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THE EFFECT OF PONTOON GEOMETRY ON THE RESPONSE OF A TLP IN WAVES

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ABSTRACT

This paper describes experiments carried out on a model Tension Leg Platform (TLP) in the Offshore Wave Basin at the Danish Hydraulic Institute (DHI). The main objective of the experiments was to obtain data that could be used to increase the understanding of the phenomena of flow separation and vortex shedding from the TLP hull and its contribution to determining the response of the TLP in waves. The design of the bilge edges of the TLP pontoons, which are square in section, were varied as being the parameter most strongly influencing separation in these types of flow. The model was constructed so that rounded bilge edges could be exchanged for sharp rectangular edges. The tests undertaken include the measurement of the model responses in regular and irregular seas at various headings. All the tests were performed for both rounded-edged and sharp-edged cases. All significant degrees of freedom were measured, but this paper concentrates on the surge response, and to a lesser extent the yaw response of the body. The results are compared with the predictions of a theoretical panel method which takes into account the effects of flow separation and vortex shedding.

INTRODUCTION

Viscous flow phenomena are of importance to many problems relating to the fluid loading of offshore vessels and fixed or floating offshore structures. The common factor in the solution of problems involving viscous effects, in so far as they are capable of solution, is that the analysis techniques employed rely heavily on empiricism. The data required is obtained through experiment, where possible, and on the basis of best estimates where it is unavailable. Viscous damping in many cases can be attributed largely to flow separation and vortex shedding from the surface and appendages of the body in question. A complete theoretical description of such phenomena entails the use of the Navier Stokes equations, which become prohibitively expensive for numerical solution for practical three dimensional cases involving investigation of a range of frequencies. Most estimates of response where viscous damping is important have therefore relied heavily on tank tests and the present paper describes the results of a set of tests of this type.

One group of theoretically based methods that have shown promise in the solution of separated viscous flow problems are those based on vortex methods (Graham, 1980, Graham and Djahansouzi, 1991). This report describes the latest in a series of experiments aimed at validating theoretical techniques involving the application of vortex based methods matched to potential flow solutions for structures floating in waves with a view to predicting the viscous damping and response of the structure. Most of the numerical work that has been carried out to date deals with responses at the wave frequency, but low frequency responses (slow drift) also considered.

The numerical method used to make comparisons with the experimental results in this work has been developed from a technique for predicting the roll damping and response of barges. The prediction of the roll motion of offshore transport barges using unseparated potential flow theory can grossly overpredict the amplitude of the motion when the incident waves are at the natural frequency of the barge. A method has been developed of matching a local discrete vortex analysis for flow about an isolated edge applied on a strip theory basis, to a global potential flow solution for the oscillatory flow about a barge (Downie, Bearman & Graham, 1988). The method enabled prediction of the roll motion of a barge floating in waves to be carried out by a purely theoretical approach carried out in the frequency domain.

Subsequently, this matching procedure was developed further so that it could be used in conjunction with a fully three dimensional boundary element solution for the global motion of floating bodies with viscous damping included for all six degrees of freedom. The method was found to give results that agreed well with experiment (Downie, Graham and Zheng, 1990a). A second approach was also developed in which the viscous separation effect at an edge was modelled by a dipole edge panel (Downie, Graham, and Zheng, 1990b).

EXPERIMENTAL ARRANGEMENT

The DHI offshore wave basin has the capability to generate three-dimensional irregular waves. A set of experiments was carried out for the model with both rounded and sharp-edged pontoon bilges for model orientations of 0° and 45° in three dimensional irregular seas.

The model used in the experiments is built of plywood and PEH tubing. In configuration it resembles a 1:50 scale simplified version of the Snorre TLP, as shown in Figure 1. It was tethered in 6 m of water by four very thin tethers, one at each corner. The tethers were made of stainless steel, and were lead through small diameter tubes in each column and connected to small electro-motors mounted on deck, so as to allow their pre-tensioning.

The pontoons of the model, which are rectangular in section, were designed and built so that the bilge edges are removable. The pontoons can thus be adjusted to have either sharp or rounded edges with a radius of curvature of 0.035 m.

The tests were carried out in the DHI offshore wave basin which has been described by Sterndorff and Skourup (1992) who refer to Aage and Sand (1984) for a more detailed description. The principle dimensions of the basin are 30 x 20 x 3 m. In the centre of the tank there is a 6 x 4 x 3 m deep pit with a removable cover, which in turn contains a 6 m deep 2.5 m diameter shaft. The model tethers were terminated at the level of the bottom of the pit. The tension in each tether was measured using load cells.

Sixty independent flap type wave makers generate waves originating along the widest side of the basin, designated y = -7m in the (x,y) coordinate system centred on the model, used here. They are absorbed on the opposite side by a 6 m wide parabolic wave absorber. Absorbers are also located along the side walls of the basin to remove cross waves. The wave makers, which can be operated individually by a computer controlled hydraulic system, are capable of generating regular and irregular long-crested and short-crested sea states. Mainly waves were generated to propagate in the positive x direction with crests parallel to the y axis but in some of the experiments they were generated to propagate in a direction inclined to the side of the basin at an angle of 15°. In these tests, the model was itself inclined at 45° so that it was inclined at an angle of 30° to the wave direction.

Conductivity type wave gauges were placed at the following (x,y) locations surrounding the model in the basin; (-2m,0m), (2.5m,0m), (4.5m,0m, (4.5m,-2m) and (4.5m,1.6m).

The model responses were measured using accelerometers and ship movement meters mounted on and connected to the model, respectively. The latter comprise potentiometer type transducers which measure translatory movements as angular displacements of the potentiometer, and which are connected by light strings to appropriate points on the model.

EXPERIMENTAL TESTS

The experimental programme included tests in regular and irregular waves at different headings and for a range of amplitudes and periods.

Regular wave tests were carried out for wave heights that ranged between 0.13 and 0.30 m and periods that ranged between 0.95 and 2.2 s. Each set was carried out for wave headings of 0°, 30° and 45°. And the three sets were carried out for both the rounded-edged and the sharp-edged models. Two extra tests were carried out for the sharp-edged body at a wave height of 0.19 m and a period of 1.5 s, and a wave height of 0.30 m and a period of 2.0 s, for each wave heading. All the regular wave tests had a duration of ten minutes.

The irregular wave tests consisted of eight tests on the rounded-edged model in two dimensional waves with the wave height ranging from 0.08 m to 0.22 m and the period from 1.5 s to 2.2 s with wave directions of 0° and 45°. The waves were scaled by 1:50 in height and 1:7.07 in period from full scale Jonswap spectra. The duration of each test was one hour. The series was then repeated with a sharp-edged model.

THEORETICAL PREDICTION

The boundary integral based method (Downie et al. 1990a) extended to allow for some small mean flow, U, or slow drift motion, together with the viscous force calculation using a modified version of the original matching procedure to incorporate the effects of mean flow has been used to compute responses of the model TLP in waves. The potential method follows the approach of Nossen et al. (1991) for the exterior flow. This computes the potential flow field to first order in the amplitude and also in the parameter $U\sigma/g$, where σ is the wave encounter frequency, involving a two term expansion of the potential and a panel distribution over the free surface as well as the immersed body surface. The matching procedure is based on the value of the velocity field induced in the neighbourhood of each shedding edge of the body by the outer potential flow. If the edge is sharp this velocity field is singular at the edge and the strength of the implied singularity must be evaluated. An inner vortex flow field which may be viscous and which has been precalculated for unit oscillatory flow around an infinite two-dimensional edge of the same local geometry is then added in proportion to the edge velocity. The forces induced by the vortex shedding at the edge are similarly added to the forces induced by the outer potential flow. This procedure is described in detail in Downie et al (1988). In the presence of a mean current the forces are modified by the presence of the current although the effect is small for currents parallel to the edge (Al-Hukail et al. 1994). Cases of large amplitude slow drift motion or mean current normal to the edge cannot be analysed by the above local method.

PREVIOUS EXPERIMENTAL VALIDATION

Flow visualisation experiments to support this method have been carried out for model barges (Downie, Bearman and Graham, 1988) which demonstrated that the vortices shed were of a similar scale to those calculated. Calculated damping coefficients of barges undergoing forced roll were compared with experimental results from a series of experiments carried out by Noble Denton Ltd (1985) for an Industrial Consortium and with the results of Vugts (1970). The predicted responses of a barge floating freely in regular waves compared well with the results from experiments on barges with sharp and rounded bilge edges carried out by Brown et al. (1983).

Also a series of experiments were conducted in the 18x9.5x2 m wave basin of the Fluid Mechanics Laboratory of the Ecole Centrale, Nantes (Downie et al., 1994). A 0.38x0.38x1.6 m rectangular model, of similar geometry to a pontoon of the Snorre TLP, was forced to undergo planar motions using a large digitally controlled motor driven mechanism. The model geometry was varied by testing with sharp edges and with rounded edges of 0.066 m radius. The results have been reported by Downie et al. (1994) and Graham et al. (1995) with some comparisons with theory including separated flow.

DISCUSSION OF THE PRESENT RESULTS

The experiments described in the present report have been intended to provide results to complement the previous experiments and to extend their scope to the case of a more complex floating body (TLP) in order to validate numerical models including viscous damping effects at the wave frequency and also study the low frequency responses. In the present case of a TLP emphasis has been placed on the effect of pontoon bilge radius, which is expected to be mainly seen in the effect of viscous damping on the responses since the changes in overall body shape are small implying only small effects on the wave damping. The response at both the wave frequency and at the low surge resonance frequency may involve separation.

The main tests in regular waves were conducted for 0° heading so that the response of the platform was, with a few exceptions, effectively entirely in surge. The wave heights were measured both in the absence of the platform and then monitored at the five stations around the platform during the tests. The waves were started impulsively causing an initial offset of the platform to occur followed by damped or sometimes undamped slow drift oscillations at the natural frequency of the platform on its tethers in surge, together with a surge response at the wave frequency, as shown, for example, in Figures 2(a) and (b).

The response at the wave frequency was calculated in each case from the time history and is compared with the predictions of theory. These predictions of response are obtained from the source panel code for the potential flow about the structure into which is incorporated the viscous matching technique to model the effect of vortex shedding from the pontoons together with the equation for the platform response, following (Downie, Graham and Zheng, 1990a). The TLP model was tested separately with rounded-edged and with sharp- edged pontoons in order to evaluate the vortex shedding effect from the bilge edges. The effect of this on the surge or sway motion at the wave frequency is seen to be both theoretically and experimentally much less pronounced than it is in single hull roll response because of the relatively larger wave damping component for these motions.

Figure 3 shows the measured wave frequency surge response for both round and sharp edges compared with the theory for sharp edges. The theoretical curves show both predicted response based on potential flow alone and predicted response including the full effects of separation from all pontoon edges, i.e. as if the edges were sharp. The measured data suggests that in the range where these two theoretical curves differ significantly separation is important in determining the response. If vortex shedding is a significant factor, it might be expected that the response for the rounded edge would be larger than that for the sharp edge since, at the wave frequency, the damping would be expected to be larger for the sharp edged body. However, both the round and sharp bilge experiments show very similar responses. This may be explained by considering the effect of the slow drift motion also. For waves of period 1.25 and 1.38 s it is apparent in the response time histories that the platform is also undergoing slow drift response at the natural surge frequency with amplitudes considerably greater than the wave frequency responses, as shown in Figure 2(b). The slow drift response amplitudes have also been calculated from the time history records and are shown in Figure 4 in combination with the wave frequency response plotted as before against the excitation (wave) frequency.

The fact that slow drift response occurs in the same range of periods as that in which flow separation significantly effects the wave frequency response may explain the fact that the rounded edge shows similar behaviour to the sharp edge in this region. The large amplitude slow drift oscillations undoubtedly cause separation on both pontoon sections whether or not they would have occurred for the rounded edge in small amplitude wave frequency motions alone. Slow drift response of a simple structure, such as a single column, only occurs in waves containing more than one frequency component, usually a random sea, through the mechanism of second order terms generating the appropriate low difference frequency excitation. However a multi-column structure, such as a TLP, can have excitation due to interference in regular waves. The second order code (Graham et al., 1992) which follows the work of Nossen, Grue and Palm (1991) for the potential flow predicts a negative wave drift damping coefficient for the model TLP in the range of incident wave periods between 1.4s and 1.2s.

Slow drift damping of the model TLP has been estimated from its initial surge response to the start up of the waves in the experiment. The impulsive start initiates either a damped or a growing response from the structure in this mode. The results are shown in Figure 5. The damping is zero or negative in the range predicted by the potential theory and where the large amplitude slow drift motion occurs. Prediction of the amplitude of slow drift response in this range depends not only on prediction of the excitation force by the higher order potential flow computation but requires values of the damping due to vortex shedding from the pontoons. This type of motion is generally, and was in the present cases, of comparatively large amplitude so that the assumptions of local vortex shedding effects made in the above method are not valid and hence the viscous damping for slow drift has not been computed.

Tests have also been carried out for the same two platform geometries but with the relative wave heading at 45° and 30° by suitably rotating the platform and in the second case changing the wave direction also. The results for periodic waves showed essentially the same behaviour of the surge motion, with respect to the wave direction but with the frequency for occurrence of slow drift motion slightly lowered. In all cases the slow drift response for the model with rounded edges was greater and over a wider frequency range than for the sharp edges indicating the higher separated flow damping for the latter.

The surge response of the TLP in two-dimensional random waves at 0° heading with $Hs = 0.18$ m and $Tp = 2.2$ s is shown in Figure 2(c). Both wave frequency and low frequency components can be discerned. The wave spectrum, $S_{\eta\eta}(\omega)$, obtained from the wave gauge (4.5m, -2m) furthest from the model is shown in Figure 6, in which the peak corresponds to a characteristic period of 2.14 s, or circular frequency, ω, of 2.93 radians/s. The spectrum for the platform surge response, $S_{11}(\omega)$, is shown in Figure 7. The smaller amplitude but broader peak is the wave frequency response over the range of the incident wave spectrum. The second, higher amplitude, lower frequency peak occurs at a frequency of 0.586 radians/s which is close to the frequency of the low frequency response that can be observed in regular waves in Figure 2(b). The surge spectrum for the rounded-edged model is shown in Figure 8. The RAO's for surge for both edges are shown in Figure 9.

From Figures 7, 8 and 9, it can be seen that the 'wave frequency' responses of the sharp- edged and the rounded-edged model are virtually identical. The absence of any apparent difference between the sharp and round edge cases is, as in the more limited range of regular wave frequencies, due to the large amplitude, slow drift oscillations provoking separation. The low frequency responses of the round-edged model, however are much larger than for the sharp-edged model which is indicative of the stronger separation and hence viscous damping, in the latter case. In the regular wave test carried out with a period equal to the characteristic period of the irregular sea, $(g/L)T = 5.48$, the rounded and sharp-edged model responses also show this trend, although it is not so marked for the regular wave tests at other frequencies, see Figure 3. The magnitudes of the response at all wave frequencies agree very well with those obtained in the regular wave tests.

ACKNOWLEDGEMENT

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CONCLUSIONS

The objective of the experiments was to investigate the influence of viscous effects, in the form of flow separation from the TLP pontoons, on the TLP responses. The numerical models predict that there is a frequency range in which the responses predicted by potential flow models differ significantly from those predicted by the models which include flow separation, or viscous, effects, as shown in Figure 3.

Analysis of the data indicates that the results for wave frequency responses predicted by the computer code including viscous (separation) effects agree well with the results of the experiments in regular and irregular waves.

The frequency range in which viscous effects appear to be important is also the range for which regular waves excite the low frequency large amplitude motions.

The occurrence of these motions probably dominate the separation process for this range of excitation frequencies.

The tests in random waves correlate well with the results obtained in regular waves.

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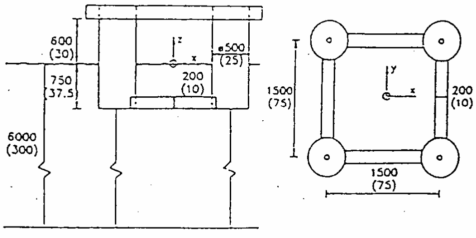

Figure 1 : Schematic of TLP Model

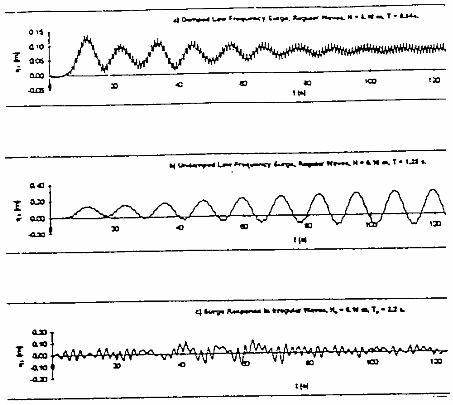

Figure 2 : Surge Responses (Round Edge)
(a) Regular Waves, Low Frequency Response Damped,
(b) Undamped
(c) Random Waves, 0^o heading.

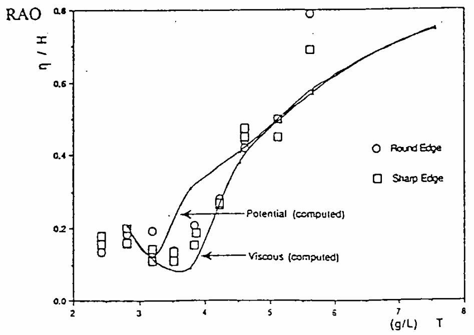

Figure 3 : Wave Frequency Surge Response (Round Edge, Regular Waves)

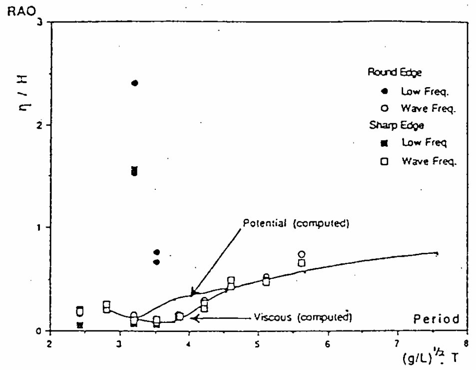

Figure 4 : Wave and Low Frequency Surge Response (Round Edge, Regular Waves)

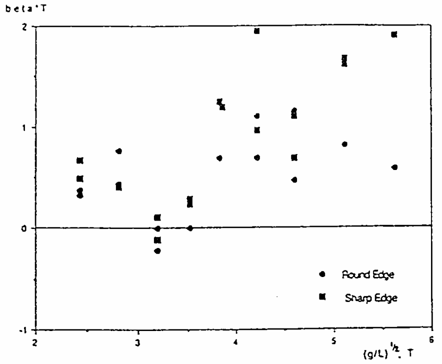

Figure 5 : Slow Drift Damping (Round Edge, Regular Waves)

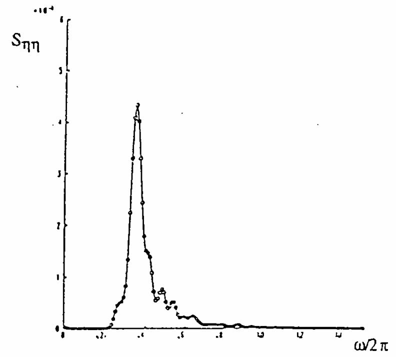

Figure 6 : Wave Spectrum $S_{\eta\eta}(\omega)$, H_s = 0.18m, T_p = 2.2s

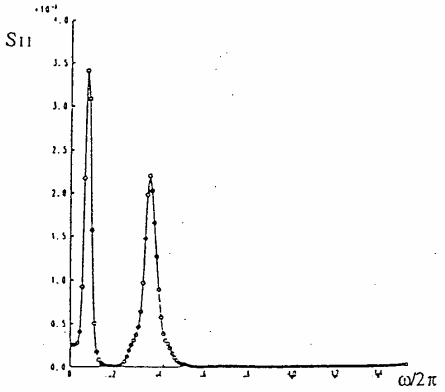

Figure 7 : Surge Response Spectrum $S_{11}(\omega)$, Sharp Edge, H_s = 0.18m, T_p = 2.2s

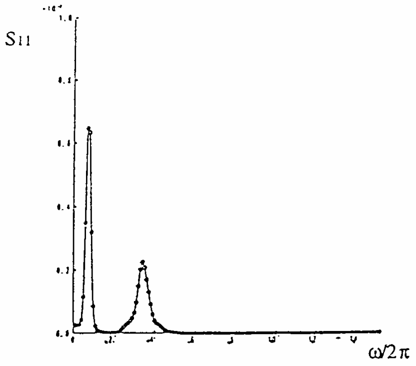

Figure 8 : Surge Response Spectrum $S_{11}(\omega)$, Round Edge, $H_s = 0.18$m, $T_p = 2.2$s

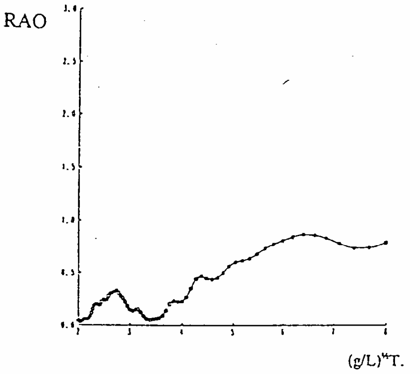

Figure 9 : Surge RAOs at wave frequencies, Round and Sharp Edges.