

STAPLA - A Variable Geometry Semi-submersible for
Floating Production

S Walker and J R Williams

Abstract

The STAbilised PLAtform (STAPLA) is a variable geometry semi-submersible concept that offers significantly improved motion response characteristics over conventional semi-submersible vessels. There are also benefits in payload carrying capacity resulting from the deep draught of the vessel in its operating condition. The variable geometry enables the vessel to 'transit' at a draught of 10 metres which allows inspections in dry dock to be performed at regular intervals.

STAPLA is designed to support drilling, production and workover capabilities in a range of water depths/environments including deep water. It is envisaged for operation in marginal field developments where exploitation of hydrocarbon reserves by alternative methods may prove uneconomic due to the harsh environment, water depth or limited field capacity. With total topsides of 20,000 tonnes including deck steel weight, the design offers an alternative to fixed platforms for such marginal fields with the advantage of mobility resulting in cost saving from early production and without cost penalties associated with field abandonment.

This paper describes the analysis methods and results which establish the design as a cost effective alternative to existing semi-submersible and fixed platform options. Correlation with model tests is discussed and the optimisation of the structure is described.

Finally, the paper concludes with a discussion of areas of further development of the design to be performed over the remaining 18 months of this three year design project. Pre-certification Design Approval is being sought at the end of this period.

DEVELOPMENT OF A NEW CONCEPT FLOATING PRODUCTION FACILITY

J J DAVISON and J R WILLIAMS

Wimpey Offshore, London

Summary

This paper describes the work and associated results involved in the development of a new concept support structure for a Floating Production Facility (FPF). The STAPLA concept is a development of the conventional Semi-Submersible with substantial improvements in the motion responses whilst also improving the payload to steel weight ratio. The motion characteristics are more akin to those of a Tension Leg Platform than a conventional semi-submersible.

The paper starts by introducing the STAPLA concept and establishing the likely design requirements for such a unit. Based on these functional requirements, the concept is researched in order to establish the potential benefit and identify the major constraints. The paper continues with the design development of a STAPLA unit based on the findings of the previous activities. The motion analysis section describes the motion response characteristics of the STAPLA designs and the method used to establish them, including model testing and correlations. The paper concludes with a discussion on areas requiring further definition and future development.

1. THE STAPLA CONCEPT

The STAPLA concept is a development of the conventional semi-submersible. The semi-submersible has been evolved over the last 20 or so years due to its ability to operate in environments which were too severe, in terms of both water depth and atmospheric conditions, for the efficient use of submersible, barge or jack-up units. During this time the semi-submersibles have become the work-horse for exploration purposes in 'harsh' environments with over 180 units completed to date. A more recent and increasing application for semi-submersibles is for production of fields which are uneconomic for development using more conventional support structures. These Floating Production Facilities (FPFs) tend to be used on either small fields, with short anticipated field lives, or in deep water.

The ability for semi-submersibles to operate in hostile environments is dependant on the unit's low motion characteristics, the capability of the heave compensation systems and the habitability for the crew (including their ability to do useful work in safe conditions). The STAPLA development of the semi-submersible concept enhances the motion characteristics while also improving the 'payload' capability.

The principal design feature of the semi-submersible type is that major buoyancy members are located well below the water plane level when in the operating mode. This not only increases the heave period, thereby avoiding resonance with incident waves, but also reduces the wave loading. The reduced loading is due to the major hull component being at a level

with reduced water particle energy from surface waves. The maximum depth at which the pontoon sections can be submerged is effectively constrained by the requirement for sufficient stability while deballasting to a shallow transit draught. A shallow transit draught is desirable as it improves mobility and also enables port entry. STAPLA avoids this constraint on maximum draught by designing in the ability to vary geometry. In this way a STAPLA unit can benefit from a further improvement in motions while maintaining the ability to enter ports.

A drilling and production STAPLA unit will offer:

- Minimal heave, pitch and roll motions enabling year round use of rigid riser ie. continuous drilling operations.
- Greatly reduced deck accelerations alleviating the resulting sloshing in production separators and improving habitability.
- Ability to achieve shallow draught for docking to facilitate inshore hook-up and commissioning, conversion, modification and maintenance activities.

2. FUNCTIONAL REQUIREMENTS

The functional requirements are the overriding considerations when designing any object. A drilling semi-submersible unit only exists as it offers an attractive efficiency in drilling an offshore well; rightly or wrongly this efficiency is invariably measured in economic terms. Similarly on FPF will only be used if it offers an economic advantage when compared to the use of a conventional facility.

While the functional requirements for a drilling unit remain relatively insensitive to the field on which it is being used, the requirements for a production unit will vary considerably from field to field. This is because the drilling process remains essentially constant while the requirement for processing of produced fluids will vary substantially, not only from field to field but during the life of a given field. As a consequence, it was decided that to design for a specific requirement was inappropriate at the initial stage of development. A topside load of approximately 14,500te was loosely established as being representative of a potential field for development by a STAPLA unit. Note that this topside load is the weight of equipment, supplies and local supporting, or secondary, steel. As it does not include the primary steel content of the deck structure, it is comparable with a conventional topsides weight of around 20,000te. This weight nominally included processing for 100,000bbl/day of produced fluids, water injection, gas lift and an extensive drilling capability with accommodation for at least 150.

It was recognised that the above topside load was generous for a unit which was to sequentially produce 3 or 4 marginal fields. For such an application a design through-put of 50,000 BOPD leading to a topsides load of around 11,000 - 12,000te, including drilling, was considered more likely. Nevertheless it was decided that a nominal topside load of 14,500te was a reasonable upper bound figure with which the potential for the STAPLA concept could be established.

Selection of a design case operating and survival environment was based on locations which are currently only explored on a seasonal basis eg. in deep water west of Shetlands. The most significant impact of the environment is on the air gap, mooring system and stability requirements.

It is worth pointing out that the likely topsides load for a drilling only STAPLA unit would be around 7,000te, assuming a 4,500te variable deck load. Another important difference between a drilling only and production unit is the requirement for mobility, effecting the selection of pontoon arrangement.

3. CONCEPT RESEARCH

The next objective of the STAPLA project was to establish the potential benefits of the concept. Originally, the intention was to develop a 'Datum Case' by enhancing an existing design of a third generation semi-submersible. This was found to be impractical due to the implications of increased pontoon scantlings, resulting from increased submergence, as well as accommodating the variable draught capability. The result was a need to develop a new design for the STAPLA concept which met the functional requirements. The basic configuration was established from the desirability of a ring pontoon, 4 columns and a deep buoyant deck structure. The benefits of such a design are the simplicity of nodal areas which are possible due to the maximum arrangement of continuous structural members and the presence of significant reserve buoyancy in the deck structure. In order to minimise the complexity of the mechanical equipment associated with the variable draft capability, the 'jacking columns' were located concentrically with the upper (main) columns. This enabled existing jackup technology to be used.

The resulting design was designated Design 1, the principal dimensions of which are given in Table I and shown in Figure 1.

Table I: Design 1: Principal Dimensions

Upper Hull:		Lower Hull:	
Deck Structure		Ring Pontoon	
Length	90m	Breadth	15m
Breadth	90m	Depth	11m
Depth	10m	Corner to Corner Length	90m
Air Gap	20m		
Main Columns		Lower Columns	
Centre - Centre Dist	75m	Centre to Centre Dist	75m
Diameter	17m	Diameter	10m
Overall Length	40m	Exposed Length	54.5m

The main feature of Design 1 is its exceptional motion response characteristics. However, being optimised with this in mind, little concession was given to considerations such as steel weight and positioning requirements.

The motion responses were established initially by model testing which served to emphasise the substantial potential of the STAPLA concept, see Section 5. The main detrimental characteristics of steel weight and current induced drag are due to its physical size and in particular the hydrostatic pressure on the pontoon sections. The total steel weight was estimated at 33,700te consisting of:

Deck Structure Primary	4,500te
Secondary	3,000te
Main Columns	5,400te
Lower Columns	7,000te
Pontoon	13,800te

It should be noted that the functional requirements are well in excess of those that can be met by conventional drilling semi-submersibles.

In order to enable the STAPLA concept to be further researched the

main constraints for Design 1 were identified. These are:

- The inability to brace the lower columns due to the concentric 'jacking column' arrangement.
- As a consequence of the above, the structural requirement for the lower columns necessitates a large diameter and leads to an undesirably low centre of buoyancy.
- The required scantlings and consequential steel weight of the pontoons.
- Penetration of the deck structure by the lower columns.

Considerable effort was made to design out these constraints. By abandoning the concentric column arrangement and having the lower columns arranged within the plan area of the upper columns, bracing could be incorporated which enabled use of small diameter lower columns. This in turn enabled the possibility of using free flooding pontoons. The use of free flooding enables the hydrostatic head both inside and outside the pontoon structure to be equalised. In this way the pontoon design pressure can be reduced by about 50%. Free flooding to avoid the hydrostatic pressure has been in use for over 80 years in ballast tank design and fairing on submarines. One further possible refinement was identified which enabled the lower columns to be raised within the space between the upper columns and the underside of the deck structure. This avoids the lower columns interfering with the deck structure layout.

4. DESIGN DEVELOPMENT

Having established that the STAPLA concept offers significant benefits over conventional semi-submersibles, the next stage was the development of an actual STAPLA design. For this activity Design 1 was used as a datum against which the effects of the previously identified enhancements could be evaluated. Due to the impact of the changes in configuration it was found necessary to establish a STAPLA Initial Design computer program. This program enabled rapid evaluation of a STAPLA design based on its principle dimensions. The first application of this computer aided design tool was to perform a parametric study to enable the interaction of design dimensions to be assessed. Based on the findings, the following design guidelines were established:

- The pontoon size should be sufficient to enable the desired transit draught, but small enough to avoid excessive ballast in the operating condition.
- The displacement of the upper columns and associated bracing should be sufficient to support the FPFs operating weight.
- The column depth/diameter ratio will depend on the required water plane area to produce a heave period of above 20 seconds.
- The spread of upper columns will be dictated by stability requirements.
- The upper hull bracing can be used to avoid excessive dimensions of the upper columns.

The above fundamental design guidelines were then used to develop the approach to the initial design of a STAPLA unit, see Figure 3. The first application of this design approach was the development of Design 2, the basic configuration of which differs substantially from that of Design 1, see Figure 2.

The comparison of Designs 1 and 2 can be summarised by considering the more significant changes. These are:

- Reduction in plan deck area by 22%, although only a 10% reduction in useable space as column penetrations have been avoided.
- Reduction of pontoon displacement by over 50% due to smaller sections and lengths.
- Reduced lower column displacement which combined with reduced pontoon

size results in an upper to lower hull displacement ratio of 1 as apposed to 0.25 for Design 1.

- Centre of buoyancy raised by 25% and a 35% reduction in displacement, which improves stability enabling a lighter deck structure due to reduced spans between the main columns.
- Reductions in steel weight of:

Pontoons	48%
Columns Lower	88%
Upper	2.5%
Deck	25%

- Introduction of upper hull pontoons/bracing and lower hull bracing with a total steel weight of 3,225te.

A more complete comparison is given in Figure 4.

In short Design 2 offers an overall reduction of steel weight of nearly 20%, assuming both designs use a similar ballasting philosophy. However, Design 1 may not be able to use the free flooding ballasting in which case the comparative saving would be substantially higher. The cost of realising this improvement is a 10% reduction in useable deck space and a reduction in heave period of about 4 seconds to 23.5 seconds. Although it does not necessarily follow that a reduction in heave period leads to an increase in the vertical plane response motions, it is usually the case. The next requirement was to quantify the effect on motions.

5. MOTION ANALYSIS

Two separate approaches were used to establish the motion characteristics of the STAPLA concept. The main approach made use of existing analytical tools while the second approach was physical model testing. The model testing was considered necessary due to the novel configuration of the STAPLA concept and the consequential lack of data against which analytical tests could be correlated. The AQWA hydrodynamic analysis package was selected and subsequently purchased as it enables wave loading to be established by Morison's approach and/or full diffraction analysis. The first motion analysis task was to correlate the full diffraction analysis results with those for the model tests, the second task being to establish the level of idealisation that can be employed with the Morison's approach while retaining reasonable accuracy. The objective was to use an inexpensive model for initial design purposes while reverting to a full diffraction analysis for verification.

The correlation between the model test and diffraction analysis results was surprisingly good with discrepancies readily explainable as scaling effects, plotting accuracy of model test results and the effects of the mooring system. In conclusion, it was felt that the diffraction analysis could be used to produce reliable wave loading and motion responses. Substantial accuracy of an idealised Morison model could be obtained by suitable selection of the added mass and drag coefficients. This was achieved by identifying the added mass and damping values which were established for a suitable frequency in a relevant diffraction analysis. Figure 5 shows the effect on heave response of varying these coefficients. It was found that the heave added mass value for the overall structure was substantially higher than anticipated, based on published data. This was due to the end plate of the upper columns of Design 2 making a significant contribution. Allowing for the input of directional, including axial, added mass coefficients in the Morison analysis option was one of several areas of AQWA which required

modification and enhancement.

The most significant findings of the motion comparison of Designs 1 and 2 are the heave and pitch/roll response amplitude operators (RAOs). While there was little change in the surge response, the change in the most important linear motion, heave, was negative as expected. Design 2 has heave RAO values of approximately twice those for Design 1. This increase seems unacceptable until it is put into context by comparison with the heave RAOs for existing FPFs, see Figure 6. The heave response of Design 1 and 2, when in conventional maximum operating conditions, are typically 20% and 40% of those for existing FPFs respectively, while the most onerous angular motion, pitch/roll, is approximately 30% of that for existing FPFs. This is the case for both Designs 1 and 2, see Figure 7. In certain circumstances the pitch/roll motion is even more significant than heave motions, particularly for the drilling riser and during casing operations. Other important effects of pitch are the accelerations induced at deck level leading to sloshing in process trains.

6. CONCLUSION AND FUTURE DEVELOPMENT

The substantial benefits of a deep draught semi-submersible have been demonstrated and are now widely acknowledged. The STAPLA concept is unique in enabling these benefits to be realised while maintaining the capability for the unit to be brought inshore. This latter feature offers reduced Capex through lower installation and commissioning costs as well as lower Opex since inshore maintenance, conversion and modification is possible.

The main areas requiring further definition and development are the detailed structural design (in particular the connection between the upper and lower hulls), intact and damaged stability, the positioning system (be it passive, active or combined), the ballasting system control and riser design for drilling, workover as well as for oil and gas production. It is anticipated that the above aspects will be addressed for a STAPLA unit designed to meet the functional requirements for a specific field development prospect. The findings of this activity will then be incorporated into a portfolio of designs ranging from a drilling only to a full drilling and major production STAPLA unit.

7. ACKNOWLEDGEMENT

Acknowledgement is made to George Wimpey PLC and the Oil and Natural Gas Directorate, Commission of the European Communities for funding, enabling the ongoing research and development of the STAPLA concept.

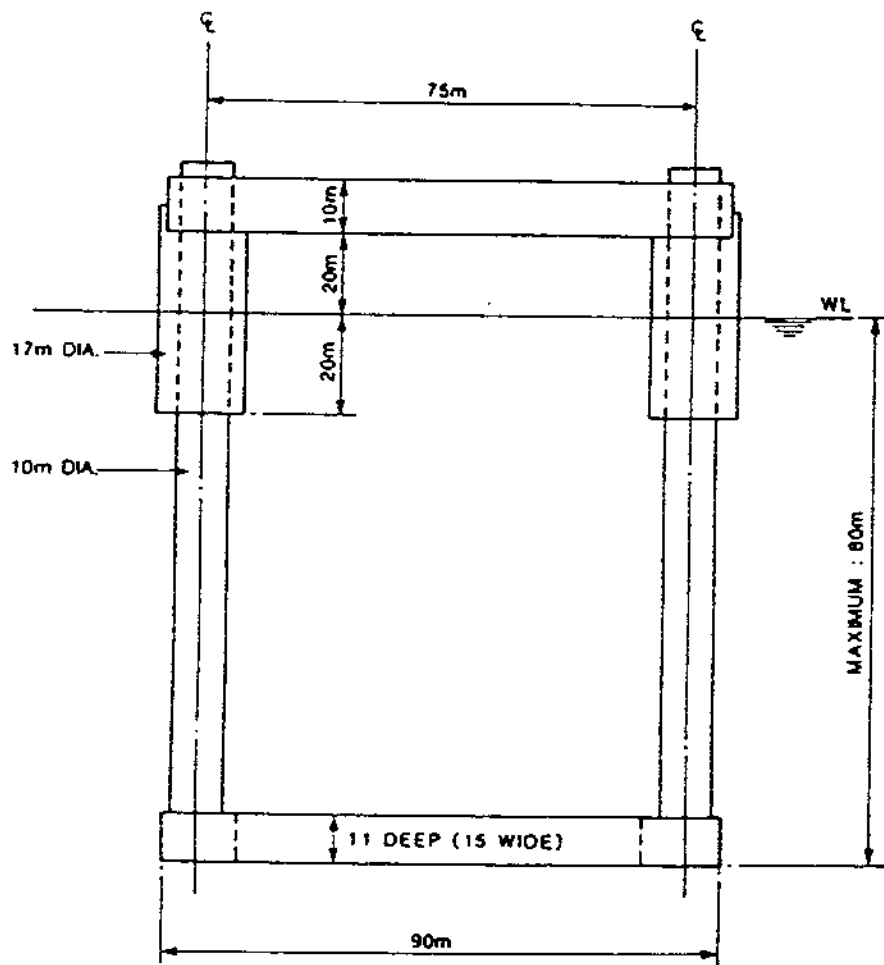


FIG. 1 : - DESIGN 1 CONFIGURATION

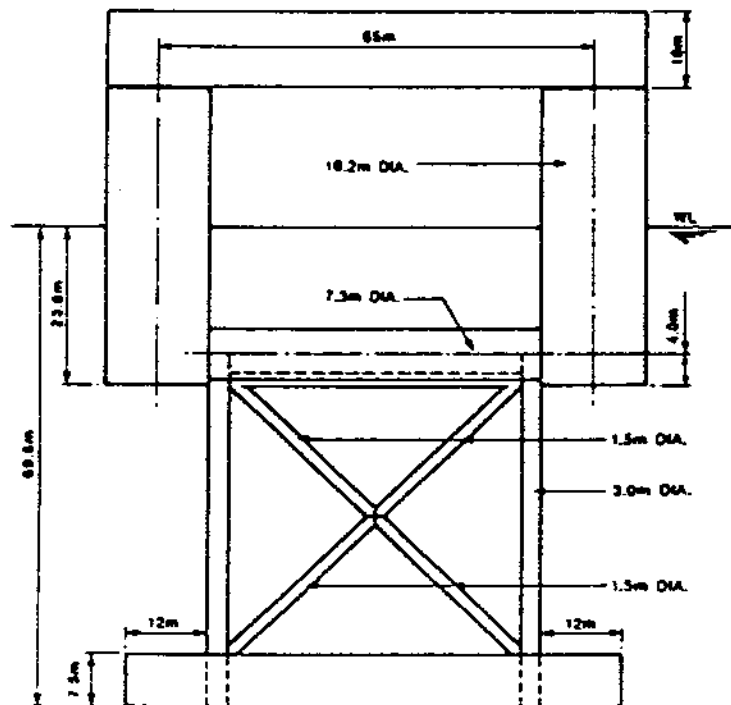


FIG. 2 : - DESIGN 2 CONFIGURATION

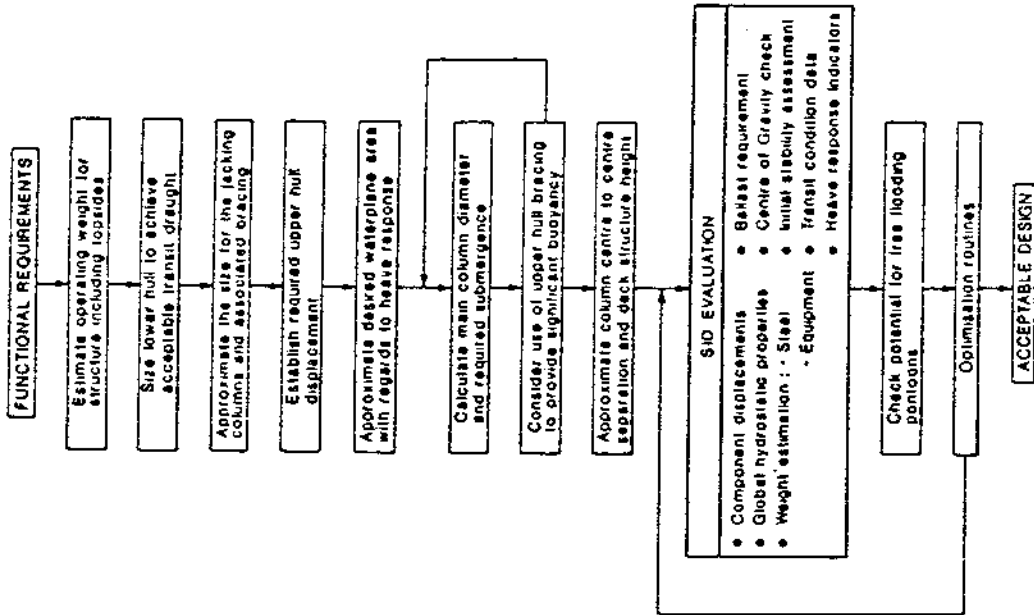


FIG. 3 : - INITIAL DESIGN APPROACH

SIMPLIFIED INITIAL DESIGN PROBLEM

DESIGN ESTIMATION (STEP 1) DESIGN 2 COMPARISON (STEP 2)

DESIGN ESTIMATION (STEP 1)	DESIGN 2	COMPARISON (STEP 2)
CC Column C/C	75.0	45.0
CD Deck Depth	19.0	16.0
CE Column E/C	21.0	18.0
CF Column F/C	21.0	18.0
CG Column G/C	21.0	18.0
CH Column H/C	21.0	18.0
CI Column I/C	21.0	18.0
CJ Column J/C	21.0	18.0
CK Column K/C	21.0	18.0
CL Column L/C	21.0	18.0
CM Column M/C	21.0	18.0
CN Column N/C	21.0	18.0
CO Column O/C	21.0	18.0
CP Column P/C	21.0	18.0
CQ Column Q/C	21.0	18.0
CR Column R/C	21.0	18.0
CS Column S/C	21.0	18.0
CT Column T/C	21.0	18.0
CU Column U/C	21.0	18.0
CV Column V/C	21.0	18.0
CW Column W/C	21.0	18.0
CX Column X/C	21.0	18.0
CY Column Y/C	21.0	18.0
CZ Column Z/C	21.0	18.0
DA Deck Area	11.0	11.0
DB Deck Bracing	11.0	11.0
DC Deck Structure	11.0	11.0
DD Deck Weight	11.0	11.0
DE Deck Height	11.0	11.0
DF Deck Length	11.0	11.0
DG Deck Width	11.0	11.0
DH Deck Area	11.0	11.0
DI Deck Bracing	11.0	11.0
DJ Deck Structure	11.0	11.0
DK Deck Weight	11.0	11.0
DL Deck Height	11.0	11.0
DM Deck Length	11.0	11.0
DN Deck Width	11.0	11.0
DO Deck Area	11.0	11.0
DP Deck Bracing	11.0	11.0
DQ Deck Structure	11.0	11.0
DR Deck Weight	11.0	11.0
DS Deck Height	11.0	11.0
DT Deck Length	11.0	11.0
DU Deck Width	11.0	11.0
DV Deck Area	11.0	11.0
DW Deck Bracing	11.0	11.0
DX Deck Structure	11.0	11.0
DY Deck Weight	11.0	11.0
DZ Deck Height	11.0	11.0
EA Deck Length	11.0	11.0
EB Deck Width	11.0	11.0
EC Deck Area	11.0	11.0
ED Deck Bracing	11.0	11.0
EE Deck Structure	11.0	11.0
EF Deck Weight	11.0	11.0
EG Deck Height	11.0	11.0
EH Deck Length	11.0	11.0
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EL Deck Structure	11.0	11.0
EM Deck Weight	11.0	11.0
EN Deck Height	11.0	11.0
EO Deck Length	11.0	11.0
EP Deck Width	11.0	11.0
EQ Deck Area	11.0	11.0
ER Deck Bracing	11.0	11.0
ES Deck Structure	11.0	11.0
ET Deck Weight	11.0	11.0
EU Deck Height	11.0	11.0
EV Deck Length	11.0	11.0
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FP Deck Structure	11.0	11.0
FP Deck Weight	11.0	11.0
FP Deck Height	11.0	11.0
FP Deck Length	11.0	11.0
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FP Deck Bracing	11.0	11.0
FP Deck Structure	11.0	11.0
FP Deck Weight	11.0	11

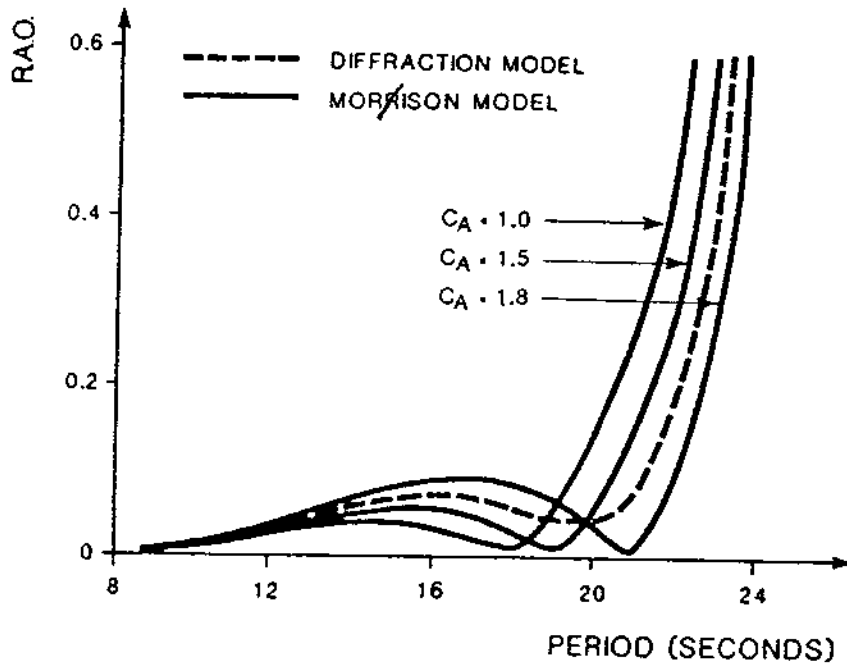


FIG. 5 : - EFFECT OF ADDED MASS COEFFICIENT ON HEAVE R.A.O'S

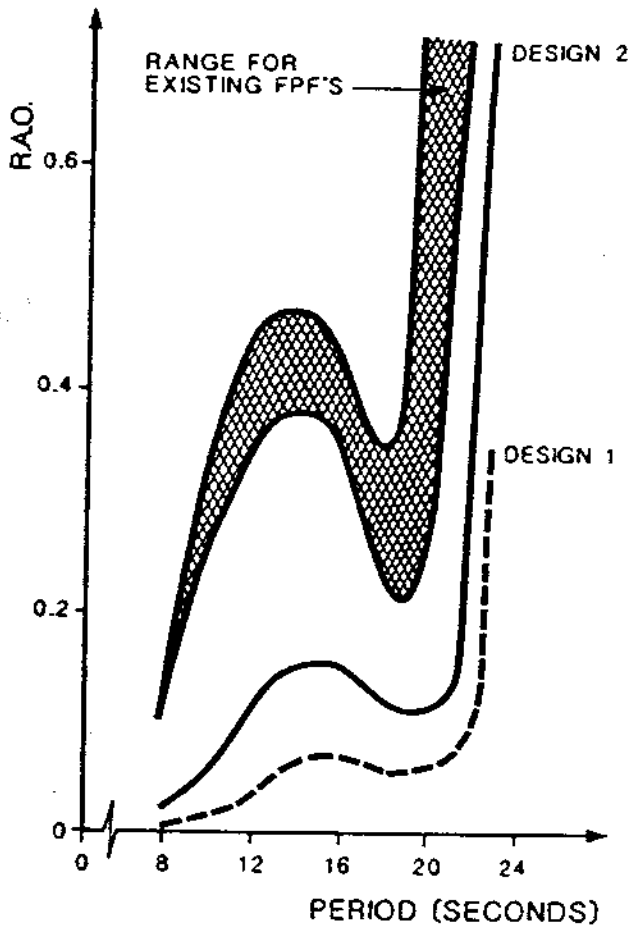


FIG. 6 : - COMPARISON OF HEAVE R.A.O'S

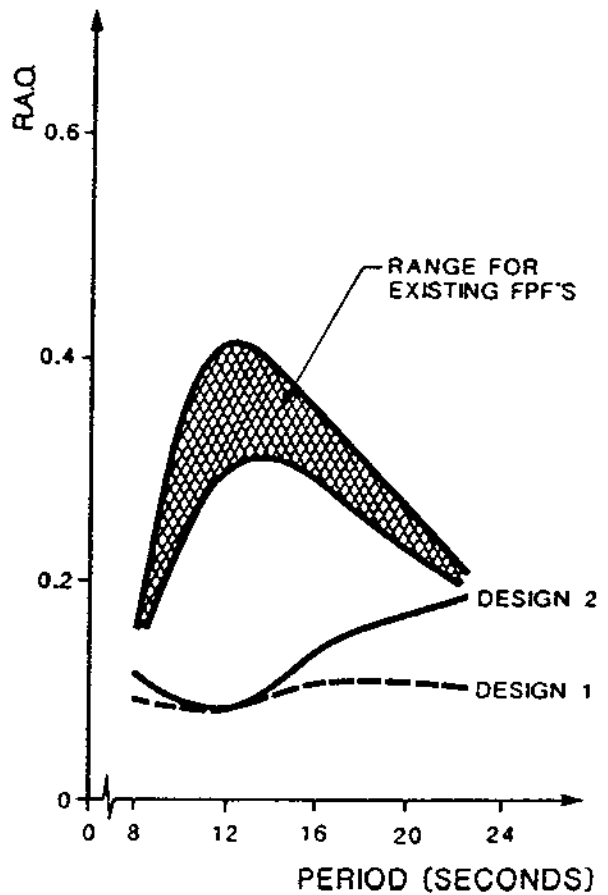


FIG. 7 : - COMPARISON OF PITCH/ROLL R.A.O'S