Brief research on arch hinge of the steel truss arch bridge by contact problem under local stress

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Abstract. Because of its wide deck, elegant design and reasonable stress, the steel truss arch bridge is suitable for urban bridges. In the steel truss arch bridge, the main arch hinge is an important structure, the local structure and the stress is complex, and it is necessary to analyze the local stress state of the arch hinge. Arch hinge problem belongs to the contact problem, this paper based on Chengdu Tianfu District Shenyang Lu Xi Duan Jin Jiang in bearing steel truss arch bridge design, take the finite element software ANSYS on the main arch hinge is locally analyzed, the arch at the junction of reliable performance test. Studies have shown that half through steel truss arch bridge should be adopted by reasonable cylindrical arch hinge, and Hertz theory is in the analysis of the arch hinge contact does not apply.

1 Introduction
Tianfu District Shenyang Lu Xi Duan Jin Jiang Bridge is located in Chengdu City, Sichuan Province, in the design process of the bridge, not only to meet the requirements of bridge design, but also have certain landscape value. After careful design than the selection, the final use of a steel truss arch bridge. The middle deck steel truss arch bridge is a kind of complex space bridge structure, which is composed of the middle steel truss and the main beam. In this system, the main force structure is the main arch and the main beam. Under the action of live loads, the main arch under motorized vehicles and non motor vehicle lanes and sidewalks load, dead load and live load through the tie bar transfer to the main arch ring, and then transmitted to the foundation, finally force transmission to the ground, the structure of force is very clear. There are several transverse beams on the main arch, the whole has a strong lateral stiffness, with good stability [1]. The steel truss arch bridge is suitable for the urban bridges with high landscape requirements and wide deck.

The main bridge of the bridge is 230m; the whole bridge width is 43.5m, the motor vehicle lane width is 22.5m, and both sides of the sidewalk width is 3.5m.

![Figure 1. View of Jin Jiang Bridge](image-url)
Arch hinge is connected arch key parts, in the design must pay attention to the component force transfer smoothly, transfer itself stress distribution is reasonable, does not appear too large stress concentration phenomenon, to ensure safety of arch hinge connection. The arch rib has a direct influence on the force of the arch hinge. In this paper, the local stress of the arch hinge is analyzed and calculated, and the reliability of the arch rib is tested\(^{[1]}\).

Tianfu District Shenyang Lu Xi Duan Jin Jiang bridge arch rib hingeless seat structure design as shown in Figure 3, the main arch arch hinge consists of a component (shake) and component 2 (shake). The arch hinge is two circular arcs in the direction of the bridge and the vertical plane. During the construction of the first arch hinge on two parts through four sets of reverse screw studs and sleeve temporary consolidation, and is connected with main arch rib section in the site connection, then hoisting, bridge the removal of the temporary connection and hinged.

Arch hinge structure are made of ZG310-570 cast steel, tensile, compressive, flexural strength design value is 225MPa, shear design value for 130 MPa, yield strength to 310 MPa, modulus of elasticity is 2.06 × 105Mpa, coefficient of linear expansion for a 12×10^-6, the bulk density is 7850kg / m3.

\[
\text{Component 1} \quad \text{Component 2} \quad \text{Arch hinge}
\]

Main arch hinge specific parameters, as shown in Figure 4 and 5.
The arch hinge bearing surface of the main arch ribs is a cylindrical arc by two with the same radius. In the loading process, the contact between the upper and lower parts by line contact into surface contact. While the size of this surface is unknown, the maximum compressive stress on the contact surface is derived by means of the deformation compatibility condition, and the finite element method is used to analyse the contact surface due to the Hertz theory does not apply here.

2 Analysis of cylindrical arch hinge
In recent years, with the popularization of computer technology, a variety of commercial finite element analysis software has been developed, and the finite element method has become a widely used and efficient numerical analysis method for solving contact problems.

2.1 Nonlinear finite element contact theory
Structural nonlinear problems can be divided into three categories: geometric nonlinearity, material nonlinearity, state nonlinearity. Contact problem is a state nonlinear problem, there are two major difficulties in the processing and calculation. First, before solving the problem, usually do not know the contact area. Second, most of the contact problems need to consider the role of friction, friction effect may be disordered, so the convergence of the problem to make the problem. For the first point, in order to use the finite element program to model the contact problem, we must first recognize which parts of the model may be in contact with each other. For second points, but the project, the arch hinge contact surface coated with grease lubrication to ensure that the arch hinge can freely rotate and prevent contact surface wear, the friction coefficient is small, does not become the solution of the control conditions.

2.2 Modelling of arch hinge
The use of the bridge is the contact of cylindrical arch hinge is a highly nonlinear behavior, the calculation of the data is relatively large. In order to carry out effective computation, it is very important to understand the physical characteristics of the problem and to establish a reasonable model. Due to the design of the main arch rib of arch hinge bearing surface is composed of two same radius of cylindrical surface of and two cambered surface tightly together. The force analysis is a kind of the contact problem. Taking into account the actual contact, as well as the elastic and plastic deformation of the material, in fact, the pressure bearing surface is in contact with the surface. Because the arch hinge bearing surface is composed of two same radius of cylindrical surface, Hertz theory here lost the significance of the application. In addition, due to the vicinity of the contact area around the deformation by the strong constraints of the surrounding media, so the point is in the three state of stress, so the use of large-scale finite element calculation program ANSYS for its contact analysis. The finite element model is built with SOLID95 solid element, the calculation model X axis represents the main arch rib tangential, the Z axis represents the transverse direction, and the Y axis is perpendicular to the axis of the main arch. In the finite element model, the bolt hole and the bolt slot which are used to consider the actual arch hinge are not reflected in the finite element model. Based on the above considerations the geometric model is established as shown in figure 6. Finite element model of the contact surface portion of the entity uses the mapped meshing, the rest of the entity are used free meshing, contact surface element division shape is a hexahedron, the rest of the unit with tetrahedral, the model is divided 378361 nodes and 224712 unit and mesh the finite element model is shown in Figure 7.
In the definition of the material, due to the calculation of elastic material error is larger, so the choice of elastic plastic materials for analysis, select the bilinear kinematic hardening model BKin. This model by Mises yield criterion and the kinematic hardening rule, to two line segments to describe the material should stress-strain relationship, as shown in Figure 8.

In order to ensure that the arch hinge can rotate freely and prevent the contact surface wear, the friction coefficient of the contact surface is small, and the value of the contact surface friction coefficient is 0.01. Contact surface with 45 and element CONTA174 contact, 45 yuan for the 3D object, conta 174 for 3d8 node element, in ANSYS program established contact on, As shown in figure 9. In addition, due to the main arch of hinged bottom surface are fixed and arch directly, on the bottom surface of the fixed constraints, constraints are a displacement.

The arch hinge is a local model which is separated from the whole model, and the boundary condition is needed to keep the stability of the local model and the consistency of the whole model. The main arch and arch bottom hinge directly is fixed, the bottom surface applied to the fixed constraint, constraint all displacement constraint. In the process of analysing the model, it has not established 2 on both sides of the baffle, which is due to the main arch rib arch hinge at the horizontal bending moment and shear force smaller can direct the arch on both sides of the hinge of Z to the translational constraint, as shown in Figure 10.
The load of the arch hinge model is applied to the contact surface between the end of the main arch rib and the arch hinge to establish the rigid connection of the joint, which forms the rigid surface, and the axial force, axial force and bending moment are applied to the surface, as shown in Figure 11.

![Figure 10. Boundary condition](image)

![Figure 11. The finite element model load](image)

The main arch hinge part extracted from the whole model will be subjected to axial force, bending moment, shear force and torque along the axial direction[2].

According to the analysis of the whole bridge, it can be known that when the load of dead load and live load + temperature + wind load is the load condition, the support reaction is the biggest, that is, as the load applied to the arch hinge in this paper, the following table 1-1:

| The most unfavorable load conditions | FY [kN] | FZ [kN] | MX [kN*m] | MZ [kN*m] |
|-------------------------------------|---------|---------|-----------|-----------|
| Dead load + Live load + Temperature + Wind | 6620 | 55082 | -5000 | 2143 |

This calculation is a nonlinear contact analysis problem, the initial infiltration tolerance is set to 3mm, the relative value of the contact stiffness is set to 0.1. Using asymmetric NR method. During the solving process, the linear search and automatic time step are activated, and the maximum step size is 100 and the minimum step size is 5.

2.3 Contact analysis results of nonlinear finite element method

Based on the finite element model of the arch hinge established in front of the model, the force under the action of the most unfavorable load conditions (dead load + live load + temperature + wind load) was calculated.

![Figure 12. Arch hinge Von Mises stress cloud](image)
Figure 13. Superstructure Von Mises stress

Figure 14. Substructure Von Mises stress of the arch hinge under the dead load
As shown in figure 12~15, the maximum equivalent stress of the arch hinge is 250MPa, which exceeds the strength design value of the material, but in the yield strength of the material. Through the comparison of, under the sway of view, further found that the equivalent stress peak value appears in shake half cylinder and the base of connecting corners, belong to the stress concentration problem; combined with shake equivalent stress peak was 157mpa and the peak within the design strength of the material. From figure 14, touching the contact part of the hinge arch should peak force to 133mpa, its position and lower shake von Mises stress peak location is corresponding, the peak within the design strength of materials to meet the design requirements[3].

From the above analysis results, we can see that the upper and lower components are in the stress concentration on both sides of the cylindrical contact surface. The focus of the equivalent stress is 250MPa higher than the allowable stress value of the material, but less than the material yield strength. In addition to other regions outside the stress concentration point, the equivalent stress is less than the material allowable stress, the surplus amount is larger, the stress transition is smooth, and meets the design requirements. The stress concentration point of the arch hinge is in the edge of the arch hinge on both sides of the arch hinge, so the design must ensure that the side of the arch hinge has a sufficiently smooth fillet, otherwise the stress concentration point is easy to occur.

3 Size optimization analysis and result comparison of main arch hinge
Because the maximum equivalent stress of the main arch hinge is larger, the space can be optimized, and by increasing the radius of the main arch hinge, the radius of the arch hinge is increased from 300mm to 450mm. The parameters of the optimized parameters are shown in Figure 16 and 17[3].

![Figure 15. Arch hinge contact stress under the dead load](image1)

![Figure 16. Shake layout](image2)

![Figure 17. Shake layout](image3)
The finite element model is established, and the nonlinear contact analysis is carried out. The stress condition of the optimized arch hinge under the most unfavorable load conditions (the dead load and the live load + temperature + wind load) is shown in figure 18–19.

Figure 18. Arch hinge Von Mises stress cloud

Figure 19. Superstructure Von Mises stress of the arch hinge
The maximum equivalent stress of the main arch hinge is 173MPa, which is less than the strength design value of the material. Under the sway of the maximum equivalent stresses 103mpa, within the design strength of materials, the arch hinge contact parts of the contact should peak force for 87.9MPa stress allowable amount of surplus than before optimization arch hinge structure, optimized the should force index were less than before optimization and structure stress situation has been greatly improved, the structure and the force transmission than before is more reasonable.
Table 1-2 The percentage of difference value between the maximum equivalent strength and yield strength

| Arch hinge radius size [mm] | Arch hinge overall Von Mises stress [MPa] | Superstructure Von Mises stress of the arch hinge [MPa] | Substructure Von Mises stress of the arch hinge [MPa] | Contact stress [MPa] |
|---------------------------|------------------------------------------|----------------------------------------------------|--------------------------------------------------|-------------------|
| 300                       | 19.4%                                    | 19.4%                                              | 49.4%                                            | 40.9%             |
| 450                       | 44.2%                                    | 44.2%                                              | 66.8%                                            | 60.9%             |

4 Conclusions
In this paper, the finite element software ANSYS is used to analyze the main arch hinge of the project, mainly analyzes the stress state under the most unfavorable load condition, the main conclusions are as follows[4]:

1. Bridge design of the arch hinge can effectively reduce the main arch foot in the face of the moment, so that the stress state of the bridge structure is more reasonable.

2. From the finite element analysis results show that, under the most unfavorable combination of loads conditions. Before optimization and after optimization of arch hinge in the non - contact parts are stress concentrated, so be sure to focuses on the stress concentration position were optimized separately, so that the concentrated stress in the diffusion and ensure the safety of the structure.

3. The stress concentration occurs at the lower arch hinge, which appears at one end of the arc contact surface of the arch hinge, but less than the design strength 225MPa. In addition to the contact part, the rest of the stress level is below 100MPa, so the structure is safe, fully meet the design requirements.

4. The peak value of the contact stress of the contact part of the front main arch hinge is 133MPa, and the optimization is reduced to 87.9MPa, which meets the design requirements. By increasing the radius of the main arch hinge, the measures to reduce the stress level are practical and effective. However, the optimization effect is not obvious, and the increased size of the arch hinge leads to an increased cost. So it is Economically unreasonable, therefore under the safety requirements of the situation, still recommended hinge arch radius of 300mm[4].

5. Half through steel truss arch bridge arch rib using cylindrical arch hinge is with economy and rationality, modelling is lightsome beautiful, structure and reasonable stress, it is worth reference other beam arch combination system bridge.

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