

Hydrodynamics of Dry Tree Semisubmersibles

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ABSTRACT

This paper presents a hydrodynamics analysis of a conceptual dry tree semisubmersible for drilling and production platforms. Computational analysis shows that the hull form of the dry tree semisubmersible can be optimized to control the cancellation period, magnitude of the heave RAO below the cancellation period and the heave natural period. The relative areas of the column and pontoon are varied to demonstrate the global effects on the hydrodynamic forces acting in these structural components while the area of the heave plate is kept constant. Results show that by keeping the displaced volume of the hull constant the relative areas of the column and pontoon can be varied to affect the magnitude of the hydrodynamic forces on the columns and pontoon and thus the shape of the heave RAO.

KEY WORDS: Dry tree semisubmersible; hydrodynamic forces; cancellation period; heave RAO.

INTRODUCTION

Top Tensioned Risers (TTRs) with dry trees allow direct vertical access to production wells and thereby offer a number of attractions for well completions and interventions. The two traditional deepwater hull forms to support TTRs are the Spar and the Tension Leg Platform (TLP). For production depths exceeding 5,000 ft the TLP may have its own challenges with tendon design, making the Spar the sole candidate (Murray et al., 2006).

Semisubmersibles are in use in some of the deeper developments using Steel catenary Risers (SCRs) to tie-back to subsea wet trees. In their traditional forms, with drafts less than 100 ft, the motions of the traditional semisubmersible are not amenable to supporting TTRs. Recent designs have increased drafts up to approximately 120 ft to improve their motions and reduce damage to SCRs but these motions are not low enough to practically support dry trees. Nonetheless, the semisubmersible has a number of functional advantages over the Spar. For example, the Spar is installed by horizontally towing and up-righting at the installation site. A heavy lift vessel must be mobilized to install the topsides using single or multiple module lifts and hook-up

and commissioning is completed at sea. The semisubmersible can have its topside modules installed and commissioned at the quayside which offers a large cost saving. The Spar has a number of stacked decks because of its single column form, whereas the semi submersible offers a large open deck area which has a number of operational advantages. The semisubmersible can be vertically wet towed in shallower water but the Spar draft of approximately 500 ft to 600 ft restricts the depths in which it can be towed.

An improved deepwater floater design is one which has the motions of the Spar and the functionality of a semisubmersible. To this end, a number of design variations, which involve combining semisubmersibles with heave plates, have been proposed. The strategy is to retract the heave plate allowing semisubmersible's draft to be shallow enough for quayside integration. The two main design considerations for these configurations are 1) to have minimum heave response at periods where wave energy is applied, particularly at the wave energy spectrum peak period, and 2) to ensure that the natural heave period is sufficiently high such that the additional vertical stiffness caused by riser tensioners does not reduce this period to a value near the wave energy periods.

To a certain extent, the magnitude of the heave RAO below the cancellation period can be manipulated by designing the relative sizes of the pontoons and columns such that the sum of the forces on the respective structural components are minimized thereby minimizing the heave motion while keeping the draft of the semisubmersible to a minimum. The natural period can be increased by means of a heave plate supported below the hull. The hydrodynamic force interaction among the columns, pontoons and heave plate can be optimized to minimize hull draft and heave performance.

This paper presents and discusses the hydrodynamic interaction among these structural components. Computations using basic geometric shapes and dimensions are used to illustrate the interactions among structural components and how they can be optimized in designs.

NUMERICAL ANALYSIS

The analysis takes a systematic approach individually analyzing the

wave forces and responses on the main components of the dry tree semisubmersible. First the forces on a column and pontoon section are investigated and then interaction between this column/pontoon section and the heave plate are analyzed. Finally the heave Response Amplitude Operators (RAOs), for three semisubmersibles with different column configurations are presented.

In the first stage of the analysis, the linear version of the hydrodynamic boundary element program described in (Lee et al., 1999) is used to compute the heave forces on the columns and pontoon sections without viscous damping effects. In the second stage, the effect of viscous damping is included through an equivalent linear damping, which is obtained from decay tests. The motion analysis program (Ran et al., 1999) was used to get such damping as well as equivalent mooring spring.

In the final stage, the motion calculation including the nonlinear damping effects in frequency domain is carried out. The motion dependent damping forces are implemented and the corresponding motions are calculated by iteratively solving the motion equations. The effects of the nonlinear damping are illustrated by comparing the results with linear damping.

Single Column Analysis

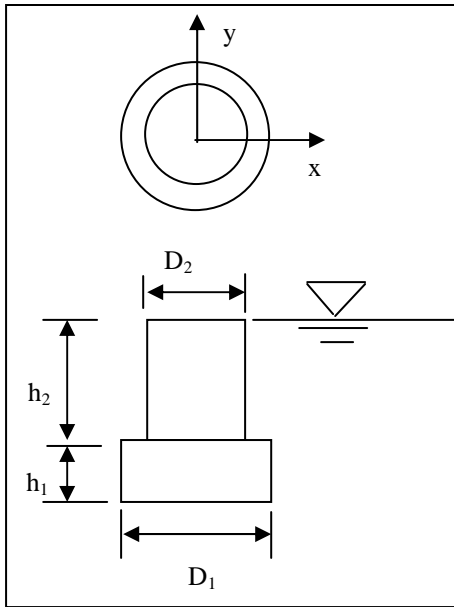


Fig. 1 Definition Sketch of Floating Single Column. $D_1 = 80\text{ft}$ and Draft= $h_1+h_2=120\text{ft}$, with D_2 and h_1 Variable.

The column and pontoon section of a semisubmersible are modeled as illustrated in Fig.1, referred to as a modular column. The column is represented as a circular cylinder of diameter D_2 and a height h_2 , while the pontoon is also as cylinder with diameter D_1 and height h_1 . The upper surface of the pontoon decreases as the ratio of the diameter D_2/D_1 increases. The first analysis investigates the hydrodynamic effect of the modular column by varying the ratio of D_2 to D_1 while keeping h_1 and h_2 constant ($h_1=35\text{ft}$, $h_2=85\text{ft}$). The total draft of the modular column ($h_1 + h_2$) is also constant at 120 ft.

Fig.2 shows the ratio of the forces on the upper and lower surfaces of the pontoon section. The figure shows that as D_2/D_1 increases, i.e., the upper surface becomes smaller, the relative vertical force on the bottom

surface increases and thus the force ratio increases.

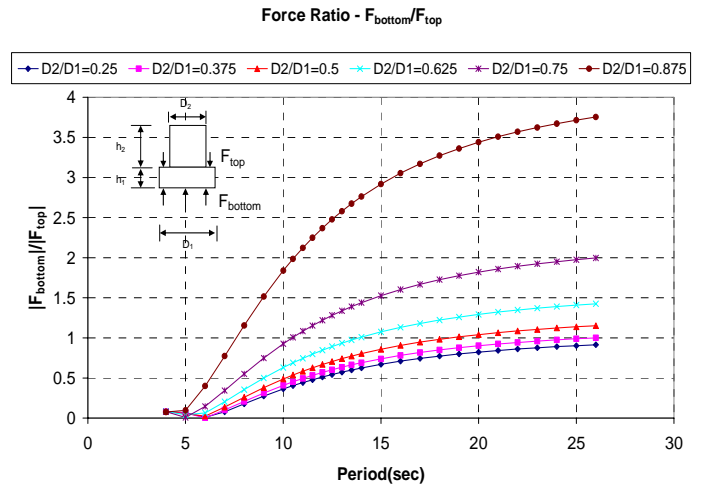


Fig. 2 Ratio of Forces on the Bottom Surface to the Top Surface of the Pontoon - Variation of Diameter Ratio (D_2/D_1)

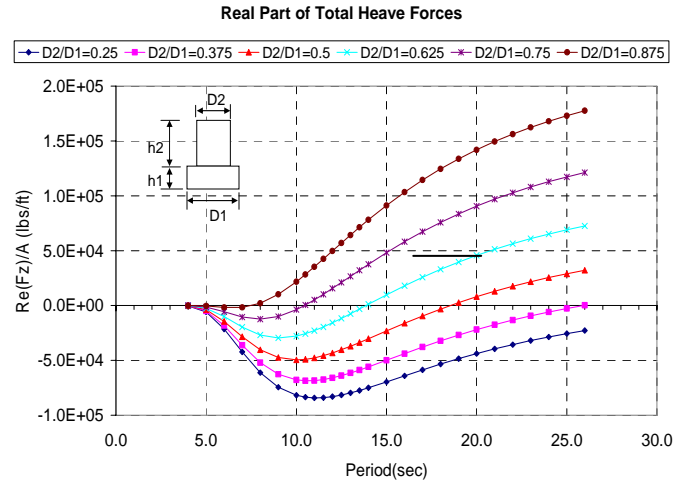


Fig. 3 Real Parts of the Total Wave Exciting Vertical Forces acting on Single Column-Variation of the Diameter Ratio (D_2/D_1)

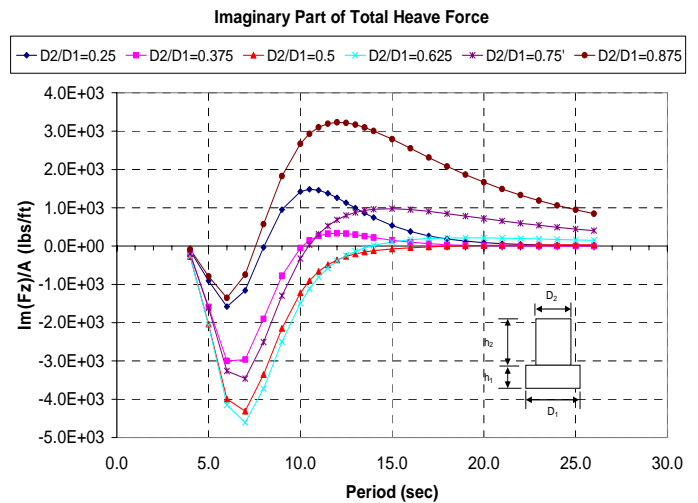


Fig. 4 Imaginary Parts of the Total Wave Exciting Vertical Forces acting on Single Column-Variation of the Diameter Ratio (D_2/D_1)

Fig. 3 and Fig. 4 show the total real and imaginary parts of the vertical force components on the modular column as a function of wave period. The figures show the imaginary part is much smaller than that of the real part and thus the wave excitation forces are considered to be in phase with the incident waves.

The second analysis investigates the hydrodynamic effect of the modular column by varying the height of the pontoon section while keeping the draft and ratio of the diameter D_1 and D_2 constant. In these computations h_1+h_2 is constant at 120 ft and D_2/D_1 is equal to 0.625.

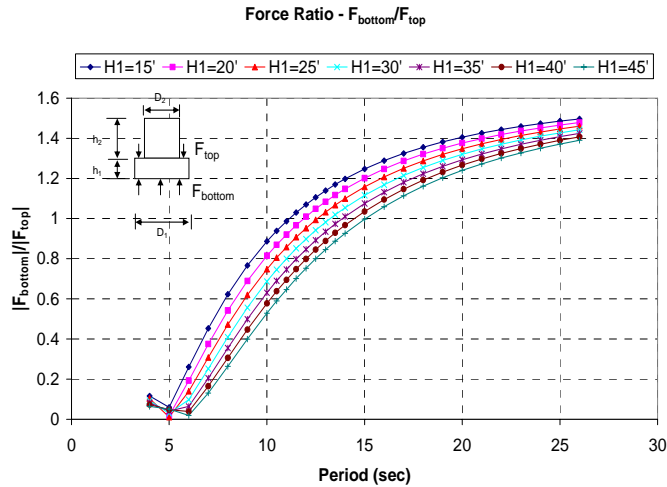


Fig.5 Ratio of Forces on the Bottom Surface to the Top Surface of the Pontoon – Variation of Pontoon Height h_1

Fig.5 shows the ratio of the forces on the upper and lower surfaces of the pontoon section. The figure shows that as h_1 increases, i.e., the height of the pontoon becomes larger, the force ratio increases. This is because of the increasing differential in the dynamic pressure in the water column.

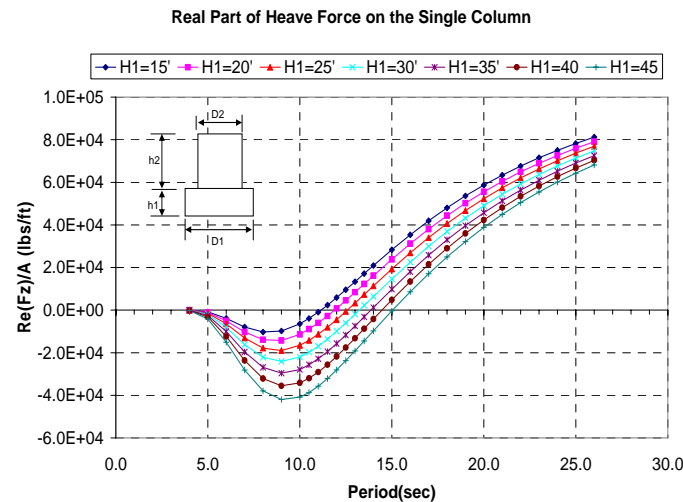


Fig.6 Real Parts of the Total Wave Exciting Vertical Forces acting on Single Column-Variation of Pontoon Height (h_1)

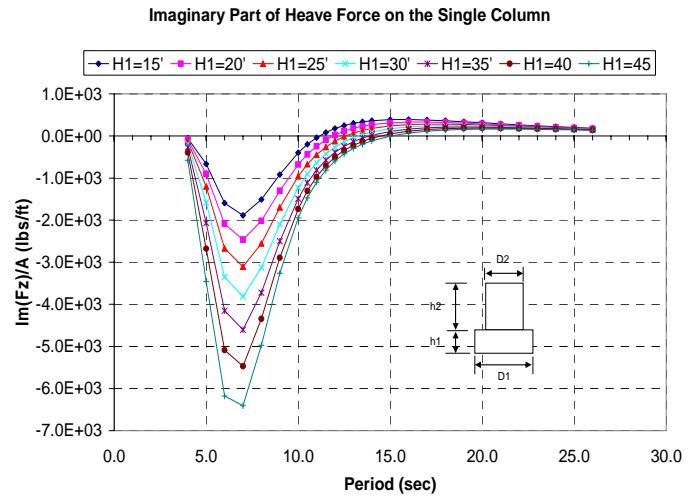


Fig. 7 Imaginary Parts of the Total Wave Exciting Vertical Forces acting on Single Column-Variation of Pontoon Height (h_1)

Fig. 6 and Fig. 7 show the total real and imaginary parts of the vertical force components on the modular column as a function of wave period. Again the figures show the imaginary part is much smaller compared to the real part and thus the wave excitation forces are considered to be in phase with the incident waves. The imaginary components are zero at the cancellation periods.

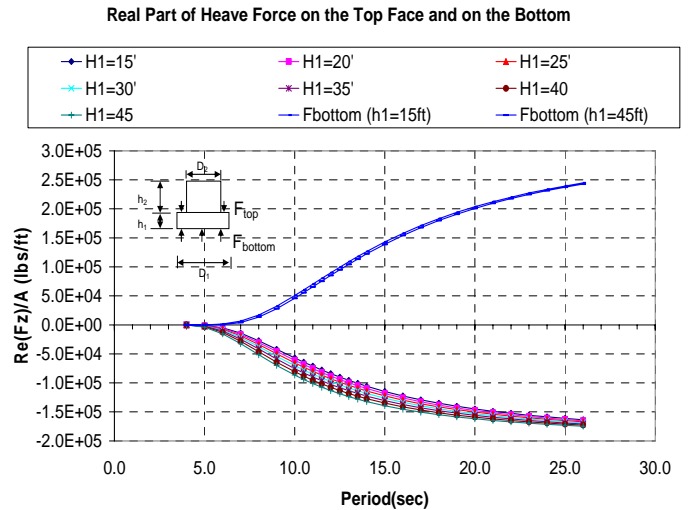


Fig.8. Sensitivity of the Vertical Force Component to the Pontoon Height(h_1) Variation – Comparison of the Real Part of Vertical Forces on the Bottom and on the Top Surface of the Single Column

Fig. 8 shows the real part of the vertical forces on the upper and lower surfaces of the pontoon for varying h_1 as a function of wave period. The data show that only a marginal change is occurred in the total force on the lower surface (F_{bottom}), while on the upper surface the total force (F_{top}) are more sensitive to variations in h_1 because of differentials in dynamic pressures.

Interactions between Columns and Heave Plate

Three hull configurations are used to examine the hydrodynamic interaction between columns and heave plate. The three configurations are assumed to support the same payload and have the same weight

distribution. The shape of the column/pontoon is varied by changing column diameter D_2 and the pontoon height h_1 such that the total displacement of the hull is kept constant. The draft and the diameter of the lower part of the modular column is held constant at 120 ft and 80 ft, respectively. The center-to-center column spacing is 160 ft.

The cases for each configuration are identified as follows:

Case 1) $h_1 = 25$ ft ; $D_2 = 54$ ft

Case 2) $h_1 = 30$ ft ; $D_2 = 52$ ft

Case 3) $h_1 = 35$ ft ; $D_2 = 50$ ft

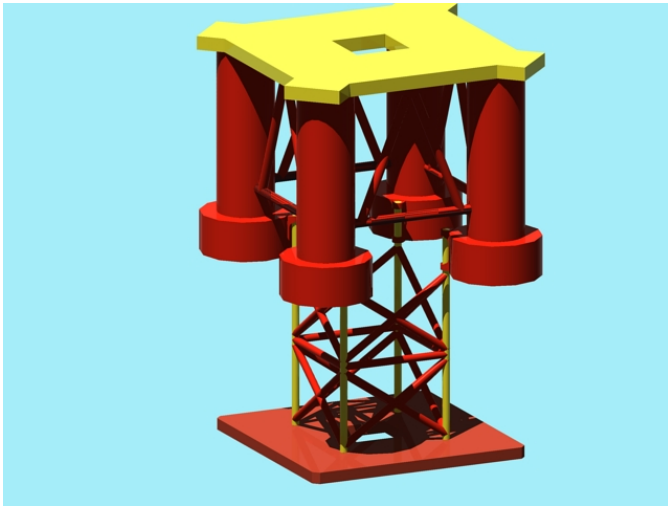


Fig. 9 Configuration of a Four Column Semisubmersible with a Heave Plate

An illustration of the semisubmersible with a heave plate is given in Fig. 9. The mooring stiffness used in the analysis is provided in Table 1. A typical 100 year hurricane wave condition in Gulf of Mexico is used in the nonlinear damping computation. The heave forces computed on the modular columns and the heave plate for Case 1, 2 and 3 are shown in Fig. 10 to Fig. 12, respectively. Each figure shows the forces computed from the linear panel method as a function of wave period. Included in the respective figures is the force contribution estimated from the equivalent damping term.

Table 1 Equivalent Mooring Stiffness – Results of the Numerical Static Offset Test

	Mooring Stiffness	
Surge/Sway	5.61134E+03	(lbs/ft)
Heave	6.89853E+03	(lbs/ft)
Roll/Pitch	1.65645E+09	(lbs-ft)
Yaw	5.56070E+07	(lbs-ft)

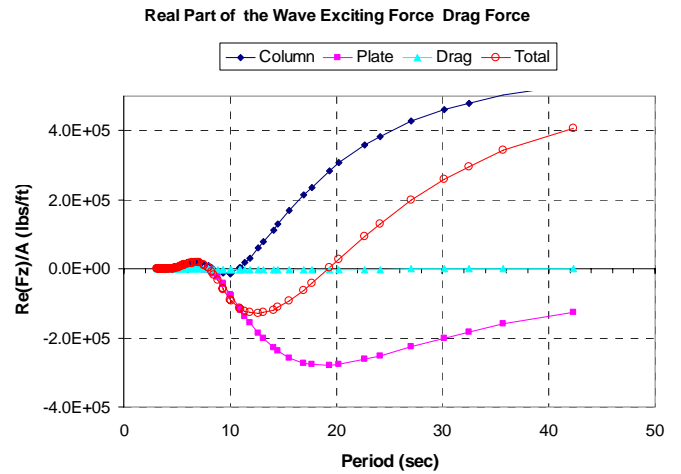


Fig.10 Real Parts of the Wave Excitation Forces on the Modular Columns and the Plate and the Drag Forces on the Plate and the Truss Members for Case 1

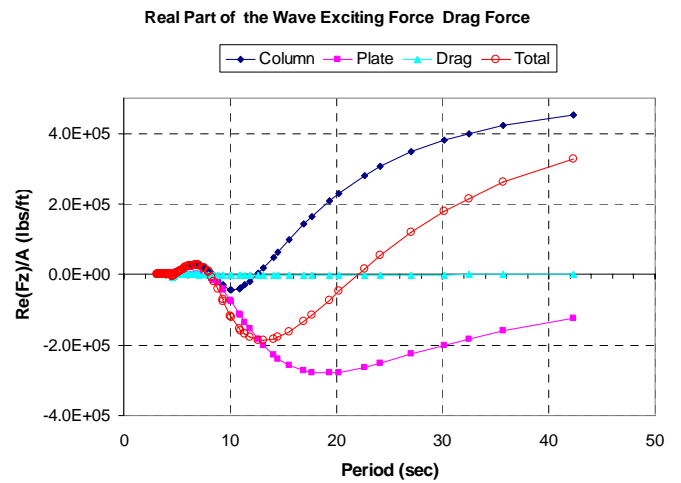


Fig.11 Real Parts of the Wave Excitation Forces on the Modular Columns and the Plate and the Drag Forces on the Plate and the Truss Members for Case 2

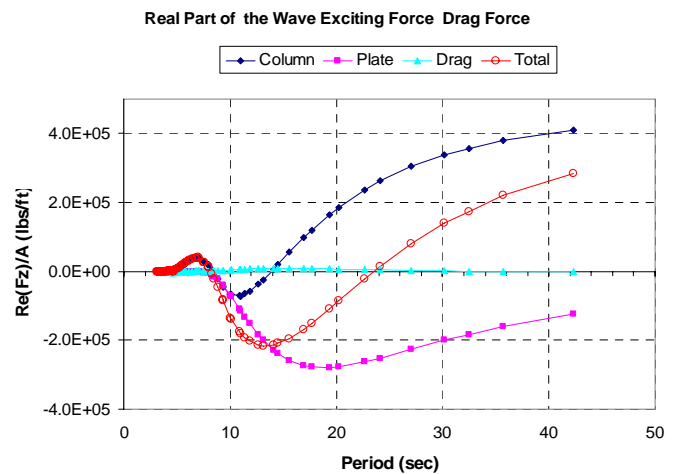


Fig.12 Real Parts of the Wave Excitation Forces on the Modular Columns and the Plate and the Drag Forces on the Plate and the Truss Members for Case 3

Since the same heave plate was used in all cases, the wave excitation force on the plate is also the same. The vertical forces on the modular columns and the heave plate are in opposite directions. As the column diameter becomes smaller in relation to the pontoon diameter, i.e., as D_2/D_1 decreases, the total hydrodynamic forces on the modular columns are smaller for a given period. Thus the resultant forces on the semisubmersible cancel at higher periods. A summary of the cancellation periods for the various cases is provided in Table 2.

Table 2 Summary of Cancellation Periods

CASE	Cancellation Period (sec)	D_2/D_1	D_2 (ft)	h_1 (ft)
1	19.0	0.675	54	25
2	22.0	0.650	52	30
3	23.5	0.625	50	35

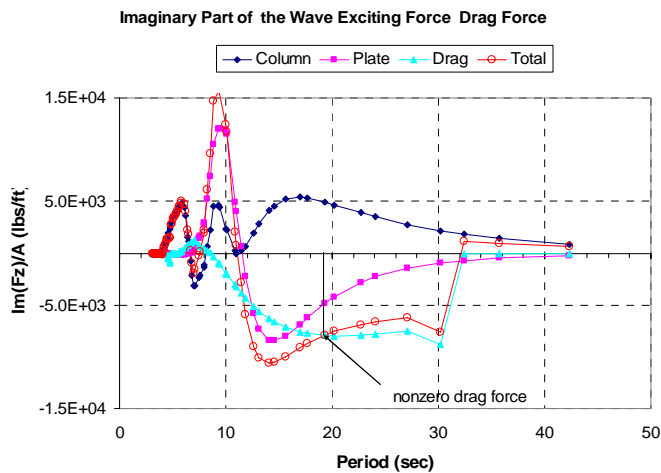


Fig.13 Imaginary Parts of the Wave Excitation Forces on the Modular Columns and the Plate and the Drag Forces on the Plate and the Truss Members for Case 1

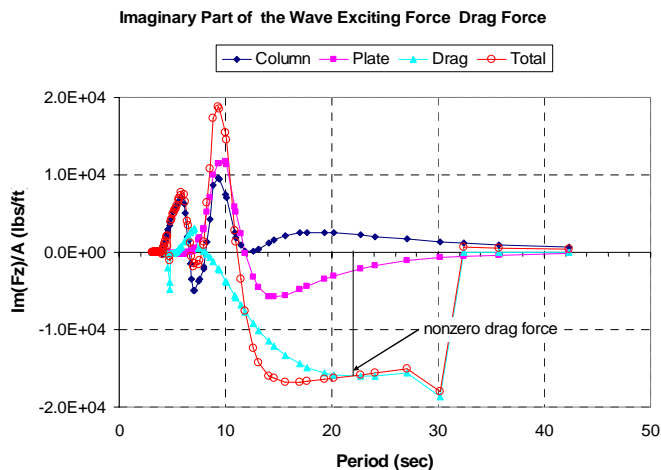


Fig.14 Imaginary Parts of the Wave Excitation Forces on the Modular Columns and the Plate and the Drag Forces on the Plate and the Truss Members for Case 2

The viscous forces shown in the respective graphs are small in comparison to the linear hydrodynamic forces. As a result they have negligible effect on shifting the cancellation period. However, the

imaginary parts of the heave forces around the cancellation period are non-zero, and they make the force magnitude at the period non-zero. Therefore, forces are not totally cancelled if the nonlinear damping is taken into account

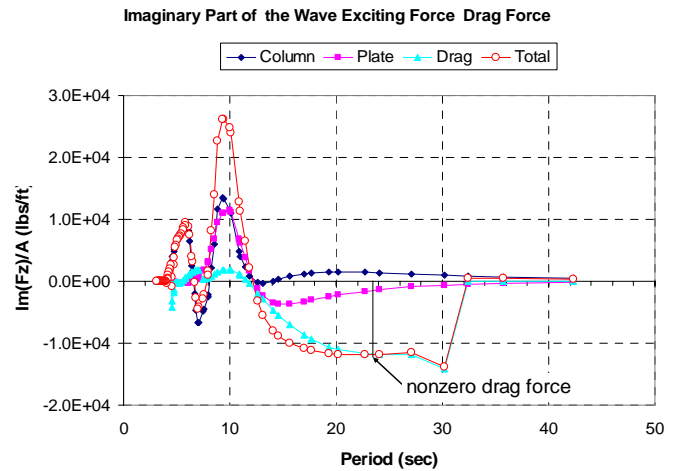


Fig.15 Imaginary Parts of the Wave Excitation Forces on the Modular Columns and the Plate and the Drag Forces on the Plate and the Truss Members for Case 3

Response Amplitude Operators

Table 3 summarizes the natural heave periods and damping ratios determined from numerical simulations of decay tests. The decay test is performed by offsetting the rigid body as much as 1 meter and releasing it. The damping factors are all obtained by averaging over four period intervals under the assumption that it is linear with respect to the hull velocity.

Table 3 Natural Periods and the Damping Ratios – Results of Numerical Free Decay Tests

	$h_1=25'$ $D_2=54'$		$h_1=30'$ $D_2=52'$		$h_1=35'$ $D_2=50'$	
	T (sec)	Damp (%)	T (sec)	Damp (%)	T (sec)	Damp (%)
Surge/Sway	205.9	4	207.5	4.3	212.6	4
Heave	26.7	2.3	27.6	2.6	29.2	2.3
Roll/Pitch	28.5	2.3	32.0	2.5	35.5	2.6
Yaw	80.0	0.5	79.9	0.5	79.9	0.5

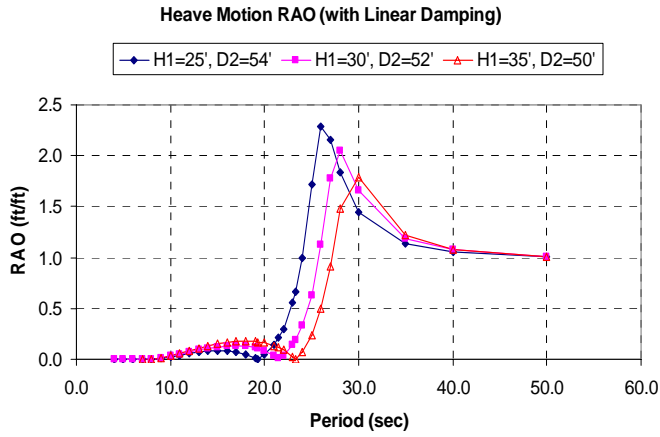


Fig. 16 Heave Motion RAOs with the Linearized Damping (WAMIT)

Fig. 16 compares the heave RAOs for the three cases considered in the analysis. In these figures equivalent non-linear damping is not included. The figure shows that the cancellation points occurred at 19, 22 and 23.5 seconds for Case 1, Case 2 and Case 3, respectively. At these cancellation periods, the heave RAO is zero because the total resultant force between the column and heave plate is also zero as shown in Figs. 10 to 12 and only linearized damping is used in the computations. The RAO's illustrate the trade off between response below the cancellation point and the natural heave period. The RAO with the lowest response has the lowest natural heave period. As the natural heave period is increased the RAO below the cancellation period is also increased. However, in all cases the RAO at 14 second is less than 0.15, which is generally adequate to support TTRs.

To make RAO more accurate, the nonlinear damping is included in the frequency domain analysis. The results are compared with the program described in (Lee et al., 1999) and shown in Fig. 17 to Fig 19 for the three hull configuration. When the nonlinear damping is included, a non-zero response occurs at the cancellation periods. This because a non-zero drag force exists at all periods even when the inertia forces on the column/pontoon and heave plate cancels each other.

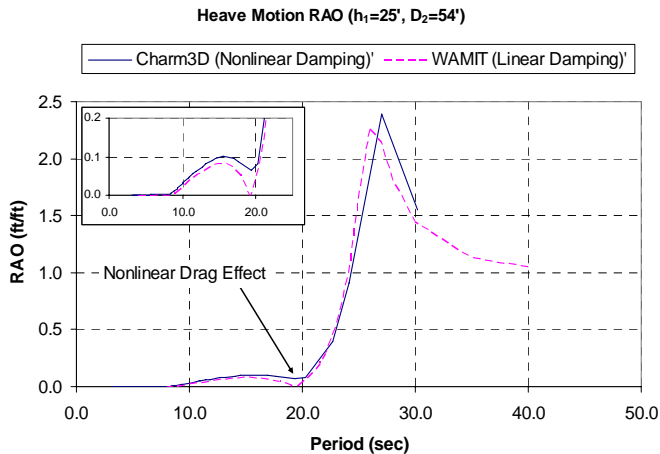


Fig.17 Heave Motion RAO of CASE 1 ($h_1=25'$, $D_2=54'$) – Comparison of the effects of the nonlinear damping and the linear damping in frequency domain

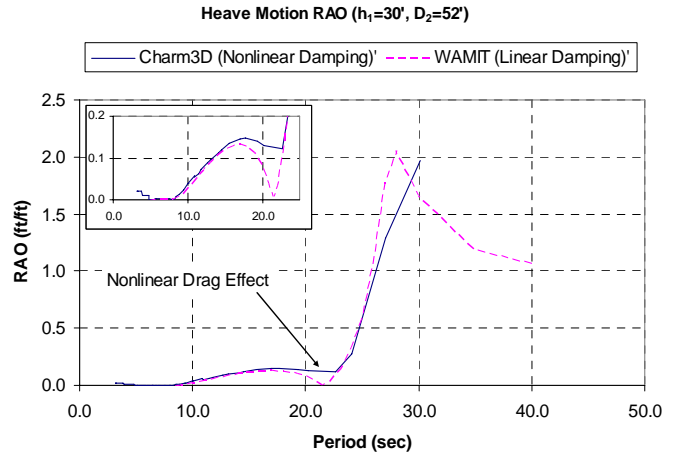


Fig.18 Heave Motion RAO of CASE 2 ($h_1=30'$, $D_2=52'$) – Comparison of the effects of the nonlinear damping and the linear damping in frequency domain

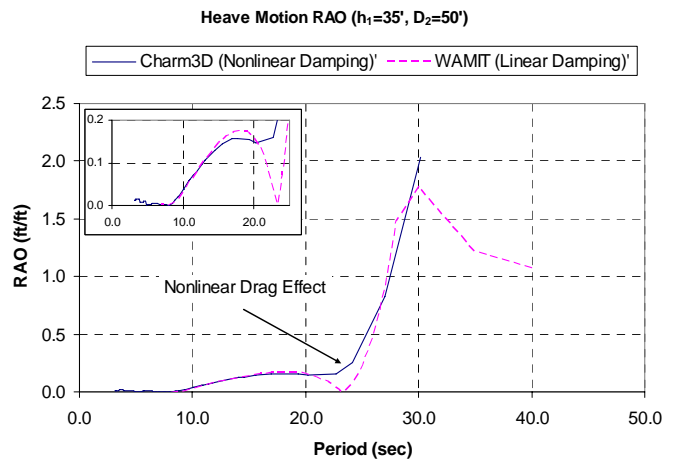


Fig.19 Heave Motion RAO of CASE 3 ($h_1=35'$, $D_2=50'$) – Comparison of the effects of the nonlinear damping and the linear damping in frequency domain

CONCLUSIONS

The main conclusions derived from the computations described in this paper are:

1. Increasing the diameter of the pontoon relative to the diameter of the column reduces the vertical force.
2. Increasing the height of the pontoon tends to increase the heave force on the column/pontoon assembly because of differences in the dynamic pressure in the water column.
3. Assuming a predetermined heave plate area and draft, the forces on the columns can be manipulated by varying the relative size of the column (and pontoon) sections. As the ratio D_2/D_1 , as described in 1) and 2) above, tends to become smaller, the total force on the columns tend to develop lower cancellation periods with a smaller heave RAO below this

period. However, the heave natural period tends to be lower as well.

4. Introducing non-linear damping makes the heave RAO at the cancellation period non-zero which is the result when linear damping only is used in the computation
5. By systematic computations an optimum hull form can be found for a particular environment. The heave plate and column can be optimized to get improved heave motion. This motion is an important aspect of a platform for dry tree solution.
6. For the Gulf of Mexico application, the dry tree semisubmersible can be easily designed to have a heave natural period of above 28 seconds by changing the size of the heave plate. The higher heave natural heave period is required to avoid resonance with wave loads when more tensioner type TTR riser is installed. For buoyancy can application the heave natural period could be designed between 20-25 seconds, so that the first rise of the RAO can be decreased. This means that the case 1 analysis, summarized in Fig. 10, is suitable for buoyancy can application, while the case 3, summarized in Fig. 12, is better suited to tensioner type TTRs.
7. Because the heave RAO below 14 second period is lowered by the heave plate, the fatigue life of structural component will be longer.

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