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أسلوب تحليل إجهاد خطوط نقل النفط عبر النهر بالحفر الكبرى
دراسة حالة خطوط نقل النفط بنهر باييانغ

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الخـلاصـة

يعتبر ارتكاز الإجهاد سببا رئيسيا لفقدان فعالية خطوط نقل النفط عبر النهر. من أجل ضمان سلامة الخطوط، من الضروري تحليل الإجهاد. تأخذ هذه الدراسة خطوط نقل النفط بنهر باييانغ كمثال لإنشاء نموذج العناصر المنتهية ببرنامج CAESAR II، كما يحلل توزيع إجهاد الخطوط. من خلال بحث هذه الدراسة، يمكن تلخيص التالي: (1) من أجل ضمان سلامة الخطوط، زاوية ميل الخطوط يجب أن تكون أقل عن 35 درجة عند التصميم؛ (2) تكون خطوط قطعة المدخل أخطر جزء، لذلك يجب أن يدقق على هذا الجزء خاصة في القطعة الثقيلة الأولى؛ (3) من أجل ضمان سلامة الخطوط، من المعقول أن تكون المسافة بين الأنبوبة المنحنية والقطعة الثقيلة الأولى 4 متر؛ (4) بالنسبة إلى تحليل طول الميل بأقصى حد، عادة يتحكم عمق الحفر داخل المجال المسموح به.

Stress analysis method for the large excavation of a river-crossing oil pipeline - a case study of Baiyang river oil pipeline

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ABSTRACT

The primary cause of pipeline failure for the river-crossing oil pipeline is the accumulation of stress. In order to ensure that the pipeline is safe, a stress analysis under operating conditions is necessary. In this study, a numerical simulation of the Baiyang river oil pipeline with a large excavation using the finite element stress analysis software CAESAR II in which the pipeline's stress distribution is analyzed. Through the engineering case study, it is concluded that: (1) the inclined degree should be set at less than 35 in order to ensure pipeline safety; (2) the most vulnerable location is located at the entrance, so the area should be carefully calibrated, especially at the first saddle weight; (3) in order to ensure pipeline safety, the first saddle weight between the bend and saddle weight is 4 m; (4) based on the analysis of limit length, the excavation depth is normally controlled in the allowable extent.

Keywords: Large excavation; oil pipeline; river-crossing; stress analysis.

INTRODUCTION

The safety and reliability of oil transportation pipelines are concerns for many experts and scholars. Its functionality is directly influenced by a number of different factors, which not only consists of construction and material defects, corrosion, false operation, and fatigue failures of pipelines, but also includes another important factor: stress (Metropolo & Brown, 2004). When the actual stress is much higher than the designed value, pipeline stress damage will occur, which can then cause leaks, fires, explosions, property losses, and potentially even casualties (Zeng et al., 2007).

The design of a pipeline that has an improved sustainable functionality must be directly founded on construction quality. In fact, the rationality of pipeline design is directly related to the structural safety of the pipeline. The main purpose of pipeline stress analysis is to ensure that the pipeline design meets strength and flexibility requirements. During the pipeline design process, many countries require a stress analysis report for the whole pipeline in an attempt to ensure both the safety and sustainable operation of the pipeline.

As river crossing of oil pipeline through extensive excavation, has changed natural conditions of original riverbed and banks; anti-washing, anti-floating and riverbank slop protection design were applied for the section of the pipeline crossing the river, in order to ensure safe operation of the pipeline and to meet the requirement for water and soil conservation (GB 50253; GB 50423).

The foundation depth is confirmed based on multiple factors: by using the calculated depth results for anti-washing, by taking into consideration that the riverbed disturbance may lower anti-washing capability, and by comparing with a similar river-crossing project, to enhance the anti-washing capability. Certain anti-washing approaches are applied during the backfill (Wang et al., 2014). For an anti-floating design, the saddle weight is chosen to fix the pipeline, so as to prevent the pipeline floating up. On the riverbed, along the pipeline route, the saddle weights are set every 3 meters, and the length between the saddle weights is 2 meters (Liu, 2006).

An oil transportation pipeline is different from a gas transportation pipeline in two major aspects: the operation temperature and the gravity load. In China, most of the crude oil is highly condensed and highly adhesive, meaning heat is required during transportation. The oil temperature is relatively higher, and since heat causes expansion and cold causes contraction, the thermal stress is also very high. Moreover, since the density of oil is higher than that of natural gas, the load's gravity is higher for the oil transportation pipeline than for the gas pipeline.

Based on the two stress-related oil pipeline characteristics (Huang et al., 2012), a stress analysis should be performed before formal operation of the river-crossing pipeline that is constructed by excavation. Also, calibration is necessary so as to ensure that the pipeline can meet the stress requirement.

During the 1930's and 40's, researchers applied structure mechanics to analyze and solve the pipeline's internal force (Watkins & Anderson, 1999). Previously, the elastic center method had been used; it was an established and simple method, but calculation error was considerably larger. In the 1950's, the structure analysis using a matrix method was used to calculate the pipeline's internal stress and to solve the force, moment, and displacement of the pipeline end point (Zhang, 1993; Peng, 1978). The inherent complexity of pipelines has led to the development of multiple methods for solving the pipeline's internal force.

In the mid 1990's, a thin-wall pipeline was chosen to reduce the construction work load and to lower the cost and production expenses (Liu & Yang, 2008; Zhang & Lv, 1999). In recent years, pipeline companies usually utilize commercial software to analyze pipe stress. The most commonly used software, including CAESAR II, ANSYS and ABAQUS, all fall in the category of finite element software. Among them, ANSYS and ABAQUS can produce more detailed results, and are applied in analyzing of local positions like the pipelines' branch junctions. As appropriate software for pipe stress analysis, CAESAR II is often more widely utilized (Wu et al., 2014; Wu et al., 2015a; Lu et al., 2016; Shang et al., 2017). The CAESAR II software, developed by Intergraph, has in-built stress check standards, and a variety of load working conditions can be added according to the actual situation of the project to better carry out static analysis, and fatigue analysis of the pipeline. CAESAR II is known for its easy operations, making it suitable to be applied under various complex conditions. Additionally, it is also popular for its reliability, as its calculations have been verified by numerous empirical studies.

In our experiment, CAESAR II was used to perform numerical simulation on a pipeline located in Western China. The positions of dangerous stress section as well as the effects that various factors had on stresses, such as external load and the pipe, etc., were analyzed and proposed corresponding engineering measures based on the analyses results.

THEORY

Pipeline mechanical model

Stress analysis of pipelines usually use finite element software. CAESAR II is a widely used software based on the beam model, so it is more applicable to analyze the stress of long-distance pipelines. Because the length of a pipeline in the axial direction is far greater than its diameter, a pipeline is usually simplified to a one-dimensional beam element model (Zhou & Murray, 1995), and the effects of cross-sectional changes are ignored (Song, 2011). In order to ensure the accuracy and simplicity of calculation (George, 1998), the length of a section of pipeline should be smaller than 20 times the pipe diameter, if the pipe diameter is larger than 12 in, and it should be smaller than 30 times the pipe diameter if the pipe diameter is smaller than 12 in.

Soil mechanical model

Long-distance pipelines are mostly buried underground. The main constraints for buried pipeline come from the soil. And these constraints can be divided into two categories. One is friction; for pipe's sudden slip has to overcome the friction and the other kind is pressure,; for pipe pushing the soil. Soil can not only constraint the pipeline movement axially, laterally and vertically, but also can bear the weight of the pipe (Peng, 1978). In real conditions, soil deformation and constraint force changes are nearly linear, and soil constraint force is the largest under the condition of tension and compression.

To do pipe stress analysis, finite element method (FEM) analysis usually divides the continuous soil into three single direction springs with a bilinear stiffness. Soil spring stiffness is approximate to the curve slope of real deformation-constraint force, while the critical condition is the maximum soil constraint force. Peng is the commonly used model to solve the soil stiffness and maximum constraint force (Peng, 1978).

In pipeline stress analysis, soil forces (Figure 1) commonly consist of longitudinal, transverse and axial forces. Each kind of lateral resistance can be simplified as continuous phase. One is elastic stage, during which resistance is proportional to the displacement of pipeline; the other one is viscous phase. At this time, no matter how much is displacement, the resistance is constant. This type of constraint can be simulated as double linear constraint. Soil can limit not only the movement of the pipe but also limit its rotation by force couple.

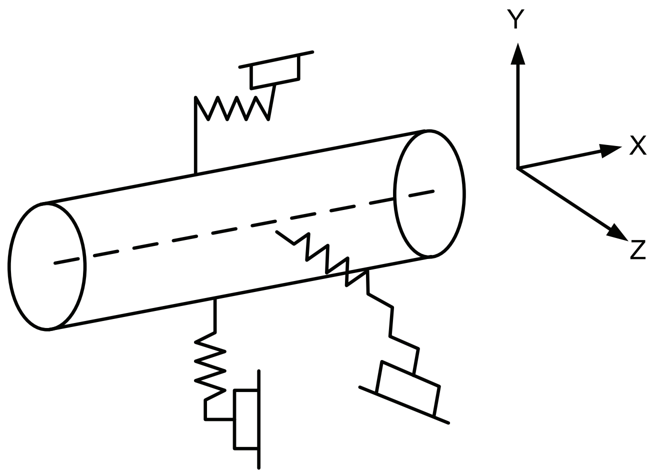


Fig.1. Schematic for the interaction between soil and the pipeline (soil spring)

Boundary condition

In order to prevent bending caused by the weight of the entire pipeline system, fixed piers are installed to eliminate the effects of the pipeline outside the model. The displacements of the pipeline on both sides of the fixed piers are independent of each other, and the change in stress cannot be transmitted through them (Jiang et al., 2013). Fixed piers are constrained from displacing and bearing axial forces, but they can bear bending moments and shear forces.

METHODS

The stress analysis for an oil transportation pipeline includes three aspects: building the pipeline model, defining the load and performing static analysis (Lu et al., 2015).

Building the pipeline model

The main content of static analysis is to establish the model in accordance with the pipeline design drawings. Building a pipeline model includes a pipeline system model and a soil model (for a buried pipeline). The basic pipeline model includes pipeline length, the direction, corrosion allowance, temperature, pressure, material, boundary input and fluid density. However, the soil model includes soil parameter input (friction coefficient, density, buried depth for crossing section, internal frictional angle of soil, overburden compaction multiplier, thermal expansion coefficient, yield displacement factor), an entrance and exit spot of soil and defined soil characteristics.

Building the load condition

After constructing the pipeline model and prior to performing the static analysis, the load condition of the simulated pipeline needs to be defined. Normally, according to the stress classification, the load condition consists of primary stress calculation condition, secondary stress calculation condition and equivalent combined stress calculation condition. At this point, the load will be added first (including the gravity load W, temperature load T and pressure load P), and then these are combined together.

Static analysis

The static force analysis results include data for the equivalent combined stress, primary stress and secondary stress. Furthermore, the maximum stress point locations on a pipeline segment and the 3-D maximum stress will be displayed.

Classification of calibrated stress

According to the failure mode of pipeline, pipe stress can also be divided into primary stress, secondary stress and equivalent combined stress (Song, 2011; ASME B31.4; Wu et al., 2015b).

The primary stress illustrates the pipeline stress that is affected by the pipeline's weight, its medium and the internal pressure.

The secondary stress represents the temperature-impacted stress.

The equivalent combined stress results from compounding both the primary stress and the Secondary Stress and are indicative of the relatively higher stress that is generated by the local stress concentration, the local structure discontinuity or the local thermal stress.

Criterion of stress calibration

The standard applicable to oil pipeline analysis is Table 403.3.1-1 in ASME B31.4 Pipeline Transportation Systems for Liquids and Slurries (ASME B31.4).

(1) Primary stress σ_H should be smaller than the 0.72 times of yield strength, which is $\sigma_H < 0.72\sigma_Y$.

(2) Secondary stress σ_E should be less than the 0.9 times minimum stress, which is $\sigma_E < 0.9\sigma_Y$, giving the following Secondary Stress of restricted pipelines formula

$$\sigma_E = E\alpha(T_1 - T_2) \tag{1}$$

Where:

E : Elasticity modules

σ_E : Secondary Stress, MPa;

T_1 : Temperature when installing the pipeline or at the time of completion, °C;

T_2 : Pipeline running temperature, °C;

α : Coefficient of thermal expansion, mm/mm/°C;

σ_Y : Specified minimum yield strength of pipe material, MPa.

(3) Equivalent Combined Stress should be less than 90% of the pipeline's minimum yield strength, which is $\sigma_{eq} < 0.9\sigma_Y$, giving:

$$\sigma_{eq} = (\sigma_H^2 - \sigma_H\sigma_L + \sigma_L^2 + 3\sigma_t^2)^{0.5} \tag{2}$$

Where:

σ_{eq} : Equivalent Combined Stress, MPa;

σ_t : Torsional stress, MPa;

σ_Y : Specified minimum yield strength of pipe material, MPa.

σ_L : Longitudinal stress, MPa.

Model validation

Due to the stress of river-crossing pipelines, it is very hard to conduct field test. So, to verify the correctness of numerical model, a simulation for the model in other reference adopting the same method was carried out, and comparison was thereby made.

CAESAR II was used to perform numerical simulation for the oil pipeline crossing Yangtze River in literature (Lan *et al*., 2015). The model has a total length of 185.2 m with symmetrical structure (towards east and west). Length of inclined sections on two sides is 17.6 m and the inclination angle is 34.6°. The average length of upper horizontal segment on two sides is 12.5 m while that of lower horizontal is 120 m. API X65 steel was adopted as the material for the pipeline with dimensions: 610 mm (D) × 11.1 mm (T). Besides, the soil type is sand with a density of 1670 kg/m^3 and an internal friction angle of soil of 32°. The pipeline route can be seen in literature (Lan *et al*., 2015).

A numerical simulation model was established using CAESAR II software, and the model was based on the methods from this paper. The literature (Lan et al., 2015) established the model using ABAQUS and the model was based on shell model. The calculation results of two methods can be compared.

Through numerical simulation using CAESAR II, it can draw the maximum stress locates at the bottom bend on west side, and the max stress is 50.61 MPa. Numerical simulation using ABAQUS in literature (Lan et al., 2015), it can draw the maximum stress locates that which is close to the west bottom bend, and the max stress is 45 MPa. Furthermore, distribution trend of stress is generally the same. It can be seen that the calculation results using CAESAR II software are more conservative and there is little difference between them. The absolute error of stress value is less than 6 MPa, which indicates the relatively high credibility of the numerical simulation method proposed in this paper.

CASE STUDY

Taking measures for reducing stress necessitates research on the stress of heavy evacuation oil pipelines and its influencing factors. One section of a pipe belonging to the Baiyang river oil pipeline project in Western China was selected for modeling and analysis. Some findings are made.

Baiyang river pipeline project introduction

Based on the design material for the Baiyang river-crossing oil pipeline project, the operation temperature is 80°C, the installation temperature is 10°C, the operation pressure is 8 MPa, and the oil density is 900 kg/m^3. Table 1 shows the pipeline parameters.

Table 1. Pipeline parameters

Material	Diameter (mm)	Straight pipe wall thickness (mm)	Bend wall thickness (mm)	Insulation thickness (mm)	Corrosion allowance (mm)	Elastic module (MPa)	Coefficient of thermal expansion ($\times10^{-6}$/°C)	Poisson's ratio	Specified minimum yield strength (MPa)
API 5L X65	457	8.7	11.1	60	1	2.034×10^5	11.8	0.30	450

From the entrance to the exit by excavation, the crossing length is around 300 m. Fixed pier 1 and fixed pier 2 were set at the entrance and exit, respectively, so as to cut off the interference from the exterior pipeline section to the crossed pipeline section. The entrance length is 25 m with one saddle weight; the western inclined pipeline is 20 m, with an inclination angle of 24.5°. The horizontal pipeline section is 300 m and contains 87 saddle weights at 3 m intervals. The inclined pipeline on the eastern side is 20 m long, and the angle is 24.5°. The exit is 25 m long with one saddle weight; the curve radius is R=10D. D is the outside diameter of the pipeline, the area tier is level 3, and the transported medium is thick oil. The soil parameters are shown in Table 2, and the layout for the pipelines is shown in Figure 2. Whole pipeline model is shown in Figure 3 and Table 3.

Table 2. Soil parameters

Soil type	Friction coefficient	Density ($kg\cdot m^{-3}$)	Buried depth for crossing section (m)	Internal frictional angle of soil(°)	Overburden compaction multiplier	Yield displacement factor (L/L/°C)
Saturated sand	0.6	2600	5	37	5	11.214×10^{-6}

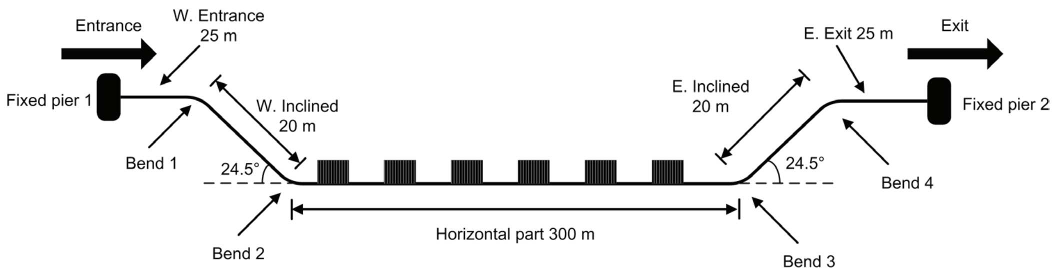


Fig.2. Diagram of the river-crossing XX pipeline layout constructed by excavation

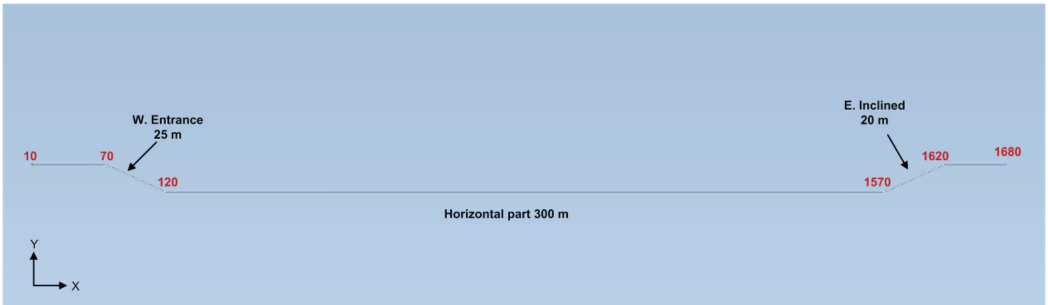


Fig.3. Schematic diagram of the whole pipeline model

Table 3. Annotation of whole pipeline model (corresponding to Figure 3)

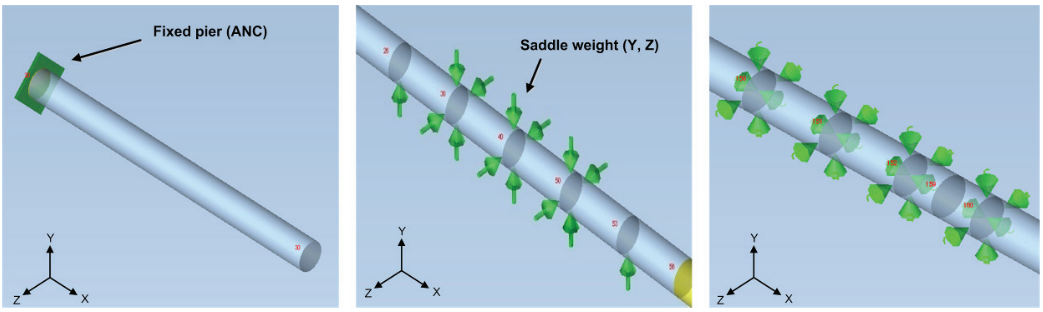
Node	Position
10	Fixed pier 1
10-70	W. Entrance
70	Bend 1
70-120	W. Inclined
120	Bend 2
120-1570	Horizontal Part
1570	Bend 3
1570-1620	E. inclined
1620	Bend 4
1620-1680	E. Exit
1680	Fixed pier 2

Building the restraints

(1) Fixed pier: The fixed pier restrains the axial displacement. Fixed piers are set at the entrance and exit so as to cut off the interference from the exterior pipeline system to the crossed pipeline section. The simplified model is ANC (as shown in Figure 4(a)).

(2) Saddle Weight: Based on the material provided by the Baiyang river crossing of oil pipelines, the saddle weight is deployed at a pipeline bend in order to prevent the floating-up of the pipeline. It is capable of doing so because the saddle weight is heavier than the pipeline's buoyancy (Pipeline restrained by stress, each saddle weight was 3 m long and weighed 500 kg. The downward pressure applied by a saddle weigh to the pipeline was calculated to be 16.33 N/cm.), and the pipeline's horizontal movement is restrained by the saddle weight, which is simplified so that the pipeline is able to bear the restraint force at the vertical and hoop direction. The pipeline's axial direction does not have any restraint force, but the pipeline can move freely. To summarize, the restraints are provided at +Z, -Z of the Z direction and +Y, -Y of the Y direction (as shown in Figure 4(b)).

(3) Soil: The soil surrounding the pipeline not only restrain the pipeline both horizontally and vertically but also restrain the frictional force in the axial direction, so the soil load is simplified to +Z, -Z of the Z direction and +Y, -Y of the Y direction and has only limited movement in the axial direction (as shown in Figure 4(c)).



(a) (b) (c)

Fig.4. Diagram of simplified restraints (a) Fixed pier, (b) Saddle weight, and (c) Soil

Building the load condition of the river-crossing oil pipeline

The operation temperature is 80°C, and the operation pressure is 8 MPa. The pipeline load includes the pipeline's weight and the transported medium, internal pressure, temperature and external force (the buoyancy of a pipeline with a diameter of 457 mm applied by water was 16.07 N/cm), which then needs to be combined.

In the oil pipeline's running condition, the primary stress of CAESAR II is shown as [SUS] $D_2=W_1+W_2+P+U$; the secondary stress is [EXP] $D_1-D_2=T$, and the equivalent combined stress is [OPE] $D_1=W_1+W_2+T+P+U$.

Where:

W_1: Pipeline's gravity;

W_2: Gravity of medium inside the pipeline;

P: Pressure load;

T: Temperature load;

U: Water buoyancy load.

RESULTS

Primary stress, secondary stress and equivalent combined stress of the nodes along the pipelines can be obtained from CAESAR II software. According to the stress analysis results, the maximum stress is located underneath the saddle weight, which indicates that the saddle weights are the key stress concentration points on the river-crossing oil pipeline.

During pipeline stress checking, usually use stress ratio to describe the magnitudes of stresses, giving:

$$SR = \sigma / \left(C\sigma_Y\right) \times 100\% \qquad (3)$$

Where:

SR: Stress ratio;

σ : Stress, MPa;

C: Design coefficient, 0.90 for equivalent combined stress, 0.90 for secondary stress, 0.72 for primary stress.

From Table 4, the maximum primary stress is located at the second saddle weight on the western standard. The stress value is 99.24 MPa, which does not exceed 324 MPa and, therefore, meets the stress requirement. However, the maximum secondary stress is generated at the first saddle weight. The stress value is 259.12 MPa, which is less than 405 MPa and therefore meets the strength requirement. The highest equivalent combined stress is also generated at the first saddle weight. The stress value is 363.09 MPa, which is less than 405 MPa, so it meets the strength requirement.

Table 4. Calibration for the primary stress, secondary stress and equivalent combined stress.

Type	Stress (MPa)	Stress concentration spot (m)	Maximum stress ratio (%)	Calibration for stress (MPa)
Maximum Primary Stress	99.24	55	30.63	324
Maximum Secondary Stress	219.94	49	54.31	405
Maximum Equivalent Combined Stress	363.09	49	89.65	405

Figure 5 shows the pipeline's equivalent combined stress as it corresponds to pipeline length during the installation (P=atmospheric pressure, T=5°C), operation (P=8 MPa, T=80°C) and testing conditions (P=12 MPa, T=15°C). The pipeline's maximum stress ratio while being operated is much larger than the ratio during the installation or pressure testing conditions, so it is important to calibrate the operation condition when performing a stress analysis.

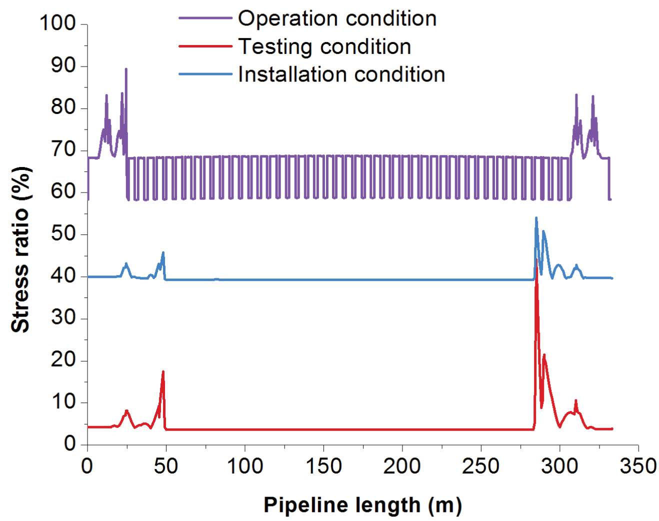


Fig.5. Distribution of equivalent combined stress ratio

Figure 6 shows the changing conditions of the primary stress, secondary stress and equivalent combined stress ratio along the pipeline length. Figure 7 shows a zoomed-in photo of the Equivalent Combined Stress ratio. Taken from Figure 6 and Figure 7, the conclusions are as follows:

1) The maximum secondary stress and the equivalent combined stress are both generated at the first saddle weight, whereas the maximum primary stress is located at second saddle weight instead. The primary stress and secondary stress as well the equivalent combined stress are generated at the saddle weight, which indicates that pipeline stress is most greatly affected by the saddle weight, which is the dangerous cross-section.

2) The primary stress is obviously lower than the secondary stress and equivalent combined stress, and the equivalent combined stress is larger than the secondary stress, which reveals that the temperature difference is the main pipeline stress factor, and internal pressure is the second most important factor.

3) Type π is the distribution of Secondary Stress that has been generated by temperature difference. The weight block constrains the axial displacement generated by the temperature, and the stress ratio between the backfill of the two saddle weight is relatively larger. The stress at the saddle weight is relatively smaller and changes unexpectedly.

4) In addition to the first saddle weight, another high stress location is the 4 bends on both sides, this is because there is a lack of support for the bends.

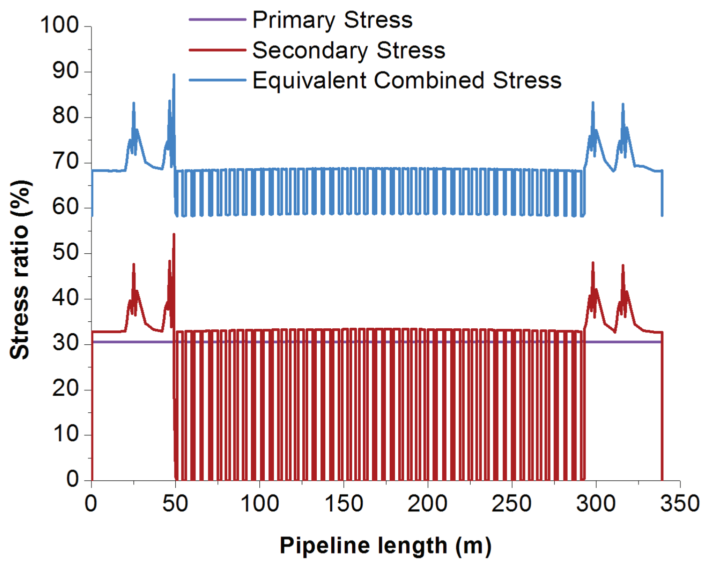


Fig.6. Diagram of stress ratio during operation

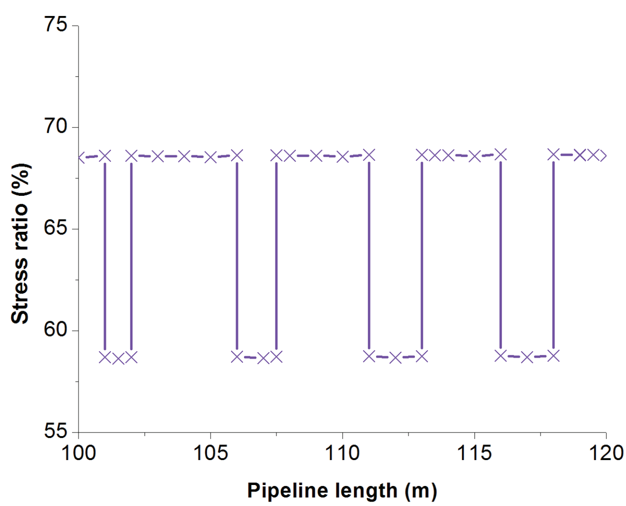


Fig.7. π Type distribution of equivalent combined stress ratio for local spot

DISCUSSION

Based on the assumption and analysis, the main influencing factors include the inclined pipeline degree, the inclined pipe length, the direction of the entrance and exit for the hot oil and the distance between the bending sections to the first saddle weight. In order to facilitate research, the benchmark piping stress analysis model was established, as shown in Figure 8.

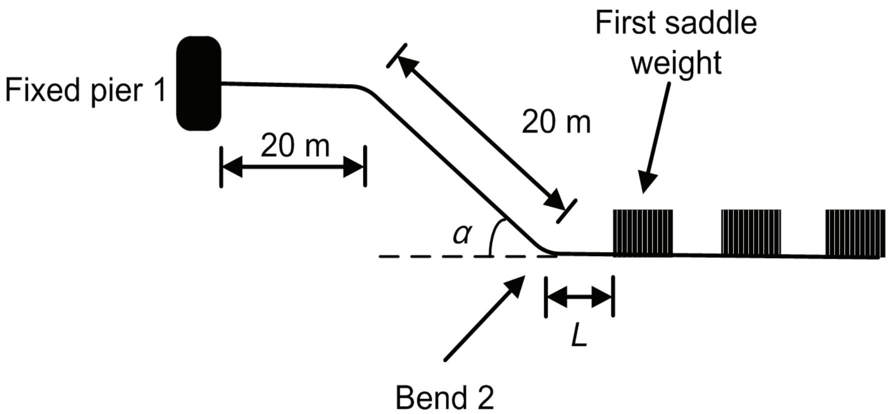


Fig.8. Base stress analysis model

Analysis on inclined degree

The pipeline stress changes along with the degree of bending pipeline. The following work was performed: an appropriate pipeline section was chosen (which is 20 m), and the inclined section is α degree. As shown in Figure 8, the operation condition was built, and the maximum stress ratio that was affected by a change of α was analyzed.

As show in Figure 9, as the pipeline gradient increases, the pipeline's maximum equivalent combined stress ratio correspondingly increases. Therefore, during the excavation design, the pipeline gradient α should be lowered to less than 35°, which will lower the pipeline's stress ratio to ensure that the pipeline is operating safely.

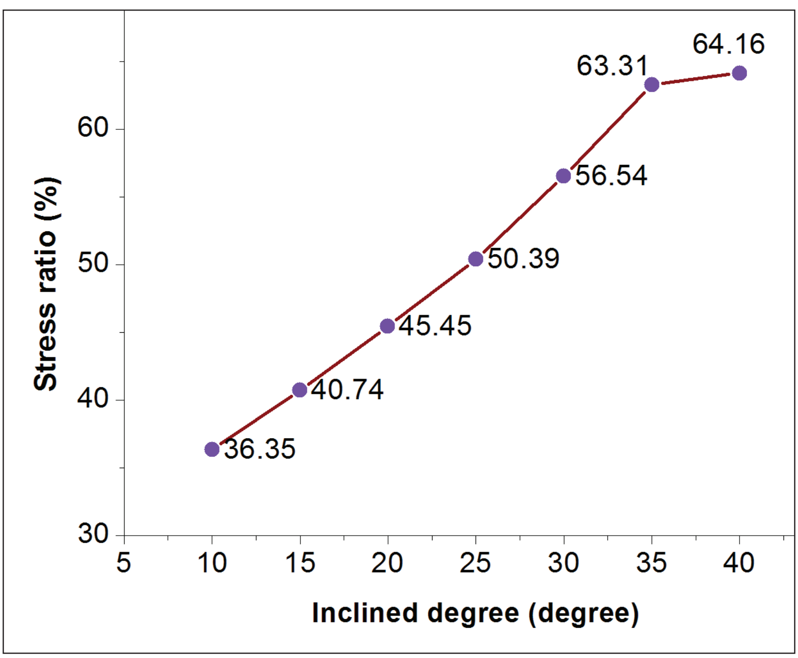


Fig.9. Equivalent combined stress ratio for different inclines in a pipeline

Analysis of the effect of the inclined pipe's length

In order to prevent exceeding stress because of a longer pipeline, it is necessary to analyze the inclined pipeline's maximum length. The entrance of the straight pipe is 10 m for the 24.5° inclined pipeline model, and the running condition is the base condition in order to confirm the maximum pipeline length.

The relationship between the highest stress concentration and the inclined degree of bending pipeline was analyzed. As shown in Figure 8, the entrance pipeline section is 24.5°, and the highest stress concentration verses the length (L) was analyzed.

After analyzing the maximum ratio of pipe section with different length, the ratio of maximum equivalent combined stress was growing with pipeline length. After fitting the maximum pipeline length diagram and the exponential figure, the corresponding limit pipeline length is: y=0.3742x+41.603 (Figure 10). When y=100 (equivalent combined stress ratio is 100%), the pipeline length limit is theoretically 156.05 m after calculation.

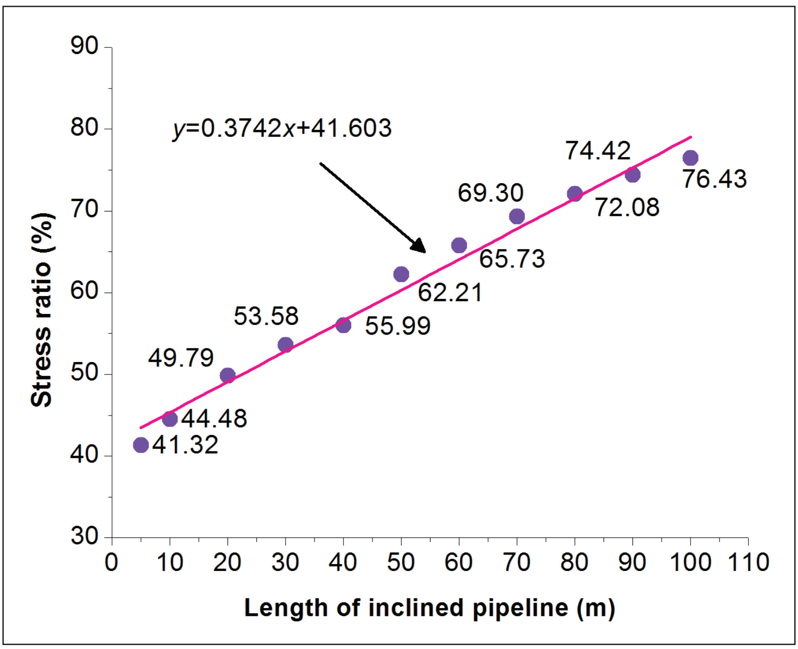


Fig.10. Ratio of maximum equivalent combined stress ratio for different inclined pipelines

Analysis of the pipeline's entrance and exit

The pipelines structure is 'inclined pipeline-horizontal pipeline-inclined pipeline', where the two inclined pipeline sections are symmetrical. Since the stresses from the two sides of a pipeline are affected by the entrance and exit (the flow direction), the stresses generated from the entrance and exit are unsymmetrical. Based on the pipeline model, 100 m pipeline sections on each side have been selected in order to compare the stress ratios of different flow directions. The entrance range is 0-100 m; the exit is 239-339 m. The stress distribution is shown in Figure 11.

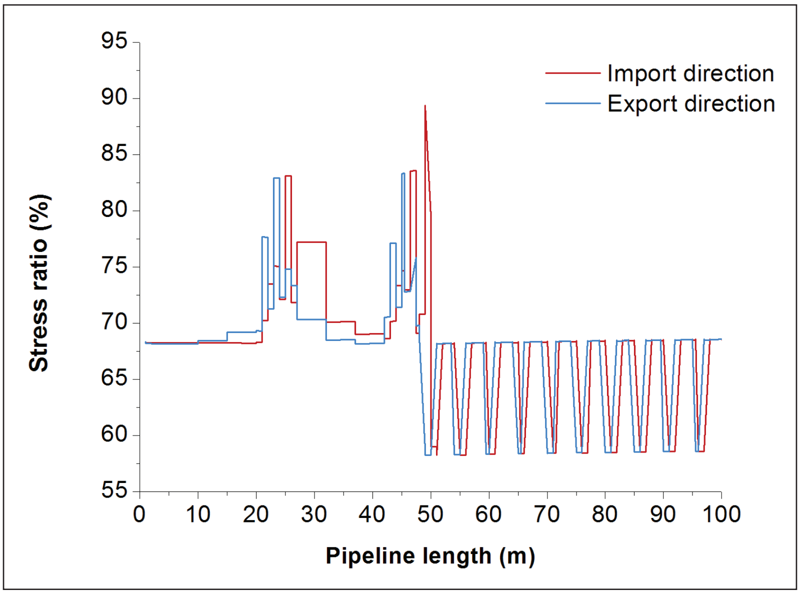


Fig.11. Equivalent combined stress ratios of entrance and exit

The flow direction in the symmetrical model is from left to right. By analyzing the equivalent combined stress ratio of the entrance and exit sections, the maximum equivalent combined stress ratio exists at the first saddle weight, and the stress ratio is 89.39%, which is at the entrance. The equivalent combined stress ratio for the entrance and exit are similar; in fact, the equivalent combined stress ratio of the entrance is almost the same. During the excavation, the most vulnerable zone is located at the entrance, so the pipeline entrance needs careful calibration, especially at the first saddle weight.

Analysis on the distance of saddle weights

From the research data, it can be found that the distance of saddle weights is not certain, which always depends on empirical parameters. Taking a straight pipe as an example, and analyze stress change laws of pipelines with different distances. The results can be found in Table 5.

Table 5. Pipelines' stress ratio of different saddle weight distance

Distance (m)	2	6	10	12	16
Stress ratio (%)	69.38	69.47	69.32	69.38	69.47

From Table 5, it can be seen that with increasing distance, pipe stress changes little. Under the premise of preventing the pipeline floating, the distance between saddle weights can be increased, so as to reduce the construction cost.

Procedures to lower the stresses for hot oil pipelines

According to the stress analysis, the most vulnerable section is located underneath the first saddle weight, the key stress concentration point. Based on the importance of pipeline excavation and considering the difficulty of repair and maintenance after installation, lowering the first saddle weight's stress value is difficult, even for pipeline safety. As shown in Figure 5, the operation condition is set as the base condition, and the relationship between the bending pipeline and the first saddle weight was analyzed.

From Figure 12, the highest equivalent combined stress ratio decreases as the interval increases. When the distance increases from 1 m to 2 m, the stress ratio dramatically decreases from 65.58% to 40.65%, which is a 24.93% drop. However, as the distance increases, the decrease in stress starts to slow down. When the distance is larger than 5 m, the stress ratio increases less than 1% per meter as the distance increases.

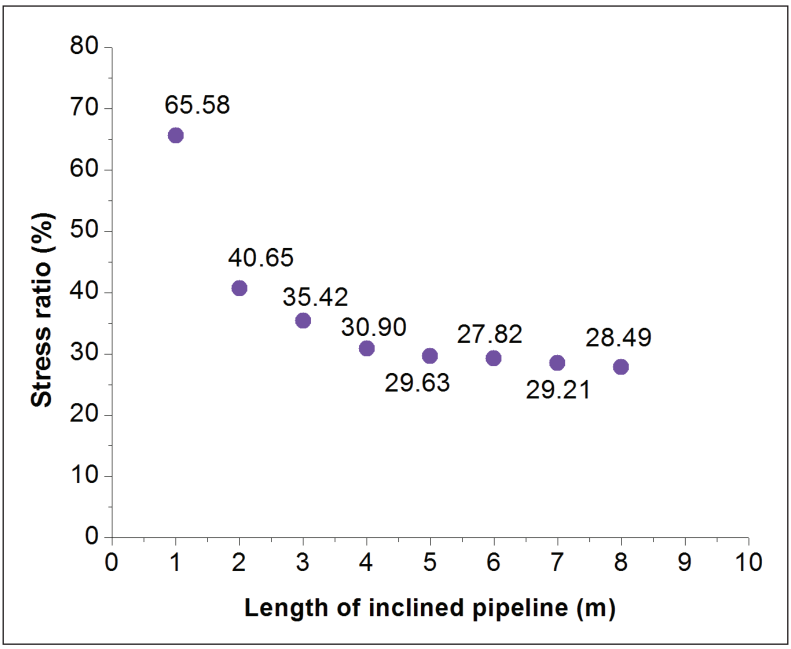


Fig.12. Comparison of maximum stress ratio between bending and saddle weight

CONCLUSIONS

In this paper, CAESAR II modeling is used for generating a method for building models of river-crossing pipelines. Performing a stress analysis of a river-crossing oil pipeline by excavation revealed that the maximum Secondary Stress and the equivalent combined stress are generated at the second saddle weight, which indicates that the saddle weight is the most dangerous cross-section location. By comparing the primary stress, secondary stress and equivalent combined stress, temperature was found to be the main factor affecting the oil pipeline stress distribution, while the internal pressure was found to be the secondary factor.

After analyzing the stress from the inclined pipeline, limit length and entrance, and the natural gas exit, the following conclusions were made: 1) During the excavation design, the inclined degree should be set at less than 35 in order to ensure pipeline safety. 2) Based on the analysis of limit length, the excavation depth is normally controlled in the allowable extent. 3) The most vulnerable location is located at the entrance, so the area should be carefully calibrated, especially at the first saddle weight.

Based on the analysis results, a procedure designed to lower the stress is suggested, and the first saddle weight between the bend and saddle weight is 4 m, in order to ensure pipeline safety. Furthermore, a method of analyzing the stress factor is proposed, which may be used by engineers and designers, and at the same time, the suggested vale extent is derived.

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