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Research Article

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Stress analysis of oil and gas pipeline parallel laying when traversing tunnels

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ABSTRACT

China-Myanmar oil & gas pipeline project covers 7,676 miles in all. The project met with complex geological conditions, construction types along the line, and long-distance oil & gas parallel laying pipeline. Because the pipeline layout and the construction are more complicated, it is necessary to make the stress analysis of oil & gas parallel laying pipeline traversing tunnels. Software CAESAR II is used to make numerical simulation on one section of oil & gas parallel laying pipeline. Through analysis we can get the main load infector effecting oil & gas pipeline stress, and the location of the most dangerous section. In the end, some feasible suggestions can be put forward for the security of oil & gas parallel laying pipeline according to the analysis conclusion.

Key words: Oil & Gas Parallel Laying Pipeline; Stress Analysis; CAESAR II; Numerical Simulation

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INTRODUCTION

China-Myanmar oil & gas pipeline project is the fourth energy input access after Central Asia oil and gas pipelines, the China-Russia crude oil pipeline, and sea-lane. This project concludes oil and gas pipeline, delivering oil into China from Southwest China instead of Malacca. It covers 7,676 miles in all, along with variety of geological conditions, such as Castor physiognomy of Yunnan-Guizhou plateau. As a result, different kinds of crossing methods are required for different regions.

The general crossing methods are shield method and mining method when crossing the mountains and large rivers, the structural form of tunnel is "deviated well-drift-deviated well". According to the current situation and research data, tunnel uses the form of pipe rack support, and import and export will be respectively installed with fixed buttresses, which are used to block the outside pipelines' effect on the tunnel [1-3].

Design of the tunnel crossing pipe installation is divided into three stages: choice of pipeline installation, piping arrangement and pipeline stress analysis. Terrain limitations and maintenance inconvenience lead to more serious the consequences of the accident for the crossing pipeline. Crossing pipeline failure for many reasons, in addition to the unreasonable design, construction quality problems, failure of pipeline corrosion, pipeline fatigue failure and other reasons, there is another important reason is that the bends cannot meet the strength requirements. Pipeline design is the basis of the quality of construction, the reasonableness of pipeline design is directly related to the structural safety of the pipeline.

Mostly recently, the China-Myanmar gas pipeline has put into operation, sooner will be the oil pipeline. Experts did less study on the stress analysis of oil & gas parallel laying pipeline crossing tunnels. Additionally, maintenance repair for pipeline under tunnels is difficult, and the oil & gas parallel laying pipeline layout is more complicated. Therefore, filling blanks of this technology as well as improve pipeline safety, it is necessary to make a stress analysis in detail towards oil & gas parallel laying pipeline traversing tunnels.

EXPERIMENTAL SECTION

Stress analysis method based on the finite element

Pipeline stress analysis usually use the of the finite element software, finite element method is to simplify the complex engineering problems to relatively simple problems and then to solve this problem. As for pipeline stress analysis, it is hard to figure out the stress of any point on pipeline, thus some particular points are keys to stress calculation. Generally, the shorter the length of the infinitesimal, the results of stress analysis more accurate, but on the other hand, if the infinitesimal length is over-short, then the calculation process is longer, the computational burden heavier as well. In order to balance calculation accuracy and simplicity, usually stipulates the practical length on stress analysis, as it shows in Table 1.

Table 1 The finite element infinitesimal length

Diameter (mm)	Length of the adjacent nodes
D>304.8	L<20D
D⩽304.8mm	L<30D

Pipeline stress checking standards

Oil & gas parallel laying pipeline in project was buried build-in pipeline. Because of transmission medium and conditions (temperature, pressure,) were different, the stress checking standards were different, too. Gas pipeline followed *ASME B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and other Liquids.* According to different causes of stress, the types of stress can be divided into first stress, secondary stress and peak stress. Table 2 and 3 are check standards for gas and oil pipeline respectively [4-5].

Table 2 Check standards for gas pipeline

Type	Check requirements
Primary stress	$\sigma_L \leq [\sigma]$
Secondary stress	$\sigma_E \leq \sigma_a$
Peak stress	$\sigma_{OPE} \leq \sigma_s$

Table 3 Check standards for oil pipeline

Type	Check requirements
Primary stress	$\sigma_H \leq 0.72\sigma_a$
Secondary stress	$\sigma_E \leq 0.90\sigma_a$
Peak stress	$\sigma_{OPE} \leq 0.90\sigma_a$

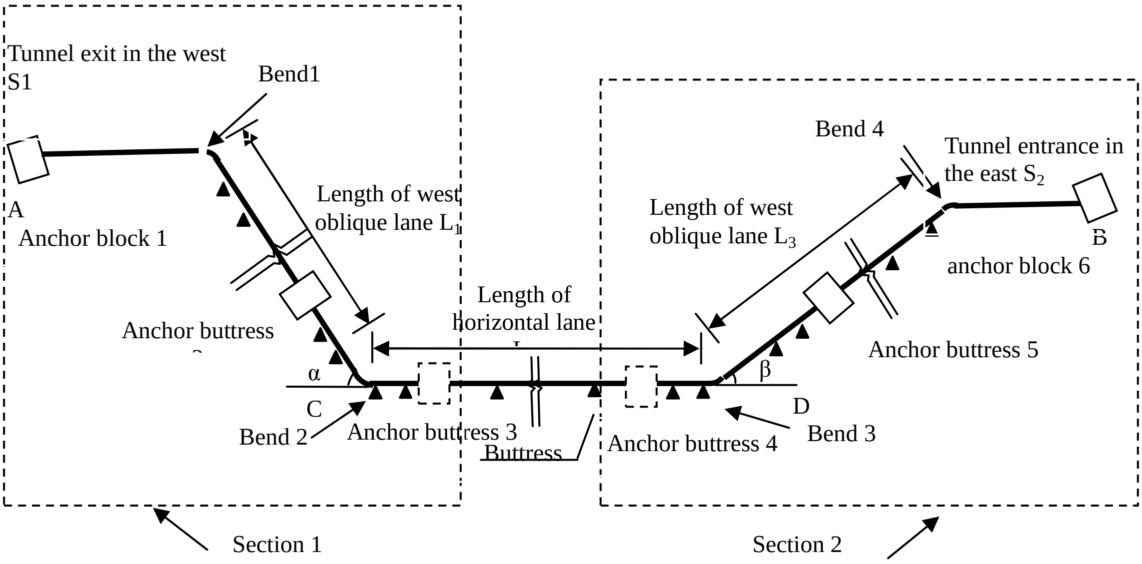

Fig. 1 Model for the tunnel structure

Tunnel model

Common layout of the pipe buttress and line in tunnel is shown in figure 1. The input and output pipeline is generally horizontal laid, with length at S_1 and S_2, without buttress; the length of west oblique lane is L_1, tilt angle is α (<50°), and the lines anchor buttress is set in the middle. At a distance of bend 2 and bend 3 in the horizontal lane is all set by lines anchor buttress, but many new pipelines has cancelled horizontal lane anchor buttress; the length of east oblique lane is L_2, tilt angle is β (<50°),at a distance of bend 3 is also set by lines anchor buttress. The two parts are almost symmetrical [6-9].

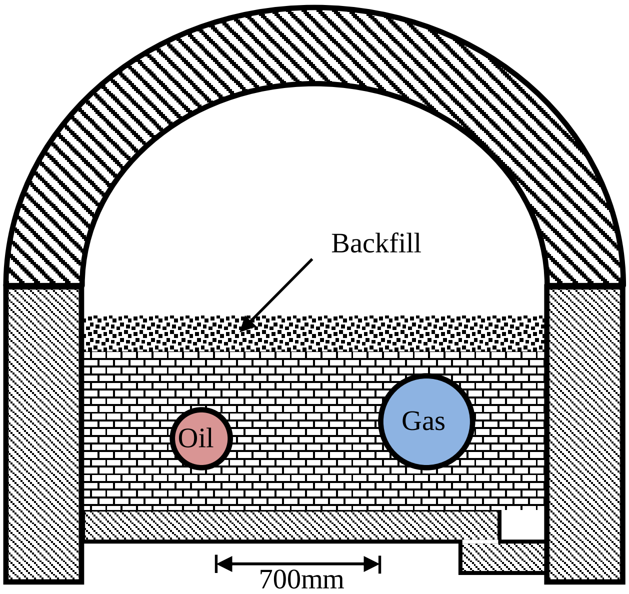

Fig. 2 Oil and gas parallel layout pipeline through the tunnel diagram

Software

In order to make the calculation simpler, we selected CAESAR II stress analysis program of the COADE, an American company. Its function is very powerful, in addition to static analysis and dynamic analysis of pipeline, it can also undertake the seismic analysis of buried pipeline, stress analysis of various components and the local joint, flange leak analysis etc, and considering the friction between the pipe element in the design, the simulation is consistent with real situation, then it can get more accurate results [10-12].

CAESAR II pipe stress analysis software can be divided into data input, choice of calculation conditions, the output analysis and judgments of three parts:

(1) Data classification: when calculation with CAESAR II, first of all, we should select and number the node which need analyze, to make the output results from the node data. Then, input data. According to the characteristics of the difference, input data is divided into pipe element structure characteristic parameters, basic parameters and boundary conditions. Pipe element structure characteristic parameters mainly refer to the shapes, structure characteristics, etc. of piping components in pipeline. Basic parameters mainly refers to the basic conditions of each pipe element in the piping, they are: calculation temperature, installation temperature, allowable stress, material grades, elastic modulus, Poisson ratio, medium density, density of piping material, thickness and the density of the thermal barrier, etc. Boundary conditions mainly refer to the piping system of each pipe element in the constraint condition, additional displacement, pipe endpoints type, cold spring, etc.

(2) Program operation: Though the program operation has been into fixed procedures performed by the computer, it must combine the calculation of conditions, and error check in process.

(i) Raw input data check

Before the calculation, computer would warn the mistakes about computation errors, at this time, design personnel are needed to check and correct the raw data according to the warning.

(ii) Choice of calculated conditions

Calculated conditions of peak stress: $L_1=W+T+P$, to get thrust of pipeline against the border;

Calculated conditions of first stress: $L_2=W+P$, to get the first stress of each point in pipeline;

Calculated conditions of second stress: $L_3=L_1-L_2$, to get the second stress of each point in pipeline;

Where *W* is self-weight load, *T* is temperature stress, *P* is inner pressure, *F* is concentrated load.

(3) Analysis and judgment of calculation results: after stress calculation of pipeline, we should analyze and judge the result, to confirm whether the data can meet with the requirements.

(4) Analysis and judgment about displacement: when the first and second stress in pipeline up to standard, displacement judgment has nothing to do with pipeline strength reliability.

RESULTS AND DISCUSSION

Project profile

According to the design material of China-Myanmar oil & gas pipeline project section XX, the length, from entrance to exit of tunnel, is 1260 meters. In the tunnel, it is all pipe supported, anchor block 4 and anchor block 7 are set in entrance and exit respectively to cut the affection of outside towards pipeline inside the tunnel. The entrance of tunnel is 30 meters in length, one anchor block; the length of west oblique lane is 310 meters, tilt angle is 25°, 16 anchor blocks are set every 18 meters, one line anchor buttress(in the middle of west oblique lane, 144 meters to horizontal lane); the length of horizontal lane is 410 meters, 22 buttress; the length of east oblique lane is 453 meters, tilt angle at 20°, 24 anchor blocks are set every 12 meters, one line anchor buttress(in the middle of east oblique lane, 144 meters to horizontal lane); The exit of tunnel is 34 meters in length, one anchor block; in addition, gas pipeline roasted bend radius of curvature R= 6D, crude oil pipeline pipe bending curvature radius R=10D, D as the pipe diameter, area grade is 3.

Numerical simulation needs two pipeline, the length of model is 1240 meters, in which tilt section is 763 meters, input horizontal length is 33 meters, output lane is 34 meters, and the distance between two pipelines is 700mm. Pipeline material of gas pipeline is APIX80, with 1016mm diameter straight saw pipe, the straight pipe and the bend section thickness is 18.4 mm and 22.2 mm respectively, operation temperature is 50℃, pipe material allowable stress is 555 MPa, operating pressure is 10 MPa, specific pipeline parameters are shown in table 4. Pipeline material of oil pipeline is APIX70, with diameter at 1016mm, the thickness is 7.9 mm, operation temperature is 25℃, pipe material allowable stress is 485 MPa, operating pressure is 9 MPa, specific pipeline parameters are shown in table 5. Table 6 showed the soil parameters.

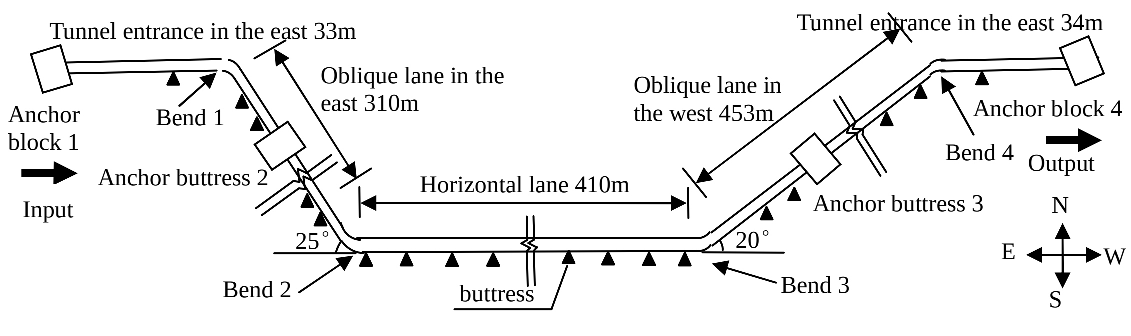

Fig. 3 Tunnel traverse in China-Myanmar oil & gas pipeline project section XX

Table 4 Gas pipeline parameters

Material	Diameter[mm]	Wall thickness of straight pipe [mm]	Wall thickness of bend [mm]	Corrosion[mm]
API X80	1016	18.4	22.2	1
Fluid density[kg/m^3]	Insulating layer thickness[mm]	Pressure[MPa]	Temperature[℃]	Allowable stress[MPa]
95	0	10	50	555

Table 5 Crude oil pipeline parameters

Material	Diameter[mm]	Wall thickness of straight pipe [mm]	Wall thickness of bend [mm]	Corrosion[mm]
API X70	610	7.9	7.9	1
Fluid density[kg/m^3]	Insulating layer thickness[mm]	Pressure[MPa]	Temperature[℃]	Allowable stress[MPa]
950	60	9	25	485

Table 6 Soil parameters

Friction coefficient	Soil density (kg/m3)	Buried depth to top of pipe (m)	Friction angle(°)	Yield displacement factor	Overburden compaction multiplier	Thermal expansion coefficient
0.4	2400	1.20	30	0.015	4	11.214

Result analysis

In software CAESAR II, one document can only have one pipeline, in order to realize the stress analysis of oil and gas parallel laying pipeline, we need to use commend *coordinate* to change the location of the datum axis so that to combine two pipeline models together. Figure 4 is the diagram of oil and gas parallel laying pipelines in the west and east part.

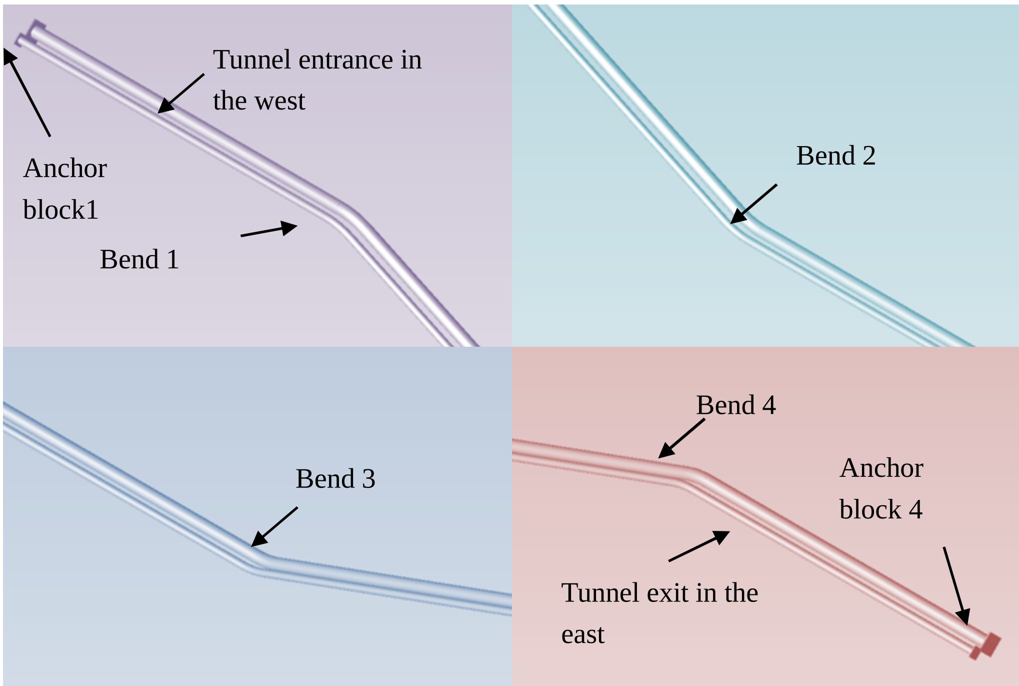

Fig. 4 Operating interface of the section modeling using CAESAR II

Through the stress calculation of each node from CAESAR II, we collect all data into Excel and draw the polygon. It is easier to know the overall stress distribution of pipeline through image file.

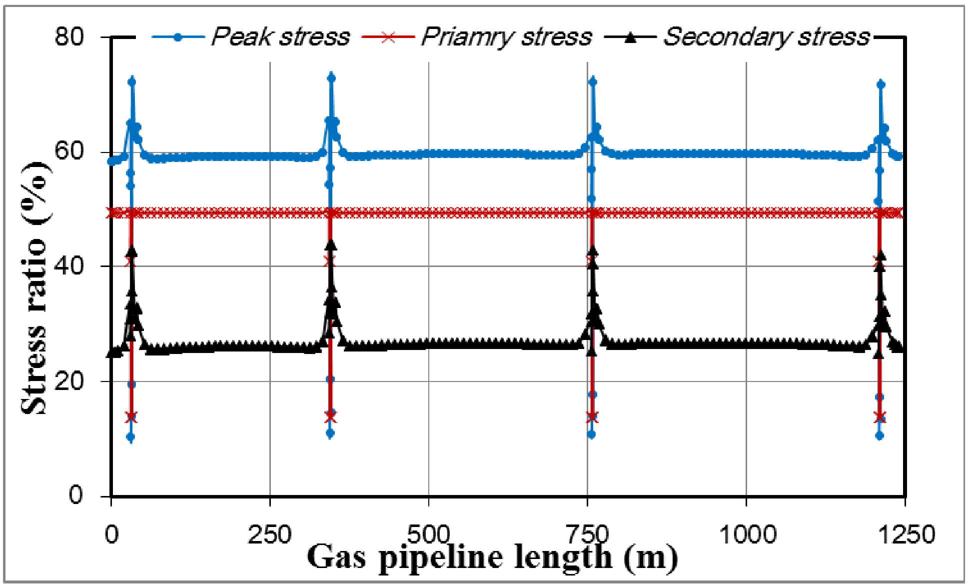

Fig. 5 Stress distribution of gas pipeline

Table 7 Gas pipeline stress check

Stress Type	Maximum stress value (MPa)	Maximum stress ratio (%)	Location	Stress check value (MPa)
Peak stress	362.19	72.96	Bend 2	496.42
Primary stress	245.38	49.43	Bend 2	496.42
Secondary stress	169.58	43.92	Bend 2	386.11

Table 8 Oil pipeline stress check

Stress Type	Maximum stress value (MPa)	Maximum stress ratio (%)	Location	Stress check value (MPa)
Peak stress	321.58	74.03	Anchor block1	434.39
Primary stress	308.89	88.89	Anchor block 1	347.50
Secondary stress	41.27	9.95	Anchor block 1	434.39

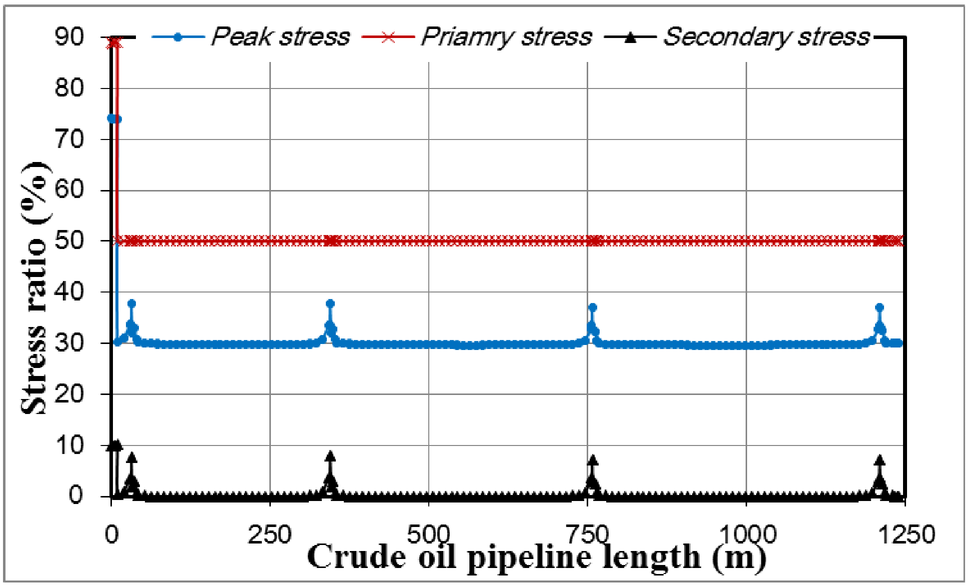

Fig. 6 Stress distribution of oil pipeline

Figure 7 and figure 8 is stress check situation of gas and oil pipeline, figure 5 and figure 6 is the distribution picture of peak, first, second stress ratio of gas and oil pipeline, respectively. From contrast, it is obviously that:

(1) From the stresses check of gas and oil pipeline, the stress of oil and gas parallel laying pipeline in C-M pipeline project section XX up to the standard ASME.
(2) From table 7, we can figure that: the peak, first, and second stress of gas pipeline were all happened at Bend 2, that is to say, Bend 2 is the biggest danger section in gas pipeline .
(3) From table 8: the peak, first, and second stress of gas pipeline were all happened at Anchor block 1, that is to say, Anchor block 1 is the biggest danger section in oil pipeline.
(4) From figure 5: for gas pipeline, the peak stress is larger than the first and the second stress, then is the first stress, and the second stress comes to the last. It means pipe thermal stress caused by temperature change affect little to gas pipeline safety.
(5) From figure 6: for oil pipeline, the first stress is larger than the peak stress and the second stress, it means load from outside (including gravity, intrinsic pressure) affect a lot to oil pipeline stress. In the figure, we can also see the average second stress is very small, the largest is 41.27 MPa, 9.95% of the stress check value, it means temperature has less influence towards oil pipeline stress.
(6) From figure 6, we can also know that: at the start of pipeline model, that is to say the anchor block 1, the peak, the first, the second stress is much larger than average stress, which means anchor block 1 undertook much stress.

CONCLUSION

Through the stress analysis of oil and gas parallel laying pipeline in C-M pipeline project section XX, we knew the location of dangerous section and the main load affecting pipeline stress during the process of gas and oil pipeline crossing tunnel.

As for gas pipeline crossing tunnel, band 2 is the dangerous section. Therefore, except for reinforcing in bends, the bend of oblique lane bottom on the gas direction should be paid much attention. If the stresses on bends are not qualified, increasing the wall thickness or adjusting the bend angle is expected.

As for oil pipeline, the stress analysis told us that the main loads affecting oil pipeline stress are gravity, inner pressure, etc.; it is because the gravity has put much influence on oil pipeline. As a result of thermal insulation layer and the soil, the second stress caused by temperature is much smaller. In a word, anchor block 1 undertook a huge stress; it is suggested to reinforce and add the pipe constraint at tunnel portals, or to change the pipeline direction to absorb a part stress using the nature bends at tunnel portals.

This research filled the technique blank of stress analysis toward oil and gas parallel laying pipeline traversing tunnels, and provided a certain foundation on protecting pipeline safety as well.

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