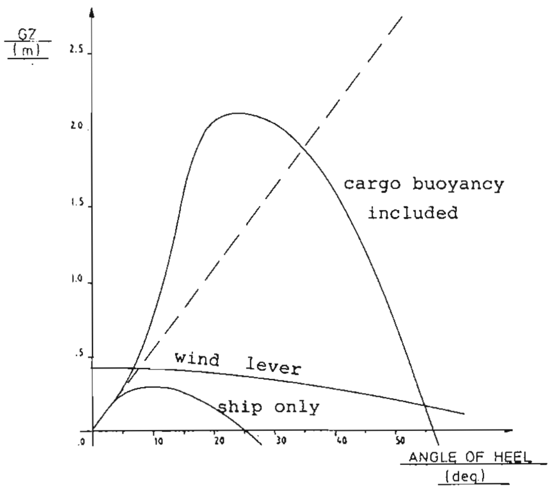


Figure 2.3 Dynamic stability with/without cargo buoyancy included.

Generally damage stability is only considered in special cases. One such case is when an approval for sailing with a draft exceeding the load line is required.

2.2 B-100 type freeboard

The International Convention on Load Lines, 1966, distinguishes two types of ships, with the following typical characteristics:

Type A ships:
1) Designed for transport of fluids.
2) Main deck in principle watertight.
3) Subdivision into many separate tanks.
4) Tanks are generally full in case of damage.

Type B ships:
1) All ships that do not have the type A 1) to 4) characteristics.

Depending on the so-called "freeboard-length" of the ship, the corresponding minimum freeboards can be found for both types of ships.

The heavy lift ships of the SERVANT class are designed to transport deck cargoes and as such are regarded as B-type ships. The Load Line Rules however, allow for decrease of B-type freeboard if the following conditions are met:

1) Freeboard length over 100 meters.
2) Sufficient measures are taken to protect the crew.
3) Hatches are strong enough in relation to the increased draft. Special care should be taken to the watertightness and securing of the hatches.
4) Ship can withstand damage to any one compartment (freeboard decrease of 60% of difference between A and B-type freeboard) or any two adjacent compartments (freeboard decrease of 100% of difference between A and B-type freeboard, i.e. B-100 freeboard) and reaches an acceptable equilibrium.

The SERVANT class vessels satisfy conditions 1) to 3), but not necessarily condition 4), which need some further elaboration.

2.3 B-100 damage stability requirements

The conventional B-100 damage stability requirements as to the extent of damage are as follows (from regulation 27 of the 1966 Load Line Convention):

a. Two adjacent tanks or compartments of the carrier and/or of the cargo are assumed to be damaged.

b. The vertical extent of damage in all cases is assumed to be equal to the depth of the ship at the flooded compartment under consideration. The buoyancy of any superstructure or deckhouse directly above the flooded compartment is to be disregarded.

c. The transverse extent of damage is equal to B/5, measured inboard from the side of the ship perpendicularly to the center line at the level of the summer load waterline. If damage of a lesser extent results in a more severe condition such lesser extent should be assumed.

d. No main transverse bulkhead is assumed damaged except if the flooding of any two adjacent fore and aft compartments is envisaged; in addition the damage may be located between two transverse bulkheads bounding side tanks.

e. If in a transverse bulkhead there are steps or recesses of not more than 3.05 m in length located within the extent of transverse penetration of damage, such transverse bulkheads may be considered intact and the adjacent compartments may be floodable singly. If, however, within the extent of penetration of damage there is a step or recess of more than 3.05 m in length in a transverse bulkhead, the two compartments adjacent to this bulkhead should be considered as flooded.

f. If a double bottom or side tank is divided by a transverse bulkhead located more than 3.05 m from a main transverse bulkhead, the adjacent double bottom or side tank should be considered as flooded. If this side tank has openings into the holds, such holds should also be considered as flooded. This provision is applicable even where such openings are fitted with closing appliances.

In the case of heavy lift ships, objection is made against item c). Since the B-100 freeboard is required for especially large cargoes such as semi-submersible or jack-up drilling rigs, this requirement is not very realistic. After all, the cargo may be protruding the ship's sides in excess of 20 meters, while the vertical distance between the waterline and the bottom of the protruding cargo is relative small, in the order of 2.5-3 meters. Locally the side shell of the carrier is thus well protected by the overhanging cargo since the entry vessel must be either very small or of sufficient size and mass to cause penetration, in spite of the cargo, see figure 2.4.

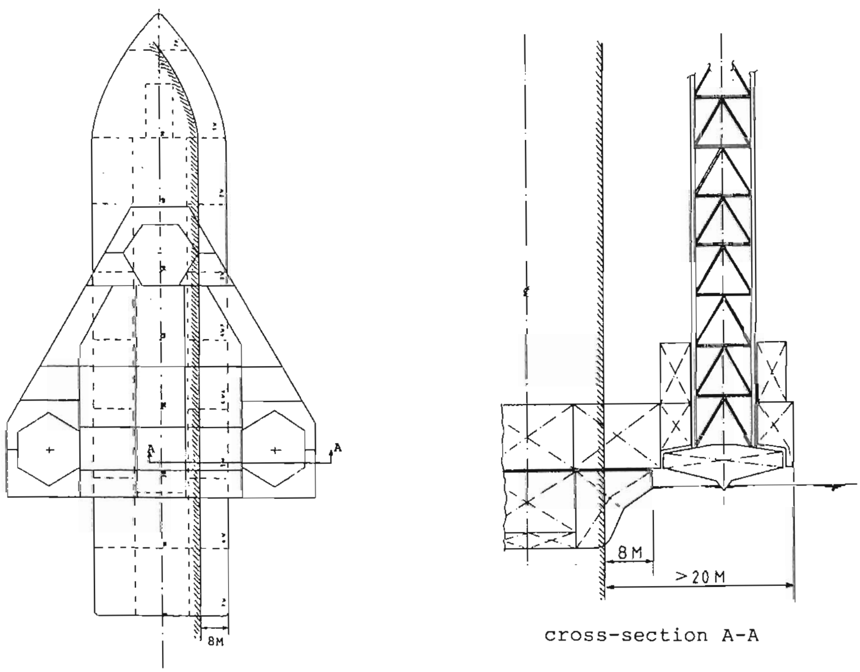


Figure 2.4 Conventional extent of damage.

Regarding the heavy lift ships of the SERVANT class as "ships of a novel kind" under Article 6 of the International Convention of Load Lines 1966. It was decided by Dutch Shipping Inspection in close co-operation with Lloyd's Register of Shipping and Wijsmuller to change item c) in such way that the contour of the cargo are taken into account or:

c. The transverse extent of damage is equal to B/5, measured inboard from the side of the ship or from theoutboard edge of the cargo (on a line normal to the center line of the carrying vessel) over that portion of its length where the cargo is protruding over the carrier's side. See also figure 2.5.

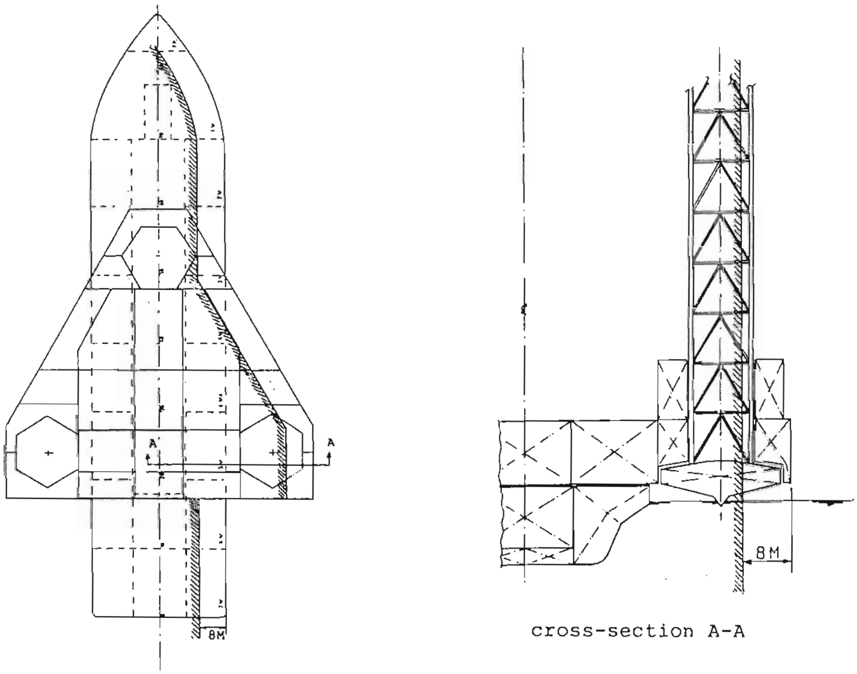


Figure 2.5 More realistic extent of damage.

After the flooding, due to the damage as described above, the vessel should be afloat in a stable condition. This condition should be defined as follows:

a. The final waterline after flooding, taking into account sinkage, heel and trim is to be below the lower edge of any opening through which progressive flooding may take place. Such openings should include air pipes and those which are closed by means of watertight doors or covers, and may exclude those openings closed by means of manhole covers and flush scuttles, cargo hatch covers, weathertight doors which are secured closed while at sea and so logged, remotely operated sliding watertight doors, and side scuttles of the non-opening type.

b. If pipes, ducts or tunnels are situated within the assumed extent of penetration of damage, arrangements should be made so that flooding cannot thereby extend beyond the limits assumed for the calculations of the damaged conditions.

c. The angle of heel due to unsymmetrical flooding should not exceed 15 degrees. If no part of the deck is immersed, an angle of heel of up to 17 degrees may be accepted.

d. When any part of the deck beyond the limits of flooding is immersed or in any case where the margin of stability in the flooded condition may be considered doubtful, the dynamic stability should be investigated.

   The dynamic stability may be regarded as sufficient if the righting lever curve has a minimum range of 20 degrees beyond the position of equilibrium in association with a righting lever of at least 0.1 meter.

e. After flooding, the metacentric height as calculated by the constant displacement method should be at least 50 mm in the upright condition.

Furthermore, it is assumed that no lateral or longitudinal displacement of the cargo is induced as a result of the collision, nor is lift-off allowed at large angles of heel.

It is required that lift-off should not occur before an angle of 20° (residual range) plus the angle of heel after damaging and flooding of the carrier and cargo.

3 APPLICATION OF NEW REQUIREMENTS

3.1 Introduction

The new damage stability requirements are applied for two dry transports:
- transport of a large jack-up rig from the Far East to the North Sea (executed in summer 1986);
- transport feasibility study of a large semi-submersible drilling rig.

Both units did have such a weight/vertical center of gravity combination that, in order to improve the stability, an increased draft was necessary. For the semi-submersible rig, an increase of width by means of blister tanks was considered.

3.2 Transport of a large jack-up rig

In the summer of 1986, the heaviest jack-up rig ever built was dry transported from the Far East to the North Sea. For a stowage plan and rig particulars, see Appendix I. During the engineering phase it was decided to improve the dynamic stability by increasing the displacement to its B-100 load line maximum. This meant that all double bottom tanks could be ballasted, resulting in a lower vertical center of gravity and an increased GM. Furthermore, the dynamic stability curve improved, because the buoyant overhang immersed at smaller inclination angles, thus providing a contribution to the righting moment, see figure 3.1.

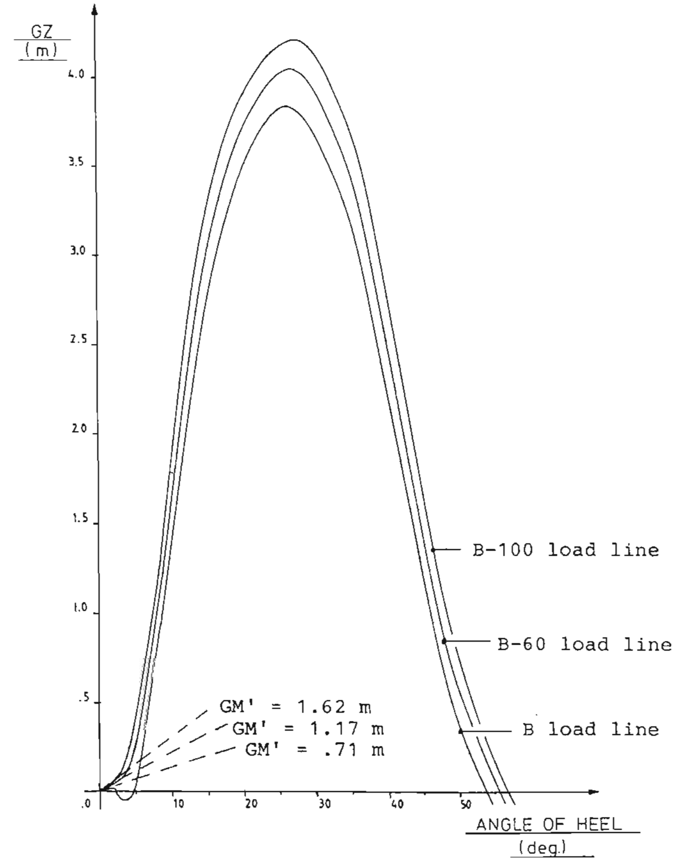


Figure 3.1 Comparison dynamic stability
3 load lines.

In order to obtain approval for the B-100 load line, the damage stability was calculated according to the new set of requirements.

The tank arrangement of the ship plus cargo is given in figure 3.2. The penetration depth (B/5 = 8 m) is also plotted in this figure.

Note that the leg wells are simplified by squares with the same area. The spudcan bottoms are assumed to be flat.

The damage stability calculations are performed using the Wijsmuller Transport B.V. inhouse computer program, developed by "Wolfson Unit MTIA", University of Southampton.

For damages on the ship, the added weight method is used. For the intact condition, all wingtanks are empty. If damaged, the tanks are assumed to flood completely i.e. the maximum weight is added. However, the maximum free surface correction is taken into account.

For damages on the rig, the lost buoyancy method is used. From the hydrostatic model of the ship plus the rig the damaged tanks of the rig are substracted, giving a new (damaged) model.

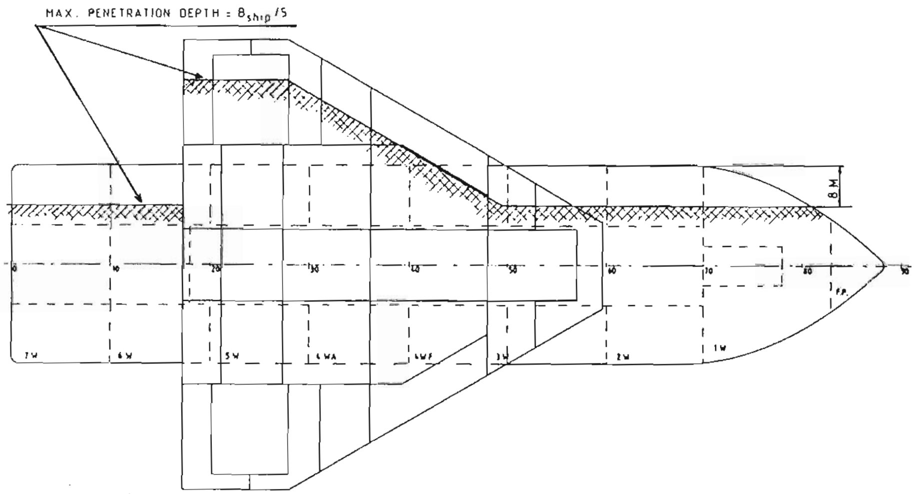


Figure 3.2 Subdivision of tanks and transverse extent of damage.

With the new hydrostatic model and the new displacement (intact displacement plus added weight of damaged tanks) the righting lever curve is calculated:

$$GZ = KN - KG' * \sin \emptyset \qquad \text{(m), see figure 3.3.}$$

where KG' is the vertical center of gravity, corrected for the free surface effects. The model is free to trim.

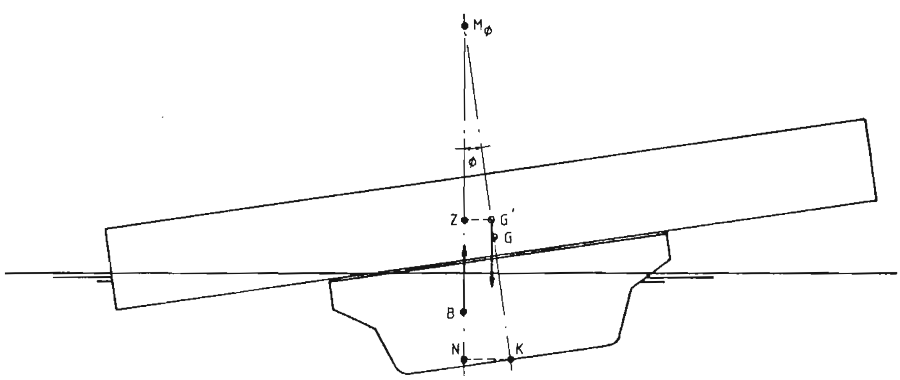


Figure 3.3 Nomenclature dynamic stability.

In total, 8 damage cases are considered. A summary of the results is given in the following table.

Table: Summary of results (jack-up rig)

	NO OF TANKS DAMAGED		EQUILIBRIUM		DYNAMIC STABILITY			
DAM. CASE	SHIP	RIG	LIST	TRIM*	** RANGE	MAX. GZ	GM'	MEETS REQ.
(-)	(-)	(-)	(Deg)	(m)	(Deg)	(m)	(m)	(-)
1	2	-	8.0	-3.01	44.0	3.35	1.70	Yes
2	2	2	8.0	-1.00	42.0	3.35	1.72	Yes
3	2	4	6.6	.01	37.9	2.70	1.73	Yes
4	1	3	6.7	.08	35.3	2.10	1.77	Yes
5	-	3	0	.72	32.3	.75	1.62	Yes
6	-	3	0	.72	30.0	.46	1.62	Yes
7	1	3	6.7	2.05	32.3	1.47	1.67	Yes
8	2	2	7.3	3.04	39.7	2.70	1.66	Yes

* + = trim by stern
** Residual range beyond equilibrium

From the table above it follows that damage case no. 1 is the worst case, with regard to the list after flooding.
Regarding dynamic stability, damage case no. 6 is the worst. However, the GZ-curve still meets the minimum requirements easily.

In case of a large angle of heel, cargo buoyancy can cause the cargo to be "lifted-off" the carrier.

The maximum angle of heel after damage occurs for case 1, having a value of 8 degrees.

It is required that lift-off should not occur before an angle of 20° (residual range) plus the angle of heel after damaging and flooding of the carrier and cargo.
In the most onerous case the total range amounts to 28° heel.
Calculations gave the following results: (see also figure 3.4).

The buoyancy force B is calculated as 12,000 T. Lift-off will occur if the uplifting moment is larger than the downturning moment around the point of rotation R.

Uplifting moment = 12,000 * 43 = 516,000 Tm
Downturning moment = 20,100 * 30.5 = 613,050 Tm

Hence no lift-off will occur.

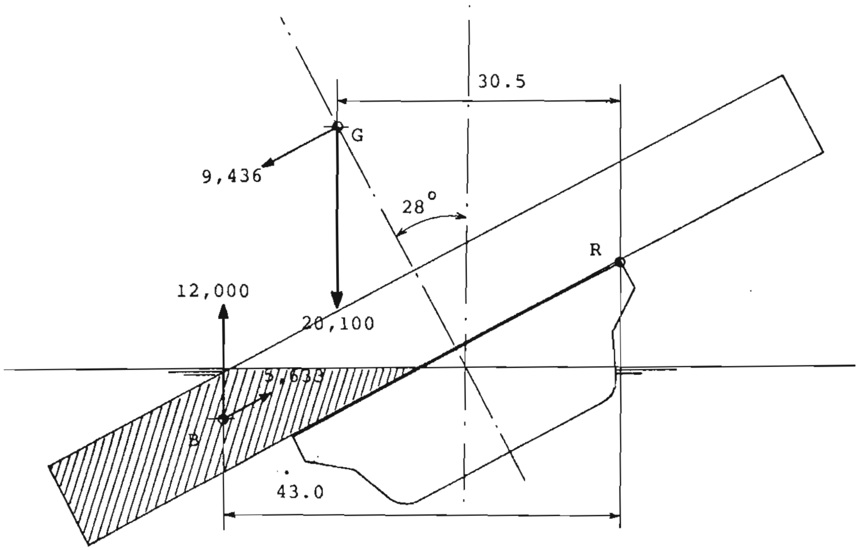


Figure 3.4 Check lift-off.

The transverse force with a list of 28 degrees equals $G_t - B_t$

B_t = 12,000 * sin 28 = 5,633 T
G_t = 20,100 * sin 28 = 9,436 T

Hence the extreme transverse force is approx. 3,800 T. Since the seafastening arrangement is designed for an extreme load of 8,300 T and above this friction may be approximated at 0.2 * 20,100 = 4,020 T, no shifting of the cargo is expected.

Above calculations were checked by Lloyd's Register of Shipping and approved after which Dutch Shipping Inspection issued the B-100 load line certificate. The transport was successfully executed.

3.3 Transport of a large semi-submersible drilling rig

A feasibility study on the dry transport of a large semi-submersible drilling rig showed that in order to improve both initial and dynamic stability, the beam of the carrier must be increased by means of blister tanks and the B-100 displacement was required. For a stowage plan and rig particulars, see Appendix II.

Analogous to the jack-up case, damage stability calculations were made in order to get approval for the B-100 load line.

The tank arrangement of the ship plus cargo is given in figure 3.5 in which also the penetration depth of 8 m is plotted.

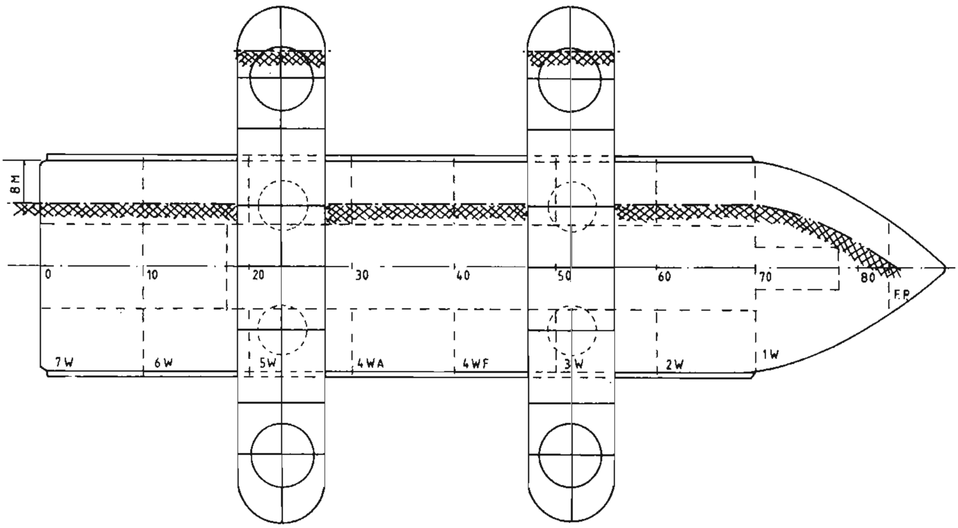


Figure 3.5 Subdivisions of tanks and transverse extent of damage.

In total, 8 damage cases are considered. A summary of the results is given in the following table.

Table: Summary of results (semi-submersible rig)

	NO OF TANKS DAMAGED		EQUILIBRIUM		DYNAMIC STABILITY			
DAM. CASE	SHIP	RIG	LIST	TRIM*	** RANGE	MAX. GZ	GM'	MEETS REQ.
(-)	(-)	(-)	(Deg)	(m)	(Deg)	(m)	(m)	(-)
1	2	-	4.5	-2.08	45.5	2.90	2.85	Yes
2	2	-	8.2	-2.94	41.5	1.98	2.85	Yes
3	2	4	7.9	-1.45	39.1	1.77	2.90	Yes
4	2	4	8.1	-0.90	38.9	1.85	2.99	Yes
5	2	2	8.0	0.00	49.0	2.52	3.03	Yes
6	2	4	9.0	0.97	42.0	1.86	3.03	Yes
7	2	4	9.0	1.71	39.0	1.82	2.96	Yes
8	2	2	7.9	1.91	47.1	2.43	2.85	Yes

* + = trim by stern
** Residual range beyond equilibrium

From the table above it follows that condition 7 is the worst case, regarding the list after flooding and the dynamic stability. However, the GZ-curve still easily meets the minimum requirements.

The floaters are divided into separate tanks. Openings in the tank bulkheads are not very likely. The tanks are only accessible from the columns.
Therefore no progressive flooding after damaging is expected.

In case of a large angle of heel, cargo buoyancy may cause the cargo to be "lifted-off" the carrier.

The maximum angle of heel after damage occurs under condition 7, and amounts to 9°.

It is required that lift-off should not occur before an angle of 20° (residual range) plus the angle of heel after damaging and flooding of the carrier and cargo.
In the most onerous case the total range amounts to 29° heel.
Calculations gave the following results: (see also figure 3.6).

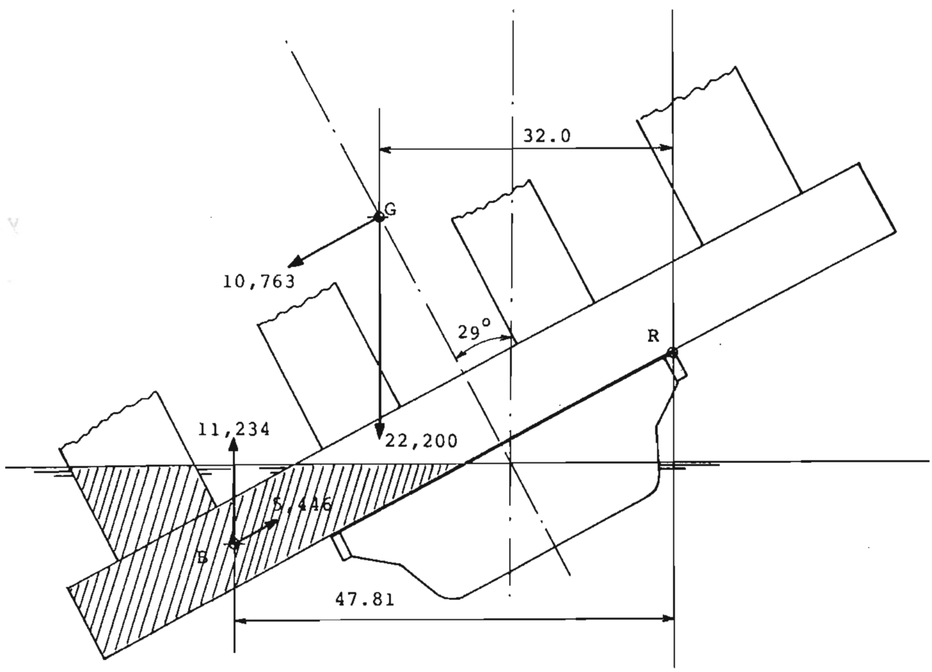


Figure 3.6 Check lift-off.

The buoyancy force B is calculated as 11,234 T. Lift-off will occur if the uplifting moment is larger than the downturning moment about the point of rotation R.

Uplifting moment = 11,234 * 47.81 = 537,142 Tm
Downturning moment = 22,200 * 32.0 = 710,400 Tm

Hence the resulting downturning moment of the rig implies that no lift-off will occur.

Transverse force of cargo at a list of 29° equals $G_t - B_t$

G_t = 22,200 * sin 29 = 10,763 T
B_t = 11,234 * sin 29 = 5,446 T

Hence the extreme transverse force is approx 5,320 T.

Since the seafastening arrangement is designed to withstand an extreme load of 6,400 T and above this friction may be approximated at 0.2 * 22,200 = 4,440 T, this transverse force will not give any problems in view of the seafastenings. No shift of cargo is anticipated.

Above calculations were checked and approved by Lloyd's Register of Shipping. The transport however did not materialize.

4 CONCLUSIONS

Buoyant cargo is secured onto the main deck of heavy lift vessels in such way that its buoyancy can be taken into account when calculating the range of intact stability. As such, the Load Line Rules were adapted to take this buoyancy into account. Furthermore, it was recognized that cargo overhang provides protection to the carrier in case of a collision. Therefore, the assumed penetration depth (B/5) should not be taken from the ship's sides, but should include this overhang. If the penetration depth of 8 meters follows the contours of the ship plus overhanging cargo, the adapted B-100 damage stability requirements are easily met.

Because of the overhang, the damage after collision is always such that either the overhang is damaged while the carrier is intact, resulting in no list, or the carrier is damaged while the overhang is intact and thus providing all the large angle stability, or a combination of both. In all three cases, a safe equilibrium and sufficient residual dynamic stability is found.

In the worst damage cases, no lift-off nor shifting of the cargo is expected.

Heavy lift transports such as the ones described above are unique in a lot of ways. Standard rules and regulations are often not applicable in these cases and special considerations are necessary.
Presently, this is well recognized within the industry and with the common goal of safe transports in mind, all parties involved (classification and statutory authorities, warranty surveyors, transport companies) can work out reliable (and realistic) solutions for judging the safety of these transports. As such, adapting the traditional damage stability requirements to better suit these type of heavy lift vessels is a good example.

APPENDIX I

Damage stability calculations of heavy lift ship transporting a jack-up rig

The principal particulars of the rig are:

a. Dimensions:

Platform

Length	:	84.00 m
Breadth	:	90.00 m
Depth	:	9.50 m
Draft at loading/unloading	:	4.05 m
Plane shape	:	Modified triangular with leg wells in the three corners

Legs

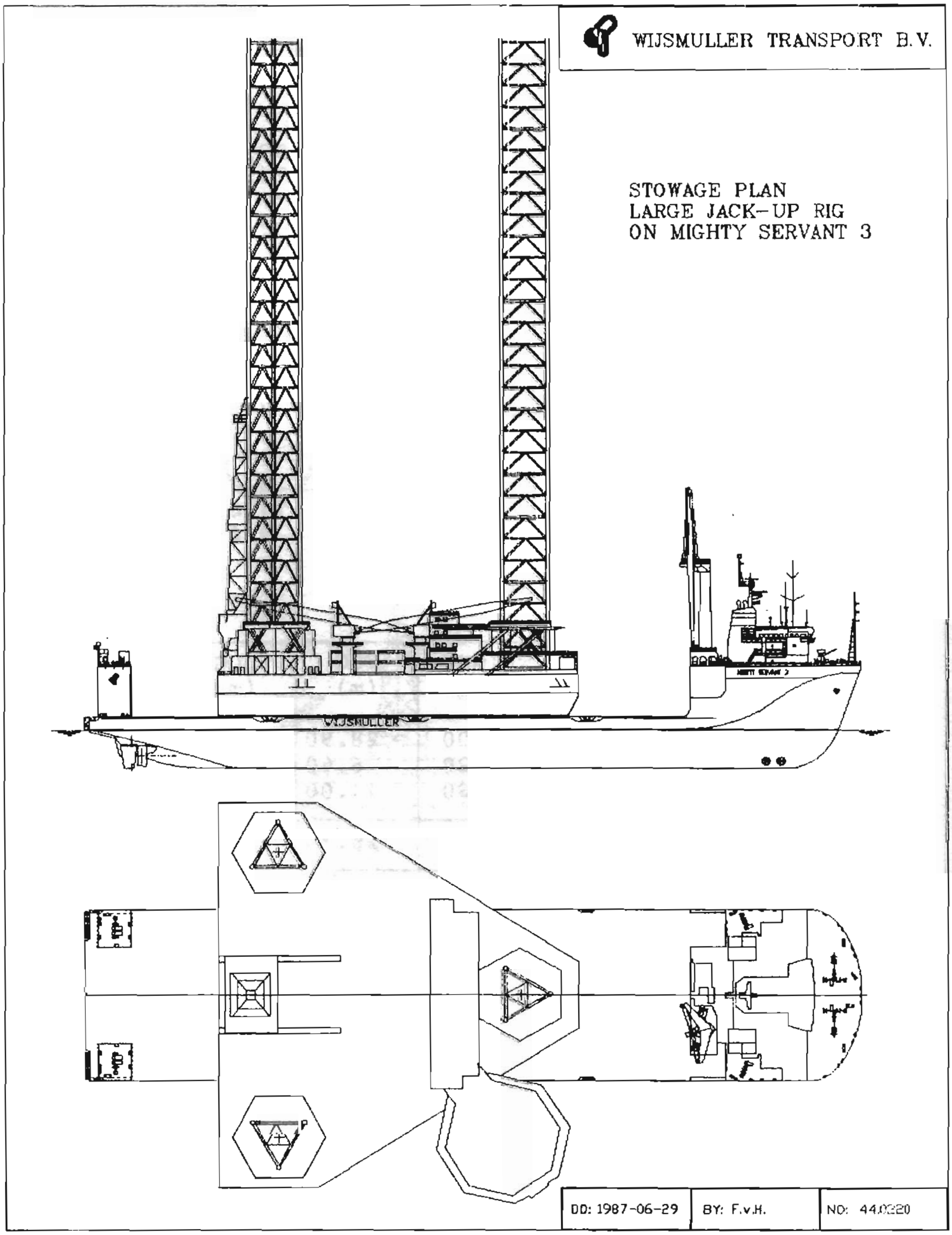
Type	:	Triangular lattice
Number	:	3
Longitudinal centers	:	56.80 m
Transverse centers	:	66.00 m
Length	:	156.80 m
Chord diameter	:	1.00 m
Chord centers	:	12.00 m

Legs are completely retractable flush with the platform bottom when they are fully elevated.

b. Weight and center of gravity:

	WEIGHT (T)	VCG (m)	LCG (m)	TCG (m)
LIGHT WEIGHT VARIABLE LOAD	19.100 1.000	28.50 6.50		
TOTAL WEIGHT	20.100	27.40	32.85	0.00

For a stowage arrangement and results of damage stability calculations, see following pages.



WIJSMULLER TRANSPORT B.V.
STOWAGE PLAN
LARGE JACK-UP RIG
ON MIGHTY SERVANT 3
WIJSMULLER
DD: 1987-06-29
BY: F.v.H.
NO:

APPENDIX II

Damage stability calculations of heavy lift ship transporting semi-submersible rig

The principal particulars of the rig are:

a. Dimensions:

<u>Rig</u>

Length	:	97.50 m
Breadth	:	72.50 m
Height	:	38.80 m
Distance between floaters	:	39.50 m

<u>Floaters</u>

Length	:	97.50 m
Breadth	:	72.50 m
Depth	:	8.50 m
Bilge radius	:	1.60 m
Draft at loading/unloading	:	7.80 m

<u>Columns</u>

Number	:	8
Diameter outer columns	:	11.8 m
Diameter inner columns	:	9.0 m

b. Weight and center of gravity:

	WEIGHT (T)	VCG (m)	LCG (m)	TCG (m)
RIG	19.600	28.90		
CHAINS	2.420	6.60		
ANCHORS	180	11.00		
TOTAL	22.200	26.30	48.75	0.00

For a stowage arrangement and results of damage stability calculations, see following pages.

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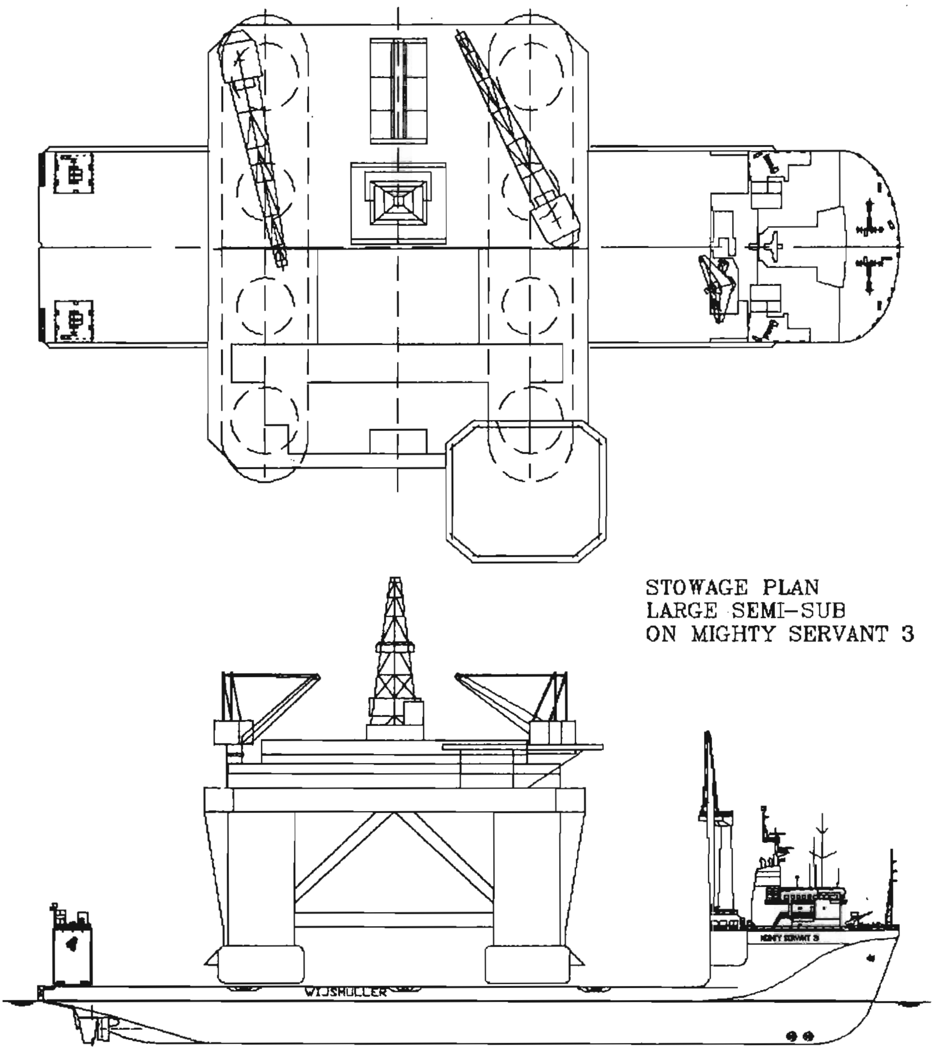

STOWAGE PLAN
LARGE SEMI-SUB
ON MIGHTY SERVANT 3

DD: 1987-07-07	BY: F.v.H.	NO: 64.1221