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Effect of Surface Waves on Submarine Pipeline during Lying

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Abstract

Submarine pipelines are essentially used for the transmission of gas and oil across oceans between countries or for transport between shore and offshore installations. The pipeline applications were studied to be installed in deep water, which exposed to different loads such as currents and waves in various directions, barge movements, seafloor interaction, etc. This paper developed a dynamic analysis of the J-lay suspended submarine pipeline during laying taking into account the effect of water depth, the direction of the wave heading, and sea state without vessel movement. The finite element program ANSYS R17.2 is used for modeling and analysis of the pipelines. The random sea state is modeled using the JONSWAP spectrum. It was found that the effect of the direction of wave heading on the bending moment from dynamic analysis of pipeline is obvious in a depth of (2 m) below water surface, and then gradually decreases until it disappears in depth of (100 m). Whereas the effect of wave height is obvious in a depth of (2 m) and then gradually decreases until it disappears in depth of (120 m).

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Keywords: Direction of the wave heading, Dynamic response, J-lay, Sea state and Submarine pipeline.

1. Introduction

Pipelines are considered to be the most economical and efficient means to transporting natural gas and oil from offshore wellheads to coastal processing facilities or offshore [1]. There are different methods of marine pipeline installations, including the conventional lay-barge method, reel barge, and various tow and pull methods [2]. As pipeline installations were developed into deeper waters, the dynamic performance of the pipeline has been significant, this was preferred by the J-lay method in the installation. In this method, the pipeline configuration from the surface to the seafloor is the curvature of one large radius leading to less stresses than other methods in the same depth of water as shown in Fig. 1 [3].

Different previous studies considered the submarine pipeline; Cowan and Andris (1977) [4] presented a method for predict the dynamic responses of pipeline system during laying when subject to excitations from high sea states and barge movements in shallow or deep water. The method incorporated a composition of coupled rigid body and flexible finite element models in a three-dimensional time domain. This method accounted for nonlinearities such as geometric in pipeline and hydrodynamic damping. Malahy et al. (1985) [5] presented a finite element model for the three dimensional, nonlinear dynamic analysis of the offshore pipeline problem during operation by the computer code OFFPIPE. Numerical integration was used to obtain the solution of a time domain for pipeline dynamic response to the loads of wave and wave induced movements of the vessel and stinger. Hong and Wei (2010) [6] both static and dynamic analyses were performed. The effect of different parameters such as wave direction, wave period and wave height were investigated by using the computer code SIMLA. They concluded that the direction of wave had a significant effect on the vertical forces. Senthil and Selvam (2015) [7] considered a J-lay pipeline numerical model analyzed using ORCAFLEX. Dynamic responses of the pipeline were studied under the effect of waves with and without barge movement. The JONSWAP spectrum was used to modeled the random sea state. They concluded that there was insignificant effect of loading of the wave without barge motion on the pipeline. Gong and Pu Xu (2016) [8] studied the effect of different sea states on the dynamic behavior of dynamic for submarine pipelines during S-lay process in deep water by using the software OrcaFlex. The results showed that the wave direction had significant effect on the dynamic responses of pipeline with the maximum reverse wave direction was the (45°), and the pipeline dynamic responses was obvious when the increasing of wave height.

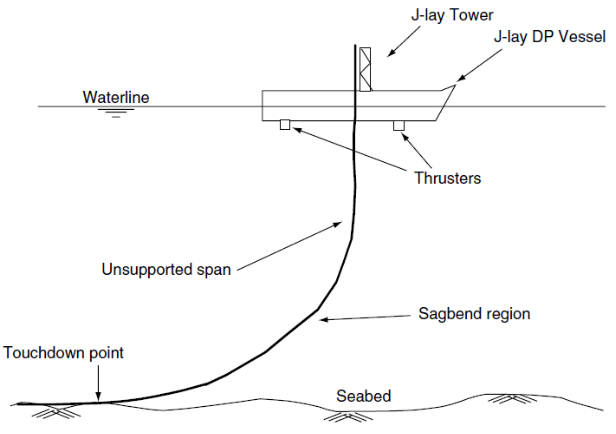

Fig.1 J-lay Method [3].

The aims of the study are to explain the effect of surface waves on the pipeline dynamic behavior. The dynamic

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responses of pipeline during installation under the effect of waves without vessel movement were evaluated. The time history analysis method is used with ANSYS R17.2 program. Three wave heading directions and three sea states have been investigated on different water depths. The depth at which the effect of the wave heading direction and sea state disappears below the water surface is also explained.

2. Finite Element Analysis

A finite element analysis model of pipeline is established by using two elements to formulate the problem un-der consideration, which are the Elastic Straight Pipe (Pipe 288) and 3D Node-to-Node Contact Element (CON-TA178) as shown in Fig. 2. The linear material and geometric nonlinearities were considered in the present work.

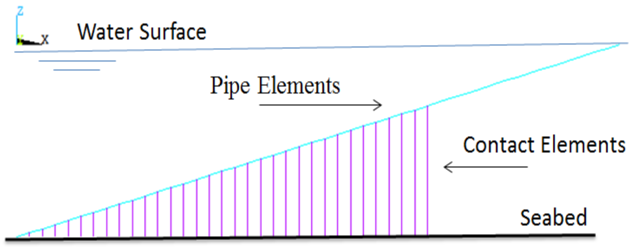


Fig. 2 Pipeline and contact elements.

The hydrodynamic forces induced by surface wave are calculated on the pipelines using the adjusted form of Morison's equation in order to take into account the relative movement between structure and water [9]. The hydrodynamic force per unit length can be written as:

$$F_T(t) = \frac{\pi D^2}{4}\rho_w C_m(\dot{v_x} - \ddot{u}) + \frac{\pi D^2}{4}\rho_w \dot{v_x} + \frac{1}{2}\rho_w C_D D(v_x - \dot{u})|v_x - \dot{u}| \quad (1)$$

Where; $\dot{u}$ and v_x are the velocity of the member and fluid, $\ddot{u}$ and $\dot{v_x}$ are the acceleration of the member and fluid respectively, C_D is the coefficient of drag, ρ_w is the density of water, D is the diameter of cylinder, v_x is the velocity of fluid, and C_m is the coefficient of hydrodynamic mass [10].

Free surface waves created by winds denote one of the major environmental impacts on marine structures. The sea surface characterization can be modeled by using irregular waves as the summation of regular type waves [11]. The inputs of random wave formula depend on kind of wave spectrum that describes the sea state characteristics. The generally used spectrum models are Pierson-Moskowitz, JONSWAP, ISSC, Bretschneider, and less used Ochi-Hubble. The JONSWAP spectrum is used in present study of random sea state modeling. The JONSWP spectrum was developed by Hassleman et al. (1973) during a (Joint North Sea Wave Project) and hence the name. The JONSWAP spectrum formula can be written by modifying the P-M formula as follows [12];

$$S(\omega) = \bar{\alpha}\, g^2\, \omega^2 \exp\left(\frac{-5}{4}\left(\frac{\omega}{\omega_o}\right)^{-4}\right) \cdot \gamma^{\exp\left(\frac{-(\omega-\omega_o)}{2\sigma^2\omega_o^2}\right)} \quad (2)$$

Where; ω: Angular frequency, ω_o: Angular frequency of spectral peak, g : Acceleration due to gravity, $\bar{\alpha}$: Phillips' constant, σ : Spectral width parameter, and γ : JONSWAP peakeness parameter.

In order to validate the developed FE model the results were compared with Senthil and Selvam [7] work, as shown in Fig. 3. The properties of this submarine pipeline are mentioned in Table 1. The random sea state is designed by use the JONSWAP spectrum with variables as listed in Table 2. Normal drag coefficient of (1.2), axial drag coefficient of (0.024) and add mass coefficient of (1.0) were considered in the analysis. The seabed is modeled as rigid and flat. It was assumed that the pipe material as API 5LX-X65 type with specified minimum yield stress (SMYS) of (448) MPa from API properties in DNV-OS-F101 code [13]. The total damping ratio including fluid added damping is 2.5 % [14].

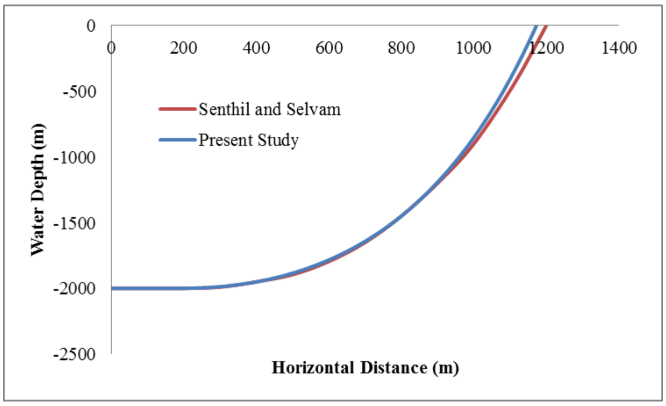


Fig. 3 Deflected shape of the pipeline.

Table 1 Properties of the pipeline in Senthil work [7].

Property	Value
Outer diameter, D_0	0.6 m
Inner diameter, D_i	0.55 m
Steel modulus of elasticity, E	2.1×10^{11} Pa
Density of steel pipe, ρ_{st}	7850 kg/m^3
Density of water, ρ_w	1030 kg/m^3
Laying angle, ϕ	80°
Water depth, d	2000 m
Applied tension force on laybarge, T	1365.78 kN

Table 2 Variables of Wave and JONSWAP spectrum [7].

Parameter	Value
Wave heading angle, θ_w	270
Significant wave height, H_S	1.77 m
Peak period, T_P	8.5 s
Peak enhancement factor, γ	3.3

3. Results and Discussion

The parameters which affecting on the stresses developed in the pipeline are the direction of the wave heading and sea states on various water depths over submarine pipeline. All these parameters are considered separately in the present dynamic analysis. To explain the effects of surface waves on the dynamic response of the pipeline during operation in deep waters by J-lay method, three directions for wave headings and three sea states were adopted in the present study. The results of the study that got from these sea states are discussed for the region below water surface which connected to the tensioner as a function of time for the effective tension forces and bending moments.

To understand the effect of the directions of the wave headings on the dynamic response of suspended pipeline, different directions of surface wave were selected equals to (0°, 45°, and 90°). The sea state is specified as a significant wave height (H_s) of (1.77 m) and peak period (T_p) of (8.5 s). This parameter was considered with submarine pipelines that lay in different water depths (2000, 1000, and 500 m). As shown in Fig. 4, the effect of the directions of the wave heading is obvious in water's depth of (2000 m) at the region of (5 m) below water surface where the most significant wave's direction is (45°). In the case of water's depth (1000 m) at the region of (3 m) below water surface, the most significant wave's direction is (0°). At water's depth of (500 m), in case of (2 m) region below water surface, the most significant wave's direction is (0°). Because of as the water depth decreases, the effect of the direction of wave heading become more obviously in this region and the revers wave direction become (0°) which is opposite direction of laying the pipeline.

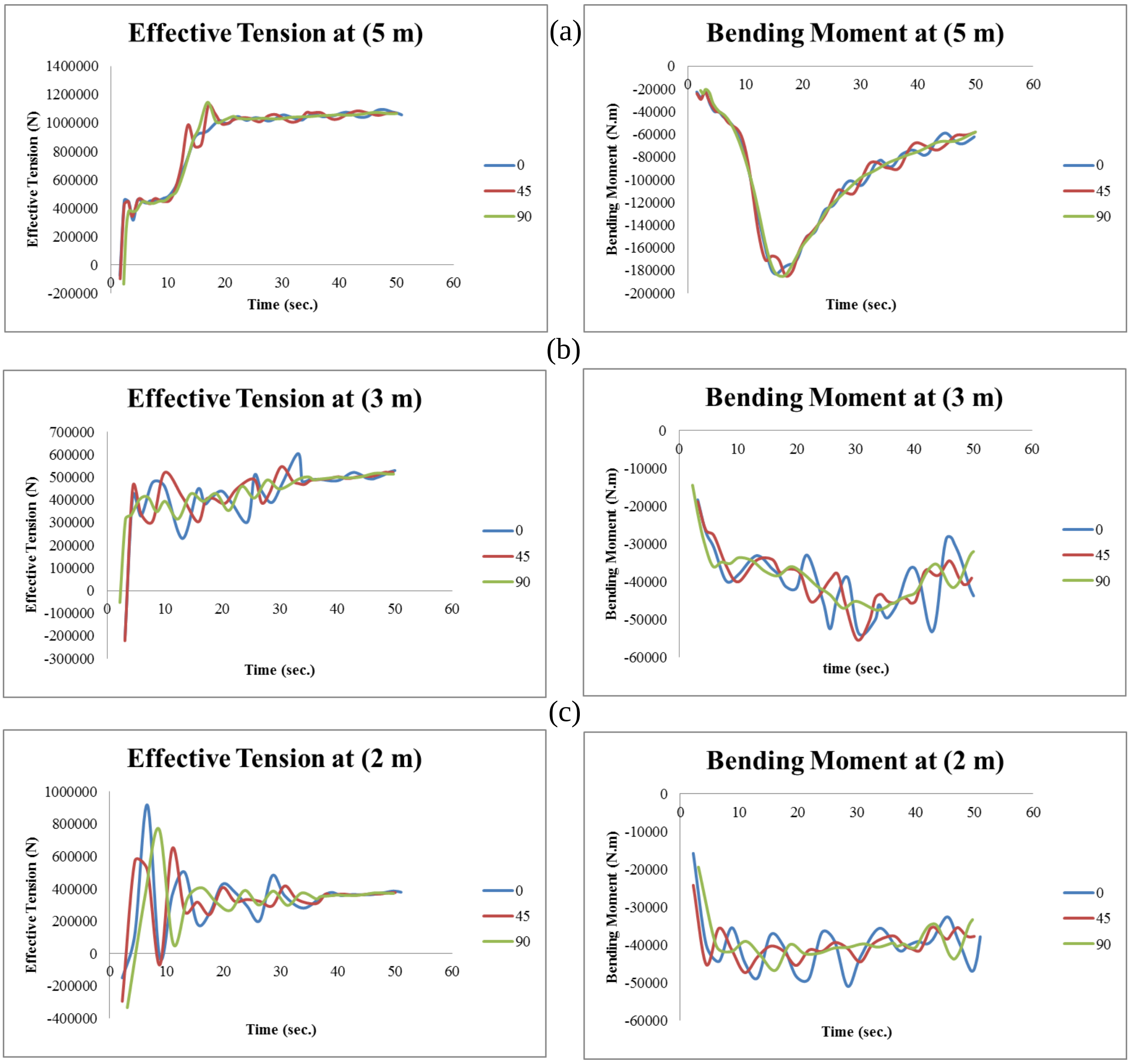
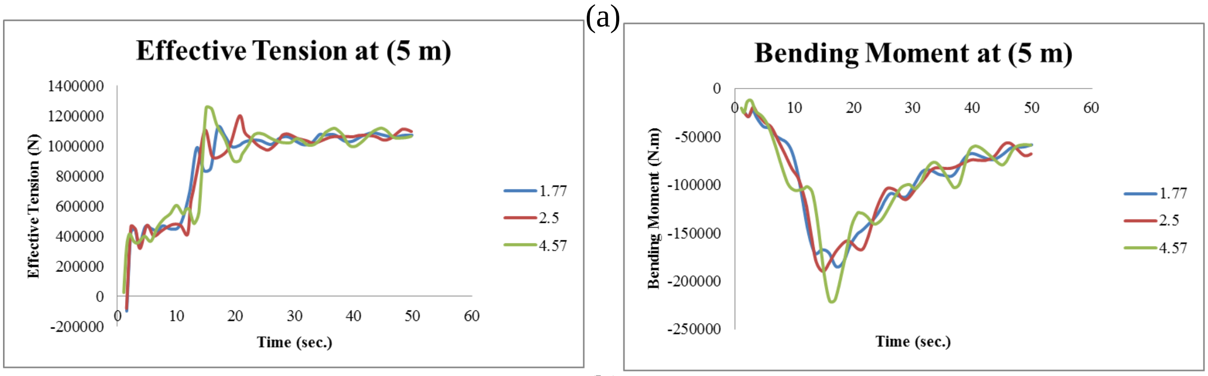


Fig. 4 Effect of the Direction of the Wave Heading on the Time History of Pipeline for Water Depths (a) 2000 m (b) 1000 m (c) 500 m.

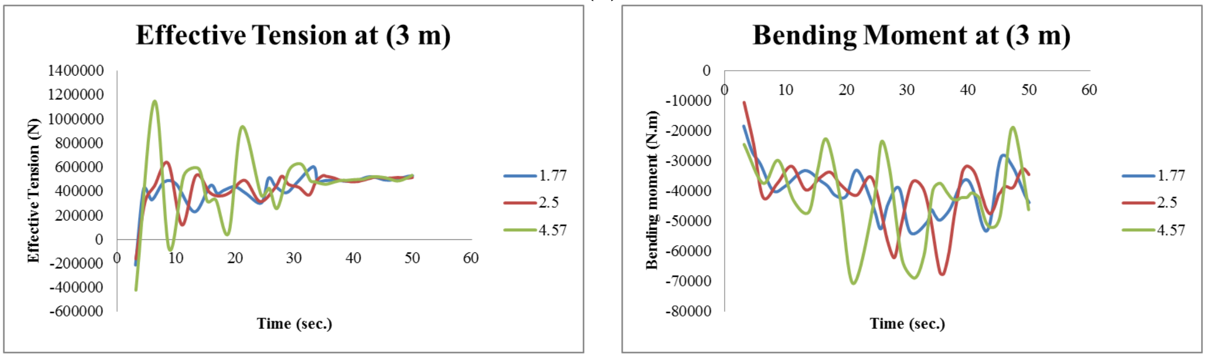
To investigate the effect of the sea state on the dynamic response of suspended pipeline under the most influence wave direction, three sea states with various of significant wave height and peak period are designated (H_s = 1.77 m, T_p= 8.5 s), (H_s= 2.5 m, T_p= 9 s) and (H_s= 4.57 m, T_p= 9.4 s). Also, this parameter was considered with submarine pipelines that lay in different water depths of (2000, 1000 and 500 m). As shown in Fig. 5, the effect of wave height on pipeline is obvious in the regions below water surface and the pipeline response increases with increasing of the wave height for all water depths because of increasing the wave loads on the pipeline.

It was noted from previous results that the effects of the direction of wave heading and the sea state on the suspended pipeline are obvious in the region below the water surface. This study has been conducted for the bending moment of the submarine pipeline at a water depth of (500 m). The effect of the direction of the wave heading on the bending moment from the dynamic analysis of the pipeline is shown in Fig. 6; the effect is obvious in a depth of (2 m) below water surface and then gradually decreases until it disappears in depth of (100 m). The effect of wave height on the bending moment from dynamic of pipeline is shown in Fig. 7; the effect is obvious in a depth of (2 m) below water surface and then gradually decreases until it disappear in depth of (120 m).

(a)



(b)



(c)

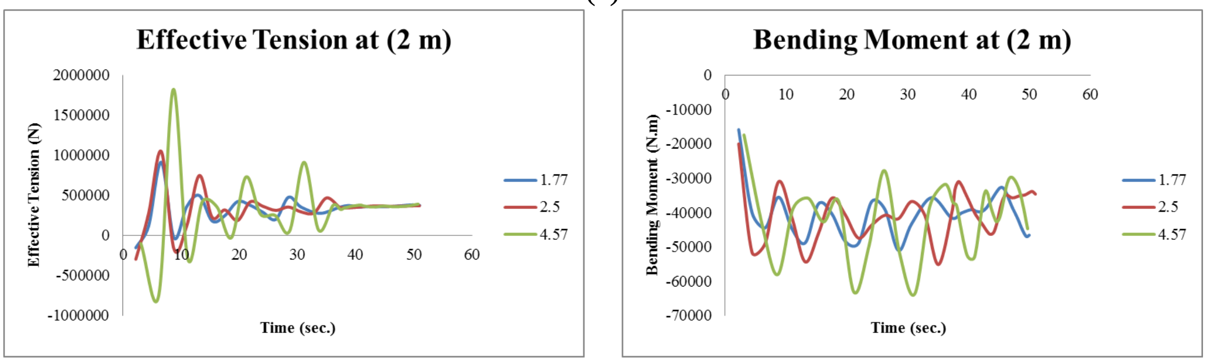


Fig. 5 Effect of the Wave Height on the Time History of Pipeline for Water Depths (a) 2000 m (b) 1000 m (c) 500 m.

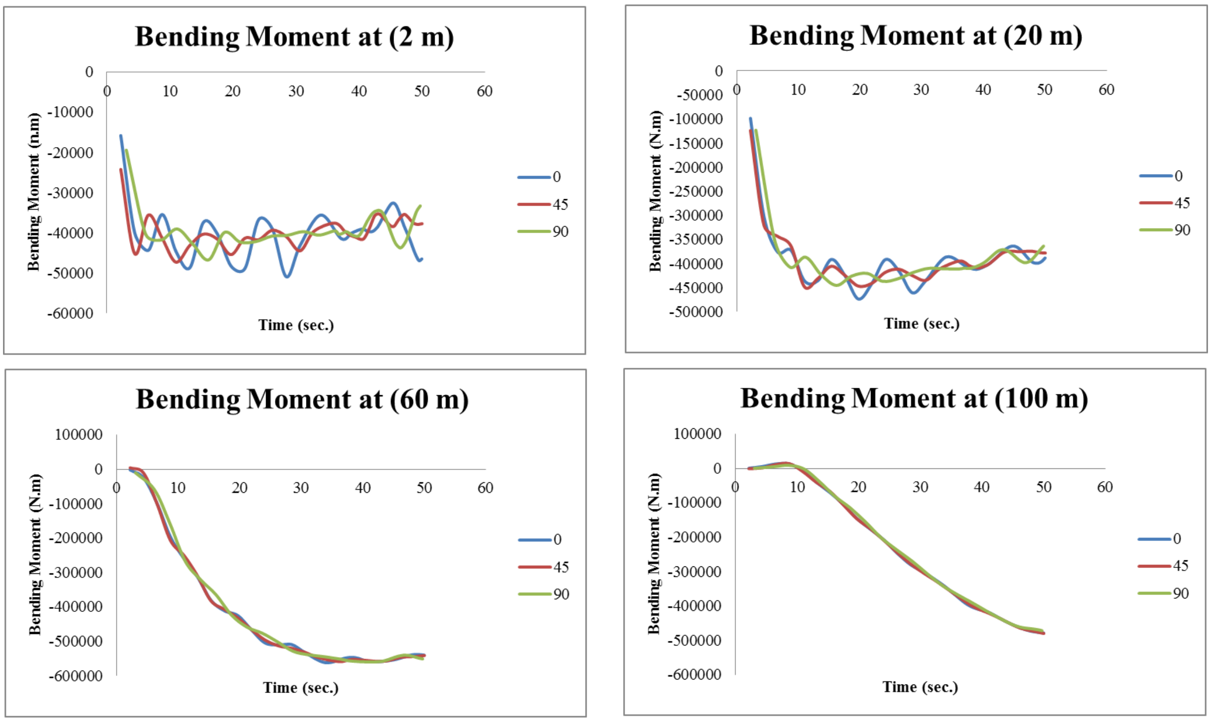


Fig. 6 Effect of the Direction of the Wave Heading on the Time History Bending Moment of Pipeline at Different Depths from Water Surface.

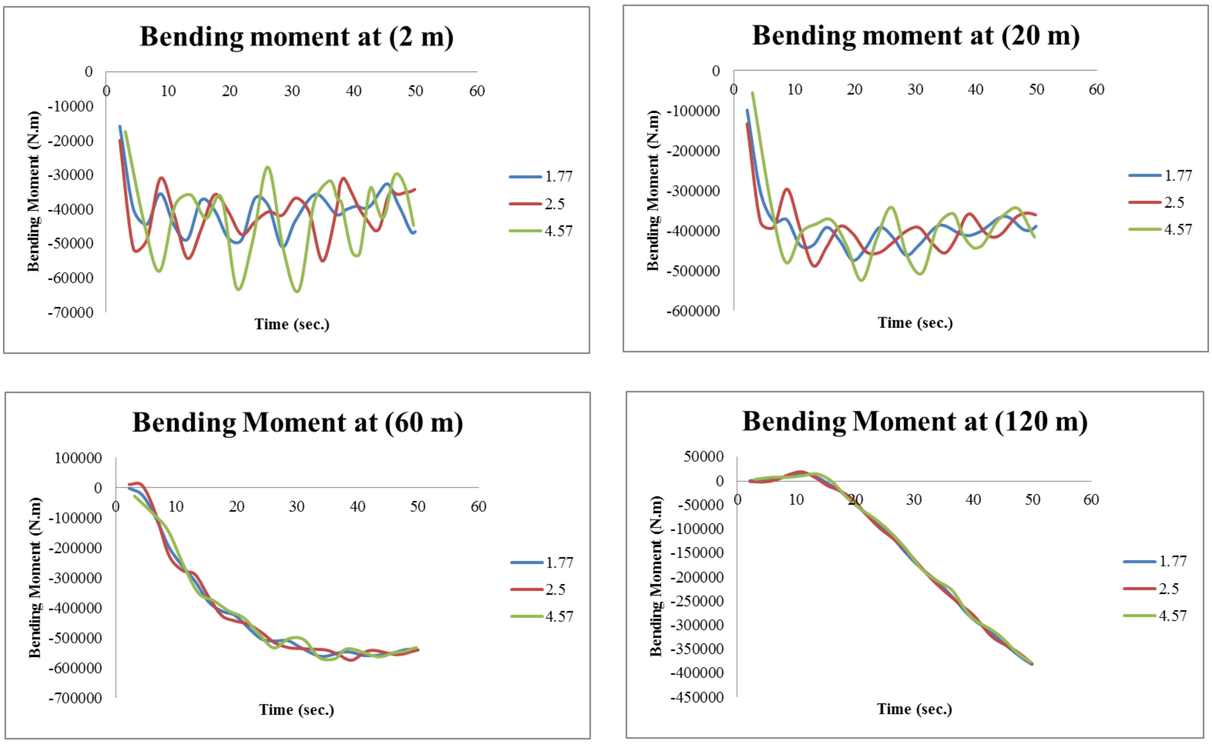


Fig. 7 Effect of the Wave Height on the Time History Bending Moment of Pipeline at Different Depths from Water Surface.

4. Conclusions

The dynamic analysis of suspended submarine pipeline during laying with different water depths, the direction of the wave heading and sea state are presented in this study. From the study the following conclusions are recorded:

1. The effect of the direction of the wave heading on the dynamic response of pipeline are obvious in the regions below water surface for, water's depth of (2000 m) where the most significant wave's direction is (45°), in the case of water's depth (1000 m) where the most significant wave's direction is (0°) and at water's depth of (500 m) where the most significant wave's direction is (0°). As water depth decreases this effect becomes more obvious.
2. The wave height effect on the dynamic response of suspended pipeline under the most influence wave heading direction for different water depths are obvious in the regions below water surface and the pipeline response increased with increasing of the wave height.
3. The effect of the direction of the wave heading on the bending moment from dynamic of pipeline is obvious in a depth of (2 m) below water surface and then gradually decreases until vanish in depth of (100 m), whereas the effect of sea state on the bending moment from dynamic analysis of pipeline is obvious in a depth of (2 m) and then gradually decreases until it disappears in depth of (120 m).

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Biographies

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