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Wave Loading on Floating Platforms by Internal Solitary Waves

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Abstract Morison's equation is used for estimating internal solitary wave-induced forces exerted on SPAR and semi-submersible platforms. And the results we got have also been compared to ocean surface wave loading. It is shown that Morison's equation is an appropriate approach to estimate internal wave loading even for SPAR and semi-submersible platforms, and the internal solitary wave load on floating platforms is comparable to surface wave counterpart. Moreover, the effects of the layers with different thickness on internal solitary wave force are investigated.

Key words: wave force, internal solitary wave, Morison's equation, semi-submersible, SPAR

INTRODUCTION

Internal solitary waves, which may cause serious threat to offshore structures, are ubiquitous in the ocean [1]. Although numerous facilities have been designed to withstand forces due to enormous surface waves, only few people have examined internal solitary waves force acting on floating structures [1-2]. In the recent decades, SPAR and semi-submersible platforms have attracted considerable attentions due to its prominent advantages in mobility and less expensive investment. With this motivation in mind, we have analyzed and calculated the forces exerted on them by internal solitary waves. At the same time, they have also been compared to surface wave loading in the present paper.

For the sake of simplicity, a two-layer fluid, bounded by two horizontal rigid walls is considered here. Based on the classic theoretical solution of KdV equation [3], both wave profile and flow field induced by internal waves can be obtained, which are characteristic of larger amplitude, longer wavelength and period. Therefore, Morison's equation turns out an appropriate approach to estimate internal wave loading even for SPAR and semi-submersible platforms in addition to jacket platform consisting of slender pipes.

INTERNAL SOLITARY WAVE VELOCITY FIELD

Consider a two-layer fluid bounded by two horizontal rigid walls in Figure1.

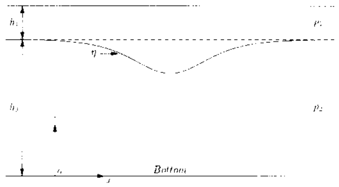

Figure 1: Wave coordinate frame in a two-dimensional Cartesian x, z coordinate system

Suppose the densities of upper layer and lower layer are ρ_1, $\rho_2(\rho_2 > \rho_1)$, respectively, assumed constant and uniform. h_1 and h_2 are the thickness for the two layers, respectively.

In 2001, Chen shouhu et al. [4] conducted experiments in the sea area between the northeast of the Donsha Islands and the northwest of the Bashi strait. The observational maximum amplitude of the depression internal solitary wave can reach to 140m and the period is about 15min with a wave speed, 0.8 1.4 m/s. Based on the above data, the major parameters of the internal solitary waves considered in this paper are summarized in Tables 1, and the corresponding surface wave parameters are given in Table 2.

Table 1: Details of the characteristics parameters of internal solitary wave

Water depth (m)	Case1: h_1=50, h_2=2950 Case2: h_1=100, h_2=2900
Water density (kg/m^3)	$\rho_1 = 1021.31, \rho_2 = 1025.0$
Wave height (m)	-140
Wave length (m)	2000

Table 2: Surface wave Parameters

Surface wave	Return period	
	1 year	50 year
Significant wave height (m)	7.7	12.2
Wave period (s)	9.7~10.3	11.0~12.5

KdV equation, describing the propagation of the internal solitary waves in horizontal direction, can be written as [3]

$$\frac{\partial \eta}{\partial t} + (C_0 + \alpha\eta)\frac{\partial \eta}{\partial x} + \beta\frac{\partial^3 \eta}{\partial x^3} = 0 \tag{1}$$

in which η is the vertical displacement of the interface from its equilibrium level, C_0 , the linear wave speed, α, the nonlinear parameter, and β , the dispersion parameter.
The wave profile and flow field induced by the internal solitary waves may be expressed as following

$$\eta\left(x,t\right) = \pm\eta_0 \sec h^2\left(\frac{x-C_pt}{l}\right) \tag{2}$$

$$\begin{cases} u_1 = \pm\frac{C_0\eta_0}{h_1}\sec h^2\left(\frac{x-C_pt}{l}\right) \\ u_2 = \mp\frac{C_0\eta_0}{h_2}\sec h^2\left(\frac{x-C_pt}{l}\right) \end{cases} \tag{3}$$

where η_0 is the amplitude of the internal solitary wave, C_p, the nonlinear wave speed and l, the characteristic width of the wave.

CASE STUDY

To demonstrate the importance of the internal solitary wave force on offshore structures, one SPAR and three semi-submersible platforms have been selected. The main dimensions are given in Table 3.

Table 3: Dimension parameters of the calculation platforms

Prototype	GVA5800M	F&G ExD	Aker H-4.3	SPAR
Number of column	4	4	8	
Operation draught (m)	20.0	20.0	23.0	Diameter
Length of pontoon (m)	108.8	101.87	115	=40.5m
Beam of pontoon (m)	16	20.12	19	Draft
Height of pontoon (m)	9.6	8.54	9.5	=198.2m
Length of column (m)	16.0	15.86	12.5 (corner), 12.5 (inner)	
Beam of column (m)	14.4	15.86	12.5 (corner), 10 (inner)	
Displacement at operation draught (m^3)	41577	46389	56900	

Note that the characteristic length of the platforms in Table 3 is far less than the characteristic wave length in Table 1, Morison's equation, in which drag and inertial coefficients and shield effects should be suitably considered in terms of Reynolds and Keulegan-Carpenter numbers as well as overall arrangement of the structure, turns out an appropriate approach to estimate internal wave loading for SPAR and semi-submersible platforms, which can be written as [5]

$$F = \frac{C_d}{2}\rho A\left|u\right|u + C_m\rho V\frac{\mathrm{d}u}{\mathrm{d}t} \tag{4}$$

where ρ denotes the water density, , the projected frontal area, , the displaced volume of the platform, . the current velocity induced by internal solitary wave, , the time, C_d and C_m are inertia coefficients. In present study, for semi-submersible platforms, $Re=O(10^6)$, $Kc=O(10^2)$, we assume upstream inertia coefficients as C_d=2.01, C_m=1.0, according to Sarpkaya and Isaccson [5], downstream coefficients as C_d=2.01×0.7, C_m=1.0×0.7 considering shield effects. While C_d=1.2, C_m=2.0 for SPAR.

Figures 2 and 3 show the results of the internal solitary horizontal wave force and pitch moment on GVA5800M in different thickness of the upper layers (50m and 100m) in a water depth of 3000m, respectively. From the Figure 2, it has been noticed that maximum wave forces are 1.32×10^4 kN and 0.8×10^4KN for the 50m and 100m thickness of the upper layers, respectively, which indicate that in the same sea environment, for different thickness of layers in two-layer ocean model, the wave load and moment is also different, and the thicker the upper layer is, the smaller the wave load and moment are, when considering influential factors. We can obtain the same conclusion from Figure 3.

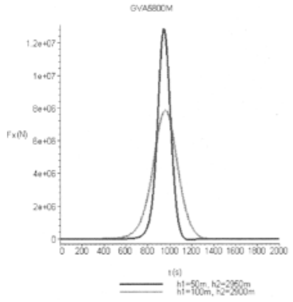

Figure 2: Comparison of horizontal force

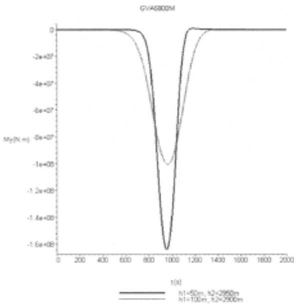

Figure 3: Comparison of pitch moment

Similarly, other results are listed in Table 4, which gives the comparisons between internal solitary wave load and surface wave load. From the Table 4, it has been noticed that internal solitary wave load can also cause serious threat to platforms in comparison with surface wave load. As an example, for one year return period and significant wave height (Table 2), the ratio of the horizontal maximum internal solitary wave force on GVA5800M to corresponding surface wave load is 37.7%, this indicates the internal solitary wave force on floating structures should not be ignored.

Table 4: I:Prototype of the platform II:Wave type III:Horizontal maximum force ($\times10^4$kN)
IV: Ratio of horizontal maximum internal solitary wave force to surface wave counterpart

I	II				
	Internal solitary wave (h_1=50m, h_2=2950m)	Surface wave (1RP,Hs)		Surface wave (50RP,Hs)	
	III	III	IV	III	IV
GVA5800	1.32	3.5	37.7%	5.2	25.4%
F&G	1.17	3.86	30.3%	5.48	21.4%
AkerH-4.3	1.68	4.36	38.5%	6.28	26.8%
SPAR	2.52	10.4	24.2%	16.0	15.8%

CONCLUSIONS

In this paper, Morison's equation is used for estimating internal solitary wave-induced forces exerted on SPAR and semi-submersible platforms and the internal solitary wave force and moment on GVA-5800, Aker H-4.3, F&G and SPAR are simultaneously provided. As a comparison, the maximum horizontal force due to surface waves with significant wave heights of one and 50 years return period are also shown in the diagrams. We can conclude that Morison's equation is an appropriate approach to estimate internal wave loading even for SPAR and semi-submersible platform, and the calculation results demonstrate that the internal solitary wave loading is comparable to that induced by surface waves and can never be neglected in the engineering design. Furthermore, we may indicate that the thicker the upper layer is, the smaller the wave loading and moment are, when considering influential factors.

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