Analysis of Influencing Factors of Equivalent Stress of Corrugated Steel Pipe Underground Comprehensive Pipe Gallery

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Abstract

With the continuous development of China 's national economy, the pace of urbanization is accelerating, the boundaries of cities are widening, and the contradiction between the speed of urban infrastructure construction and urbanization is gradually emerging. Problems such as road zippers, urban waterlogging, and aerial cobwebs continue to emerge, seriously affecting the image of the city.The underground integrated pipe gallery can promote the information upgrading of comprehensive operation and maintenance of intelligent underground pipelines, gradually realize the collection, real-time monitoring, automatic early warning and intelligent disposal of various operation and maintenance parameter information of underground pipelines, build a new standard system for intelligent construction of urban infrastructure, and improve the urban ecological infrastructure system.Most of the existing studies in China analyze the mechanical properties of steel bellows in the elastic stage, and there are few analyses on the mechanical properties of steel bellows culverts in the plastic state. In this paper, the plastic state of steel corrugated pipe culvert is analyzed, and the mechanical behavior of steel corrugated pipe under large deformation state is obtained.

Keywords

Steel Pipe; Plastic State; Finite Element; Equivalent Stress; Analysis.

1. Introduction

Underground utility tunnel refers to the public tunnel which is used to centrally lay municipal pipelines such as electric power, communication, radio and television, water supply, drainage, heat and gas in urban underground, which is called the ' lifeline ' of urban operation [1-4].. The urban underground comprehensive pipe gallery belongs to the long-distance linear structure, which needs to go through different geological landform along the way. Now the main structure types of the underground pipe gallery are cast-in-place reinforced concrete structure and prefabricated structure. The assembled steel utility tunnel structure adopts corrugated steel plate (pipe), which has been successfully verified in the application of highway bridges and culverts. It has good horizontal and vertical displacement compensation function in terms of deformation coordination. The whole steel utility tunnel structure and soil work together to form a ring pressure state through local beneficial deformation. In the construction of urban utility tunnel, steel corrugated pipe structure has attracted wide attention in the engineering field with many advantages, and has great development potential.

Compared with rigid concrete members, the steel corrugated pipe utility tunnel has the following advantages [5-9]:

(1) Under the condition of 5 % deformation, it still has high compressive strength and ring stiffness, which can effectively avoid uneven settlement.

(2) After special anti-corrosion treatment, the service life can reach 100 years.

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(3) 10 % of the weight of concrete precast structure, transportation costs, construction hoisting.

(4) A variety of cross-section shape structure in various forms, there are elbows, tee, four-way.

(5) Fast construction and high construction efficiency ; installed in front, the back can be backfilled ; construction is not affected by seasonal climate, and can be carried out all year round.

(6) Cost-effective, compared with other materials, the comprehensive cost can be reduced by more than 20 %.

2. Calculation and Finite Element Modelling of Steel Corrugated Pipe Culverts

2.1 The Iowa Formula

M.G Spangler conducted an investigation on the relationship between soil variation and pipe culvert deflections [10-13]. In this study, it was assumed that the loads exerted on the culvert were evenly distributed at the top, and the coefficients for soil passive resistance were determined by a field experiment. The Iowa assumption is depicted in Fig. 1.

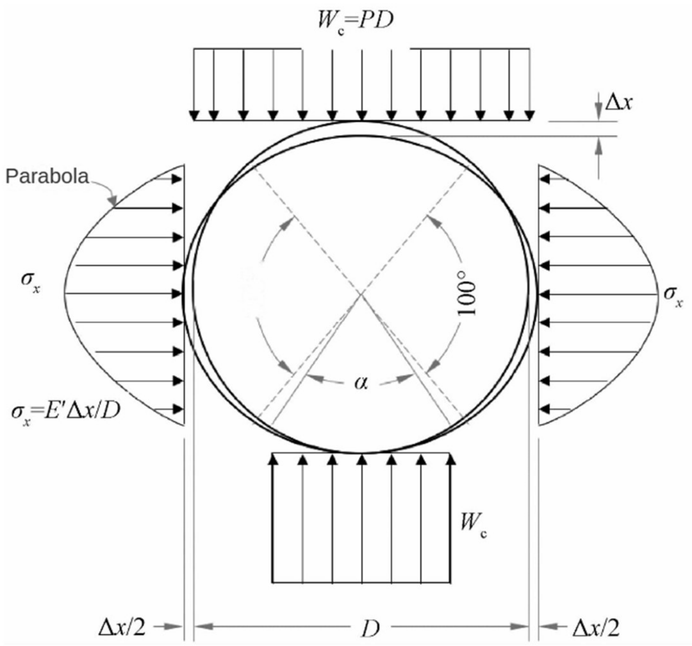

Fig. 1 The Iowa formula assumes

The Iowa formula serves as the foundation for theoretical examination of flexible buried pipelines [14-16]. This study should be grounded in the diverse characteristics of the pipe and involve an assessment of the structural attributes of both the pipe and the surrounding soil. The formula is expressed as follows:

$$\Delta x = \frac{D_L K W_c r^3}{EI + 0.061 e r^4} \tag{1}$$

2.2 Finite Element Modelling of Steel Corrugated Pipe Culverts

2.2.1 Establishment and Selection of Constitutive Model of Soil

Soil is composed of soil particles, pore water and gas. In most practical applications, the geometric size of the soil is very large, the microscopic effect is homogenized, and it is idealized as a continuum. Its mechanical properties can be studied in the framework of continuous medium mechanics, that is, the upper material is regarded as a continuous medium or solid material at the macro level. The

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constitutive model of soil material is to establish the mathematical model of the macroscopic properties of soil material [17]. The establishment of the constitutive model of soil is to make appropriate mechanical description and mechanical calculation for the deformation of the upper body material under load from both qualitative and quantitative aspects according to the different conditions of stress development. The research on the deformation characteristics of soil under load is mainly divided into nonlinear elastic theory and elastic-plastic theory. The nonlinear elastic theory is a stress-strain relationship established on the basis of the elastic theory E, considering the nonlinear characteristics of the soil material. The elastic-plastic theory is to apply the classical plastic theory to the constitutive relationship of the soil, considering some special properties of the soil, so as to establish the elastic-plastic theoretical model of the soil [18].

According to the research on the deformation characteristics of soil by nonlinear elastic theory and elastic-plastic theory, the nonlinear constitutive models of soil mainly include Duncan-Chang nonlinear elastic model, Drucker-Prager ideal elastic-plastic model, modified Cambridge model and Lade double yield surface model. Because the Drucker-Prager yield criterion is used in the calculation of the nonlinear finite element software ANSYS, in order to facilitate the comparison with the general finite element software ANSYS, the program in this paper adopts the same yield criterion as ANSYS [19-20]. Due to the limited time, this program only uses Drucker-Prager ideal elastic-plastic model, other models can continue to supplement in the future research.

2.2.2 Build Finite Element Model

The steel bellows structure is discretized into an 8-node 181 shell, enabling accurate simulation of the forces and deformations experienced by thin steel structures. The foundation soil, along with the backfill and gravel bedding structure, is represented as a cohesive unit in the discretized model. To simulate its behaviour, an 8-node solid 185 element with compressible properties is chosen. The corrugated steel pipe exhibits a wavelength of 200mm, a wave height of 55mm, a thickness of 7mm, and a diameter of 5m. The horizontal direction of the corrugated pipe on each side of the pipe culvert is equal to 1.5 times the diameter of the pipe culvert, resulting in a distance of 20 meters, denoted as 4D. The foundation model incorporates a height of 1 metre, while the upper section of the pipe is filled with backfill material that has a diameter twice that of the pipe.

The contact surface between the soil and the steel bellows exhibits varying degrees of freedom. These degrees of freedom are crucial in establishing the connection between the shell unit and the solid unit through the employment of the MPC coupling method. The boundary conditions imposed on either side of the soil mass solely restrict the horizontal deformation. The bottom of the soil body is subject to consolidation constraints, and the rest of the surface is set as a free surface.

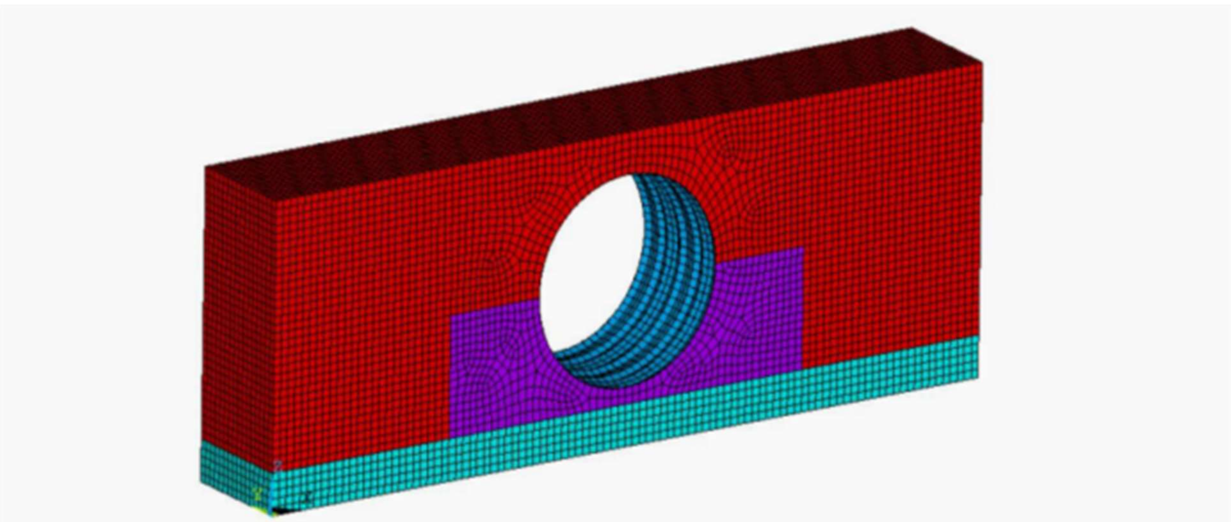

Fig. 2 Steel Corrugated Pipe Culvert Model

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2.2.3 Material Parameter

Table 1. Material Parameter

Parameters	Corrugated Steel Pipe Culvert	Foundation	Bedding Soil	Backfilling Soil
Modulus of Elasticity (MPa)	210×10^3	200	150	60
Poisson's Ratio	0.3	0.25	0.25	0.3
Density (kg/m^3)	7.85×10^3	2.2×10^3	2.0×10^3	1.80×10^3

2.2.4 Working Condition

Table 2. Finite Element Simulation Condition

Working Condition	1	2	3	4	5	6	7	8	9	10	11
Backfilling Soil(m)	20	24	28	32	36	40	44	48	52	56	60

2.2.5 Measuring Point Position

Seven measuring points were taken on the section of the steel corrugated pipe culvert. The position of the measuring points taken by the pipe culvert model is shown in the figure :

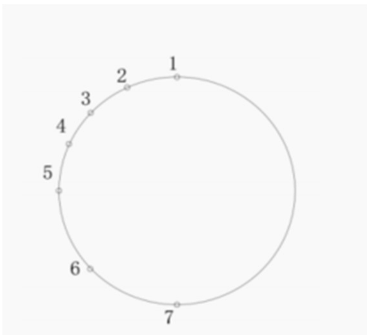

Fig. 3 Steel wave pipe culvert measuring point location selection

3. Equivalent stress analysis of pipe culvert

3.1 Variation of equivalent force with pipe diameter

Equivalent stresses at the location of measurement point 1 of each pipe culvert were selected for analysis.

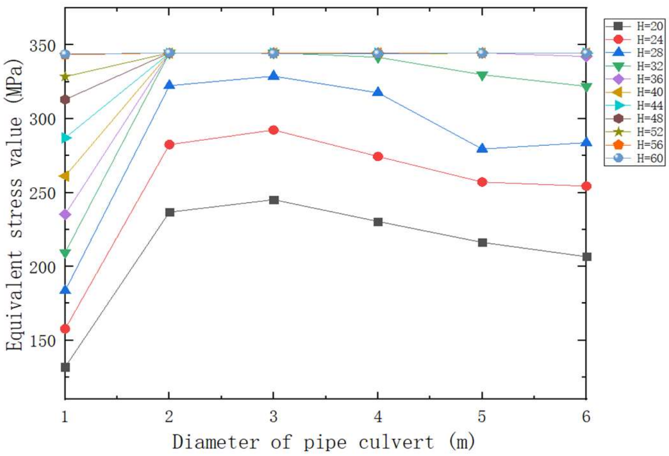

Fig. 4 Changes of different equivalent stress values with pipe diameter

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From the figure, with the increase in pipe diameter, when the equivalent force value at the top of the pipe culvert is less than the yield strength of the steel corrugated pipe culvert, the equivalent force of the pipe culvert becomes larger with the increase in pipe diameter. When the equivalent force of the pipe culvert reaches the yield strength, the steel corrugated pipe culvert enters the plastic stage, and its equivalent force tends to increase with the increase in pipe diameter.

3.2 Variation of Equivalent Force at Measurement Points with Pipe Diameter

Select the filling height of 60m when the steel corrugated pipe culvert has been in the plastic state. The study of the steel corrugated pipe culvert in the plastic state of the equivalent force of each measurement point with the change rule of the diameter of the pipe.

With the increase in pipe diameter, it did not reach the yield strength of the measurement point. The equivalent force value gradually increased, and when it reached the yield limit, in addition to the measurement point 7, the rest of the measurement point of the equivalent force value tends to stabilise. The equivalent force of the measurement point 7 with the increase in diameter of the pipe gradually decreased. This is because at the bottom of the pipe there is a good cushion layer.

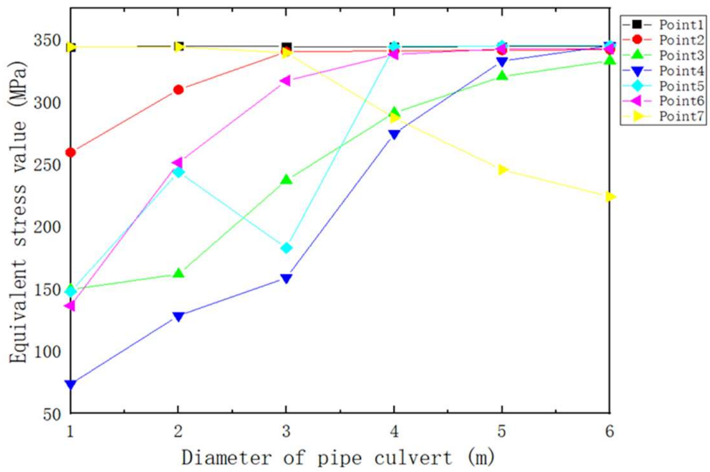

Fig. 5 Equivalent stress values at different measuring points

3.3 Changes in the position of the peaks and troughs on the equivalent force

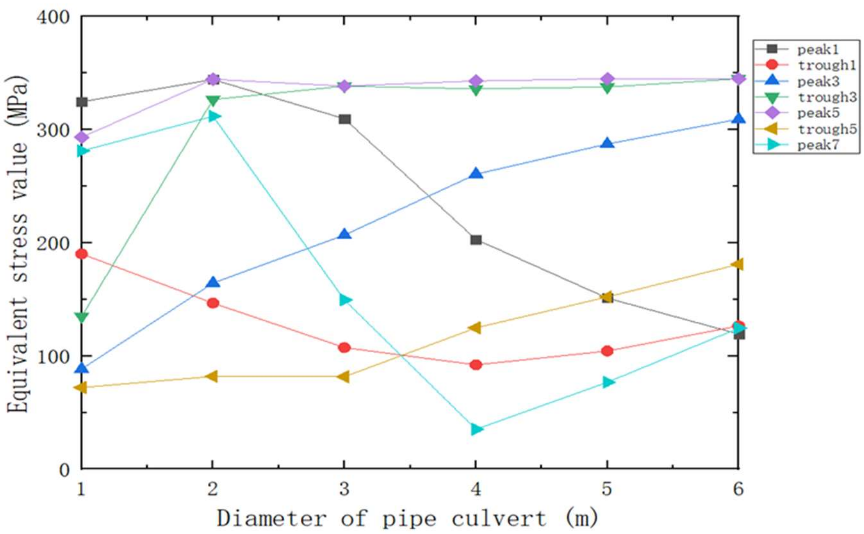

Fig. 6 Comparison of peak and trough equivalent stress at each measuring point

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As can be seen from the figure13, the peak position of measurement point 1 remains unchanged with the increase of the diameter of the pipe culvert, but the trough position gradually decreases with the increase of the diameter of the pipe culvert. The rest of the measurement points of the peak and trough position show the same rule of change, and the equivalent force of the peak of each point is greater than that of its trough equivalent force. Due to the existence of waveforms, the wave crest position is the first to be loaded by the soil pressure, so the stress at the wave crest position is greater.

3.4 Variation of Equivalent Stress with Fill Height

Variation of the equivalent stress value with fill height at measurement point 1.With the gradual increase of the filling height, the equivalent force of each diameter of the pipe culvert is increased. When the steel corrugated pipe culvert is in the elastic state, the equivalent force in the filling height is a linear increase in the change. When it reaches the plastic state, the equivalent force of each diameter of the steel corrugated pipe culvert is gradually converging to the yield strength.

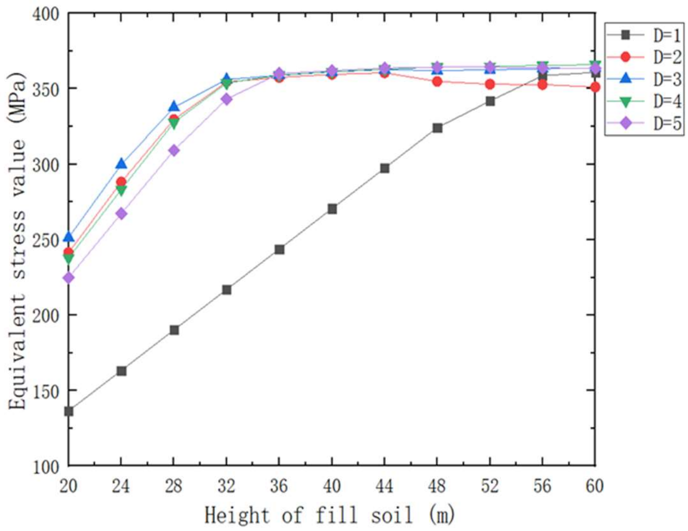

Fig. 7 Change of equal effect force with filling height under different pipe Diameters

3.5 Variation of the Equivalent Force at the Measurement Point with the Height of the Fill

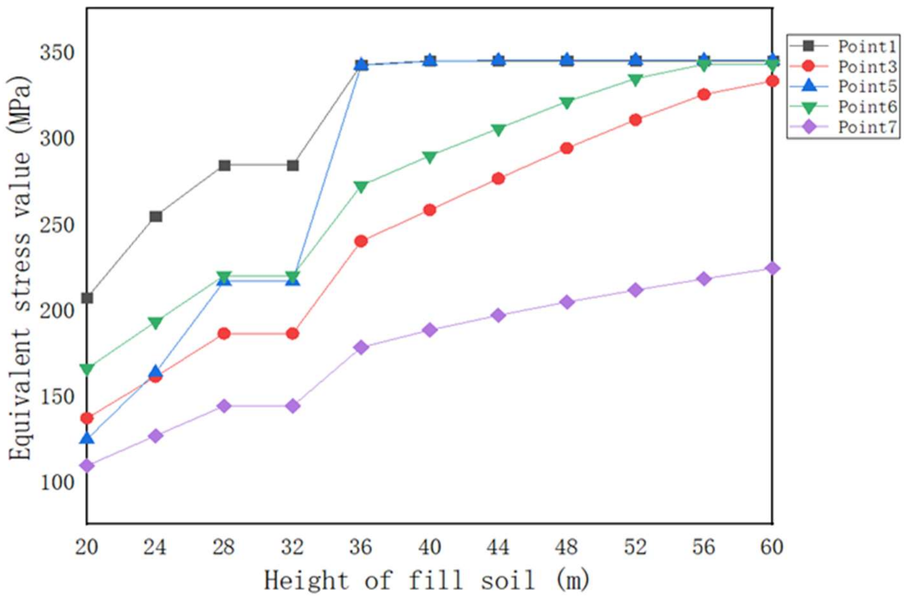

Fig. 8 The equivalent stress of each measuring point varies with the filling height

Each measurement point of the pipe culvert under 6 m of pipe diameter was selected for simulation with the increase in filling height.It can be seen that the equivalent force at the top of the pipe culvert (measurement point 1) is greater than that at the rest of the measurement points during the elastic phase. And with the gradual increase of the filling height, the equivalent force of point 5 grows the fastest, the equivalent force of point 3 and point 6 grows at the same rate, but the equivalent force of point 6 is larger than the equivalent force of point 3. When the filling height is 60m, the upper part of the pipe culvert basically reaches the yield strength.

4. Conclusion

(1)For the equivalent stress, with the increase of pipe diameter, the equivalent stress of the pipe culvert increases with the increase of the diameter of the pipe culvert. When the steel corrugated pipe culvert enters the plastic stage, its equivalent stress tends to a fixed value with the increase of pipe diameter.

(2)The peak position of the measuring point 1 remains unchanged with the increase of the diameter of the pipe culvert, but the trough position gradually decreases with the increase of the diameter of the pipe culvert. The peak and trough positions of the other measuring points show the same variation law, and the peak equivalent stress of each measuring point is greater than its trough equivalent stress.

(3)The equivalent stress at the top of the pipe culvert is greater than the equivalent stress of the remaining measuring points. With the gradual increase of filling height, the equivalent stress growth rate of measuring point 5 is the fastest, and the equivalent stress growth rate of measuring point 3 and measuring point 6 is the same, but the equivalent stress of measuring point 6 is greater than that of measuring point 3.

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