Application of Stress Analysis Software in Oil and Gas Pipeline

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Abstract. With the rapid development of China's national economy, the development of the petrochemical industry is particularly rapid, high-temperature and high-pressure pipelines are widely used in the oil and gas storage and operation industries. The design level becomes the key to measuring whether a design unit can win in the fierce market competition, and one of the core technologies is the stress analysis of the pressure pipeline. CAESAR II pipeline stress analysis software is more popular in the international one of pipe stress analysis software. Its data input is simple and the graphic display is intuitive, which is easy for beginners to master, but also has a strong engineering practicality. This article will discuss the advantages and problems of CAESARI stress analysis software in practical applications, and use examples to perform relevant analysis.

1. Purpose of stress analysis of oil and gas pipelines

With the development of China's national economy, the construction of oil and gas pipeline facilities and other infrastructure has gradually increased, the construction length has been greatly increased, and the construction environment has become more complicated, which has brought new requirements for the stress safety analysis of pipelines. CAESAR II as recognized pipe stress checking software is widely used in pipeline design. The so-called stress analysis of the pipeline refers to a physical concept that reflects the difficulty of deformation of the pipeline, that is, the ability of the pipeline to absorb thermal expansion and cold contraction and other displacement deformation through its own deformation. Through the stress calculation of the pipeline, the following objectives can be achieved [1]:

1) Make the stress in the pipes and fittings not exceed the allowable stress value;
2) Make the pipeline load of the equipment connected to the piping system within the allowable range of the manufacturer or international norms;
3) Make the local stress of the pipe orifice of the equipment connected with the piping system meet the requirements of the specification;
4) Calculate the design loads of supports and constraints in the piping system;
5) Optimize piping design.
2. The establishment of stress analysis model and its analysis process

2.1. Determination of calculated temperature and calculated pressure

Because the design temperature and design pressure are usually too conservative, and the pipeline is running under normal operating conditions for most of the time, in general, the calculated temperature and calculated pressure can be taken as the operating temperature and operating pressure, but the most unfavourable situation should be considered. When the design temperature and design pressure are not much different from the operating temperature and operating pressure, the calculated temperature and calculated pressure can also be taken as the design temperature and design pressure. In short, the calculated pressure of the pipeline should not be lower than the highest pressure expected during normal operation or the corresponding operating pressure at the harshest temperature; The calculated temperature of the pipe shall not be lower than the maximum (minimum) temperature expected in normal operation or the harshest temperature under other working conditions, and the maximum (minimum) value shall be taken, or both shall be considered for calculation. Working conditions with special requirements for the process (referring to the coupling of temperature and pressure) should also be considered [2].

2.2. Analysis process

The stress analysis of the pipeline can be divided into static analysis and dynamic analysis. The pipeline stress analysis conducted recently is mainly static analysis. The static analysis of the pipeline system requires calculation conditions (temperature, pressure, etc.), pipeline material properties (elastic modulus, the coefficient of linear expansion, allowable stress, etc.), pipeline size (diameter, Wall thickness, length, spatial direction, restraint method, etc.) are input into the CAESAR calculation program as basic data. These data have changed along the pipeline, and nodes have been established where changes have occurred. In this way, the whole pipe segment is divided into several units, and each unit is composed of two nodes. CAESAR II adopts the method of inputting unit by unit, and the input of units is completed by filling in forms. The CAESAR II software program is considered in three dimensions, that is, considering the three directions of X, Y, and Z. The program defines the first node coordinate as (0, 0, 0) by default.

CAESAR II program for input pipe shape have a graphical display function, and has a self-checking function for errors. The graphic display generally includes the following elements: the number and position of the nodes, the outer diameter of the pipe, the wall thickness of the pipe, the length of the pipe, the position and restraint form of the support and hanger, the thickness of the insulation material, the concentrated load and the uniform load the pipe bear, types of pipe materials and rigid components.

After the first input has been error checked, the first step of the pipeline model analysis is to define the static conditions. The possible loads on the high-temperature and high-pressure pipeline include gravity load (including pipeline weight, insulation material weight, medium weight, etc.), pressure load, displacement load (including pipeline thermal expansion and contraction displacement, end point additional displacement, etc.), seismic load, impact load, Transient flow impact load (such as pressure shock when the safety valve takes off and the valve quickly opens and closes), pressure pulsation load and machine vibration load (such as vibration of rotary equipment, etc.). After the load is determined, various loads are combined according to different requirements to judge the safety of the pipeline.

Judging the safety and reliability of the pipeline is different from the conventional pressure vessel design method. During the initial operation of the high-temperature and high-pressure pipeline, the pipeline is allowed to yield locally, or the stress in the opposite direction is pre-added by means of cold tightening method. The stress of high-temperature and high-pressure pipeline can be roughly divided into three categories: primary stress, secondary stress and peak stress. The primary stress refers to the stress generated by the internal pressure, self-weight and other external loads of the pipeline, which is self-limiting; the secondary stress refers to the normal stress and shear stress caused by the obstruction of pipeline deformation; The peak stress is the local structure of the pipe fitting that
is discontinuous, with stress concentration or local thermal stress, the sum of the attached to primary stress or secondary stress.

The static calculation results of the high-temperature and high-pressure pipeline generally include: the stress of each point of the pipeline, the stress of each constraint on the pipeline, and the displacement of each point on the pipeline, etc.

2.3. Points for attention
There are several issues to be noted in the use of CAESAR II, which are explained here.

After the first input is completed, the CAESARII program must perform data inspection before performing static calculations. For fatal errors that occur during the inspection process, the engineer must return to the Piping Spreadsheet state to make corrections in order to ensure the reliability of the data.

There are three commonly used combinations of working conditions [3]: one is the operating state (OPE): it is generally composed of gravity, pressure, uniform load, end point displacement, concentrated load and temperature; second is the continuous state (SUS): it is generally composed of a combination of gravity and pressure, also including concentrated load and uniformly distributed load.; the third is pure thermal state. (EXP): The difference value between the above operating state and the continuous state. The design of the working condition combination must be scientific. Pipeline stress check generally includes primary stress check and secondary stress check.

3. Application in a project

3.1. Basic information
A natural gas transmission pipeline has a diameter of 1016mm and a wall thickness of 19.2mm, the material of the pipeline uses L485. Due to routing restrictions, the pipeline must be laid on a steep slope section with a maximum slope of about 70 °. The high steep slope section has a horizontal length of 164.3m and a vertical height difference of 183.3 m, the stress calculation of the oil and gas pipeline under this working condition is required to analyze the safety of the pipeline during construction and operation. The basic parameters are as Table 1:

| Name                      | Unit | Numerical value |
|---------------------------|------|-----------------|
| Pipeline installation temperature | °C   | 5               |
| Maximum operating temperature | °C  | 25              |
| Design pressure            | MPa  | 10              |
| Test pressure              | MPa  | 12.5            |
| Soil type                  | —    | Sandy soil      |
| Buried depth of pipe top   | m    | 1.5             |
| Angle of soil internal friction | °   | 30              |
| Temperature change         | °C   | 20              |
| Degree of compaction       | —    | Medium compaction |

3.2. Model establishment
In the simulation of working conditions, two working conditions are adopted. The pipeline pressure test working condition is used to simulate the construction condition when the pipeline is not backfilled, and the pipeline operating condition is simulated after the pipeline backfill is used. The model is as follows:
3.3. Analysis results

3.3.1. Analysis results of pipeline pressure test conditions without backfilling. From the stress check results, the stress of the pipeline under all working conditions is within the allowable stress range, and the maximum normal stress (330 MPa) is only 76% of the allowable stress (434MPa). Thus, it can be seen that the pipeline is safe from Table 2.

Table 2. Stress distribution table of pipeline pressure test conditions without backfilling

| Node | Specification stress value (KPa) | Percentage of allowable stress (%) |
|------|---------------------------------|-----------------------------------|
| 10   | 331                             | 76.1                              |
| 20   | 123                             | 28.3                              |
| 30   | 331                             | 76.1                              |
| 40   | 108                             | 24.8                              |
| 50   | 124                             | 28.5                              |
| 60   | 113                             | 26.1                              |
| 70   | 103                             | 23.7                              |
| 80   | 104                             | 24                                |
| 90   | 331                             | 76.1                              |
| 100  | 105                             | 24.2                              |
According to the calculation results, under this working condition, the pipe is axially pulled and the maximum axial tension (internal force) is 630kN, which is located at node No. 10 (anchored pier). The maximum axial stress of the pipeline is 109MPa, which is the tensile stress and is located at the No. 10 node (anchored pier). When the pipeline is axially stretched, no axial instability will occur.

3.3.2. Analysis of operating conditions after pipeline backfilling. From the results of stress check, the stress of the pipeline under the operating conditions is within the allowable stress range, and the maximum is only 71% of the allowable stress. Thus, it can be seen that the pipeline is safe from Table 3.

Table 3. Stress calculation results of operating conditions after pipeline backfilling

| Buried model | Allowable stress [B31.8] | Maximum specification stress [B31.8] | Maximum axial stress | Maximum hoop stress | Determination         |
|--------------|--------------------------|---------------------------------------|----------------------|---------------------|----------------------|
| Extremum     | 434                      | 308                                   | 40                   | 264                 | Meet specifications  |
| Node number  |                          | 53                                    | 91                   | 11                  |                      |

3.3.3. Analysis conclusion. The calculated stress of the high and steep slope is less than the allowable value under the pressure test condition and the operating condition, and the pipeline is safe.

4. Conclusion
CAESAR II can be widely used in stress analysis of oil and gas storage and transportation pipelines, which makes the stress analysis of complex oil and gas pipeline systems more accurate, the pipeline system is more reasonable and safe, and can effectively improve the level of pipeline design and design efficiency.

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