Analysis of Influence of Different Parameters on Structural Stability of Beam String Beam

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Abstract. The string beam structure is a new type of space structure, which satisfies the requirements of buildings for large spans, has good application value and broad application prospects. In this paper, the influence of the three-parameter ratio of the span, the prestress value and the number of strut on the stability of the beam string is studied. The modeling of the string member is carried out by SAP2000 software. The simulation results show that the arch structure of the stringed beam has the best stability when the span ratio is 0.25. When appropriate prestressing is applied to the structural cable, the stability of the structure will be significantly improved. The number of struts is not as good as possible. Considering the influence of the struts on the structure, choose the right amount.

1. Introduction

In modern architecture, the traditional beam-column structure system has been difficult to meet the practical and economic requirements, and a new type of structure--string string structure application has become more and more extensive. Beam String Structure (BSS) is a new type of structure obtained by placing prestressed cables under the arches of traditional arch structures and arranging a certain number of struts between the arches and the cables [1].

Figure 1. Schematic diagram of the string

The arch is a good compression component, but the arch is subject to bending and is prone to buckling. The cable is a tensile member with excellent performance, but the inherent defect of the cable is that it cannot be pressed.

Therefore, the string-string structure is to use the rigid compression-bending member as the upper compression member, and the cable as the lower tension member, and the two adopt the fish-belly arrangement, and the rigid struts are connected between the two, and the rigid struts are on the one hand. It provides support points for rigid bending members to prevent strength damage and buckling. On the other hand, as a node of the cable, it provides structural rigidity for the cable [2].
The stringed beam has the advantages of strong bearing capacity and small structural deformation during use. With the deepening of research, the application of the structure in today's engineering structure has become more and more extensive, but many factors affecting the structural stability of the stringed beam should also be carried out. Research and analysis [3].

According to the characteristics of the self-structure of the string beam, the model is simulated and analyzed by SAP2000 software, and the effects of structural span ratio, cable prestress and number of strut on the stability bearing capacity of the beam string are studied. To promote the application of the structure in actual engineering.

2. Calculation model

In order to comprehensively study the influence of different parameters on the stability of the beam string structure, this paper uses the finite element software SAP2000 to accurately model the model [4]. The numerical simulation of the model includes buckling analysis and deflection analysis, and establishes different parameters by changing the parameters of the string beam. The model to compare and find the law.

The size of the calculation model is based on the design of the ceiling of a railway station. After the model scale is simplified, the structure is simplified and representative of the support of the upper arch and the lower cable, because the stability problem outside the plane is not considered. The simplified model is shown in Figure 2 below.

![Figure 2. Schematic diagram of the model structure](image)

The calculation model simulation assumes:

1. The restraining manner of the two ends of the rigid bending member in the model is a fixed hinge bearing.
2. The rigid connecting rod and the rigid bending member are hingedly connected.
3. The rigid strut and the cable are hingedly connected to ensure that the rigid brace remains in the force-bearing form of the two-bar after the rigid bending member is bent.
4. The cable is not under pressure.
5. Due to the large bending rigidity of the intermediate strut, the bending deformation of the strut is neglected.
6. In the prestressed stage, the deformation of the strut is neglected, and the structure after the prestressing is applied as the initial structure.

The model material is defined as shown in Table 1 below.

| member           | section (mm) | area (mm²) | Linear expansion coefficient (1/C) | Elastic Modulus (MPa) | material       |
|------------------|--------------|------------|------------------------------------|-----------------------|----------------|
| Rigid bending member | φ70×3        | 631.5      | 1.17×10-5                          | 2.06×10⁵              | Q345           |
| Rigid strut      | φ32×2.5      | 231.7      | 1.17×10⁻⁵                          | 2.06×10⁵              | Q345           |
| Cable            | φ4           | 98         | 1.84×10⁻⁵                          | 2.00×10⁵              | High strength wire bundle |
3. Numerical simulation analysis

3.1. Arch span ratio effect

The span of the stringed beam is generally large. When the traditional straight beam arrangement forms a huge bending moment in the span, the arch structure can effectively solve this problem. The arch can increase the vertical stiffness of the structure and reduce the displacement in the span.

In this simulation, the buckling analysis is performed on the arch members with different span-to-span ratios under the same stress conditions (both arches are uniformly loaded with 10kN). The buckling factors corresponding to the respective span ratios are shown in Table 2. The buckling mode with a span ratio of 0.1 is shown in Fig. 3. The buckling factor and axial force data of each sagittal ratio lower arch are shown in Fig. 4.

| Vector span ratio | First order buckling factor | Second order buckling factor | Cross-shaft force (kN) | Bearing axial force (kN) |
|-------------------|-----------------------------|------------------------------|------------------------|-------------------------|
| 0.05              | 5.16                        | 11.5                         | -15.2                  | -15.5                   |
| 0.1               | 9.52                        | 21.61                        | -7.7                   | -8.3                    |
| 0.15              | 12.85                       | 29.35                        | -5.2                   | -6.1                    |
| 0.2               | 14.75                       | 34.32                        | -3.9                   | -5.2                    |
| 0.25              | 15.29                       | 36.65                        | -3.2                   | -4.7                    |
| 0.3               | 14.76                       | 36.82                        | -2.7                   | -4.6                    |
| 0.35              | 13.51                       | 35.44                        | -2.4                   | -4.5                    |
| 0.4               | 11.92                       | 33.09                        | -2.1                   | -4.6                    |
| 0.45              | 10.26                       | 30.20                        | -1.9                   | -4.8                    |
| 0.5               | 8.7                         | 27.13                        | -1.7                   | -4.9                    |

Figure 3 shows the first two-order buckling modes when the span ratio is 0.1. The first-order buckling mode is centrally symmetric, the second-order buckling mode is axisymmetric, and the buckling modes of other sagittal ratios follow the same law.

It can be seen from Fig. 4 that as the span ratio increases, the buckling factor also increases, and reaches a maximum at the sagittal ratio of 0.25 and then begins to decrease, that is, when the sagittal
ratio is 0.25, the most stable, first order. The buckling factor was 15.29. It can be seen from the axial force diagram that when the sagittal cross-section is relatively small, the axial force is relatively large, which is due to the large angle of the reaction force provided by the arch.

In general, there is an optimum value for the span ratio of the stringed beam under load. This is because if the span ratio is infinitely increased, the deformation of the arch will be deflected downwards in the mid-span portion, and the two sides will flex upwards, which causes the side span to be pulled, and the structural stress will begin to become unfavorable.

3.2. Prestress value influence

The string-string structure is a typical rigid-flexible hybrid system. Generally, a certain pre-stress is applied to the string. The function is to pre-generate a certain inverse arch value of the structure, thereby reducing the deflection of the structure under the load [5]. At the same time, however, excessive prestressing on the structure can cause damage to the structure. It is still a problem worth discussing whether to apply prestressing to the structure and how much prestressing is applied.

In this paper, the nonlinear finite element method is used to analyze the structure of the structure, and the influence of different prestress values on the buckling factor and deflection of the beam structure is analyzed and compared.

In the SAP2000 software, the cable can be modeled in the form of a steel beam, where the steel bundle can be defined as a load or a unit. Through several simulations, when the steel beam is simulated as a load, the stable bearing capacity does not change, so the steel beam is defined as a unit for simulation.

A uniform load of 10kN was applied to the arch, and prestressing of 15kN, 25kN, and 35kN was applied to the model cable under the same conditions of other working conditions. The simulation results are shown in Figure 6, Figure 7, and Table 3.

![Figure 5. simulation model](image)

The test model in Fig. 5 is established in the finite element software, and the buckling analysis is performed after the load mode is defined and the load condition is applied.

The software simulation results are as follows:

1. Comparison of buckling factors

   (a) Apply pre-stress 15kN  
   (b) Apply pre-stress 25kN  
   (c) Apply pre-stress 35kN

![Figure 6. Buckling factor simulation results](image)

2. deflection comparison

   (a) Apply pre-stress 15kN  
   (b) Apply pre-stress 25kN  
   (c) Apply pre-stress 35kN

![Figure 7. deflection simulation results (mm)](image)
The simulation results are organized as shown in Table 3 below.

### Table 3: Simulation results

| Prestress value (kN) | Buckling factor | Deflection (mm) |
|----------------------|-----------------|-----------------|
| 15                   | 17.48           | 11.26           |
| 25                   | 19.13           | 12.88           |
| 35                   | 20.80           | 14.45           |

By analyzing the simulation results, the following conclusions are obtained:

1. From Fig. 6, when the prestressing force is applied to the cable, the buckling factor is increased and the bearing capacity is improved. It shows that applying proper prestressing helps to improve the stability of the beam-string structure.

2. It can be seen from Fig. 7 and Table 1 that when the prestress value is applied to the structure, the deflection of the structure changes little, indicating that the change of the initial prestress has little effect on the structural displacement.

### 3.3. Strut number influence simulation

In order to study the influence of the number of struts on the internal forces and displacements of the structure, three calculation models with different numbers of struts are used: Model 1, Model 2, and Model 3. The modeling model is a prestressed beam-string model with the same parameters. The difference is that the struts are 1, 3 and 5 respectively. Its structural model is shown in Figure 8.

![Figure 8](image)

(1) Number of poles 1     (2) Number of poles 3     (3) Number of poles 5

The calculation model sets two load combinations, one is 1: dead load + live load; the second is: prestress + dead load + live load (the load of the dead load is self-pressing, the live load is the uniform load applied to the arch 1kN, the prestress is a temperature stress of -30 °C applied to the cable). To compare and analyze the influence of different strut numbers on the deflection, bending moment, axial force and shear force of the string beam structure under the same working condition. The software simulation results are as follows:

1. Buckling deformation diagram of each model

![Figure 9](image)

(1) Number of poles 1     (2) Number of poles 3     (3) Number of poles 5

(2) The deflection, bending moment, shear force and axial force values of the three models are collated. The results are shown in Table 4 below.

### Table 4: Simulation result

| Pole | Deflection (mm) | Bending moment (kN.m) | Shear force (kN) | Axial force (kN) |
|------|-----------------|-----------------------|-----------------|-----------------|
| 1    | -0.51           | -207                  | 0.645           | 27.69           |
| 3    | -0.38           | -413                  | 0.726           | 27.42           |
| 5    | -0.32           | -470                  | 0.697           | 27.92           |

By comparing and analyzing the simulation results of three different models, the following conclusions are obtained:

1. When the beam-string structure is in a certain load combination, the maximum deflection of the structure changes with the increase of the number of struts, but the amplitude is small, so the number
of struts has a certain influence on the deflection of the string beam, but it is not supported. The greater the number of rods, the better.

(2) Analysis Table 4 shows that when the number of struts increases, the bending moment of the structure increases, but the axial force and shear force do not change much. Therefore, selecting the appropriate struts can make the chord beam structure more stable. It also saves steel.

4. conclusion

In this paper, SAP2000 model is used to analyze the effects of the three parameters of the span ratio, the prestress value and the number of struts on the stability of the string beam. The conclusions are as follows:

(1) The span ratio is a parameter that has a great influence on the structure of the string beam. Under the load, each structure has a most suitable span ratio, which is found by simulation. Generally, the structural stability is best when the span ratio is 0.25

(2) The application of prestress is the basis of the stringed beam member. When the structural cable is properly prestressed, the bearing capacity of the steel bar will be significantly improved, making it more widely used in practical engineering.

(3) Reasonable arrangement of the struts can improve the stability and safety of the structure. It can be seen from the simulation results that it is most suitable when three struts are generally arranged. Moreover, when the number of struts exceeds a certain value, it will adversely affect the structural stress, and also cause waste of materials.

(4) The beam-string structure fully exerts the compression characteristics of the arch structure and the tensile strength of the cable. Its structural stress is reasonable, the bearing capacity is strong, the number of components is small, and transportation and construction are convenient. It is worthy of promotion and application in practical engineering.

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