Research Journal of Applied Sciences, Engineering and Technology 7(22): 4775-4778, 2014
DOI:10.19026/rjaset.7.864
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: January 23, 2014 Accepted: March 08, 2014 Published: June 10, 2014

Research Article

Mechanical Analysis of Submarine Oil Pipelines Considering Overhanging of Transition Section

Liu Yuanyong, Li Fang and Wei Xiuting
School of Mechanical Engineering, Shandong University of Technology, Zibo, 255049, P.R. China

Abstract: The purpose of the study is to protect the safety of the submarine pipelines by establishing and analyzing mechanical model of the overhanging pipeline. The calculation equations of the force and deformation of the overhanging pipeline are presented in this study. In especial, the transition section is introduced to analyze the overhanging oil pipeline. The calculation equations of the moment, stress and deformation of the overhanging pipeline by considering the premise of sediment reaction are created. The software FORTRAN is used to carry out numerical simulation and the changing laws of bending moment, stress and deformation of overhanging pipeline are obtained. On the basis, the calculation equations of maximum bending moment, maximum stress and maximum deformation can be also obtained. Therefore, theoretical support for calculating submarine pipelines is provided, which has great significance for the analysis and treatment of the overhanging of submarine pipelines.

Keywords: Bending moment, deformation, overhanging, stress, submarine pipelines

INTRODUCTION

Submarine pipeline is an important component part of the production system in offshore oil field, protecting the safety of the submarine pipelines is an important part of guaranteeing safe production and the protection of the Marine environment (Zhao *et al*., 2006). In the unstable conditions of submarine, the seabed near the submarine pipeline is strongly eroded, which will cause the overhanging phenomenon of submarine pipelines that can increase the length of the overhanging pipe (Luo and Wang, 2009). Not only its own weight, but also environmental effects of the submarine currents are born by the overhanging pipeline. Therefore, fatigue breaking and static strength breaking may occur. The destruction of the pipe may be caused by the overhanging pipeline, which will lead to oil leakage and other major marine pollution incidents. Furthermore, this will result in not only economic losses but also adverse social impact. In order to determine whether the pipeline is safe or not, it is necessary to establish an analysis model of the overhanging pipeline and calculate the stress (Wang *et al*., 2004; Deng *et al*., 1998). According to the mechanical fatigue properties of the materials, actual stress σ is compared with the fatigue limit σ_{-1} and the yield limit σ_s of the pipeline material, the conclusion can be reached. If σ is smaller than σ_{-1}, the pipeline material is in an infinite lifetime and safe. If σ is between σ_{-1} and σ_s, the pipeline material is in a limited lifetime and fatigue damage will be appeared. If σ is greater than σ_s, the pipeline material is in a limited lifetime and static strength damage will be appeared. Therefore, the study on the overhanging pipeline has a great importance for the failure determination and governance of the overhanging pipeline.

The overhanging section of pipeline will sink under the action of external force and parts of both ends supported by sediment will sink a certain distance, too. The length of pipeline section affected by sediment is called the transition length, which must be considered to analyze the horizontal overhanging pipeline. Currently, the studies on the mechanical analysis of the submarine pipelines focus on two aspects, i.e., theoretical analysis and finite element simulation. In the theoretical analysis, the stress distribution, vortex induced vibration, nonlinear vibration and fatigue life of the overhanging pipeline are studied using clamped or simply supported boundary conditions by many scholars at home and abroad, but the transition length can not be considered. For example, overhanging pipeline simplified as simply supported beam or both ends clamped beam model is recommended by DnV specification and have great access to the actual two ends of the overhanging pipeline constraints, the constraint of soil can't be reacted well (Zhang *et al*., 2010; Wang and Lian, 1997). In the finite element simulation, the natural frequency calculation and stress analysis are done based on considering the transition length by some scholars. However, the study is only on computer simulation, the theoretical equations are not formed (Gong *et al*., 2004; Yang *et al*., 2011; Zhang and Wang, 2013).

Corresponding Author: Liu Yuanyong, School of Mechanical Engineering, Shandong University of Technology, Zibo, 255049, P.R. China

Through the stress analysis of submarine oil pipeline, the gradient forces processed by the support of sediment to pipeline are applied on pipeline; mechanical model of the overhanging pipeline is also created in this study. The bending moment, stress and deformation calculation equations of the overhanging pipeline are established in the premise of considering the transition section, theoretical support is provided for the calculation of submarine overhanging pipelines. Therefore, the purpose of this study is to protect the safety of the submarine pipelines by establishing and analyzing mechanical model of the overhanging pipeline.

METHODOLOGY

Analysis model: The overhanging phenomenon formed by the pipes buried in a certain depth of soil exposed above the seabed under the erosion of the ocean currents. Two ends of the overhanging pipeline are buried in the seabed mud, as shown in Fig. 1.

Overhanging pipeline will sink under the action of external forces, parts of both ends supported by sediment will sink a certain distance, too. So the support of sediment must be considered to analyze the horizontal overhanging pipeline. When the distance to the overhanging section is far enough, the impact of overhanging section can be ignored, this position can be treated as a fixed fulcrum according to Saint-venant theorem. The applied force sediment to pipeline changes with the distance from its location to fixed fulcrum, the closer the distance, the smaller the reaction force of sediment, so the force sediment to the pipeline can be considered as linear force, as is shown in Fig. 2. In the figure, a is the transition length, l is the overhanging span, q is the outer force.

Mechanical analysis: It can be seen from Fig. 2 that the force on the pipeline is symmetrical distribution. So it is enough to calculate the first half during the analysis of stress and deformation, the other half and first half are symmetrical.

Stress calculation: The forces and bending moments of fulcrum are zero, the outer force q equals to the total reaction of sediment F according to the mechanical model:

$$F = ql \tag{1}$$

Therefore, the force of sediment is:

$$\nabla F = \int \frac{ql}{2a} dx = \frac{x}{2a} ql \tag{2}$$

where, x is the distance to the fixed fulcrum, $0<x<a$.

Bending moment equations of pipeline can be obtained, in the transition section:

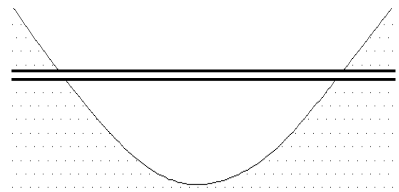

Fig. 1: Physical model of overhanging pipeline

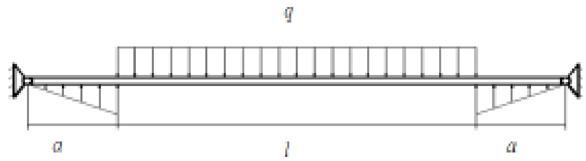

Fig. 2: Stress model of overhanging pipeline

$$M = \frac{ql}{4a} x^2 \tag{3}$$

In the overhanging section:

$$M = -\frac{q}{2} x^2 + (a + \frac{l}{2})qx - (\frac{al}{4} + \frac{a^2}{2})q \tag{4}$$

The stress can be calculated according to the bending moment:

$$\sigma = \frac{M}{W} \tag{5}$$

where, W is the bending section coefficient.

Deformation calculation: The stress deformation of pipeline is much smaller than overhanging span, so the equation of deflection curve is:

$$\frac{\mathrm{d}^2 w}{\mathrm{d} x_2} = \frac{M}{EI} \tag{6}$$

where,
E = Modulus of elasticity
I = Inertia moment

The deformation equation of pipeline can be obtained by putting the initial conditions and continuous conditions into the formula after second integral on formula (6).
In the transition section:

$$w = \frac{ql}{EI} \begin{bmatrix} \frac{1}{48a} x^4 - \\ (\frac{1}{12} a^2 l + \frac{1}{8} a l^2 + \frac{1}{24} l^3) x \end{bmatrix} \tag{7}$$

In the overhanging section:

$$w = \frac{q}{EI}\begin{bmatrix} -\frac{1}{24}x^4 + (\frac{1}{6}a + \frac{1}{12}l)x^3 - \\ (\frac{1}{4}a^2 + \frac{1}{8}al)x^2 + \\ (\frac{1}{6}a^3 - \frac{1}{8}al^2 - \frac{1}{24}l^3)x - \\ (\frac{1}{24}a^4 + \frac{1}{48}a^3 l) \end{bmatrix} \tag{8}$$

NUMERICAL SIMULATION

A kind of submarine oil pipeline is selected to calculate and analyze, the material of pipeline is X56, the size is $\phi 325 \times 14.5$ mm, the overhanging length formed is 30 m. The main parameters of pipeline are as follows.

The parameters of pipeline: $E = 2.06e11$ Pa, $u = 0.3$, density is 9850 kg/m^3.

The forces of the pipeline are as shown in Table 1.

The software of FORTRAN is used to program and solve the bending moment equations, the stress equations and the deformation equations of pipeline. The transition length taken is 10 m, the forces of overhanging pipeline can be obtained, as are shown in Fig. 3 to 5.

It can be seen from Fig. 3 that bending moments exist at overhanging section and transitional section of overhanging pipeline, which changes from small to large and then from large to small. The bending moment of the transition section is small, the maximum bending moment occurs at the middle of overhanging section.

The maximum bending moment can be calculated as follows:

$$M_{\max} = \frac{qla}{4} + \frac{ql^2}{8} \tag{9}$$

It can been from Fig. 4 that the curves of stress is similar to the bending moment of overhanging pipeline, the stresses of overhanging section and transition section change from small to large, then from large to small, the maximum stress occurs at the middle of overhanging section.

The maximum stress can be calculated as follows:

$$\sigma_{\max} = \frac{M_{\max}}{W} = \frac{ql}{4W}(a + \frac{l}{2}) \tag{10}$$

It can be seen from Fig. 5 that maximum deformation occurs at the middle of overhanging section.

The maximum deformation can be calculated as follows:

Table 1: The forces of the overhanging pipeline

Force project		Value
Weight of pipeline		1523 N/m
Current forces	Lifting force	417 N/m
	Drag force	596 N/m
Weight of oil		717 N/m
Resistance force of viscous		1.34 N/m
Buoyancy		1008 N/m
Pressure of transferring oil		2 MPa

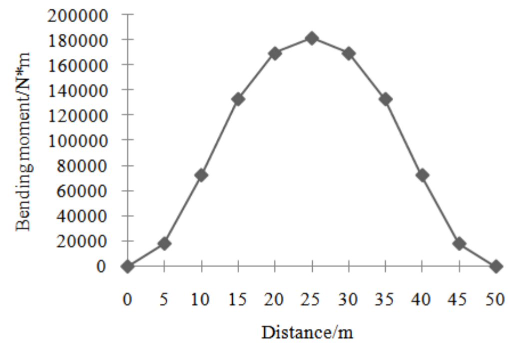

Fig. 3: The bending moment of the pipeline

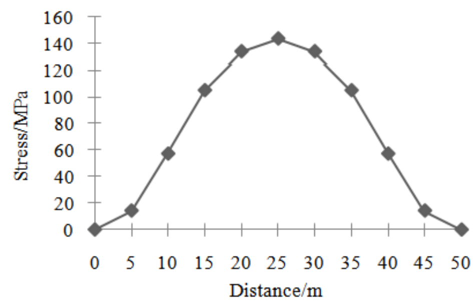

Fig. 4: The stress of the pipeline

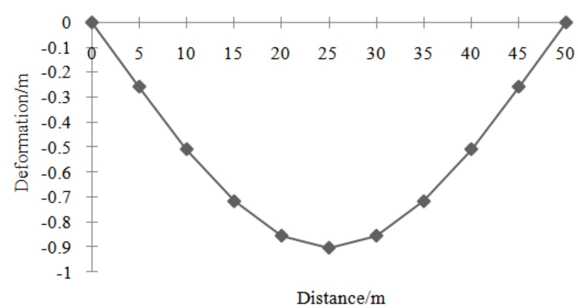

Fig. 5: The deformation of the pipeline

$$w_{\max} = \frac{q}{EI}\begin{pmatrix} -\frac{1}{16}a^3 l - \frac{1}{8}a^2 l^2 \\ -\frac{7}{96}al^3 - \frac{5}{384}l^4 \end{pmatrix} \tag{11}$$

CONCLUSION

Through the stress analysis of submarine oil pipeline, mechanical model of the overhanging pipeline is created based on the gradient forces processed by the support of sediment to pipeline. The calculation equations of bending moment, stress and deformation of overhanging pipeline are obtained by considering the transition section. Though numerical simulation, the conclusion can be reached that maximum bending moment, stress and deformation all occur at the middle plane of the overhanging pipeline. On the basis, the calculation equations of maximum bending moment, stress and deformation of overhanging pipeline are obtained, which provide theoretical support for calculating submarine overhanging pipelines and have an important significance for overhanging analysis and treatment of overhanging pipelines. According to the calculation equations, the calculation results are related to the transition section length, which will need to be investigated further in future.

REFERENCES

Deng, D.P., H.X. Zhou and Y.P. Xing, 1998. Calulation of pipeline inner force and distortion during transverse landslide body. Oil Gas Storage Transport., l7(7): l8-22 (In Chinese).

Gong, A.M., S.Y. Fu and H.Y. Huang, 2004. The application of ANSYS in filled conduit analysis. J. Anhui Inst. Archit. Ind., 12(5): 51-55 (In Chinese).

Luo, S. and J.H. Wang, 2009. Study of the critical length for oil pipe line on the turbulent impact vibration. Nat. Gas Oil, 27(4): 13-15 (In Chinese).

Wang, W. and Z. Lian, 1997. A study on the calculation model of vertical pipe. Nat. Gas Ind., 17(5): 63-66 (In Chinese).

Wang, F.H., X.W. Zhao and H.Y. Wang, 2004. Mechanics analysis and calculation of the high pressure pipe at loess collapse situation. Oil Gas Storage Transport., 23(6): 25-27 (In Chinese).

Yang, Y., B.D. Yan and K.X. Liao, 2011. Computing analysis of the suspended segment stress of oil pipelines. Acta Petrol. Sin., 32(5): 911-914 (In Chinese).

Zhang, R.P. and R.R. Wang, 2013. Application of the direct discontionuous galerkin finite element method for the calculation of soil temperature field of oil pipeline. J. Liaoning Shihua Univ., 33(2): 36-38 (In Chinese).

Zhang, K.Y., Y. Wang and Y.B. Ai, 2010. Analytical solution to interaction between pipelines and soils under arbitrary loads. Chinese J. Geotech. Eng., 32(8): 1189-1193 (In Chinese).

Zhao, Z.G., A.L. Yao and X.F. Zhao, 2006. The type of geological hazard long-distance pipeline, the prevention and control measures and prediction methods. Petrol. Eng. Construct., 32(1): 7-12 (In Chinese).