Structural Analysis of Steel Bifurcation Pipe with a Crescent Rib in a Hydropower Station

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Abstract. In hydropower project, steel bifurcated pipe is a key diversion structure, and its stability and safety are very important. However, there are still some deficiencies in the current research on the mechanical behavior of steel bifurcated pipe, especially in the open and buried state. In this paper, the working conditions of steel bifurcated pipe in hydropower station under open and buried state are analyzed in detail. Mises stress distribution in the open pipe state was studied and it was found that the maximum stress concentrated in the pipe joint and the inner bottom of the crescent rib, but did not exceed the yield strength of the material. Besides the crescent rib, the tensile stress distribution in other pipe joints had a certain regularity. The influences of clearance value and elastic resistance coefficient on the stress and rock sharing ratio of steel bifurcated pipe were studied by sensitivity analysis. The results show that the structural stress is homogenized and the stress distribution is symmetrical when considering the action of surrounding rocks. This paper summarizes the stress characteristics of steel bifurcated pipe without considering the action of surrounding rock and the change law of surrounding rock sharing, which provides important theoretical support and design reference for hydropower station engineering.

Keywords: steel bifurcation pipe; crescent rib; Structural analysis; hydropower station

1 INTRODUCTION

Steel bifurcation pipe is one of the important pipeline structures in hydroelectric power plants, which is used to guide water flow and control the flow direction and pressure of water flow. The analysis of steel bifurcation structure is one of the key links to ensure the safe and reliable operation of hydropower station. Shaohong P et al. deeply discussed the design and analysis method of steel bifurcated pipe in hydropower station, introduced various stress conditions of turnout pipe structure and how to make a reasonable design according to water pressure[1-3]. The stress distribution and variation

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of steel bifurcated pipe under different water level and flow conditions are also discussed, which provides an important reference for hydropower engineers. Kraszewski B et al. used the finite element method to conduct a detailed analysis of the stress of steel bifurcation pipe in hydropower station under hydrostatic pressure. The results show that the stress distribution inside the bifurcated pipe is different under different water level and pressure conditions. In order to improve the safety and stability of the bifurcated pipe, an optimal design scheme is proposed by simulating the force under different working conditions[4-6].Some important research results have been provided in the field of structural analysis of steel bifurcations in hydropower stations, including bifurcations design, finite element analysis, structural health monitoring and seismic design[7-8].

Although some aspects of steel forked pipe have been deeply discussed in the past studies, there are still many unknowns about the stress distribution and its influencing factors in the open and buried state. Especially when considering the action of the surrounding rocks, how to change the stress state of the steel forked pipe is still an urgent problem to be solved. Therefore, this paper aims to fill the research gap and deeply explore the mechanical behavior of steel bifurcated pipe under different working conditions, in order to provide a more accurate theoretical basis for the design of hydropower station engineering

2 ANALYTICAL METHOD

The buried steel bifurcation pipe is adopted in the water diversion of a hydropower station. The shape of the steel bifurcation pipe is symmetrical "Y" shape with inner reinforced crescent rib. As shown in Figure 1, the bifurcation Angle of the steel bifurcation pipe is 70°, the inner diameter of the main pipe is 5360mm, the maximum design value of internal water pressure is 673.5m head. The steel is 800MPa grade steel, the thickness of tube shell is 60mm, the thickness of crescent rib is 120mm, and the HD value is up to 3609.96m·m. Due to the high HD value of the steel bifurcation pipe in this project, considering the complex structure and stress conditions of the steel bifurcation pipe, it is necessary to use three-dimensional finite element analysis and calculation, and optimize the design to ensure the safety of the project.

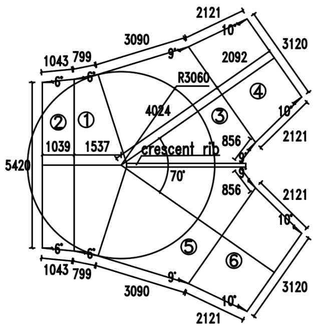

Fig. 1. Structure of steel bifurcated pipe (unit: mm)

The analysis software used is ANSYS, which is one of the most comprehensive and widely used finite element analysis software for general structure in the world. In this calculation, three-dimensional finite element analysis method is used to simulate the deformation and stress state of steel bifurcation pipe under internal and external hydraulic pressure, and the sensitivity analysis of key parameters such as the value of bifurcation pipe gap and the elastic resistance coefficient of surrounding rock is carried out, and the rules are analyzed and summarized.

In this calculation, there are two models of open pipe and buried pipe, and the accuracy of element division is the same. On the basis of open pipe model, the latter uses Contac52 contact element to simulate the constraint effect of surrounding rock and backfill concrete on steel bifurcating pipe. Considering a 2mm corrosion margin, the calculated wall thickness of the main and branch pipes is 58mm.

3 ANALYSIS CONTENT

(1) The "open pipe rule" is used to limit the sharing rate of buried bifurcates in surrounding rock. Even without considering the internal water pressure of surrounding rock, the maximum stress of the bifurcates does not exceed the yield strength of the material, so as to limit the minimum thickness of pipe wall and rib plate and ensure the safety of buried bifurcates;

(2) Through the three-dimensional finite element calculation of the operating condition (buried bifurcation pipe), the stress distribution of the steel bifurcation pipe shape to be designed initially is determined, and the rationality of the stress distribution is judged;

(3) The sensitivity analysis of different gap values and different elastic resistance coefficients of the recommended shape is carried out to understand the influence of gap and surrounding rock elastic resistance coefficient on the stress distribution and deformation of the bifurcation pipe.

4 ANALYSIS OF CALCULATION RESULTS

4.1 Open Pipe Working Condition

Under the operating condition of open pipe, when the internal water pressure is 6.6MPa, the Mises stress distribution of the whole steel bifurcation pipe and crescent rib is shown in Figure 2~3. The maximum Mises stress of steel bifurcating pipe appears at the connecting part of the 1# pipe joint and the inner bottom of the 3# and 5# pipe joints, and the maximum value is 541MPa, which is less than the yield strength of 650MPa. The maximum Mises stress in the rib plate of the crescent rib appeared in the medial middle part, with an extreme value of 435MPa, and the overall stress distribution gradient of the crescent rib was large.

From the point of view of the distribution of tensile stress, except the rib of the crescent, the distribution of the other pipe joints has a certain law, and the middle part of the pipe wall and the turning point are mostly the parts with large tensile stress. It can be seen that the tensile stress distribution of the crescent rib and its adjacent joints is complex, and the variation gradient is large. The tensile stress far from the crescent rib changes slowly, and the tensile stress is larger at the point with the maximum radius of the common tangent sphere, which is the point with the maximum tensile stress except the crescent rib. Although the overall maximum tensile stress of steel bifurcation pipe is 541MPa, it has not exceeded the yield strength of 800MPa high-strength steel of 650MPa.

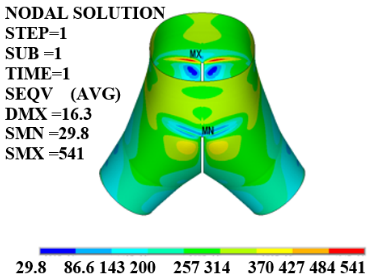

Fig. 2. Mises stress of steel bifurcated pipe under open pipe condition (unit: MPa)

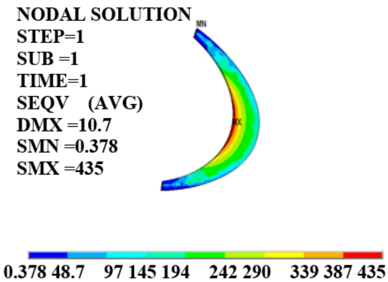

Fig. 3. Mises stress of crescent rib (unit: MPa)

As shown in Figure 4, from the overall deformation of the steel bifurcated pipe, the horizontal sides shrink inward, the upper and lower sides expand outward, and the vertical deformation is up to 16.3mm, which appears at the top and bottom of the 2# pipe section.

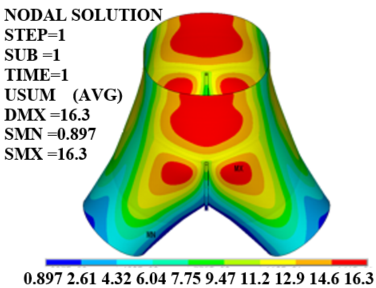

Fig. 4. Schematic diagram of overall deformation of steel bifurcated pipe (unit: mm)

4.2 Buried Pipe Conditions

(1) Sensitivity Analysis of Gap Value.

When the elastic resistance coefficient K0=3000MPa/m, the extreme stress of each steel bifurcated pipe joint and the sharing rate of surrounding rock are calculated with different gap values, and the relationship between the stress of each part of the steel bifurcated pipe and the sharing rate of surrounding rock is shown in figure 5 and 6.

It can be seen that with the increasing gap value (δ=0mm, 0.5mm, 1mm, 1.5mm and 2mm), the stress in each part of the steel bifurcated pipe gradually increases, and the sharing ratio of surrounding rock also decreases. If the gap value is further increased, the stress distribution of the steel bifurcated pipe is closer to the stress state of the open pipe.

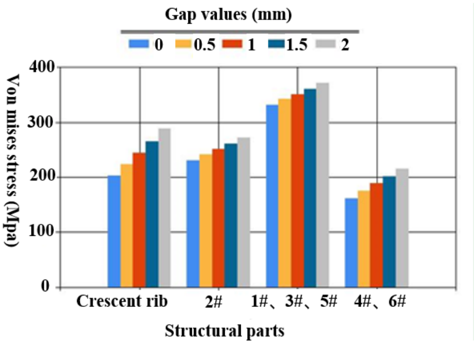

Fig. 5. Mises stress at different parts of steel bifurcated pipe with different gap values

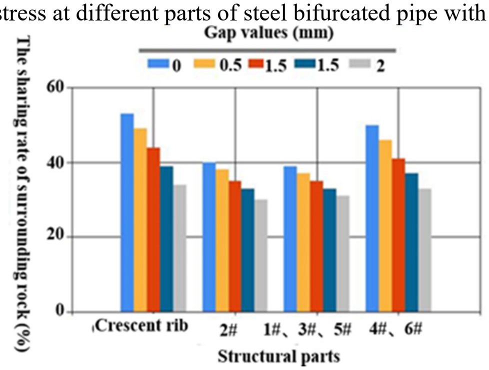

Fig. 6. The maximum sharing ratio of surrounding rock at different parts of steel bifurcated pipe with different gap values

(2) Sensitivity Analysis of Elastic Resistance.

When the gap value is 1mm and the elastic resistance coefficient K0 is different, the extreme stress and surrounding rock sharing ratio of each joint of the steel bifurcated pipe are calculated. The relationship between the stress and surrounding rock sharing ratio of each part of the turnout pipe is shown in figure 7 and 8.

It can be seen that with the continuous increase of K0 value (K0=1000, 2000, 3000, 4000 and 5000 MPa/m), that is, the constraints of surrounding rock on the steel lining continue to increase, and the stress in each part of the steel bifurcated pipe gradually decreases, and the sharing ratio of surrounding rock also increases.

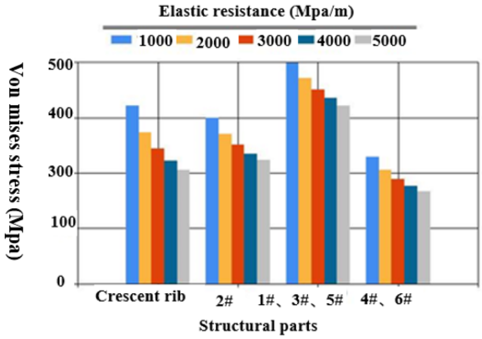

Fig. 7. Mises stress at various parts of steel bifurcated pipes with different K_0 values

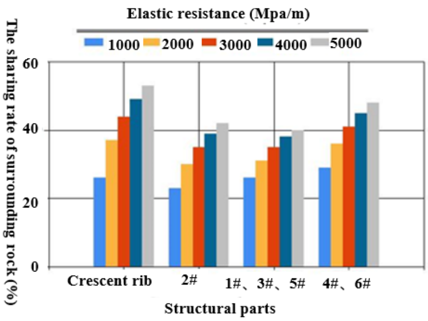

Fig. 8. The maximum sharing ratio of surrounding rock at different parts of steel bifurcated pipe with different K_0 values

5 CONCLUSION

1. If the effect of surrounding rock is not considered, the Mises stress of steel bifurcated pipe under the maximum designed internal head of 6.6MPa would be inward shrinkage on both sides and outward expansion on both sides. The maximum Mises stress of steel bifurcated pipe was 541MPa, which was less than 650MPa at the joint of the inner bottom of the 1# pipe joint, 3# pipe joint and 5# pipe joint on both sides of the crescent rib. All parts of the turnout pipe are still in linear deformation.

2. Considering the action of surrounding rock, the structural stress of steel bifurcated pipe can be homogenized. The Mises stress on the crescent rib of the steel switch was 244MPa, less than the resistance limit of 300MPa for the rib, and the Mises stress on the pipe wall was 351MPa, less than the local film stress + bending stress limit of

397MPa for the base condition (gap value was 1mm and elastic resistance factor K0=3000MPa/m).

3. As the elastic resistance coefficient K0 of surrounding rock increases, the sharing ratio of surrounding rock increases accordingly. The sharing ratio of surrounding rock decreases with the increase of gap value.

4. The structure of the steel bifurcated pipe is symmetrical, so the stress distribution is also symmetrical. The maximum tensile stress of steel bifurcated pipe appears at the junction of 1, 3 and 5 pipe joints, and the maximum tensile stress of crescent rib appears in the middle inner part, and it is also the most easy to yield. The stress distribution of crescent rib has serious eccentric bending phenomenon, which is unavoidable in the structure itself, and is also a general rule of crescent bifurcation pipe.

5. However, there are still some limitations in this study, such as the failure to fully consider the effects of material nonlinearity and complex geological conditions on structural stress. Future studies can further explore the influence of these factors on the mechanical behavior of steel bifurcated pipes, in order to provide more comprehensive and accurate theoretical support

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