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Research Article

Stress Analysis of Shallow Sea Gas Pipelines

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Abstract: Shallow sea gas pipelines usually operate in complicated and changeable regional environments and can generate corresponding stresses and displacement under the influence of internal pressures, earthquakes, waves and other loadings. An unevenly distributed stress will lead to shallow sea gas pipeline failure easily. In order to ensure the safety of pipeline, it is necessary to research the stress conditions of the shallow sea gas pipeline and check whether it can meet the safety requirements or not. In this study, we analyze the stress conditions of shallow sea gas pipelines of two laying modes in XX areas using stress analysis software CAESAR II, discuss the loading conditions under the operating condition and determine the position of the key point where pipeline damage is most likely to happen, the bend pipe. The comprehensive experiments show that underground method more secure than the sea-bed method, it greatly improves the reliability of the shallow sea pipeline running. Our research provides a theoretical basis for the construction of shallow sea gas pipelines.

Keywords: CAESAR II, gas pipeline, shallow sea, stress analysis

INTRODUCTION

Submarine gas pipeline is the main way for the development of marine oil and gas fields and the cross-sea transport of oil and gas. It is the fastest, safest and economical and reliable offshore oil and gas transport. Pipeline is a very safe oil and gas transportation, but there have been numerous pipeline failure incidents in the past few decades, this not only affects the normal order of production, pose a threat to the safety of workers, but also cause tremendous losses to the country's economy and national life. Experts and scholars more and more attention to the security issues of the submarine pipeline. Among them, the stress factor is the key issue, during the operation process, stress on the turning point or section plane tends to exceed the allowable stress due to the influence of internal pressure and external loads, which result in pipeline damage at the stress concentration point and leave the pipeline in a dangerous operating condition. Therefore, it is necessary to analyze stress conditions of shallow sea gas pipeline, which can provides safety basis for the design and construction of pipelines.

Since the 1970s have a shaped of software products for pipe stress calculation, it has been developed into a mature product line. Currently, more widely pipe stress analysis software CAESAR II, AutoPIPE and Triflex which CAESAR II's application is the most widely used. COADE developed for the preparation of CAESAR II has a powerful static and dynamic calculation and analysis capabilities. In addition, PENG engineering company SIMFLEX-II pipe stress analysis software compact, more powerful subsidiary database, the calculated results are automatically compared with ASME B31.3, B31.1 standard and so on, while in the process of curing the API-610, API-661, B16.5 and other American chemical pipeline professional standard and the operation is simple.

We analyze the stress conditions of shallow water gas pipelines of two laying modes using stress analysis software CAESAR II, determine the position of the stress key points and contrast two ways of stress ratio at the key point, attempts to arrive at the best laying method of shallow water pipe (CNPC, 1995; The American Society of Mechanical Engineers, 2010).

STRESS ANALYSIS OF SHALLOW SEA GAS PIPELINES

Due to the intimate contact with soil, shallow sea gas pipelines would be loaded with both hoop stress and axial stress.

Hoop stress: The hoop stress is on the buried pipeline:

$$\sigma_y = -\frac{D_1 K_b W_s r I_t}{EI_t + 0.06 K_h r^4} \times \frac{1}{Z_t} \tag{1}$$

where,

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D_1 = Time coefficient
K_b = Bending moment coefficient
K_h = Horizontal soil coefficient
I_t = Inertia moment
Z_t = Section modulus of steel pipeline
W_z = Overburden pressure per unit length along pipe axis direction

Axial stress: Pipeline axial stress includes axial stress caused by internal pressure, temperature stress caused by temperature difference and bending stress.
The axial stress caused by internal pressure:

$$\sigma_p = -v\sigma_y + \frac{P_i d_i}{4t} \tag{2}$$

Temperature stress:

$$\sigma_T = \alpha E \Delta t \tag{3}$$

Bending stress:

$$\sigma_b = \pm \frac{M}{Z} \tag{4}$$

where,
v = Poisson's ratio
P_i = Internal pressure of pipe, where negative pressure indicates being pressed
d_i = Inside diameter
α = Coefficient of linear expansion, here we use 1.2×10^{-5}/°C
E = Elastic modulus of Steel pipeline
Δt = Temperature difference, °C
M = The vector sum of bending moment in the vertical and horizontal directions
Z = Cross-section bending modulus

Checking conditions for shallow sea pipeline stress: During the design process, when we check pipeline stress, we preset a limit stress [σ] as the criteria to verify the strength requirements within the pipe fittings limit stress range; it is recommended that pipeline stress should not exceed 90% of the pipeline's allowable stress.

According to the standards, synthetic stress should meet:

$$\sigma_A = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x\sigma_y + 3\tau_{xy}^2} \le \eta\sigma_F \tag{5}$$

where,
σ_x = Axial stress
σ_y = Hoop Stress
τ_{xy} = Tangential shear stress
η = Utilization coefficient
σ_F = Minimum yield limit

If this can be achieved, it means that the undersea pipeline design is reasonable, safe and reliable.

Due to thermal expansion and contraction, curvature mutation, endpoint additional displacements or restraints, pipeline will be loaded with the corresponding axial stress, shear stress, bending moment and moment of torque. Generally, stress calculation needs the checking of primary stress, secondary stress and the operating stress.

Case study of shallow sea gas pipelines: This study uses the general pipeline stress analysis software CAESAR II to analyze XX shallow sea gas pipeline stress, which is based on the American ASME B31.8 Gas Transportation and Distribution Piping Systems (The American Society of Mechanical Engineers, 2010). The specific steps of model establishment are piping input, soil model, wave load input and operating conditions of shallow sea gas pipelines (Wang *et al*., 2009).

Table 1: Pipeline parameters

		Wall thickness [mm]		
Material	Diameter (mm)	Straight pipe	Pipe bend	Fluid density (kg/m^3)
API 5L X70	1016	25.4	31.8	95
Corrosion (mm)	Pressure (Mpa)	Temperature (ºC)		Allowable stress (MPa)
5	10	64		485

Table 2: Ocean model

Wind speed (m/s)	Effective wave height (m)	Effective cycle (s)	Density of sea water (kg/m^3)
46	13.8	10	1025
Water depth (m)	The sea velocity (m/s)	Middle velocity (m/s)	Underwater velocity (m/s)
87	1.73	1.37	0.85

Table 3: Soil model

Soil model	Friction coefficient	Soil density (kg/m^3)	Buried depth to top of pipe (m)	Friction angle (°)	Yield displacement factor	Over-burden compaction multiplier	Thermal expansion coefficient
Soil model 1	0.6	1120	1.50	20	0.015	5	11.214
Soil model 2	0.6	1300	1.50	20	0.015	6	11.214
Soil model 3	0.6	1300	0	20	0.015	6	11.214

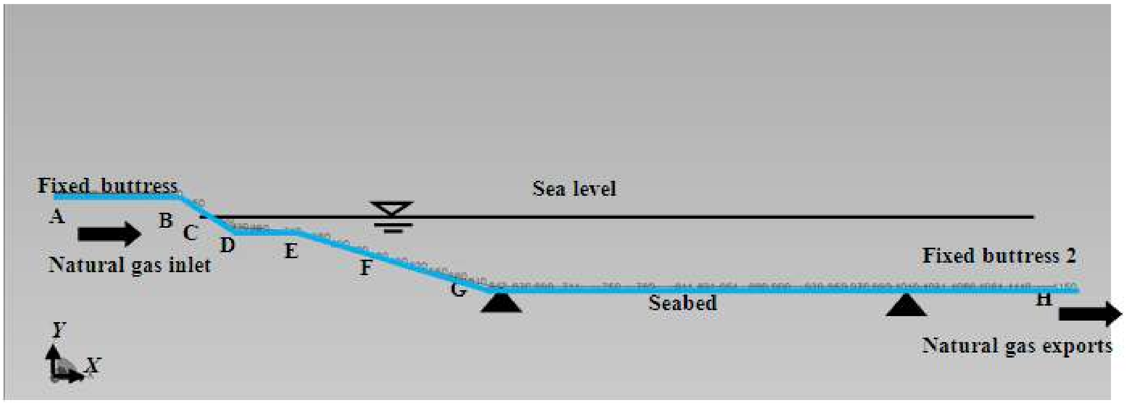

Fig. 1: Schematic diagram of shallow sea pipeline

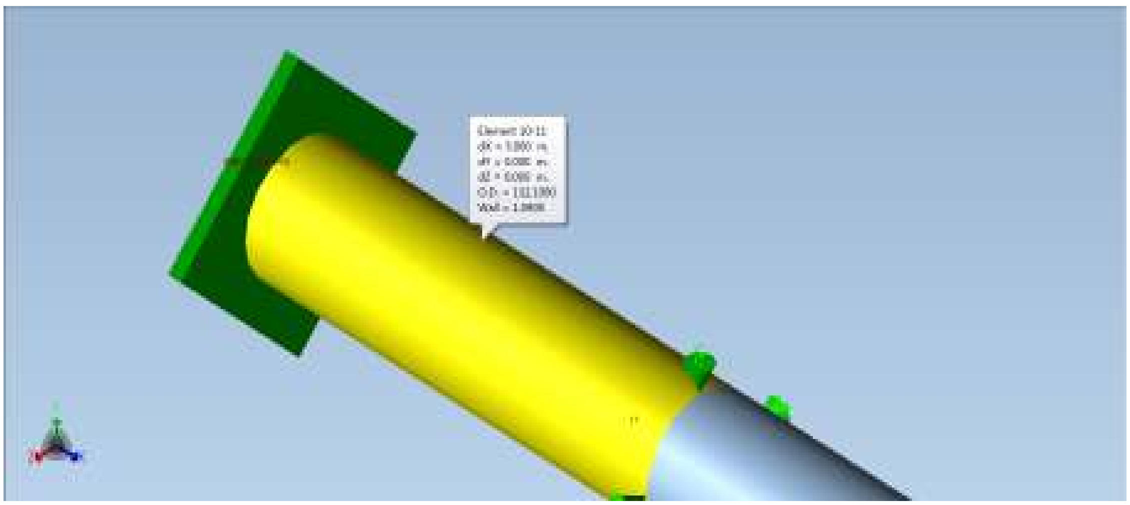

Fig. 2: Fixed buttress

Table 1 to 3 show the design data and geological and hydrological data of shallow sea gas pipelines in XX. Figure 1 shows the schematic diagram of shallow sea pipeline model.

METHODOLOGY

The explanation of shallow sea pipeline model 1 (Underground) and model 2 (placed above the seabed laying) are as follows:

Model 1 (underground): According to the XX shallow sea gas pipeline's design data, the length of pipeline model is 903.58 m and each end of the pipe will be respectively installed with fixed buttress 1 and fixed buttress 2 (Fig. 2), which is used to block the outside pipelines' effect on the model. The length of the shore pipeline AB is 103.19 m. The length from coast to shallow sea pipeline is 300.39 m, longitudinal gradient is 5°-30° (the longitudinal slope of BC and BD sections are 30°, the longitudinal slope of the DE section is 5°, the longitudinal slope of the EF section is 20° and the longitudinal slope of the FG section is 15°). The length of pipeline above seabed is 500 m. The entire pipeline devices were buried under the seabed. As to the AB and BC segments of the pipeline, we will adopt direct in ground measure and used soil model 1, while for the remaining segment of the tubes, we will use soil model 2.

Model 2 (placed above the seabed laying): According to the design data, the entire length of the pipeline model is 903.58 m and each end of the pipe was respectively installed with fixed buttress 1 and fixed buttress 2, which are used to block the outside pipelines' effect on the model. The length of the shore pipeline AB is 103.19 m. The length from the coast to the shallow sea pipeline is 300.39 m, which gives a longitudinal gradient of 5°-30° (the longitudinal slope of BC and BD sections are 30°, the longitudinal slope of the DE section is 5°, the longitudinal slope of the EF section is 20° and the longitudinal slope of the FG section is 15°). The length of the pipeline above the seabed is 500 m. AB and BC segments will be settled

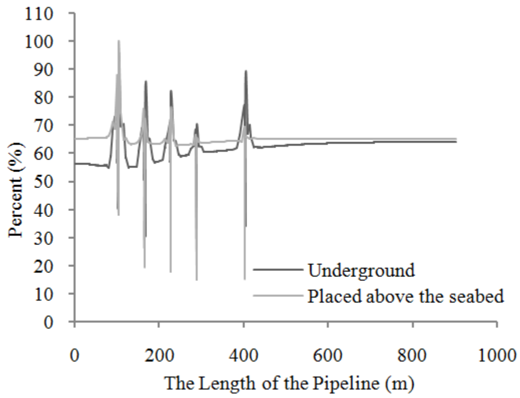

Fig. 3: The operating stress ratio of two laying mode pipelines

Table 4: Comparison of two ways of laying pipe positioned at the operating stress

Bend	B (%)	D (%)	E (%)	F (%)	G (%)
Underground	95.54	84.77	81.26	69.78	88.50
Seabed	99.33	75.74	75.45	65.50	65.83
The ratio of stress change	-3.79	+9.03	+5.81	+4.28	+22.67

+: The operating stress of key stress point for underground pipeline which tends to be higher than that of sea-bed pipeline; -: The operating stress of key stress point for underground pipeline which tends to be lower than that of sea-bed pipeline

by the measure of direct the ground, using soil model 1. And the remaining segment of the tube uses soil model 3. The pipeline will be placed above the seabed and one stable block (a simplified model for constrained Z and Y) will be settled every 30 m (Tang, 2003).

RESULTS

According to the two design data, we analyzed the stress conditions respectively. The operating stress ratios of two laying mode pipelines are shown in Fig. 3.

According to the check of operating stress, primary stress and secondary stress, the highest operating stress ratio of underground shallow sea pipeline is 95.54%, which happened at the bent pipe B. The primary stress's highest stress ratio is 40.92%, which happened at the fixed buttress 1. The secondary stress's highest stress ratio is 64.66%, which happened at the place near the bent pipe B. The highest operating stress ratio of shallow sea pipeline which is settle above the seabed is 99.33%, which happened at the bent pipe B. The primary stress's highest stress ratio is 42.57%, which happened at the bent pipe G. The secondary stress's highest stress ratio is 68.75%, which happened at the bent pipe B. For the highest value of the operating stress, primary stress and the secondary stress did not exceed [σ] = 434369.7000 KPa, so the two laying mode pipelines meet the strength requirements.

Table 4 shows the operating stress in key stress point contrast ratio (Huang *et al*., 2012; Sha *et al*., 2013; Wang, 2002) (Note: The pipeline check allowable stress is 90% of the pipe allowable stress.)

CONCLUSION

This study provides a superior method for pipeline stress analysis. Through stress analysis of shallow sea gas pipelines of two different laying modes, we ascertain that the position of the stress key point of shallow sea gas pipelines is at the pipe bends and confirm that the maximum operating stress appears at the bent pipe B. This stress analysis method can precisely locate the key stress point. Therefore, designers can make improvements by changing the relative parameters and operating conditions and take effective measures to reinforce pipeline weak points according to the analysis results. Between the two laying modes, the operating stress of straight underground pipeline tends to be slightly lower than that of sea-bed pipeline, while the stress value of sea-bed pipeline at pipe bends tends to be significantly lower than that of underground pipelines. Neither of the maximum operating stresses exceed the limit value [σ] thereby meeting the safety requirements, so both of the laying methods are safe. Therefore, it is necessary to combine safety, economics and construction difficulties when determining which kind of shallow sea pipeline laying mode can be chosen.

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