Wave Loads Computation for Offshore Floating Hose Based on Partially Immersed Cylinder Model of Improved Morison Formula

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Abstract: Aimed at wave load computation of floating hose, the paper analyzes the morphologic and mechanical characteristics of offshore hose by establishing the partially immersed cylender model, and points out that the results of existing Morison equation to calculate the wave loads of floating hose is not precise enough. Consequently, the improved Morison equation has been put forward based on its principle. Classical series offshore pipeline has been taken as example which applied in the water area of different depth. The wave loads of pipeline by using the improved Morison equation and compared the calculation results with the existing Morison equation. Calculations for wave loads on pipelines in different depth were accomplished and compared by the improved Morison equation and the existing Morison equation. Results show that the improved Morison equation optimizes the accuracy of the computation of wave load on floating hose. Thus it is more suitable for analyzing the effects of wave loads on floating hose and useful for mechanic analysis of offshore pipeline.

Keywords: Method improvement, morison equation, offshore floating hose, wave load.

1. INTRODUCTION

The offshore floating hose is widely used in port and ocean engineering due to its light weight, high tensile strength and ability to achieve rapid deployment and withdrawal. As an important part of FPSO system, floating hose are used to deliver the crude oil which extracted from offshore field to shuttle tankers. Moreover, it has played an important role in the implementation of water-oil replenishment at sea for The Navy warships. Whether in the state of transporting oil or not, the hose are always floating on the sea under buoyancy for its light weight. Therefore, the floating hose are vulnerable to ocean current and waves.

Morison's equation (Morison *et al.* 1950) is used for estimating the hydrodynamic forces on the relatively slender members of offshore structures and is perhaps the most widely quoted and used equation in offshore engineering. Julian Wolfram [1] has proposed an alternative approach to linearization which yields corresponding linear forms that produce unbiased estimates for the outputs from nonlinear equations. The linearization factors for Morison's equation have been found for the cases of expected fatigue damage and expected extreme environmental load. The Morison equation inertia and drag coefficients were estimated by Julca Avila [2] with two parameter identification methods that are the weighted and the ordinary least-squares procedures. Error analysis showed that the ordinary least-squares provided better accuracy and, therefore, was used to evaluate the ratio between inertia and drag forces for a range of Keulegan-Carpenter and Reynolds numbers. Two small-scale field experiments on the effectiveness of Morison's equation have been carried out by Paolo Boccotti [3]. The agreement between Morison’s equation and the observation data is valuable which proved the method presented in an earlier paper [4] to be suitable for field experiments and is recommended for future work. Yang, Wanli [5] presented the expanded Morison equation, which can afford hydrodynamic pressure caused by inner water and outer water simultaneously. The practical application of the expanded Morison equation has been explored through analyzing a continuous rigid-framed deep water bridge. The results demonstrate that it is an approximate, convenient and efficient way to estimate the hydrodynamic pressure caused by both inner and outer water under earthquakes.

Many researches have been conducted the wave loads acting on offshore structures and the offshore structures are classified as large or small scale one according to the influence of wave movement on them. At present, offshore isolated pile [6-8] and submarine oil pipeline [9-11] are main subjects of wave forces effects on small-size offshore structures. Researches aimed at the calculation of wave load of floating hose are relatively rare and Morison formula [12-14] which includes the inertia term (depending on wave acceleration) and the drag term (depending on square velocity)

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directly brings about inaccuracy. Thus, it is necessary to improve the Morison equation under the condition of the shape and loading features of hose floating on the sea. Improving the accuracy of calculation of wave loads on hose is of vital importance for better analysis of the effects of marine hose on wave loads and safe use of floating hose.

2. MORISON EQUATION

Morison equation, a semiempirical formula based on flow theory, has been widely used in the calculation of wave loads of small-scale marine structure whose ratio of radius and length is less than 0.2. The theory assumes that the small-scale marine structure has no significant effect on the wave motion, and that the effects of waves on the structure is mainly composed of viscous effect and the added mass effect.

In case of a cylinder upright on the sea suffering the waves from the positive direction of axis x in which the intersection of seafloor and axis of cylinder is taken as the origin of XOZ coordinate system. Morison holds that the wave-induced force which offshore structures are subjected to the inertia term (depending on wave acceleration) and the drag term (depending on square velocity). The derivation of the formula on the calculation of wave loads is presented as follow just taking one supposition as the premise that the drag force caused by wave movement and the one due to the unidirectional steady flow has the same mechanism.

$$\begin{aligned} f_H &= f_D + f_I \\ &= \frac{1}{2} C_D \rho A u_x \left|u_x\right| + \left(1 + C_m\right) \rho \overrightarrow{V_0} \frac{\partial u_x}{\partial t} \\ &= \frac{1}{2} C_D \rho D u_x \left|u_x\right| + C_M \rho \frac{\pi D^2}{4} \frac{\partial u_x}{\partial t} \end{aligned} \tag{1}$$

Where f_H is the horizontal wave forces acting on certain height of cylinder, f_D is the horizontal drag force, f_I is the horizontal inertial force, C_D is the drag coefficient, V_0 is the volume of displacement of unit height, A is projection area of unit height vertical to the wave motion direction, u_x is the velocity in horizontal direction of wave particle, C_m is the added mass coefficient, C_M is the mass coefficient, and D is the diameter of the cylinder.

3. THE IMPROVED MORISON EQUATION

Slender cylinder is often used as basic structure of ocean engineering and the deducing of its Morison equation are also based on the cylinder model. The diameter of floating hose is much smaller than the wavelength of the incident wave. Thus, it is assumed that the floating hose has no significant influence on wave movement and the effect of waves on the structure is mainly composed of viscous effect and the added mass effect. Offshore floating hose is flat with nothing in it but turn into cylindrical shape in oil-transferring state and always floating in the sea due to its light material and low density conveyance medium, as shown in Fig. (**1**). The formation and change of the drag force is closely related with the boundary layer formed on the surface of the column body. In other words, it is closely related with the projected area of the column per unit length in the vertical direction. Shown as Fig. (**2**), only part of the hose is immersed in sea and the height below the sea level is less than the diameter of the pipe. The relations are as follows.

$$\begin{cases} A_1 = 1 \times h \\ A_2 = 1 \times D \\ A_1 < A_2 \end{cases} \tag{2}$$

Where A_1 represents the projected area of floating pipe per unit length in the vertical direction of the flow, A_2 represents the projected area of vertical cylinders per unit length in the vertical direction of the flow.

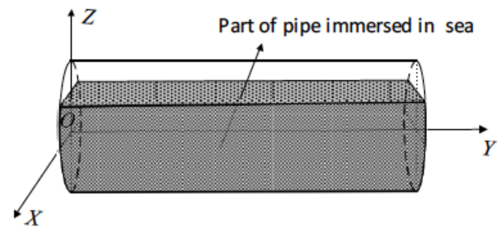

Fig. (1). The schematic diagram of offshore floating pipelines.

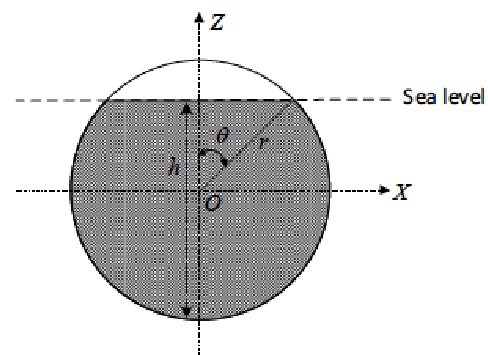

Fig. (2). The sectional view of offshore floating pipelines.

Flow inertia force is caused by the disturbance of fluid pressure distribution due to the existence of structure. The volume of displaced fluid and pressure distribution without structure are key factors of flow inertia force. As is shown in diagram 1, the volume of displaced fluid of offshore floating pipe is less than that of vertical cylinders per unit length, and relationship can be described as follows.

$$\begin{cases} V_1 = 1 \times S_1 \\ V_0 = 1 \times \dfrac{\pi D^2}{4} \\ V_1 < V_0 \end{cases} \tag{3}$$

Where V_1 represents the volume of displaced fluid of offshore floating pipe per unit length, S_1 represents the projected area of per unit floating pipe in the vertical direction of center axis of pipe, V_0 represents the volume of displacement of per unit vertical cylinders. According to the analysis of key factors closely related to wave loads, a conclusion can be drawn that using the existing Morison formula to calculate the wave load of floating hose is inaccurate. Thus, it is necessary to improve the Morison equation aiming at the calculation of wave load of floating hose.

Where h represents the height of immersed pipe below the sea level, θ represents half of the corresponding central angle of the bow-shaped above sea level.

Centre of mass is taken as the origin of XOZ coordinate system and the wave, ocean current, wind, gravity and buoyancy loads are applied to the partially submerged pipe. Stress analysis of floating pipe has been represented in the Fig. (**3**).

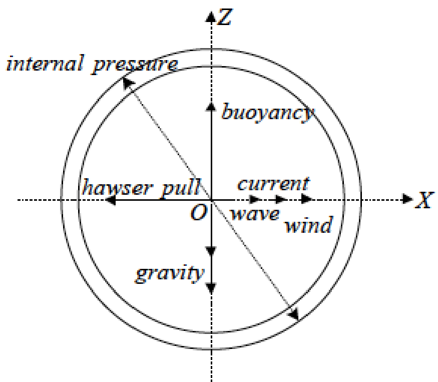

Fig. (3). The stress analysis of offshore floating pipelines.

This is an extreme case where the loads of current, wave and wind has the same direction, resulting in the maximum horizontal load on the pipe. According to the force balance principle, the following formula could be formed.

$$\begin{cases} F_B = G_1 + G_2 \\ F_P = F_{wind} + F_{wave} + F_{current} \end{cases} \tag{4}$$

Where F_B represents the buoyancy loads of pipe, F_P represents the anchor force in the horizontal direction, G_1 represents the weight of floating hose, G_2 represents the weight of oil transporting in the hose. The specific forms of each load are shown in formula (5).

$$\begin{cases} F_B = S_1 \times L_1 \times \rho_1 \\ G_1 = \pi\left[\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - d_1\right)^2\right] \times L_1 \times \rho_2 \\ G_2 = \pi\left(\frac{D}{2} - d_1\right)^2 \times L_1 \times \rho_3 \end{cases} \tag{5}$$

Where S_1 represents the projected area of per unit floating pipe in the vertical direction of center axis of pipe, L_1 represents the unit length, ρ_1 represents the density of seawater, ρ_2 represents the density of floating hose, ρ_3 represents the density of oil transporting in the hose, D represents the outer diameter of floating hose, d_1 represents the thickness of floating hose.

$$S_1 = \frac{\pi\left(\frac{D}{2} - d_1\right)^2 \times L_1 \times \rho_3 + \pi\left[\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - d_1\right)^2\right] \times L_1 \times \rho_2}{L_1 \times \rho_1} \tag{6}$$

Thus, the flow inertia force acting on the floating hose could be described as follows.

$$\begin{aligned} f_I' &= C_M \rho_1 V_1 \frac{\partial u_x}{\partial t} \\ &= C_M \rho_1 S_1 \frac{\partial u_x}{\partial t} \end{aligned} \tag{7}$$

The shaded part area in Fig. (**2**) can be described in the other way as follows.

$$\begin{cases} S_1 = S_{sector} + S_{triangle} \\ S_{sector} = \frac{2\pi - 2\theta}{2\pi} \times \pi r^2 = \left(\pi - a\cos\frac{h-r}{r}\right) r^2 \\ S_{triangle} = (h-r) \times \sqrt{r^2 - (h-r)^2} \\ r = \frac{D}{2} \end{cases} \tag{8}$$

The height of immersed pipe below the sea level can be calculated by combining two equations and the flow drag force applying on the floating hose could be described as follows.

$$\begin{aligned} f_D' &= \frac{1}{2} C_D \rho_1 A_1 u_x |u_x| \\ &= \frac{1}{2} C_D \rho_1 h u_x |u_x| \end{aligned} \tag{9}$$

To sum up, the improved Morison equation which adapted for the analysis for offshore floating hose can be described as follows.

$$\begin{aligned} f_H' &= f_D' + f_I' \\ &= \frac{1}{2} C_D \rho_1 A_1 u_x |u_x| + C_M \rho_1 V_1 \frac{\partial u_x}{\partial t} \\ &= \frac{1}{2} C_D \rho_1 h u_x |u_x| + C_M \rho_1 S_1 \frac{\partial u_x}{\partial t} \end{aligned} \tag{10}$$

Where u_x represents the horizontal velocity of wave particle at the center of the hose, $\frac{\partial u_x}{\partial t}$ represents the horizontal acceleration of wave particle at the center of the hose.

4. WAVE THEORY

Airy wave theory, Stokes wave theory, solitary wave theory and conical wave theory are used to calculate the wave forces acting on a offshore structure based on different situations frequently. Zhu Yan-rong [15] presented the application conditions of different wave theory as follow.

Choosing the suitable drag and mass coefficient is crucial to calculate wave load of offshore structure by using the Morison equation. Many domestic experts and scholars have conducted a lot of works on optimization of those parameters and some recommended values are listed in Table **2**. Usually, it is essential to carry on the hydrodynamic experiment in water so as to determine the value of specific coefficient [16].

5. EXAMPLES

Floating hose is widely used in exploitation and transportation of offshore oil field. The article calculated the wave loads of widely used offshore pipe in the fourth sea level by using Morison equation and improved Morison equation respectively. The parameters of pipeline and level 4 waves are listed in Tables **3** and **4**.

The height h and the projected area S_1 can be obtained by taking above parameters into the formula (6) and (8).The result is listed in formula (11).

$$\begin{cases} h = 95.1mm \\ \dfrac{h}{D} = 0.834 \\ S_1 = 0.0091m^2 \end{cases} \tag{11}$$

Hence, 83.4% of floating pipeline is immersed in the sea. According to the applicable conditions of wave theory presented in Table **1**, the Airy theory should be chosen when the water is more than 4 meters deep and the Stokes theory will be more suitable when it is between 2 and 4 meters deep. Code of Hydrology for Sea Harbour pressed in 1998[17] has settled the value of C_D and C_M in China sea area.

Table 1. The applicable conditions of wave theory.

Condition	Wave Theory
$d/L \ge 0.2, H/L \le 0.2$	Airy wave theory
$0.1 < d/L < 0.2, H/L \ge 0.2$	Stokes wave theory
$0.04 \sim 0.05 < d/L < 0.1$	Conical wave theory Solitary wave theory

$$\begin{cases} C_D = 1.2 \\ C_M = 2 \end{cases} \tag{12}$$

5.1. Airy Wave Theory

Taking depth equal 6 as an example, the Airy theory is more suitable for wave loads calculation of offshore hose than others. The velocity and acceleration of wave partials in the horizontal direction should satisfy the condition of formula (13).

$$\begin{cases} u_x = \dfrac{\partial\varphi}{\partial x} = \dfrac{Hgk}{2\omega}\dfrac{\cosh\left(k\left(z+d\right)\right)}{\cosh\left(kd\right)}\cos\left(kx-\omega t\right) \\ a_x = \dfrac{\partial u_x}{\partial t} = \dfrac{2\pi^2 H}{T^2}\dfrac{\cosh\left(k\left(z+d\right)\right)}{\sinh\left(kd\right)}\sin\left(kx-\omega t\right) \end{cases} \tag{13}$$

Where u_x represents the horizontal velocity of wave partial, a_x represents the horizontal acceleration of wave partial, φ represents the velocity potential of wave partial, k represents wave number which presented in formula (14).

$$k = \frac{2\pi}{T} \tag{14}$$

The velocity and acceleration of wave partials in the vertical direction should meet the condition of formula (15).

$$\begin{cases} u_z = \dfrac{\partial\varphi}{\partial z} = \dfrac{Hgk}{2\omega}\dfrac{\sinh\left(k\left(z+d\right)\right)}{\cosh\left(kd\right)}\sin\left(kx-\omega t\right) \\ a_z = \dfrac{\partial u_z}{\partial t} = -\dfrac{2\pi^2 H}{T^2}\dfrac{\sinh\left(k\left(z+d\right)\right)}{\sinh\left(kd\right)}\cos\left(kx-\omega t\right) \end{cases} \tag{15}$$

Table 2. The recommended values of C_D and C_M.

Wave Theory	C_D	C_M	Comments	References
Linear theory	1.0	0.95	Mean values for ocean wave data on 13-24 in cylinders.	Wiegel *et al.* (1957)
	1.0-1.4	2.0	Recommended design values based on statistical analysis of published data.	Agerschou and Edens (1965)
Stokes 3rd order	1.34	1.6	Mean values for oscillatory flow for 2-3 in cylinders.	Keulegan and carpenter (1958)
Stokes 5th order	0.8-1.0	2.0	Recommended values based on statistical analysis of published data.	Agerschou and Edens (1965)

Table 3. Parameters of floating pipeline.

$D(mm)$	$d(mm)$	$\rho_1(g/cm^3)$	$\rho_2(g/cm^3)$	$\rho_3(g/cm^3)$
114	6	1.025	1.25	0.83

Table 4. Parameters of level 4 waves.

$L(m)$	$T(s)$	$\omega(s^{-1})$	$c(m/s)$	$H(m)$
20	3.57	1.93	5.6	1.25

For the calculation of wave load by Morison equation, parameters of level 4 waves in Table **4** are used to calculate the velocity and acceleration of wave partials in formula (13) and formula (15) at the beginning. After that, the wave load could be worked out by submitting the above result along with the external diameter and cross section area of the pipe to formula (1). For the calculation of wave load with Improved Morison equation, the velocity and acceleration of wave partials still need to be figured out. Afterwards, the wave load could be calculated by submitting those results along with the height h and the projected area S_1 to formula (10) by using the Matlab program. Extreme value of wave loads by using the Morison theory and Improved Morison theory are listed in Table **5**.

Wave load variations are shown in Fig. (**4**) and Fig. (**5**) by using the Matlab program.

5.2. Stokes Two Order Wave Theory

Taking depth equal 3 as an example, the Stokes theory should be chosen for wave loads calculation of offshore hose in this situation. The velocity and acceleration of wave partials in the horizontal direction should satisfy the condition of formula (16).

$$\begin{cases} u_x = \dfrac{\partial \varphi}{\partial x} = \dfrac{H\pi}{T} \dfrac{\cosh\left(k\left(z+d\right)\right)}{\sinh\left(kd\right)} \cos\left(kx-\omega t\right) \\ \quad + \dfrac{3}{4}\left(\dfrac{H\pi}{T}\right)\left(\dfrac{H\pi}{L}\right) \dfrac{\cosh\left(2k\left(z+d\right)\right)}{\sinh^4\left(kd\right)} \cos 2\left(kx-\omega t\right) \\ a_x = \dfrac{\partial u_x}{\partial t} = 2\left(\dfrac{H\pi^2}{T^2}\right) \dfrac{\cosh\left(k\left(z+d\right)\right)}{\sinh\left(kd\right)} \sin\left(kx-\omega t\right) \\ \quad + 3\left(\dfrac{H\pi^2}{T^2}\right)\left(\dfrac{H\pi}{L}\right) \dfrac{\cosh\left(2k\left(z+d\right)\right)}{\sinh^4\left(kd\right)} \sin 2\left(kx-\omega t\right) \end{cases} \tag{16}$$

The velocity and acceleration of wave partials in the vertical direction should satisfy the relationship as formula (17).

$$\begin{cases} u_z = \dfrac{\partial \varphi}{\partial z} = \dfrac{H\pi}{T} \dfrac{\sinh\left(k\left(z+d\right)\right)}{\sinh\left(kd\right)} \sin\left(kx-\omega t\right) \\ \quad + \dfrac{3}{4}\left(\dfrac{H\pi}{T}\right)\left(\dfrac{H\pi}{L}\right) \dfrac{\sinh\left(2k\left(z+d\right)\right)}{\sinh^4\left(kd\right)} \sin 2\left(kx-\omega t\right) \\ a_z = \dfrac{\partial u_z}{\partial t} = -2\left(\dfrac{H\pi^2}{T^2}\right) \dfrac{\sinh\left(k\left(z+d\right)\right)}{\sinh\left(kd\right)} \cos\left(kx-\omega t\right) \\ \quad - 3\left(\dfrac{H\pi^2}{T^2}\right)\left(\dfrac{H\pi}{L}\right) \dfrac{\sinh\left(2k\left(z+d\right)\right)}{\sinh^4\left(kd\right)} \cos 2\left(kx-\omega t\right) \end{cases} \tag{17}$$

Thus, the wave load using Stokes two order wave theory may follow the example of Airy theory. Parameters of level 4 waves are used to calculate the velocity and acceleration of wave partials in formula (16) and formula (17). Thus, the wave load could be calculated by submitting those results along with the height h and the projected area S_1 to formula (1) and (10). Extreme values of wave loads through the use of Stokes theory are listed in Table **6**.

Wave load variations are shown in Fig. (**6**) and Fig. (**7**) by using the Matlab program.

5.3. Analysis

It can be seen from Fig. (**4**) that the time-domain waveform based on improved Morison equation is similar to that of Morison equation and the value of wave loads based on improved Morison equation is smaller than those based on Morison equation. This is not a coincidence. The regulation can be found in Fig. (**5**) to Fig. (**7**). Wave loads of offshore hose in case of depth equal 6 and depth equal 3 are listed in Table **7**.

Where F_0 represents the wave loads based on Morison equation, F_1 represents the wave loads based on Improved Morison equation, F_2 represents the difference between the value of F_0 and F_1.

$$F_2 = F_0 - F_1 \tag{18}$$

P represents the ratio of F_2 to F_0. This index shows the various degrees between two methods.

$$P = \frac{F_2}{F_0} \times 100\% \tag{19}$$

Some characteristic value could be found through the statistical analysis of ratio P in horizontal and vertical direction with different wave theories shown in Table **8**.

Where P_1 represents the ratio P referring to horizontal wave load in Airy theory, P_2 represents the ratio P referring to vertical wave load in Airy theory, P_3 represents the ratio P referring to horizontal wave load in Stokes two order wave theory, P_4 represents the relative P referring to vertical wave load in Stokes two order wave theory.

The maximal value of ratio P is 23% and the mean value of it is upright to 15% indicating that it is not precisely enough by using the existing Morison equation to calculate the wave loads of floating hose and the improved Morison equation is more suitable for this situation. The difference between the value of F_0 and F_1 can be visualized in Fig. (**8**) and Fig. (**9**) with the use of Matlab program.

Table 5. Extreme value of wave loads with the usage of Airy theory.

Technique	The Horizontal Wave Loads		The Vertical Wave Loads	
	Max Value	Mix Value	Max Value	Mix Value
Morison theory	89.46	-89.2	82.90	-83.0
Improved Morison theory	75.35	-75.2	75.55	-75.6

The unit of values in above table is N/m.

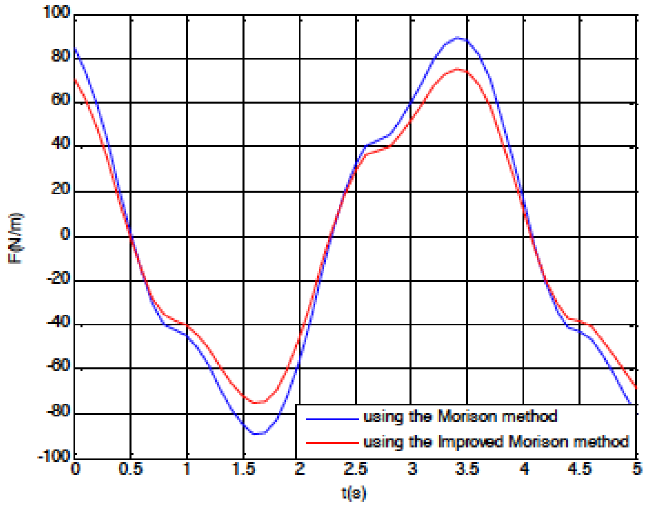

Fig. (4). The comparison of horizontal wave force between the use of the improved Morison equation and existing Morison equation in airy theory.

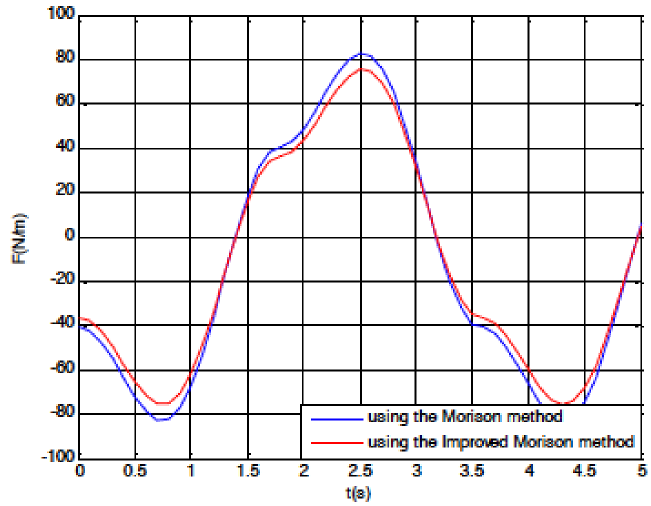

Fig. (5). The comparison of vertical wave force between the use of the improved Morison equation and existing Morison equation in airy theory.

Table 6. Extreme value of wave loads through the use of Stokes theory.

Technique	The Horizontal Wave Loads		The Vertical Wave Loads	
	Max Value	**Mix Value**	**Max Value**	**Mix Value**
Morison theory	257.48	-88.95	123.01	-124.42
Improved Morison theory	215.59	-74.76	103.39	-104.94

The unit of values in above table is N/m.

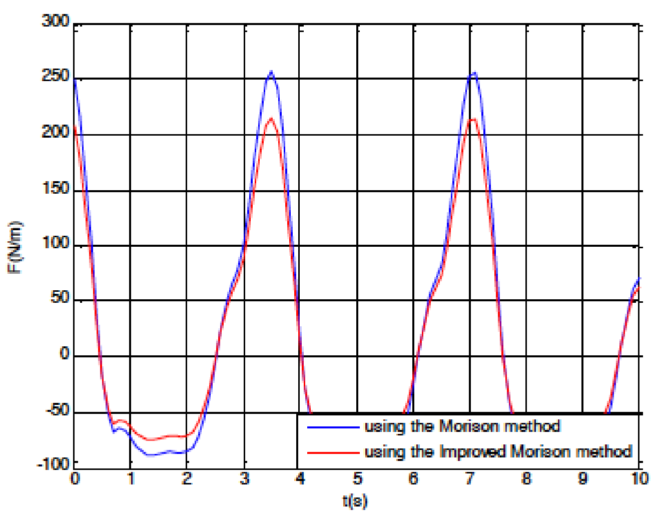

Fig. (6). The comparison of horizontal wave force between the use of the improved Morison equation and existing Morison equation in in Stokes theory.

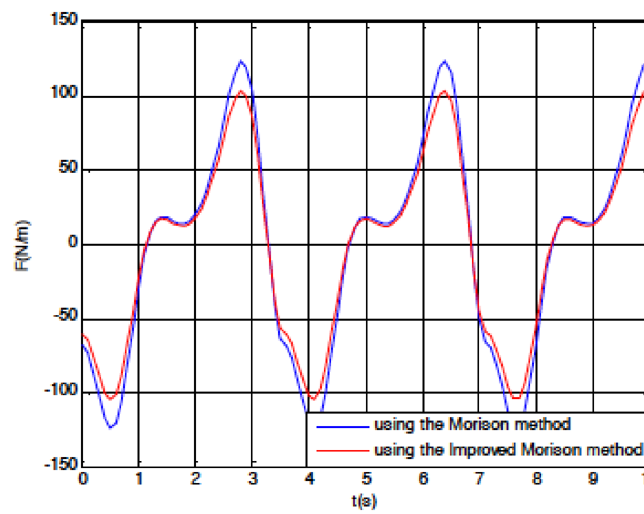

Fig. (7). The comparison of vertical wave force between the use of the improved Morison equation and existing Morison equation in Stokes theory.

The main reason for this phenomenon is that Morison equation is based on vertical cylinder model and supposes the infinitesimal section is completely immersed in water. Thus, the displacement volume is considered as cylinder volume and the projected area of per unit length in the vertical direction of the flow are considered as the external diameter of the hose by default. However, the hoses are always floating on the sea under buoyancy whether they are in the state of transporting oil or not and only part of them are immersed in the sea. The displacement volume and the projected area of per unit length in the vertical direction of the flow is determined by the mechanical equilibrium in the

Table 7. The wave load of floating hose in different depth.

Wave Theory	t(s)	The Horizontal Load (N/m)				The Vertical Loads (N/m)			
		F_0	F_1	F_2	*P*,%	F_0	F_1	F_2	*P*,%
Airy theory	0.00	84.21	70.25	13.96	16.58	-40.71	-36.29	-4.42	10.85
	0.30	41.36	33.27	8.09	19.56	-54.89	-49.40	-5.49	10.01
	0.90	-42.64	-38.01	-4.63	10.85	-77.18	-70.62	-6.56	8.50
	1.50	-85.24	-72.28	-12.96	15.20	17.72	15.38	2.34	13.21
	2.10	-38.43	-30.78	-7.66	19.93	56.15	50.56	5.59	9.95
	2.70	42.73	38.09	4.64	10.86	76.00	69.57	6.44	8.47
	3.30	86.09	72.93	13.15	15.28	-19.93	-17.39	-2.54	12.75
	3.90	35.47	28.25	7.22	20.36	-57.44	-51.75	-5.68	9.90
	4.50	-42.90	-38.23	-4.67	10.89	-74.71	-68.41	-6.30	8.44
	5.00	-80.33	-68.45	-11.89	14.80	6.42	5.10	1.32	20.49
Stokes theory	0.00	249.75	208.35	41.41	16.58	-68.20	-60.80	-7.40	10.85
	1.00	-72.73	-63.18	-9.56	13.14	-29.47	-22.68	-6.79	23.04
	2.00	-85.42	-71.22	-14.20	16.62	19.45	17.25	2.20	11.32
	3.00	101.48	88.82	12.66	12.47	102.33	84.77	17.55	17.16
	4.00	19.84	12.73	7.11	35.85	-120.51	-102.31	-18.19	15.10
	5.00	-88.54	-74.15	-14.39	16.25	18.37	16.72	1.65	8.98
	6.00	-26.56	-20.55	-6.01	22.64	70.70	60.98	9.72	13.75
	7.00	253.20	212.77	40.42	15.97	-49.81	-45.20	-4.61	9.25
	8.00	-64.86	-57.46	-7.40	11.41	-66.67	-54.18	-12.49	18.73
	9.00	-86.31	-72.02	-14.30	16.56	13.97	12.45	1.52	10.91
	10.00	71.51	63.65	7.86	10.99	122.13	102.41	19.72	16.15

Table 8. Some characteristic value of the ratio *P*.

Parameter	P_1	P_2	P_3	P_4
Max value	20.36	20.49	22.64	23.04
Average value	15.43	11.26	15.26	14.01

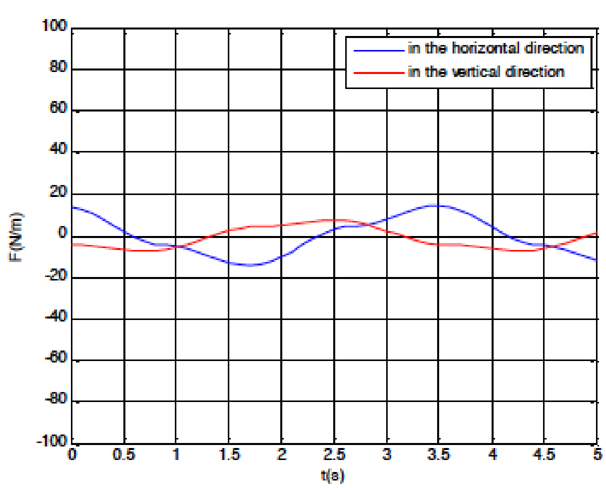

Fig. (8). The variation of wave load difference based on Airy theory.

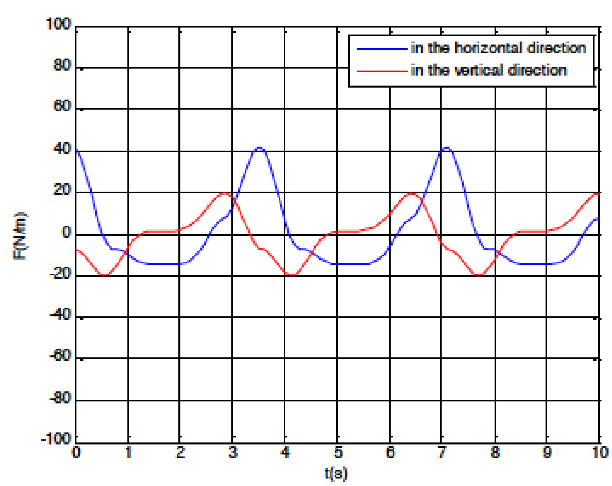

Fig. (9). The variation of wave load difference based on Stokes theory.

vertical direction. Obviously, the displacement volume is smaller than cylinder volume per unit length and the projected area of per unit length is smaller than the default value. Hence, the wave load of floating hose in practical situation is smaller than the calculation based on Morison equation.

CONCLUSION

For the wave load of offshore floating hose, results based on the Morison equation are overrated. The Improved Morison equation is proposed by establishing the partially immersed cylinder model which contained morphologic and mechanical characteristics of floating hose. In case of the floating hose deployed in 6-meter deep and 3-meter deep water, the wave load based on improved Morison equation is more precisely than the previous one. The accuracy of wave loads can be improved about 15%. Thus, the improved Morison equation is more precisely and meaningful for analysis of marine hose mechanics.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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