Evaluation Study of Free Spanning Subjected to Hydrodynamic Loads

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Abstract

Suspended spans generally occur in subsea pipelines as a result of the irregularity of seabed. Additionally the suspended spans mostly result from the scouring phenomena around the installed non-buried pipeline. So as to discuss the hydrodynamic surrounding the pipeline and determining the significant deflections and associated stresses of the subsea pipeline in unsupported part, therefore, it's very necessary to study the hydrodynamic surrounding the pipeline in detail. A two main aims have been done in this study, first assess the stresses at free span section and the second one was the effect of soil characteristics in contact area between pipeline and the seabed soil. A combined model of stresses/lateral displacement has been made. An ANSIS model has been built on the offshore pipelines as a consequence of the combined hydrodynamic loads such as wave/current effects. The calculations have been computed by using the finite element method for the free span to describe the surrounding environment in more accuracy. The pipeline stresses intensity increases with closing to free span center. This is attributed to the fact that *UY* and *UZ* have more maximum values at these region.

Keywords: Free span, Subsea pipelines, Finite element method, Hydrodynamic load.

الخلاصة

تحدث ظاهرة الفضاء المعلق الغير مسنود بصورة عامة عند مد خطوط الأنابيب على ارض متموجة التي تحدث نتيجة لعوامل التعرية للتربة المحيطة بالأنبوب المكشوف الغير مدفون. لذلك من الضروري دراسة حركة المائع حول خط الانبوب المتولدة وحساب مقدار الهطول والاجهادات المتولدة لهكذا نوع من خطوط الأنابيب الغائصة تحت الماء. في هذا البحث تم تسليط الجهد لتخمين وتحري الاجهادات خلال جزء الأنبوب المعلق الغير مستند على تربة قاع البحر ودراسة تأثير خصائص هذه التربة عند نقاط الاستناد على سلوك خطوط الأنابيب. تم عمل نموذج لفضاء الأنبوب المعلق باستخدام برنامج (ANSYS) الذي يعتمد على نظرية العناصر المحددة وكذلك تم إدخال تأثير حركة الموجة والتيار لغرض وصف البيئة المحيطة بالأنبوب بدقة اكبر. بينت النتائج المستحصلة من الدراسة ان شدة الاجهادات تتزايد كلما اقتربنا إلى مركز الفضاء الحر.

الكلمات الافتتاحية: الفضاء الحر، خطوط أنابيب المنصات البحرية، طريقة العناصر المحددة، أحمال الهيدروداينمكية.

1. Introduction

One of the serious problems, during the operational state, for the structural shelter of pipelines is uneven areas in the seafloor, as they enhance the development of free spans. The unsupported parts of pipeline that are touching the seabed at his ends, may form because of the maladjustment of seabed or artificial supports like rock, beams, another pipeline (DNV-RP-F105, 2006), or the scouring of underlying soil, (Yaghoobi, 2012), in construction of on-bottom (unburied) method which presents a common construction method in offshore pipelines systems, since this method results to reduce of construction time and associated costs (Georgiadou, 2014). Consequently, in the on-bottom offshore pipeline, single and/or multiple free spans (L) along its length are formed (Fig. 1). When a pipeline is in a free span, fluid flow caused by waves or currents or both will cause vortices to be formed and shed in the wake of the flow which can lead to fatigue damage in the pipe (Carl, 2002).

Under this framework, numerous researchers have developed and utilized various numerical models for the examining of different aspects in the dynamic behavior of free span pipelines.

In (Elsayed, 2012) the outhor proposed an approach based on the developing of a nonlinear finite element model for the viewing of subsea pipelines for free spanning. Combined stresses/lateral displacement is functioning on subsea pipelines as a result of combined hydrodynamic loads, particularly wave/current effects that are calculated making use of the finite element model for free spans.

(Project Consulting Services INC.,1997) the study establishes a method to evaluate and analyze the pipeline of free spans, based on the information generating from the research.The information that concluded from the work is used to outline preventative and steps which are corrective for the subsea pipeline free spans.

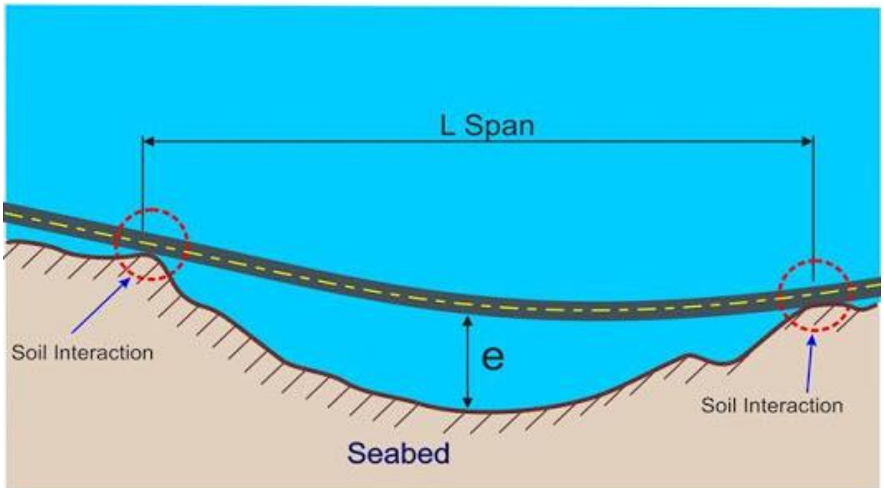
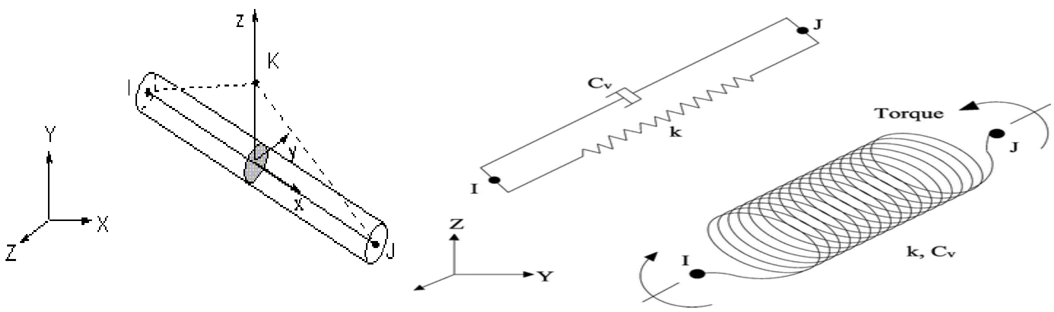


Figure 1. span performed on seabed

2. Numerical Model

The composite of hydrodynamic loads and pipe-soil interface considers most challenges that have difficult in the submarine pipeline model (Kristian, 2008). A nonlinear finite element model (FEM) is applied to model the hydrodynamic forces and the interaction between pipeline and soil of seabed in free spanning analysis using general package of ANSYS, Inc. Release 16.1 program. The analysis model includes Friction forces and soil stiffness representation and it contains two elements, the first is PIPE288 model a total length of the pipeline. PIPE288 has two-nodes with six degrees of freedom at each node (displacement in the x, y, and z directions and rotations about the x, y, and z directions), Fig. (2-a), and the second one is COMBIN14 that used to represent pipe-soil interaction at side spans of pipeline (the shoulders). The element COMBIN14 has two-nodes with three degrees of freedom at each node: displacements in the x, y, and z directions of option longitudinal spring damper. Fig. (2-b)(ANSYS Help). Figure 3 shows geometric configuration of pipeline in ANSYS software with global coordinate system. Where mid span length was divided into 50 element of PIPE288 with element length equals to 0.24m, and side span was divided into 20 element of PIPE288 for each side (10 elements through 4.5 m starting from shoulder beginning and 10 elements through 1.5m at shoulder ending). Same arrangements have been made for shoulder model with element COMBIN14.



a- Pipe288 element **b- Combin14 element**

Figure 2: elements used in the Ansys Model

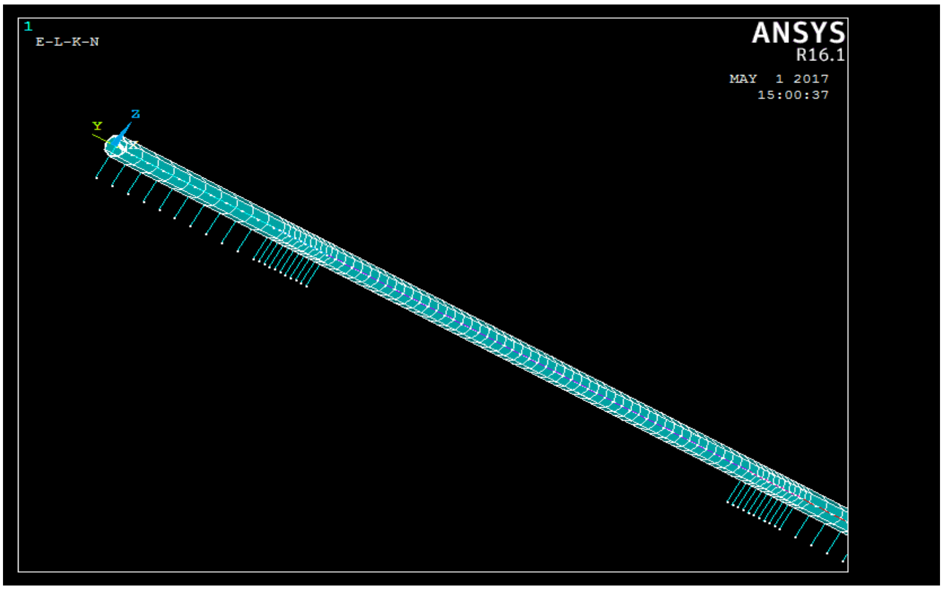


Figure 3. Modeling pipeline in ANSYS software

3. Boundary Conditions

The displacements in X, Y and Z directions for the node of the element combin14 that symbolized by "α", see Figure 4, should be fixed. The nodes are located at ends of the pipeline, "β", treated as no displacements and rotation in all directions. The other nodes of the pipeline are leaved to be free and symbolized by "γ ".

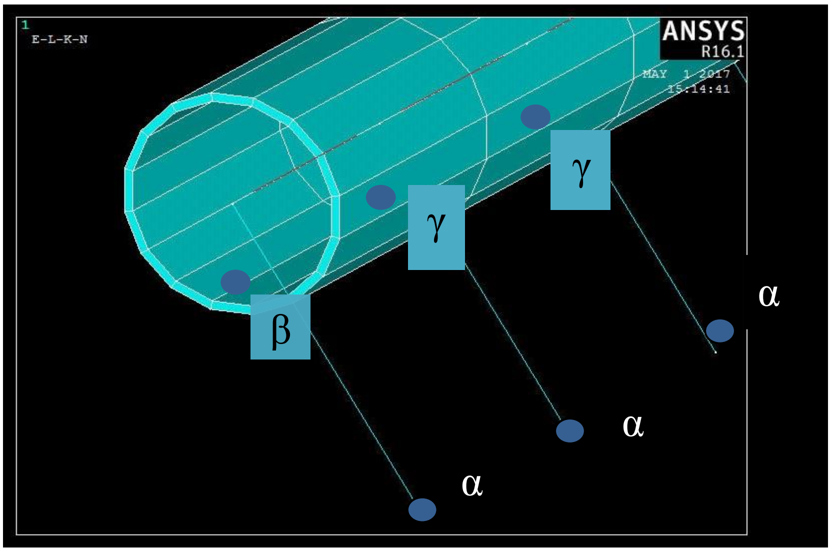


Figure 4. Boundary conditions in the ANSYS Model

4. Loadings

Figure 5 explains submarine pipeline with proposal loads that exerted on the free span part. The loads can be easily sorted into two groups: (a) static loads that is resulting from weight, buoyancy, internal pressure and steady current, (b) dynamic loads that appears from the motion of water around the pipeline free span which is generated by current and waves as shown in table 1. The acting of hydrodynamic loads, on the free span, which are divided into two groups: 1) drag, lift, and inertia forces, and 2) flow induced vortex shedding on free span, the effect of VIV in the present paper is not taken into consideration.

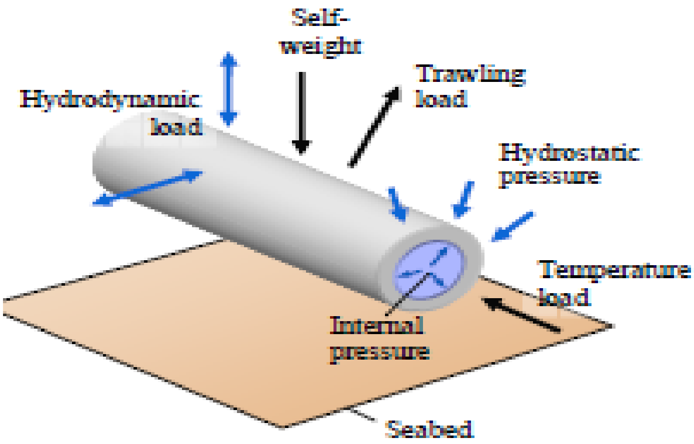


Figure 5: Typical exerted loads on the free-span of a submarine Pipeline (Kristain, 2008).

Table 1: Loads Acting on the Offshore Pipeline Free Span

Load	Analysis Type
Self Weight	Static
Buoyancy	Static
Internal pressure	Static
Hydrostatic Pressure	Static
Current Drag Force	Static
Steady Lift Force	Static
Wave Drag Force	Dynamic
Inertia Force	Dynamic

5. Analysis Procedure

The evaluation and assessment of free spans must consider the number of variables that can be classified into the following categories:

- Pipeline materials properties at the free span.
- Pipeline contents properties at the free span.
- Pipeline supports and the behavior of the pipeline free span geometrically on the bed of sea.
- Environmental properties around free span.

The data of these categories are listed in table 2.

First, a static analysis is achieved that includes the calculation of the static response of the pipeline due to the static loads which is included in Table 1. Afterward the dynamic analysis is conducted by applying wave action in normal direction on the free span. The ocean loads are input globally by using ocean commands which is involve the current and/or waves effect, drag, lift and buoyancy.

The following are the input groups of the ocean-loading which are available (ANSYS help, 2016):

- Basic (required for any ocean loading)
- Current (optional, for applying drift current)
- Wave (optional, for applying a wave state)
- Zone (optional, for applying local ocean effects)

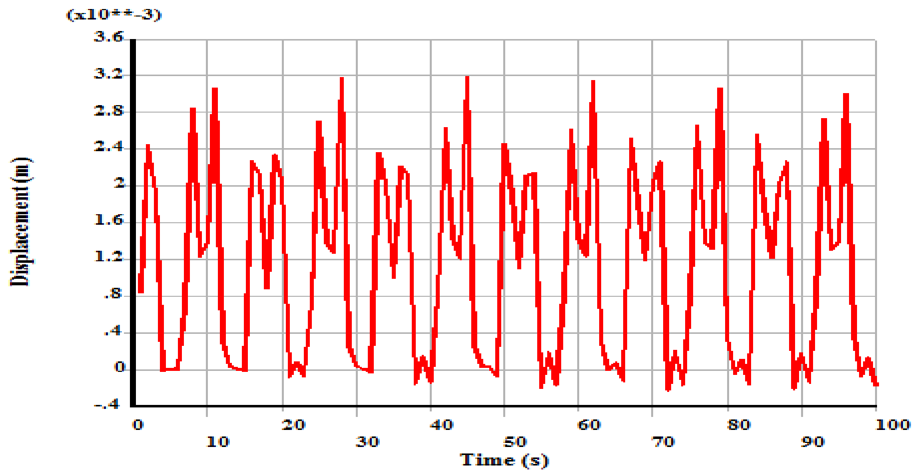
The wave is input along with Airy wave theory (often known as linear wave theory). In the fluid dynamics, the Airy wave theory gives a description that is certainly linearized for the propagation of gravity waves on the surface layer of a homogeneous fluid. The theory supposes that the layer of the fluid has a uniform mean depth, furthermore the fluid flow is inviscid, irrotational and incompressible.

Table 2: Properties of Free Span

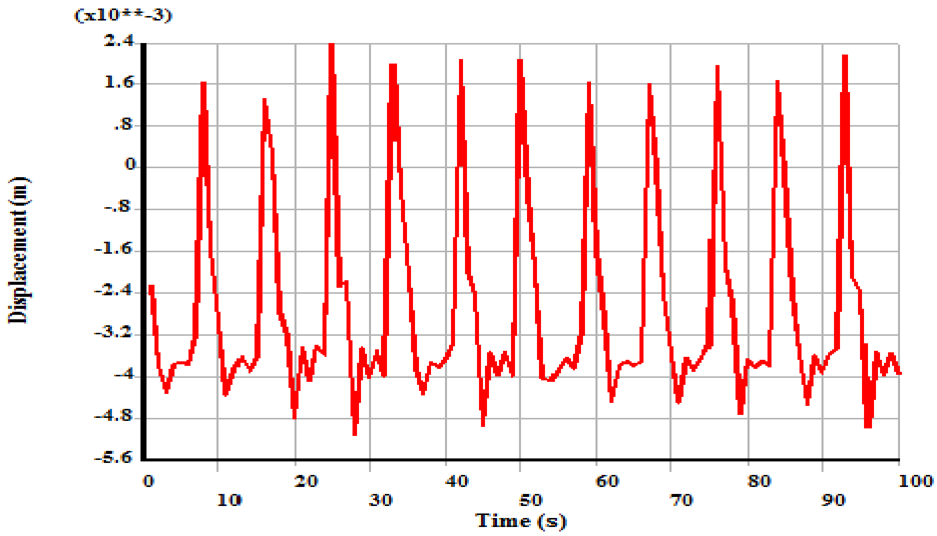
Pipeline Outside Diameter(m)	0.3227
Pipe Wall Thickness(m)	0.0127
· Young's Modulus(Pa)	$21 * 10^{10}$
Poisson's Ratio	0.3
Density of Steel(Kg/m^3)	7850
Internal pressure(Pa)	$21 * 10^5$
Water depth(m)	37.0
Density of Sea Water(Kg/m^3)	1025
Sea Current Velocity(m/s)	0.41
Boundary conditions	Fixed-Fixed
Span Length(m)	12.0
Shoulder Length(m)	6.0
Wave high(m)	9.5
Wave period(s)	8.5
C_{Dy}, C_{Dz}, C_M	0.5, 0.5, 2
Sea bed soil type	Loose sand

6. Results and Discussion

Figs. 6a-6b show the time series of displacements in y-direction (U_Y) and in z-direction (U_Z) respectively only at node 27, which is located at the center of the unsupported pipeline. It must be mentioned that the effect of different load conditions on the pipeline's displacements is more obvious in the case of $U_Z$compared to U_Y, where the maximum absolute value of U_Z is larger than value of U_Y



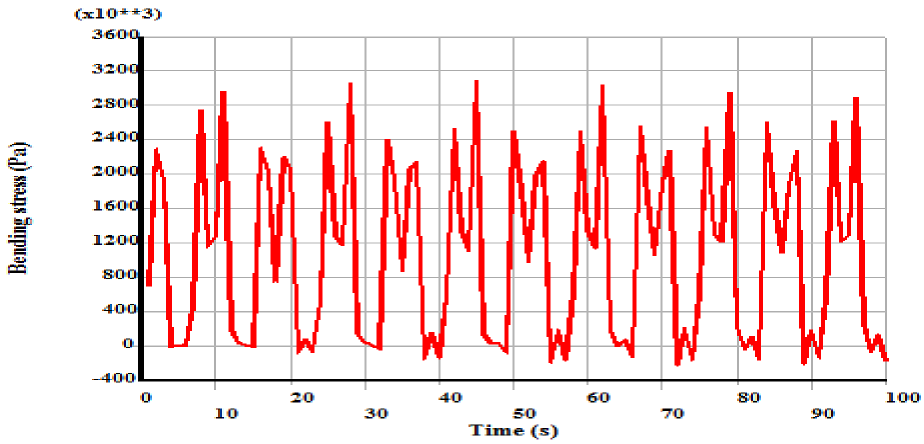
(a)



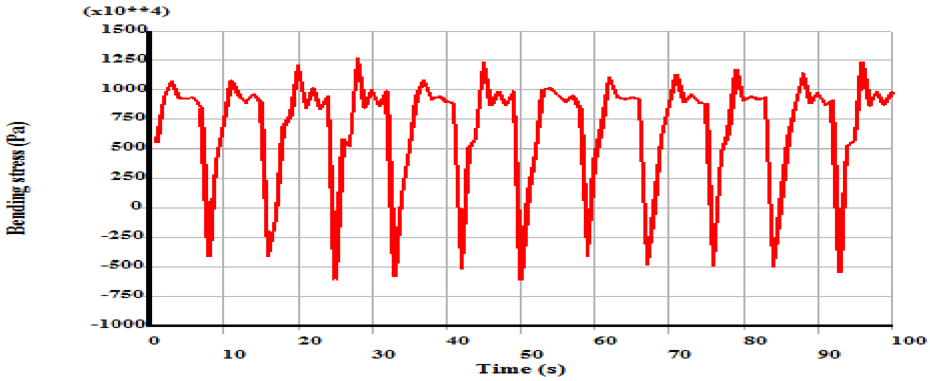
(b)

Figure 6. Time Domain of U_Y (a) and U_Z (b) at node 27

Figs. 7a~7b illustrate the time domain of 6_{bY} and 6_{bZ} at node 27. The effect of weather conditions is more significant in the case of 6_{bZ} (Fig. 7b), in which a larger increase of the peak values and the amplitudes of 6_{bZ} is observed compared to 6_{bY} (Fig. 7a). It could be seen the effects clearly in Figs. 8a~8b which shows the hydrodynamic force in y-direction(F_Y) and in z-direction(F_Z) respectively.

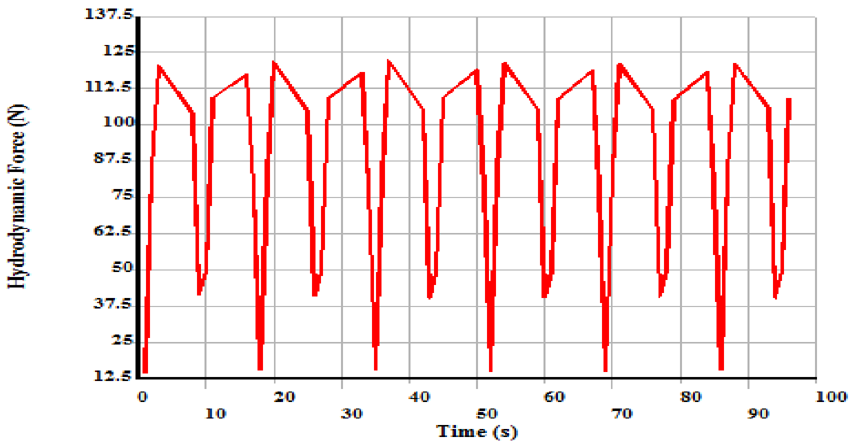


(a)

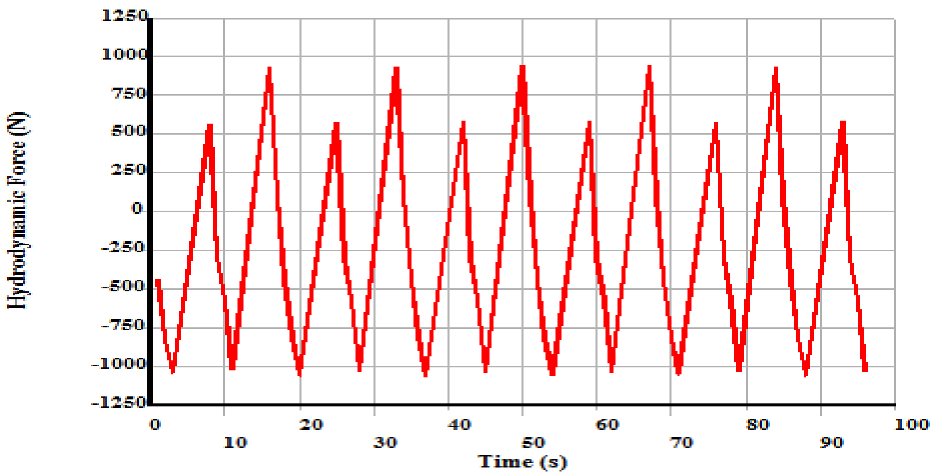


(b)

Figure 7. Time Domain of Bending stresses σ_{bY} (a) and σ_{bZ} (b) at element 26



(a)



(b)

Figure 8. Time Domain of hydrodynamic forcesF_Y (a) and F_Z (b) at element26

Fig.9 and Fig.10, show the displacement and bending stress configurations in y-direction and z-direction along the total length of the pipeline (free span (Lf) plus part of pipeline's shoulders (Ls)) are shown respectively.

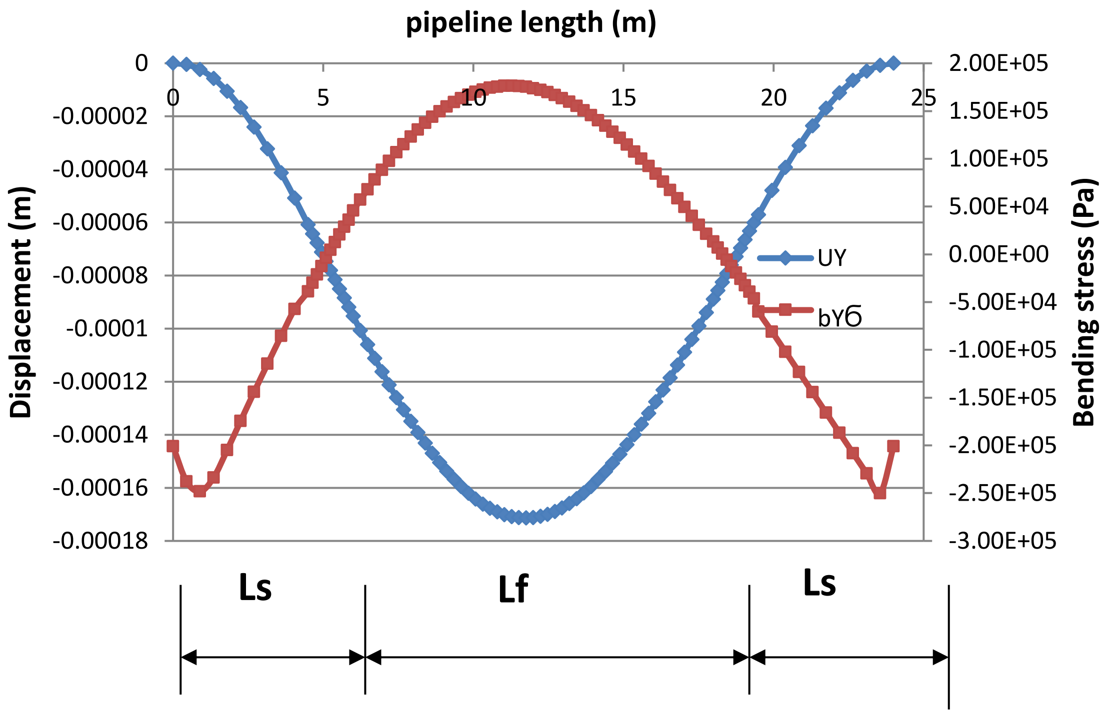


Figure 9. Displacement (U_Y) and Bending stress (6_{bY}) configurations along total length of pipeline

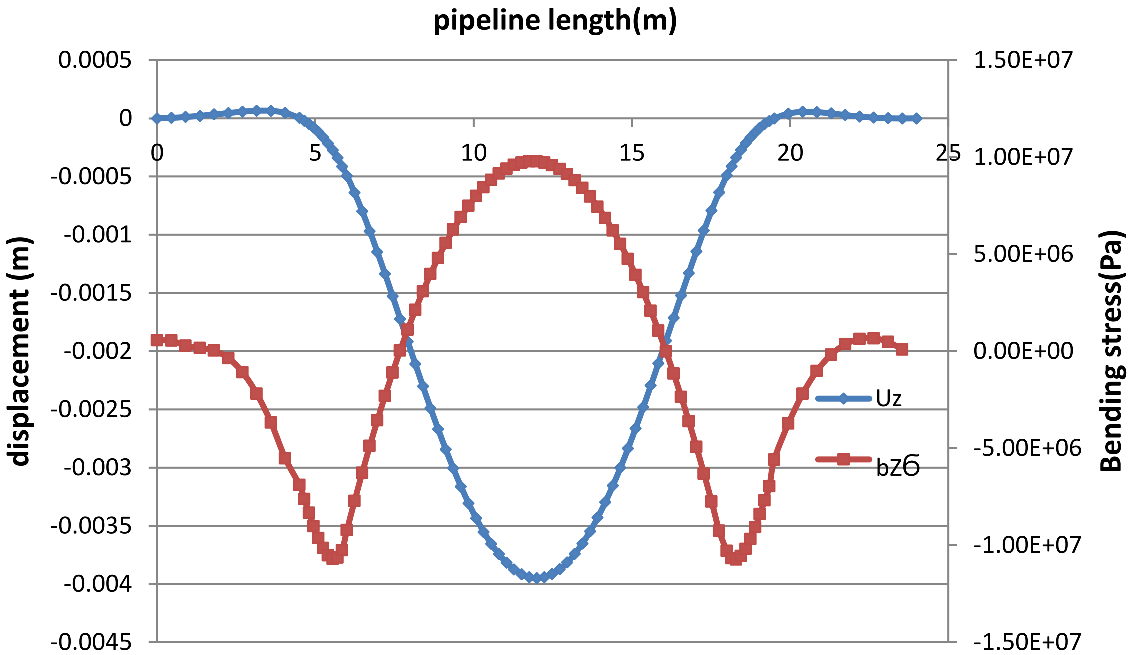


Figure 10. Displacement (U_Z) and Bending stress (6_{bz}) configurations along total length of pipeline

As in Figures 9 and 10 display the pipeline stresses intensity which is increases when closing to the free span center. This result is attributed to the fact that *UY* and*UZ* have more maximum values at these region.

7. Conclusions

The dynamic behavior of a single free span offshore pipeline is analyzed in this work and the effect of various factors/parameters (different design conditions, wave and current characteristics, soil characteristics and boundary conditions at the ends of the pipeline) on its dynamic behavior is established.

- It should be mentioned that the effect of different load conditions on the pipeline's displacements is more obvious in the case of U_Z compared to U_Y, where the maximum absolute value of U_Z is larger than value of U_Y.
- The effect of weather conditions is more significant in the case of 6_{bz} (stresses in z-direction). Where a larger increase of the peak values and the amplitudes of 6_{bz} are observed compared to 6_{bY}.
- The pipeline stresses intensity increases with closing to free span center. This is attributed to the fact that *UY* and *UZ* are affected more maximum values at these region.

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