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The Design of a Variable Draught Semi-submersible Floating Production Vessel

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ABSTRACT

This paper reports results of the design of a variable draught semi-submersible, which is targeted at the development of marginal deep water fields. The platform is column stabilised, but it incorporates a jacking mechanism which enables the platform to change its draught from 50 m to 10 m. The platform absorbs the advantages from both purpose built deep draught platforms and conventional shallower draught semi-submersibles. It combines excellent motion response characteristics with the ability for conventional dry dock inspection, maintenance, re-fitting and re-use. The emphasis of the paper is on the motion responses and the jacking system.

1. INTRODUCTION

Floating production systems face ever increasing competition from both fixed structures and subsea systems tied back to existing infrastructures. With the advances of technology, the cost of light weight fixed platforms continuously falls below expectation, and their applications have penetrated into water depths which was conventionally believed to be practical only for floating production systems or some compliant structures. The challenge from the subsea production systems lies with the improvement of multiphase transportation technique which enables unprocessed satellite stream to be passed over long distances. The competition has limited the opportunity of floaters, as evidenced from the UKCS where floating production systems were only increased by four from two in 1984 to six in 1990.

Floaters may have better opportunities in the development of marginal oilfields where the small recoverable reserves make the mobility essential. To increase the viability of floaters, it may be necessary to develop innovative technologies. Two particular requirements are: (a) good motion responses, and (b) ability for re-fitting and re-use (e.g. dry dock inspection and maintenance).

With these requirements in mind, a design study was carried out to develop a variable draught semi-submersible floating production vessel, code named as STAPLA. In this short paper, we will discuss the underlined design philosophy and the particular characteristics unique to the STAPLA.

2. THE DESIGN

The STAPLA (Stabilised PLAtform) design is a hybrid production of conventional semi-submersible and jack-up technologies. It absorbs advantages from both kind structures.

The basic configuration is shown schematically in Figure 1. The most fundamental feature of the STAPLA vessel is that it is column stabilised, but capable of changing its draught from 50m to 10m by use of a conventional jacking mechanism. Figure 1 shows its configurations in both the operation position and the transit position. By dropping the lower hull to a 50m operating draught, the vessel achieves very good motion response characteristics which are normally achieved by purpose-built large draught vessels. On the other hand, by raising the lower hull to a 10m draught, it is possible to perform dry dock inspection and maintenance. In this way, an economically viable FPS is devised which fulfils the two basic requirements.

The principal dimensions are shown in Figure 2. The weight breakdown at three draughts is given in Table 1.

The design of STAPLA followed the minimum Opex development routes, as opposed to the Capex development routes. The design objective is to devise a versatile, easy to redeploy platform operating in deep waters susceptible to severe environment.

The STAPLA vessel is designed to support a number of functions including drilling, production and workover. It has a production throughput of 50,000 bopd and can accommodate up to 150 personnel. It is capable of continuous production all year-round without any "down-time" (thus to minimise the operational cost), although certain amount of drilling "down-time" is necessarily allowed to avoid the vessel to be over-sized.

Regarding field criteria, the STAPLA vessel is intended for operation in the development of marginal fields where exploitation of hydrocarbon reserves by alternative methods may prove uneconomic for one or more of the following reasons: (i) small field capacity, (ii) deep water, (iii) harsh environment.

It is suggested that the vessel would be re-used to sequentially produce from 3 or 4 marginal fields throughout its life. The duration at each location would typically be 5 to 7 years.

This implies that the most suitable marginal fields for deploying STAPLA are these under 100 million barrels recoverable reserves and usually in exposed waters. Most North Sea marginal fields are this type, such as in the areas West of Shetland, Haltenbanken, Tromso Patch, etc.

Adopting the constraint that no more than 20% of recoverable reserves can be extracted in any one year and that the potential field would be marginal with a life of approximately 6 years, a typical field specification for the design is as follows:

Field type : oil
Recoverable reserves : 60 million barrels
Maximum throughput : 50,000 bopd
Water depth : 1,000 metres
Drilling depth : up to 16,000 feet
Location : harsh environment/remote area

Regarding environmental criteria, the most severe environmental conditions that are likely to be encountered in European Waters were used for the design. A realistic example representing the environment of West of Shetland is given in Table 2.

The operating limits were primarily imposed by the heave compensator stroke and the allowable angle for drilling strings, together with the acceleration limits on the process plant. Other considerations such as the limits on heave equipment handling and comfort of personnel are also important, but for the STAPLA design they impose less stringent restraints and therefore are usually automatically satisfied.

It has been considered that for medium depth waters or relatively benign environmental conditions, rigid risers are likely to be used for production by STAPLA. The relative motions between the floating structures and the rigid lines must be absorbed by a compensation system. Because a compensator has a finite stroke, a maximal heave limit must be imposed. If the motion exceeds this limit during severe weather the risers must be disconnected and production suspended.

For the design, the operation criteria were chosen as 3.65 m for heave range and 5° for pitch/roll range. These values were collated from vessel operating manuals and reported values in the literature. These criteria were satisfied from a statistical sense, with the probability of exceedence of 1.2% (of hourly mean wind).

The design of such a versatile platform involves a lot of parameters including deck payload, hydrostatic stability, motions responses, construction, installation and etc. A small change in one respect usually have extensive effects over a wide range. The design is inevitably an iterative process. As a wide range of choices are open, a structured strategy is necessary to assist the convergent speed of the design.

Table 3 shows the principal operational characteristics.

3.0 MINIMISATION OF MOTIONS

A spectral approach was used to appraise the motion characteristics. The procedure is shown by the flow chart in Figure 3. The root mean square (RMS) value of the motion response to irregular seas was used to assess the motion performance. In fact, the RMS values reflect the energy absorption by the vessel. The hourly mean wind was used as a primary measure of the environmental conditions, so that the operational "down-time" could be conveniently estimated.

In calculations of response amplitude operators, i.e. R.A.O.s, linear wave theory was applied. Only the first order wave exciting forces and added mass and damping (including drag damping when analysing the resonant response) were considered for the design purpose. The second order drift forces were calculated but were not regarded as design considerations at early stages.

The heave motion of STAPLA is very good compared with existing and propose semi-submersibles, as shown in Figure 4, including DSS10,000 [1], Trosvi BINGO [2] and Gran Gulf [3]. The comparison is particularly in favour of th STAPLA vessel in the short period range. For example, for waves between 8 t 17 seconds the heave R.A.O of STAPLA is only about half or one third of othe vessels.

The heave response curve can be easily tuned. The key is to control t parameters, namely, the natural period and cancellation period.

The natural period in heave is determined by the water plane area (hydrostatic restoring stiffness) and the total mass (displacement + added mass). It is usually kept very long to set the resonance response point far away from the appreciable energy region in the wave spectrum. However, too long a natural period will give less favourable response in the short period range. This is because a long natural period is associated with a long cancellation period which makes cancellation at low periods ineffective.

It is known that a semisubmersibles has a cancellation point. This arises from the opposing forces on horizontal and vertical members, i.e. the out of balance dynamic pressure force on the bases of the surface piercing columns and the inertia force on pontoons and other horizontal members. This inertia force is a result of the difference in dynamic pressure on the pontoon upper and lower horizontal surfaces as well as the Froude-Krylov component which acts on the displaced volume directly. Both components of inertia load are vertically downwards at the wave crest. The pressure component on horizontal members is also downwards in the crest as dynamic pressures are higher on the upper pontoon surface. hence this load is opposed to the dynamic pressure load.

A special feature of the STAPLA vessel is the large horizontal surface resulting from the step change in diameter between the upper and lower columns. This surface is unavoidable for telescopic vessels of the STAPLA type and it was found that it plays a significant role.

The effects of draught on the heave response was studied. Figure 5 shows the response curve at several draughts including two deep draughts 60 m and 80 m. It can be seen that the response at 50 m is quite good. It must be pointed out that the lower period end is of close relevance as that is the region the wave energy is. Increase the draught could reduce the motion further, but this was restrained by the pitch response as described below.

The pitch overturning moment curves are shown in Figure 6 at different draughts. Figure 6 clearly demonstrates that the pitch overturning moment is the minimum at 50 m draught. Whether to decrease the draught or increase the draught from 50 m the pitch moment always increases. This suggests that the 50 m draught may be the optimum for the pitch motion. Indeed this was confirmed by the analysis of pitch responses to random seas: the RMS value of pitch response is the smallest at 50 m draught.

The resulting pitch responses of the STAPLA vessel are very good. As shown in Figure 7, the pitch R.A.O is consistently smaller than that of DSS 10,000 [1] and Trosvik BINGO [2].

The reason for the 50 m draught being the optimum is really that the effective line of action of horizontal forces closely passes through the centre of gravity of the vessel.

The key to good pitch response design can therefore be simplified into a matter controlling the relative position of the line of action of horizontal force and the centre of gravity. When changing from shallow draught to deep draught, the centre of gravity starts from a position above the line of action of horizontal forces (which moves), then moves to coincide with the line of action and eventually overtakes it to a position below. The pitch moment therefore decreases from a relative large value, reaches its minimum and finally begin to reverse the trend to increase. So far, we have not mentioned the moment caused by the vertical force at the bases of columns. In fact, for pitch motions of large draught semisubmersibles they are far less important compared with the horizontal force.

There are a number of other changes with draught variation. For example, with an increase of draught the radius of gyration of mass (i.e. moment of inertia) and added mass will increase; the metacentric height GM and hence natural period will change. These changes were taken into account, although they have less significant impact on the motion characteristics.

As for wave drift, the surge response is of major concern for mooring or dynamic positioning systems. We suggest the use of 8 mooring lines for intermediate water depths up to 600 metres, and dynamic positioning for deeper waters.

The omni-directional response of the vessel in heave, pitch and surge is a good feature. The arrangement of mooring lines is insensitive to the prevailing wind directions.

4.0 CHANGE OF DRAUGHT CONSIDERATIONS

As shown in Figure 1, the variable geometry in STAPLA is achieved by means of telescopic column sections, whereby the lower 9m diameter sections can recess into the 16m diameter upper hull columns.

A jacking system is requried to provide a physical connection between the upper and lower hulls and to enable the lower hull to be raised/lowered relative to the upper hull. This will be installed at the lower end of the upper columns as shown in Figure 8.

The first question we faced is the large jacking load. At the operating air gap of 16m the interface force on the jacking mechanism is of the order of 2600T per leg. As conventional technology suggests a maximum interface load of 1800T during jacking down of the pontoon it is advisable to reduce the air gap to 8m as the upper hull is negatively buoyant and the lower hull is positively buoyant. This reduction in air gap increases the buoyancy of the upper hull and reduces the interface load (static component) to around 1600T per leg.

Water is excluded from the void above the lower columns by compressed air as required when the top of the lower columns are lowered below the still water level.

The following procedure are chosen:

1. Ballast down the vessel to an air gap of 8 metres.
2. Jack down the lower legs one increment (1 or 2 metres depending on jacking system)
3. Ballast down the vessel to 8m air gap using pontoon tanks.
4. Repeat steps 2 and 3 until the desired extension is achieved (58m draught).
5. Engage the locking-off system.
6. Deballast the vessel to the operational air gap (16 metres)

Figure 9 shows the interface load during installations.

With the appropriate jacking procedure, we have a choice either a Friede and Goldman - Combined Jacking/Rack Chock System or a Gusto - Positive Engagement Jacking System, both are comfortably capable of accommodating the interface loads. At the start of the operation, the interface force is at its maximum value of 1600T per leg.

Another problem we faced with the variation of draught is the stability. This is measured by the metacentric height GM.

Because the upper columns are of annular form, it is found necessary to compress the void left in the inner upper columns when the lower columns are jacked down below the water level. Extensive studies were carried out and it was ensured that ample stability is available in all intact cases and severe damaged cases as required by certifying societies.

Figure 10 shows the stability during installations.

5. CONCLUDING REMARKS

A vessel has been designed which has the following characteristics:-

(1) Good omni-directional motion response characteristics.
(2) Variable draught to allow inspection, maintenance and modification for multiple field use.
(3) Sufficient payload capacity for both drilling and production.
(4) Ample stability and reserve buoyancy in both intact and damaged conditions.
(5) Comparable steel weight to payload ratio to conventional semi-submersibles.

Compared with existing semisubmersibles, the STAPLA vessel is extremely versatile and have much better motion performance, although care should be taken in certain areas associated with the telescopic column design.

REFERENCES

1. "New generation semi design for 10,000-ft waters - with a payload of 10,000 tonnes" Ocean Industry, December 1983.

2. "BINGO 3000 - A success story", Ocean Industry April 1981.

3. "Gran Gulf: Cost-effective semi for Gulf of Mexico", Ocean Industry, April 1985.

	TRANSIT	TRANSIT SURVIVAL	OPERATING
DECK PAYLOAD	5242	6542	7032
DECK STRUCTURAL PRIMARY	3400	3400	3400
DECK STRUCTURAL SECONDARY	3000	3000	3000
UPPER COLUMNS	4089	4089	3089
LOWER COLUMNS	1320	1320	1320
BRACINGS	252	252	252
PONTOON STEEL	9387	9387	9387
FLUIDS IN PONTOONS	800	2400	2400
BALLAST WATER	493	10542	16333
TOTAL WEIGHT	28000	41000	49000

TABLE 1 Weights for Different Operations

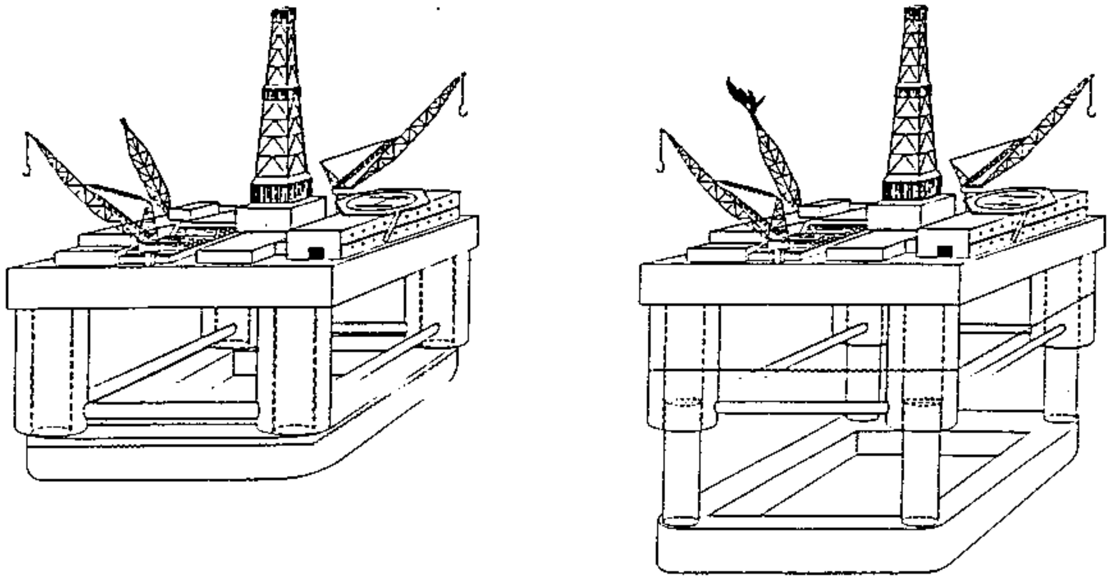
		Extreme Environmental Conditions (1 in 50 years)	Normal Operating Conditions (12 per year)
RANDOM WAVES			
Significant height, H_s	(metres)	18.0	8.5
Zero crossing period, T_z v	(secs)	15.0	11.0
Storm duration	(hours)	6	6
DETERMINISTIC WAVES			
Max. wave height H_m	(metres)	33.0	15.5
Wave period, T	(secs)	20.0	15.0
RANDOM WIND			
Hourly mean wind at 10m	(m/sec)	41	27
3 sec. gust speed	(m/sec)	58	37
1 min. mean speed	(m/sec)	48	31
CURRENT			
At surface	(m/sec)	1.00	0.86
At mid-depth	(m/sec)	0.39	0.32

TABLE 2 Environmental Criteria - West of Shetland

	Transit	Transit Survival	Operating
Air Gap(m)	31.5	17	16
Draught(m)	10	24.5	50
Displacement (tonnes)	28000	41000	49000
Heave Natural Period (Sec)	10.3	19.6	20.5
Metacentric Height (m)	49	8.1	7.1
Centre of Gravity(m)*	18	-2.8	-21.8

* measured from still water line

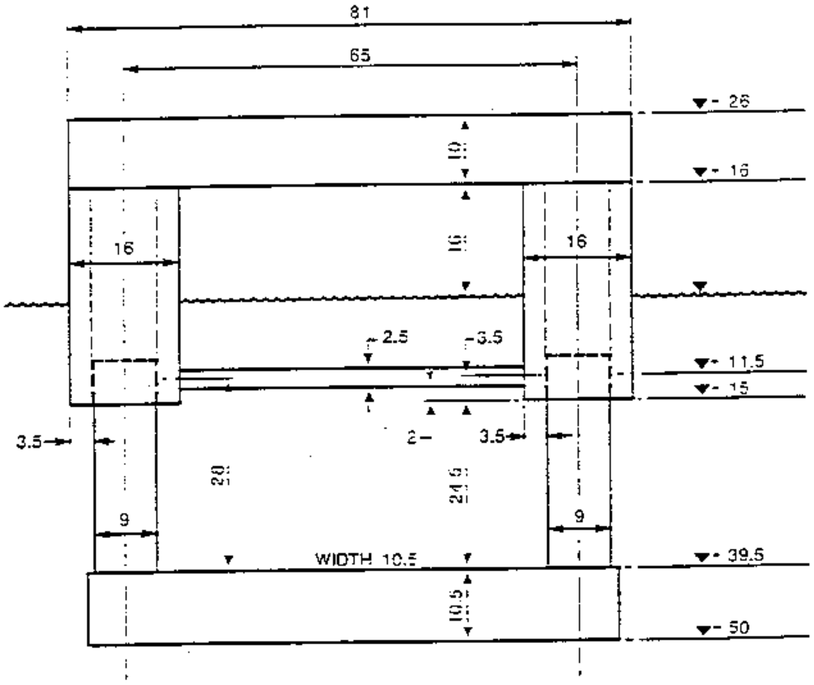
TABLE 3 Principal Operational Characteristics



TRANSIT CONFIGURATION

OPERATIONAL CONFIGURATION

FIG 1 VARIABLE DRAUGHT SEMI-SUBMERSIBLE



ALL DIMENSIONS IN METRES.

FIG. 2 OPTIMISED STRUCTURAL ARRANGEMENT

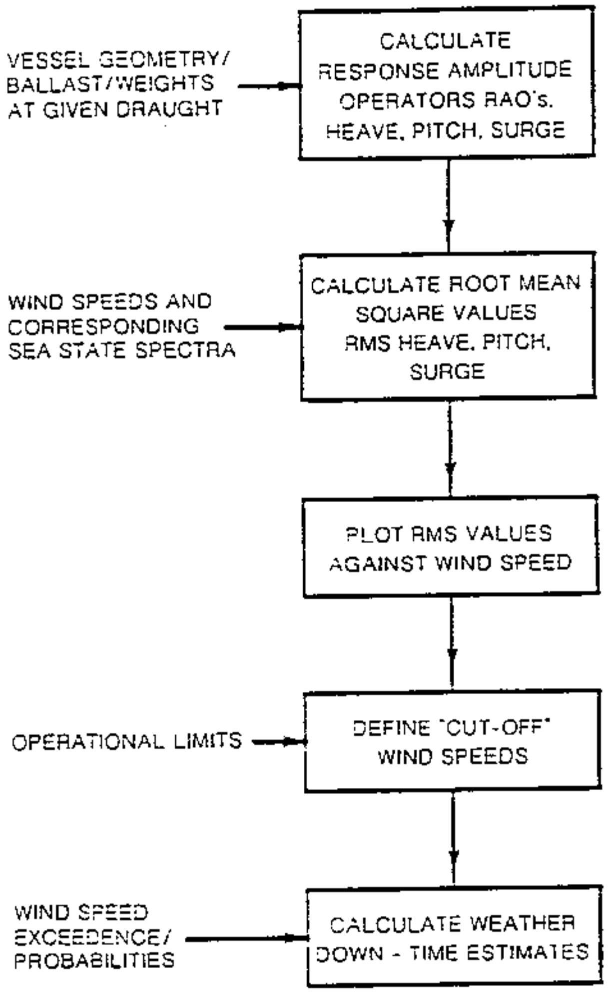


FIG 3 ECONOMIC EVALUATION OF THE EFFECT OF INCREASING DRAUGHT

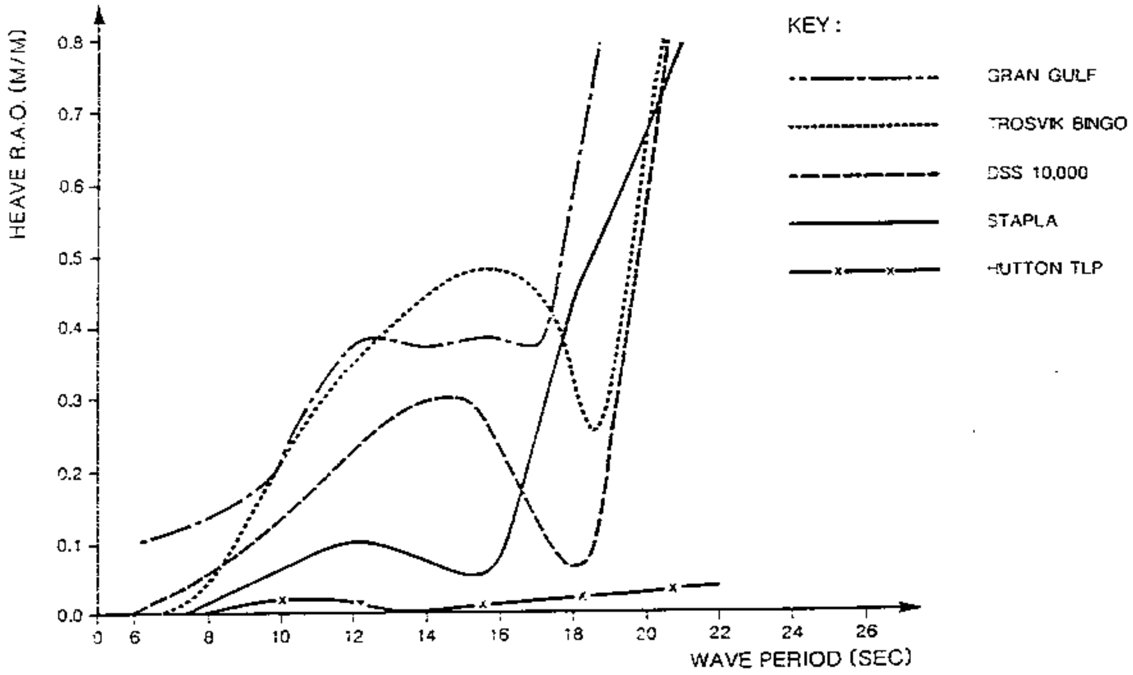


FIG. 4 COMPARISON OF HEAVE RESPONSE AT 0° WAVES (OPERATING DRAUGHT)

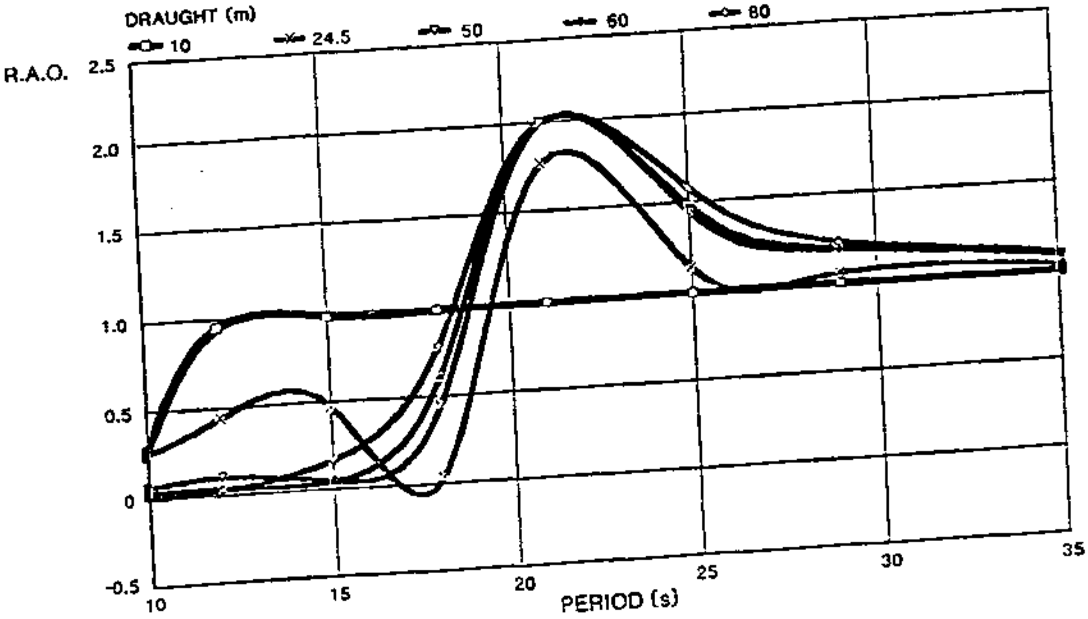


FIG. 5 HEAVE RESPONSE AMPLITUDE OPERATOR

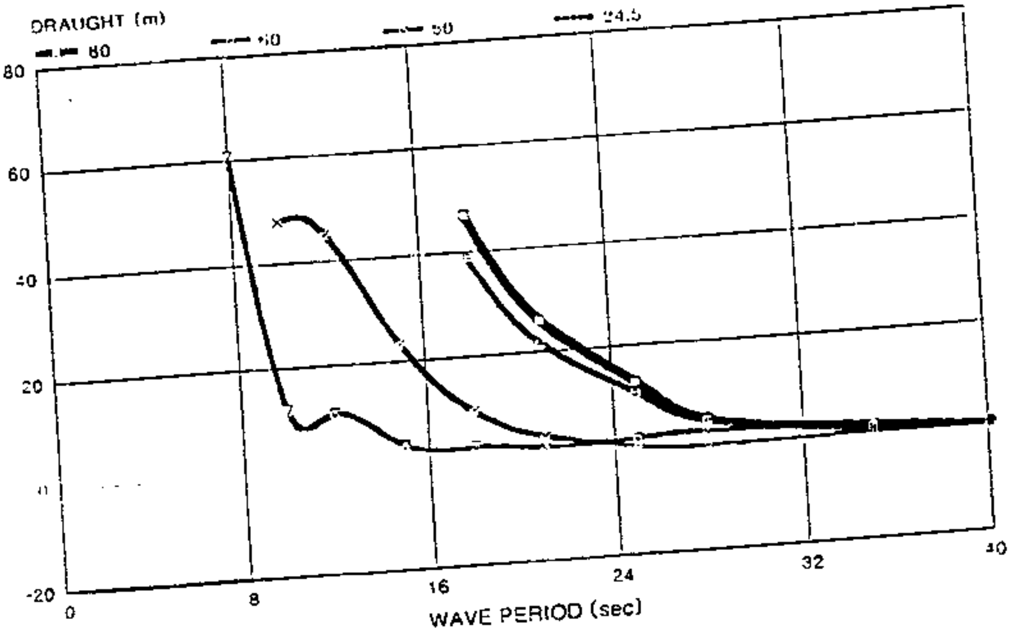


FIG. 6 STAPLA PITCH OVERTURNING MOMENT

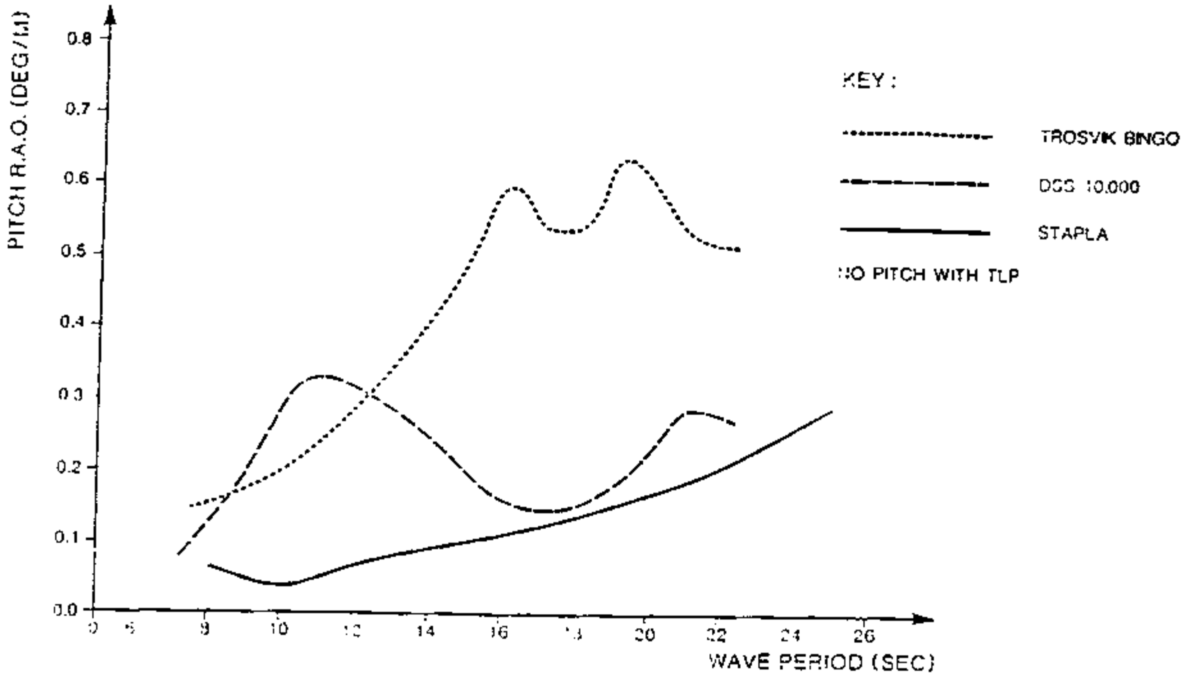
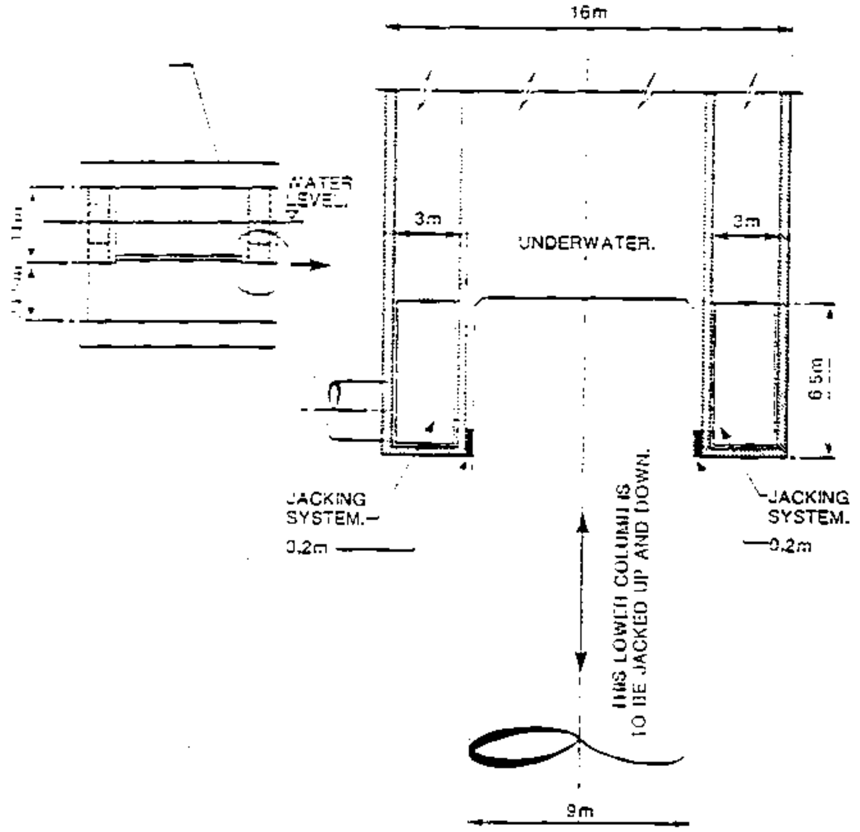


FIG.7 · COMPARISON OF PITCH RESPONSE AT 0° WAVES (OPERATING DRAUGHT)



DESIGN REQUIREMENTS :

ENVIRONMENT : UNDERWATER.
JACKING LOAD : 1,800 TONNES PER LEG.
HOLDING LOAD : 2,500 TONNES PER LEG.
JACKING LENGTH : 24.5 METRES.

FIG.8 ARRANGEMENT OF JACKING/CONNECTION SYSTEM

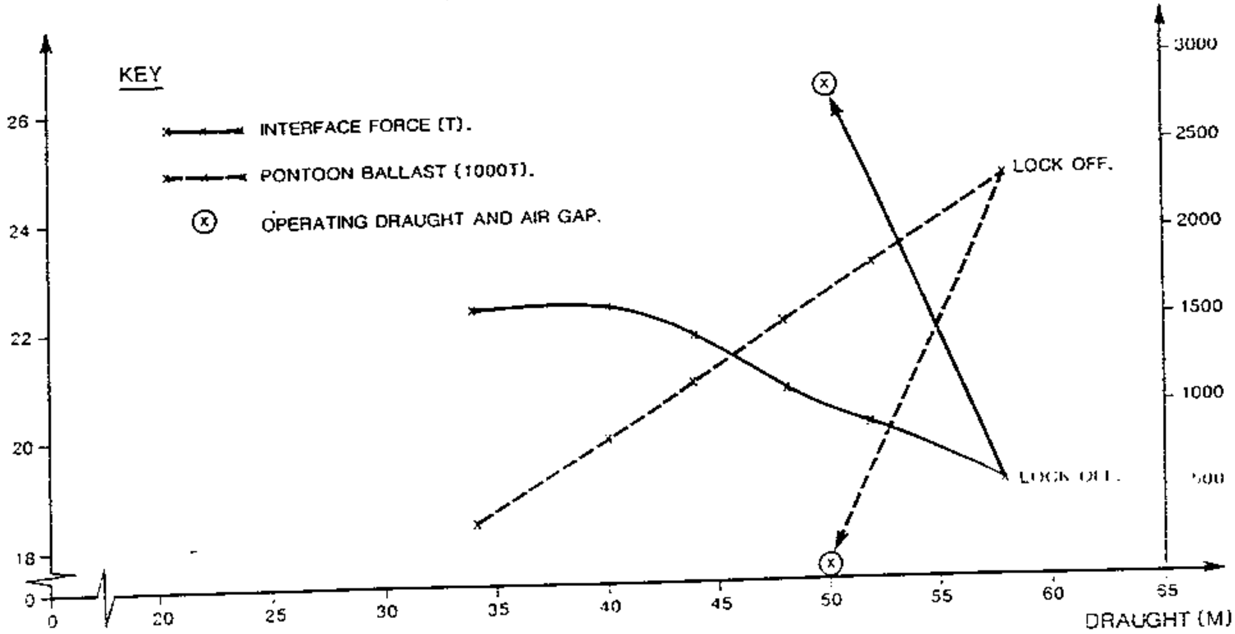


FIG. 9 INTERFACE FORCE AND PONTOON BALLAST DURING INSTALLATIONS

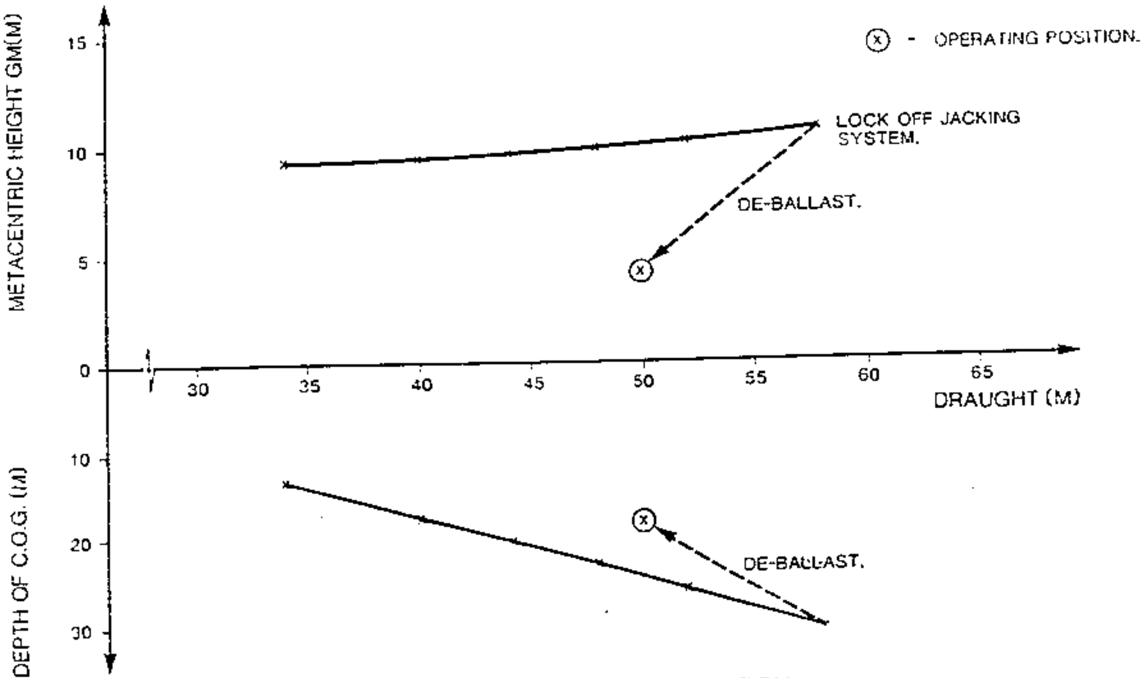


FIG. 10 STABILITY DURING INSTALLATION