FINITE ELEMENT ANALYSIS FOR SUSPENDED SUBMARINE PIPELINES DURING INSTALLATION

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ABSTRACT

The stresses induced in submarine pipelines during installation for static analysis are investigated using the finite element method. Static analysis of pipelines during installation is characterized by a combination of geometrical nonlinearities and extreme flexibilities of the system, considering that the pipeline is an elastic body, and not subjected to environmental loads. Development and validation of the static nonlinear FEM model for simulation and control of the elastic pipeline is done by using computer code ANSYS Release 11. Influence of applied tension force and pipe wall thickness on the deflections and bending moments are investigated.

KEYWORDS

Submarine pipeline, Finite element analysis, Non-linear analysis, J-lay installation method, S-lay installation method.

التحليل باستخدام طريقة العناصر المحددة للانابيب الغاطسة في البحر أثناء عملية التثبيت

السيد محمد جبار و د. عدي عدنان

الخلاصة

يتناول هذا البحث دراسة وتحليل الاجهادات المتولدة في خطوط الانابيب الغاطسة تحت سطح البحر أثناء عملية الانشاء باستخدام طريقة العناصر المحددة. يتميز التحليل الساكن لخطوط الأنابيب أثناء الانشاء بأنه مبني على أساس الجمع بين الخصائص الهندسية اللاخطية و المرونة العالية للنظام، معتبرا ان خط الانابيب هو عبارة عن جسم مرن وغير معرض للأحمال البيئية. ان الدراسة الحالية قد تم اجراءها باستخدام برنامج ANSYS الإصدار 11. في هذا البحث، قد تم دراسة تأثير قوة التوتر المسلطة على الانبوب وكذلك تأثير سمك جدار الأنبوب على قيم الازاحات والعزوم المتولدة في الانابيب.

1. INTRODUCTION

A submarine pipeline is any pipe system or part thereof which is submerged in water. Submarine pipelines are fairly commonplace and are responsible for transporting hundreds of millions of tons of often hazardous materials safely across the oceans every year. These materials include a wide range of fluid or gaseous mediums ranging from crude oil to gas, treated sewage, and fresh water. Although the range of transported materials is diverse, the most common large submarine pipeline systems transport natural gas (Braestrup et.al 2005).

The most common type of submarine pipeline is the traditional steel, Fig. (1), which is usually used to transport hazardous materials such as gas, hydrocarbons, and oil. Steel pipelines are generally installed from specially equipped ships in one of two ways. The first is a system of completed lengths of pipe held on large rolls on the deck of the ship which are laid out behind the moving vessel in much the same way as a submarine cable. The second method involves fabricating the pipe on board prior to laying it on the sea bed. Depending on prevailing conditions, the pipeline may either be laid out on the surface of the sea bed or buried (Braestrup et.al 2005 and Yong Bai, 2001).

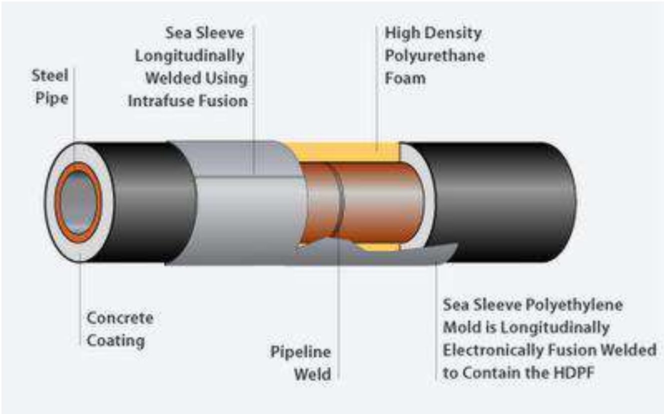


Fig. 1. Steel pipe system

Most of the underwater pipelines have an external coating to protect them against corrosion complemented by a cathodic protection system that prevents external corrosion if the coating is damaged. Also Many pipelines have additional concrete weight coating to provide stability on sea bed against waves and currents and to give the anti-corrosion coating protection against mechanical damage (John Brown Engineers, 1997). Some pipelines may have one or more additional layers of thermal insulation required to maintain the fluid contents at a high temperature (Mohitpour et. al, 2000). Other pipelines may have internal coating as corrosion protection and to provide a smooth inner surface to reduce the resistance to flow. Submarine pipelines are trenched or buried in order to provide shelter against hydrodynamic forces and to protect them against mechanical damage, to provide thermal insulation and resistance to upheaval buckling (Yong Bai, 2001and John Brown Engineers, 1997).

This research aims to develop a finite element model to study the behavior of submarine pipelines during their installation. And by this model we can make some studies such as calculating the bending moments and consequent stresses that induced in the pipeline during installation, selecting the appropriate pipe wall thickness to withstand the high laying moments and consequent stresses, studying the effect of tension force that applied at the barge end on the behavior of the pipeline.

Many researchers have dealt with submarine pipelines during installation such as Dareing and Neathery (1970). They adopted the finite difference method for determining deflections in submarine pipelines experiencing large bending. The used trail solution to obtained the desired solution by successive iterations. They assumed a catenary passes through the end points and having a zero slope at the bottom end at the first trail solution because deflections of the portions of long pipes are almost similar to catenaries.

Hakim(1982) employed a finite difference technique for the static analysis of the submarine pipeline during laying by a stinger-barge system. The formulation was an extension of the conventional procedure for the beam problem including the effect of the geometrical nonlinearity. The problem was formulated as a regular boundary value problem with three end conditions at the seafloor and one at the barge end. He developed a computer program to compute deflections, bending moments, axial forces and shear forces for submarine pipeline in various field conditions and to present the results in a graphical form. He found that the trial deflected shape of the pipeline could be specified by using a polynomial if the boundary conditions at the sea floor end and deflection at the barrage end are specified

Bernitsas and Vlahopoums (1990) suggested a model for the pipeline as a thin-walled, slender, extensible or inextensible tubular beam-column. It is subject to gravity, lateral friction from the seabed, nonlinear three-dimensional deformation dependent hydrodynamic loads, and torsion, distributed moments, varying axial tension, internal and external static fluid forces. The problem was solved numerically by developing a nonlinear incremental finite element algorithm which features condensation and principles of contact mechanics. Condensation was used along with the geometric constraints to formulate a condensed problem which produces reaction forces. The nonpenetration, nonadhesion and friction constraints were used to model the seabed and stinger constraints and to identify the constrained degrees of freedom. In this study, the effect of water depth have been studied numerically for both S- and J-type pipelaying methods. They found that in S- pipelaying method two peaks appear in the maximum equivalent stress graphs, one located in the unsupported pipeline section and the other in the stinger supported section. In deeper water, the unsupported pipeline length is longer, and the touch down point is further away from the lay vessel.

Callegari et. al (2003) studied the pipeline that have been installed by the “J-Lay” method, which consists in laying submarine pipelines with a straight stinger at near vertical angles. He discussed analytical models developed to analyze the static and dynamic behavior of a pipeline during J-lay operation. One of these models is the catenary model which gave a deformed shape very close to the that obtained from FEM analysis, but it did not provide a direct assessment of the bending moment. A more refined model is obtained by treating the pipeline like an “elastica” with no weight and an inflection point, which means that in the deformed shape there is a point with zero curvature. In this model such point coincides with the ramp on the vessel, point at barge end so it is possible to assume that in this point the bending moment is null. The pipe span that is laid on sea bottom is modeled as a beam on elastic foundation, adopting Winkler’s model, since its length is longer than the suspended pipe span, it can be treated like an infinite length beam. It is assumed that the loads acting on the suspended pipeline during the laying operation are the gravitational and hydrostatic forces and no torsional moment is applied. The solution obtained by integrating the elastica model with inflection point by means of the finite differences scheme gives results that are comparable with the output of FEM packages.

Mohammed J. M. (2012) investigated the stresses induced in submarine pipeline during the installation by using finite element method. This analysis was characterized by the combination between the geometrical nonlinearities and the extreme flexibilities of the system, considering that the pipeline is an elastic body, and not subject to environmental loads. The influence of various parameters such as applied tension force, water depth and pipe wall thickness were investigated in this study, also comparison between J-lay and S-lay methods was performed and presented graphically and discussed. It was found that if the value of tension force (600kN) was doubled, the moment induced in pipe dropped down to half and the direct stresses increased by 1.5 time with tension force increment of (400kN). It was observed that the results which obtained from S-lay method are 8 times more than those obtained from J-lay method in deep water.

2. PIPELINE MODELING

The structural analysis of an offshore pipeline under construction and installation deals with the computation of deformations, internal forces, and stresses as a result of external loads and the structural properties of the pipe. Since the long pipe of several hundred meters is very elastic and behaves almost like a string, the pipe string behavior is highly dependent on the water depth. The structural deformation of the pipe during construction depends on the method and equipment used for installation, the structural properties of the pipe and the environmental loads (Jensen G. A., 2010).

The mathematical model of pipelaying is comprised of the pipeline model and its boundary conditions, and geometric constraints imposed by seabed and stinger. It is assumed that the pipeline material is homogeneous, isotropic, and linearly elastic. Pipeline was assumed to have circular cross-sections and locally stiff so that plane sections remain plain after bending, straight and free of structural imperfections in the unloaded condition, and it is axially restrained at their lower end. The seabed was assumed to be flat and rigid. The stinger is assumed as a rigid with one end attached to the lay vessel and it described by a quadratic polynomial as shown in Eq. (1). Also, it was assumed that there is no friction between the pipeline and the stinger (Bernitsas M. M. and Vlahopoums N., 1990).

$$X = -0.0012Z^2 + bZ + C \tag{1}$$

It is assumed that the loads acting on the suspended pipeline during the laying operation are the gravitational and hydrostatic forces and no torsional moment is applied, see Fig. (2). Furthermore, Archimedes' buoyancy can also be looked like an effect lowering the weight of the suspended pipeline (Rienstra S. W., 1987).

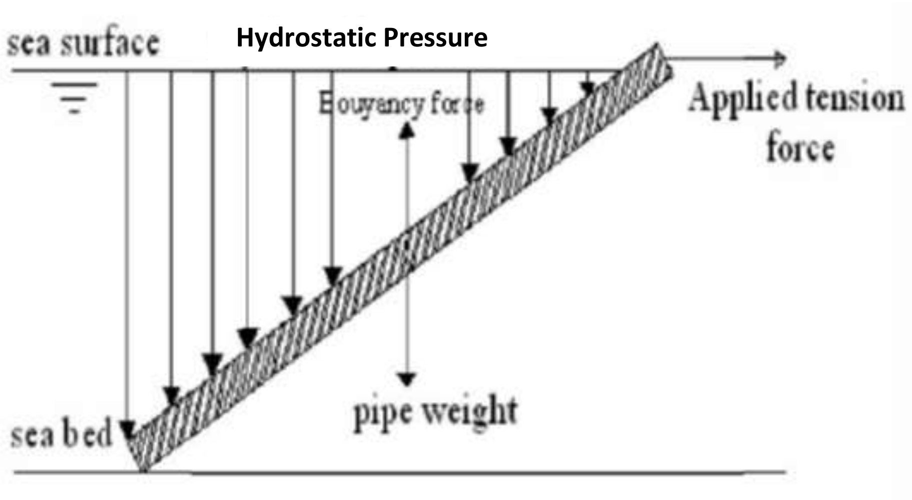


Fig. 2. Applied loads on pipeline

The gravity force (F_g) of the circular pipe could be computed as given below (Jensen G. A., 2010);

$$F_g = \frac{\Pi}{4}\left(D_o^2 - D_i^2\right)\rho_s g \tag{2}$$

Where: D_o = Out diameter,
D_i = Iner diameter,
ρ_s = Density of the steel pipe, and
g = Gravity acceleration.

Buoyancy force for the submerged pipe of volume V (Jensen G. A., 2010) is;

$$F_b = \rho_w V g \tag{3}$$

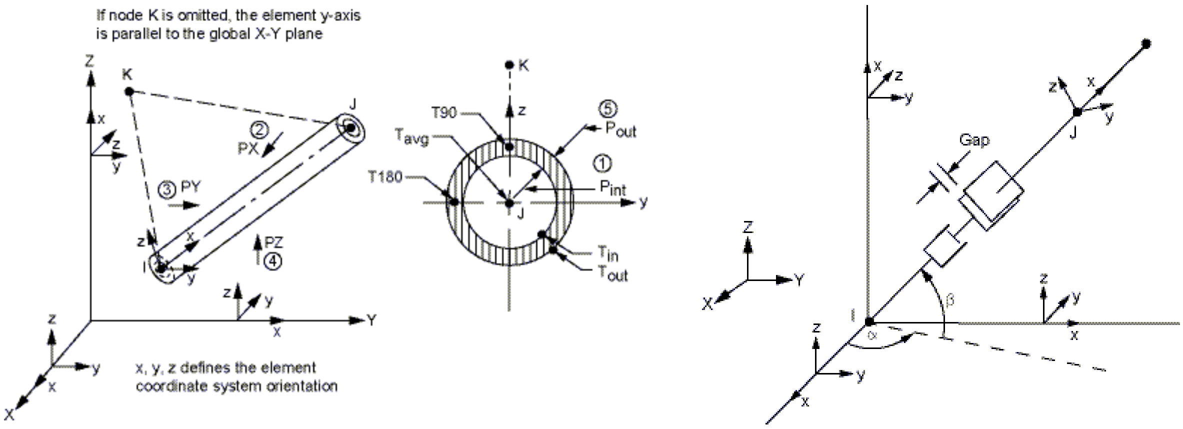
Where; ρ_w = Density of water.

3. FINITE ELEMENT MODEL

The purpose of developing this finite element model for pipeline installation is to calculate the load effects on a pipeline during the installation. In this study, the modeled pipe was subjected to the effect of pressure, longitudinal force and bending to stimulate the structural failure of the pipe. Both geometrical and boundary conditions nonlinearity (sliding, friction, contact, etc) were considered at failure. The effect of wave and current forces and the motions of laybarge on the submarine pipeline were not involved in this analyses.

A two nodal uniaxial element (PIPE16), Fig. (3-a), was used to simulate the discretization of the pipeline, this element has tension-compression, torsion, and bending capabilities with six degrees of freedom at each node; translations in the x, y, and z directions and rotations about the x, y, and z axes (ANSYS Element Reference, 2006).

CONTA178 element was used to represent contact and sliding between see bed and PIPE16 element. This element has two nodes with three degrees of freedom at each node with translations in the X, Y, and Z directions, Fig.(3-b). The element is capable of supporting compression in the contact normal direction and Coulomb friction in the tangential direction. The seabed was assumed to be flat and rigid and it was defined by the (x, z) plane as y = 0. Figure (4) shows the pipeline and contact elements.



(a) PIPE16 element **(b) CONTA178 element**

Fig. 3. PIPE16 and CONTA178 elements

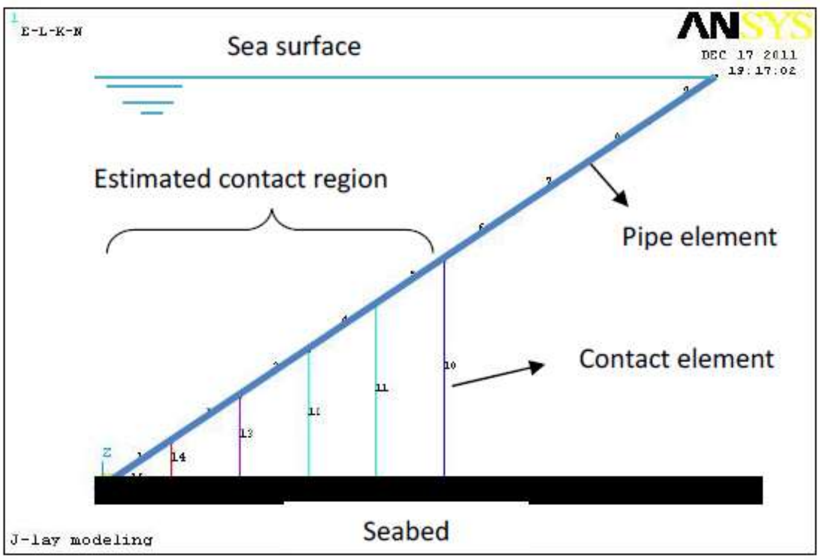


Fig. 4. Pipeline and contact elements.

4. COMPARISON OF RESULTS

To check the validity of the adopted model in the present study by using ANSYS program, it was made two comparative studies for submarine pipeline problems; the first comparison was made with that of Bernitsas (Bernitsas M. M. and Vlahopoulos N., 1990), while the second was made with that of Dareing (Dareing D. W., and Neathery R. F., 1970).

4.1 COMPARISON WITH BERNITSAS

In this comparison, a model of S-pipelaying method in (125m) water depths, was adopted. This model was subjected to tension force of (580kN) at the barge end. The properties of the pipeline used in these applications are summarized in Table (1).

Table 1. Pipeline properties in Bernitsas Model.

Property	Value
External diameter, D_o	0.61 m
Internal diameter, D_i	0.58 m
Diameter of coating, D_c	0.71 m
Density of steel pipe, ρ_{st}	7900 kg/m^3
Density of water, ρ_w	1025 kg/m^3
Density of coating, ρ_c	3000 kg/m^3

Figure (5) shows the results of the pipeline deflections by using ANSYS program in comparison with Bernitsas. It can be concluded that there is good agreement between these two methods of analysis due to the convergent values of deflection which have been calculated.

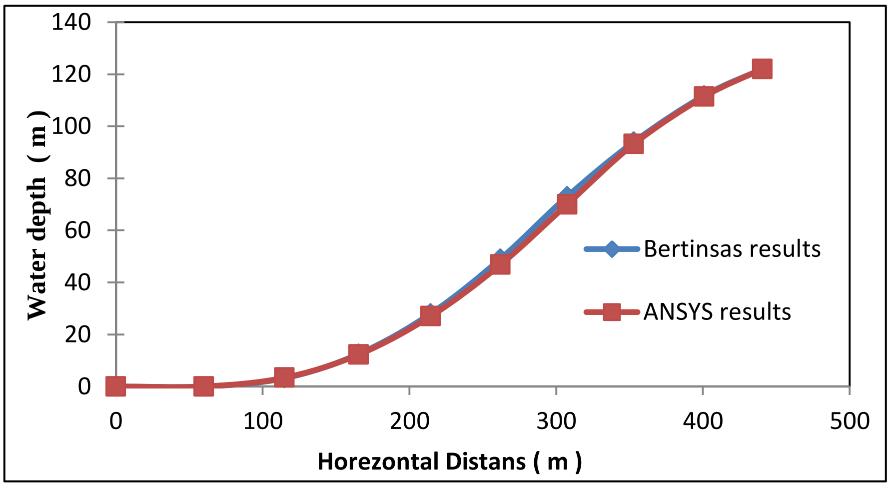


Fig. 5. Deflection curves along the horizontal distance of the pipeline (ANSYS and Bernitsas).

4.2 COMPARISON WITH DAREING

In this comparison, the pipeline is laid at a water depth of (91.45m) and it subjected to tension forces of (226.3kN). Table (2) shows the properties of the pipeline.

Figure (6) shows the results of finite element analysis which adopted in this study in comparison with the results that obtained by Dareing. As it was seen in the previous comparison, there is a good agreement between Dareing model and FEM by using ANSYS program because of the substantial convergence in the obtained results.

Table 2. Pipeline properties in Dareing Model.

Property	Value
External diameter, D_o	1.2 m
Wall thickness, t	0.0126 m
Diameter of coating, D_c	1.42 m
Effected pipe weight, W	2.327kN/m
Modulus of elasticity, E	2×10^8 kN/m^2

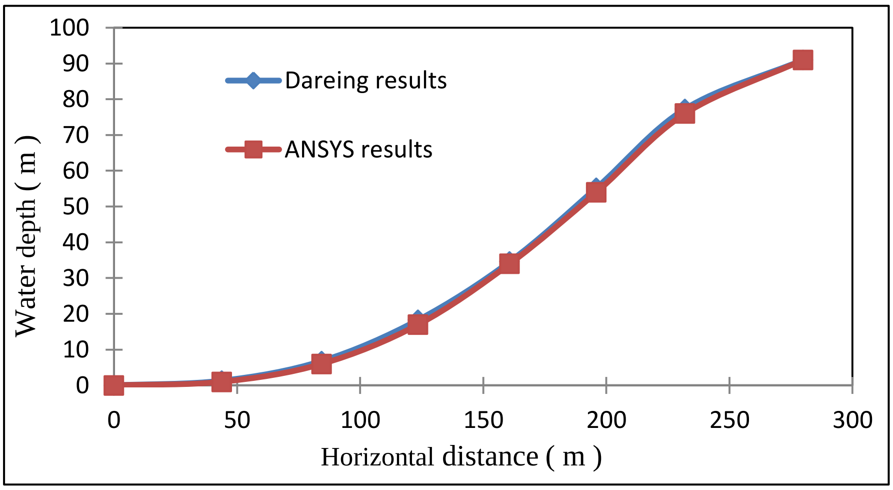


Fig. 6. Deflection curves along the horizontal distance of the pipeline (ANSYS and Dareing).

5. PARAMETRIC STUDY

The parameters that are included in the present study are; the effect of tension force at the barge end, wall thickness of the pipeline.

5.1 EFFECT OF TENSION FORCE AT THE PARGE END

Four values for tension forces (600, 800, 1000, 1200, 1400)kN were assumed to investigate the effect of applied tension force at the barge on the suspended pipeline during installation process at (67m) of water depth. The stinger end point coordinates are (x_u, z_u) = (72, 455) for the upper point, and (x_L, z_L) = (50, 345) for lower point. Same properties for the pipeline and its coated which reported by Bernitsas are adopted in this study, as listed in Table (1).

Figures (7 and 8) show respectively, the differences in the values of deflection and bending moments along the horizontal projection of the pipeline (z-axis) until the upper point of the stinger.

It can be observed from Fig. (7) that the deflection values, at the sag bend region between touch point at seabed and the stinger tip, decrease with increasing the applied tension force. It can be noticed that the deflection curves, at the sag bend region, close together with increasing the tension forces.

Figure (8) shows that the zero bending moment occurs at the touch down point and the this value increases intensely to reach the maximum positive bending moment in sag bend region. Afterward, the bending moment has closer values for some distance then they decrease intensely to the zero at the inflection point before the stinger tip and from this point the negative bending moment occurs along the stinger onward to the barge end where maximum negative bending moment occurs near the stinger tip. As in the deflection curves, the curves of bending moment close together and the bending moment values decrease at the sag bend region with increasing the tension forces. Figures (9 and 10) show that the increasing in the tension forces causes to decrease the values of maximum positive and negative bending stresses, which their curves have the same form of the bending moment curves, with a decreasing rate. For all values of the applied tension forces, the values of induced stresses did not exceed the allowable stresses for steel pipes that listed in the specifications of AMSE B31.4 (ASME B31.4, 2016).

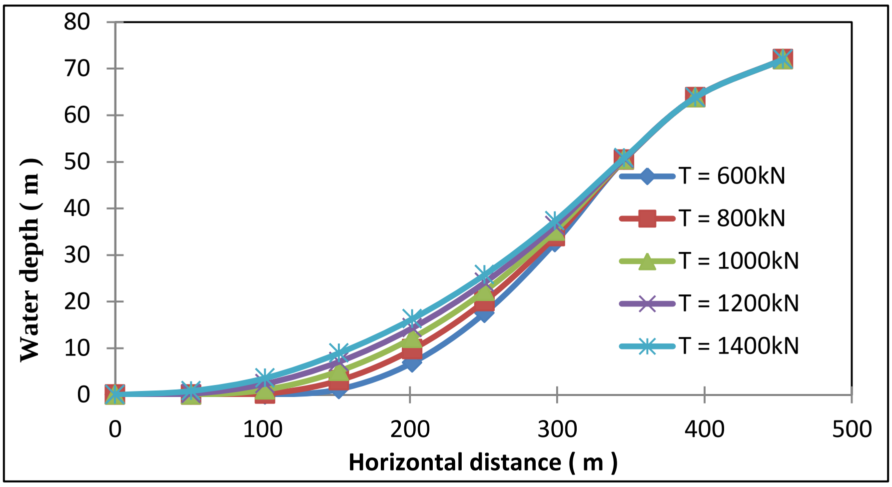


Fig. 7. Deflection values along the horizontal projection of the pipeline for different values of tension force

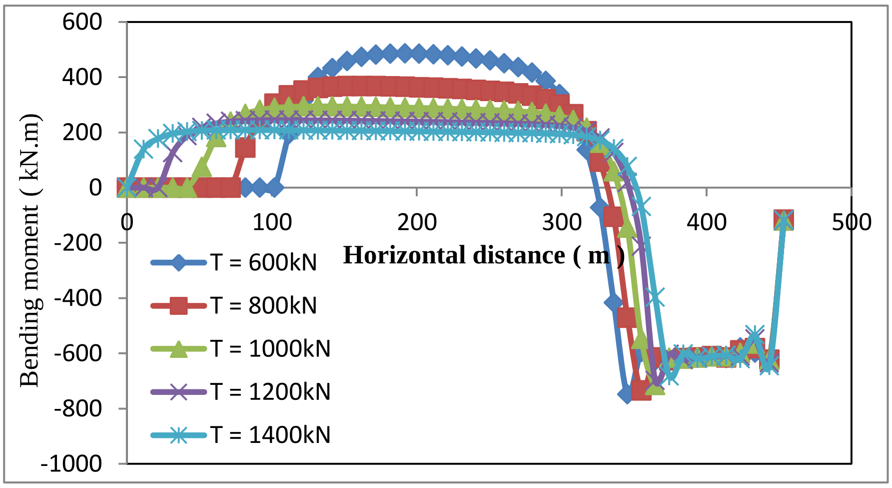


Fig. 8. Bending moment values along the horizontal projection of the pipeline for different values of tension force

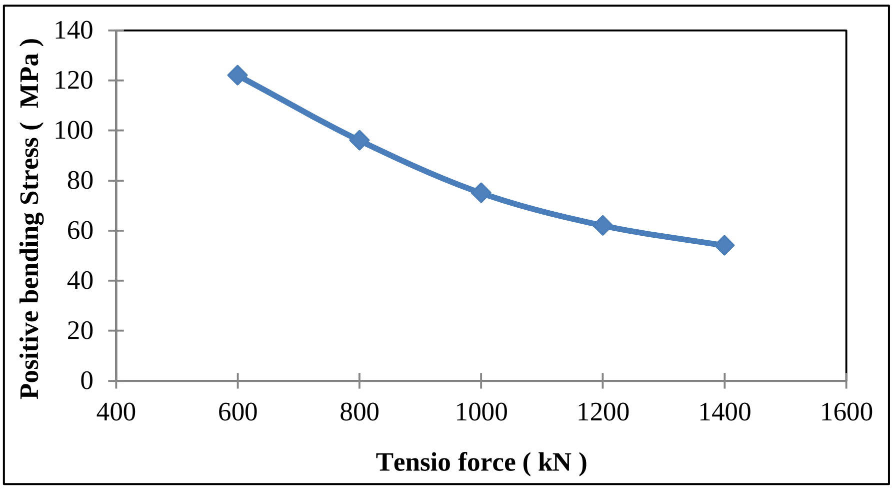


Fig. 9. Relationship between maximum positive bending stress and the tension force

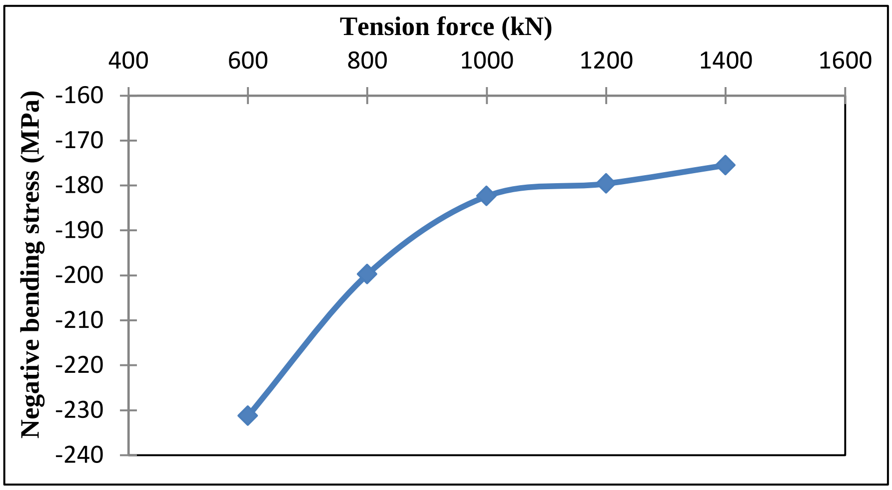


Fig. 10. Relationship between maximum negative bending stress and the tension force

5.2 EFFECT OF THE WALL THICKNESS

Due to the importance of the wall thickness selection is one of the most important and fundamental tasks in designing of offshore pipelines, four different values for the pipe wall thickness (30mm, 35mm, 40mm, 45mm) under the effect of tension force of (600kN) have been studied with assuming the same water depth and stinger coordinates of the previous studied parameter. The outer diameter and other properties for the steel pipe in addition to the properties for the coating are listed in Table (1).

Figure (11) shows that the deflection values, along the horizontal distance of the pipeline, are increased in the sag bend region, between the touch point with see bed and stinger tip, with increasing of the wall thickness of the pipeline because of the increasing in the submerged unit weight of the pipeline. It can be seen that the deflection curves along the suspended pipeline close together with the increasing in the wall thickness of the pipeline.

Accordingly, the increasing in the values of the wall thickness of the pipe causes to increase the values of the positive and negative bending moments due to the decreasing in the length of the sag bend region with increasing the weight of the pipeline, as shown in Fig. (12). Then, it can be seen from Figs. (13 and 14) that the increasing in the wall thickness of the pipeline causes to increase the values of maximum positive and negative bending stresses.

As explained in the previous studied parameter, for all values of the wall thickness, the values of induced stresses did not exceed the allowable stresses for steel pipes.

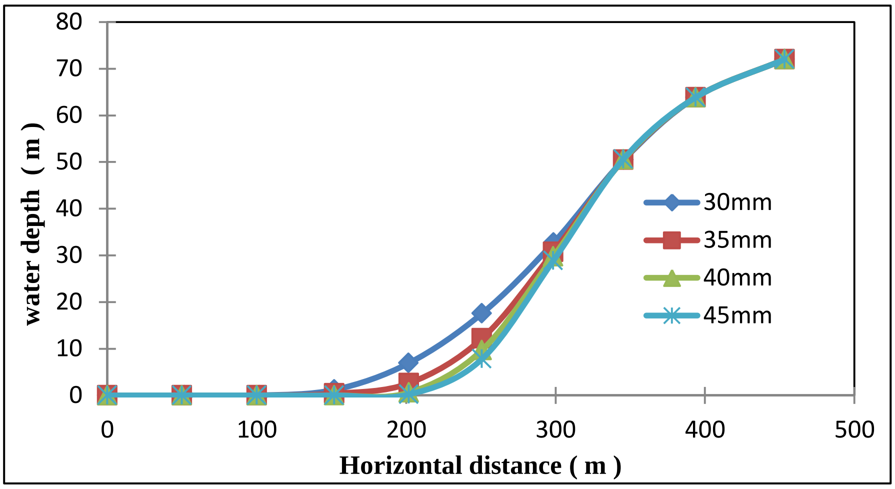


Fig. 11. Deflection values along the horizontal projection of the pipeline for different values of wall thickness of the pipe

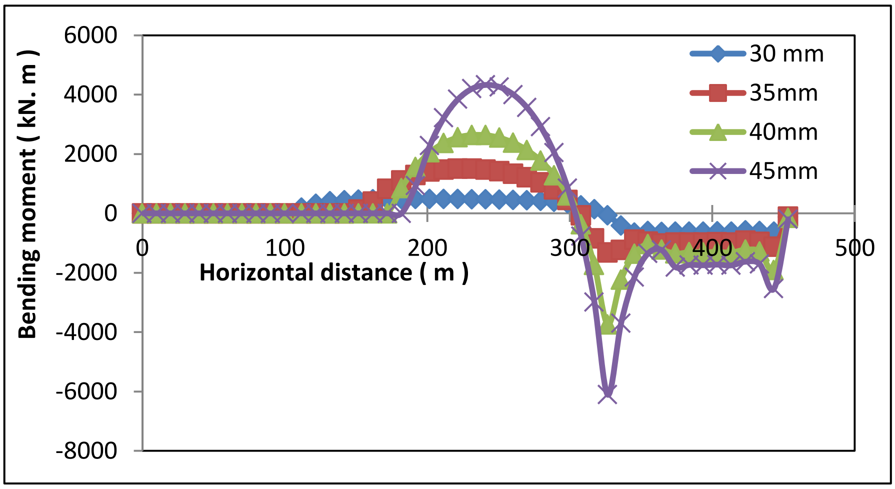


Fig. 12. Bending moment values along the horizontal projection of the pipeline for different values of wall thickness of the pipe

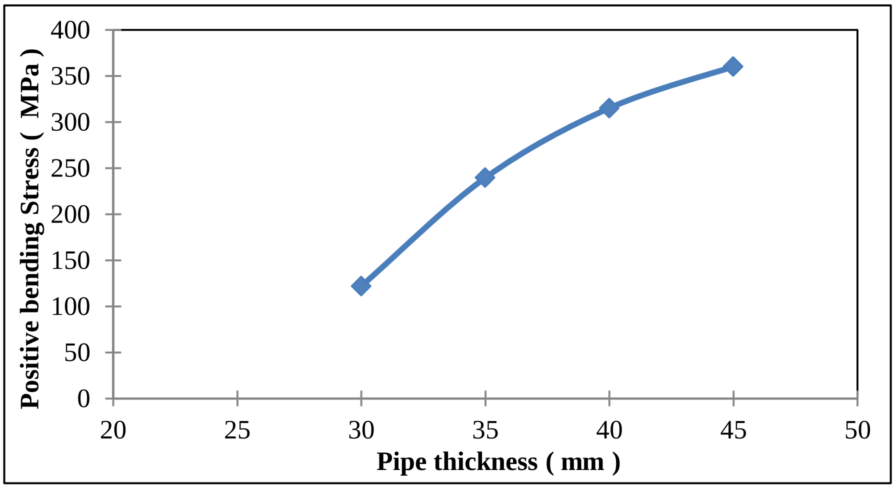


Fig. 13. Relationship between maximum positive bending stress and thickness of the pipe wall

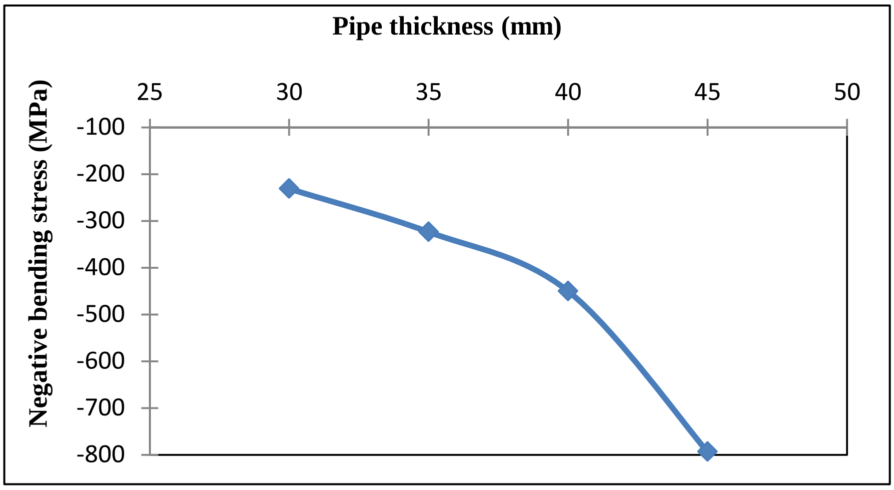


Fig. 14. Relationship between maximum negative bending stress and thickness of the pipe wall

6. CONCLUSIONS

Based on the finite element analysis carried throughout the present study, the following conclusions can be drawn;

1- The simplified static model which adopted to represent the pipeline during installation based on finite elements by using ANSYS program is quite simple, practicable for studying different parameters, and gives acceptable results.
2- Deflection values, at the sag bend region between touch point at seabed and the stinger tip, decrease with increasing the applied tension force.
3- Effect of the applied tension force at the barge end decreases with increasing their values.
4- Increasing the applied tension forces causes to decrease the values of maximum bending stresses.
5- Deflection values, at the sag bend region between touch point at seabed and the stinger tip, increase with increasing thickness of the pipeline wall.
6- Increasing the thickness of the pipe wall causes to increase the values of maximum bending stresses
7- In all studied cases, the values of induced stresses did not exceed the allowable stresses for steel pipes.

7. REFERENCES

American Society for Mechanical Engineers (ASME), 2016 "Pipeline Transportation Systems for Liquid Hydrocarbonds and other Liquids", B31.4.

ANSYS; "Element Reference", Release 11, Swanson Analysis Systems, Inc., 2006.

Bernitsas M. M. and Vlahopoulos N., 1990, "Three-Dimensional Nonlinear Static of Pipelaying Using Condensation in an Incremental Finite Element Algorithm" Computers and Structures Vol. 35, No. 3, pp. 195-214.

Braestrup M. W., Andersen J. B., Andersen L. W., Bryndum, M., Christensen C. J., and Nielsen N., 2005, "Design and Installation of Marine Pipelines", Blackwell Science Ltd.

Callegari M., Carini C. B., Lenci S., Torselletti E., and vitali L., 2003, "Dynamic Models of Marine Pipelines For Installation in Deep and Ultra-Deep Waters: Analytical and Numerical Approaches" Congress of Theoretical and Applied Mechanics 2003.

Dareing D. W., and Neathery R. F., 1970 "Marine Pipeline Analysis Based On Newton's Method With Arctic Application" Journal of Engineering For Industry, ASME, Nov.

Hakim S. A., 1982, “A Numerical Scheme For Analysis Of Submarine Pipelines” M.Sc. thesis, College of Engineering, Basrah University..
Jensen G. A., 2010, “Offshore Pipelaying Dynamics” Ph. D. thesis, Norwegian University of Science and Technology (NTNU), Trondheim.
John Brown Engineers, Constructors , 1997, "The Abandonment of Offshore Pipelines Methods and Procedures for Abandonment" Health and Safety Executive, London.
Mohammed J. M., 2012 “Static Analysis of Stresses Induced in Suspended Submarine Pipeline During Installation Using Finite Element Method” M.Sc. thesis, College of Engineering, Basrah University.
Mohitpour M., Golshan H., and Murray A., 2000 "Pipeline Design and Construction a Practical Approach" second edition, ASME International pipeline Conference in Calgary, Alberta.
Rienstra S. W., 1987, “Analytical Approximations For Offshore Pipelaying Problems” Mathematics Consulting Department, University of Nijmegen, Netherlands
Yong Bai, 2001, “Pipelines and Risers” Elsevier Ocean Engineering Book Series, Volume 3.