Research on Dynamic Characteristics of Mechanical Fast Loading Trolley Bridge in the Urban Rail Construction

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Keywords: Traffic jams, Steel trussed girder-bridge, Steel trussed cable-stayed bridge.

Abstract. With the rapid development of urban rail transit, more and more rail projects such as light railway and subway have been constructed in recent years. Rail constructions often locate in the main roads and always occupy a part of road, so the traffic capacity of the original road declines drastically and traffic jams occur. For the car playing a remarkable role in the traffic jams, this paper puts forward two types of structure, steel trussed girder-bridge and steel trussed cable-stayed bridge, as the car overpass, which is a special path only for cars. Presented and analyzed the model of the structures by the finite element program of ANSYS, the results of model analysis show that the strength and safety of the two structures can both meet the relevant specifications. Making further efforts on comparison of mechanics and construction features, the steel trussed cable-stayed bridge has been presented, for its advantages of quickly assembled with standard unit of steel truss cable-stayed, light weighted, self-balanced, rapid construction, and less damage to the road surface

Introduction

The development of urban transportation is greatly motivated by the traffic demand, so, served as an important transportation system of the urban traffic, the construction of rail transportation causes public attention gradually. Some large engineering projects begin to be constructed one by one in large and medium-size cities, such as light rail, metro, etc. Take Wuhan for instance, the rail line 1st, 2nd and 4th have been begun to construct since 2007. Because these projects constructed at the same time, the given heavy traffic became heavier. Among the traffic constitution, cars occupy a large proportion of all the vehicles, so leading cars pass the construction section orderly and quickly is the key to solve the traffic jams. One effective path to solve the problem is to offer a restricted lane – an overpass for cars. The efficiency of the structure in traffic dispersion has been demonstrated by using simulation system VISSIM.

In order to meet the need of fast, economy and less influence of construction to the traffic, this paper puts forward two types of car overpass: steel trussed girder-bridge and steel trussed cable-stayed bridge. Such bridges with two pieces of truss plate and transverse connection can provide a tunnel-like car pass way, which also makes the full use of spatial features of the truss structure. The distance between the two pieces of steel truss is decided according to the width of the traffic lane and the height is chosen according to both the clearance demand for cars, and the bending rigidity of the steel truss. The foundation of the bridges is simple, at the end of the approach bridge set up a thrust blocking; the approach bridge and the original road junction use concrete casting; the pier excavts strip foundation and be anchored at the four corners; the steel trusses anchor with concrete footing by bolts. By these means, the foundation does not need
large area excavation, the construction time can be shortened and the influence to construction is minimised.

**Structure Selection of the Car Overpass**

**The First Scheme: Steel Trussed Girder-Bridge**

The full bridge includes approach bridge and main bridge, the slope of the approach bridge is 1/15 (according to *Design Code for Garage*, the clause 4.1.7 the maximum slope allowed is 1/6.67). The approach bridge is composed of five standard steel truss codes which is 6m×3.0 m×2.4m, and the main bridge includes six (which can be added or reduced according to practical conditions) standard steel truss codes; in the joint of approach bridge and main bridge, one frame pylon with 3 standard steel trusses codes which is 3.6m×3.0m×4.8 added. The floor system is located in the lower lateral bracing of the truss frames, and will composed by corrugated steel plate and 60mm thick concrete (or pave with 60mm pretensioned concrete plate). Each standard cell truss joints by high strength bolts.

**The Second Scheme: Steel Trussed Cable-Stayed Bridge**

Based on the first scheme, this scheme utilizes the frame pylons as tower column, and adds 24 stayed-cables which are symmetrically arranged on the both sides of the tower. By the action of the stayed-cables, the vertical displacement of the steel truss reduces, and the sectional dimension of the truss can be decreased. At the same time, the half range of the truss can realize self-balancing without setting any brackets and a part of load can be transferred to the tower, then the load transfers from the tower to foundation. The front views of the two schemes are shown in figure 1 and figure 2.

![Figure 1. The front view of the steel truss girder bridge.](image1)

![Figure 2. The front view of steel trussed cable-stayed bridge.](image2)

**Analysis of the Structure Behavior**

**Establishment of the Finite Element Modes**

(1) Element selection: While using the finite element method to simulate steel trussed cable stayed bridge, it is necessary to choose different elements to simulate different components for
their different mechanic features. Under the action of load, the steel truss and the tower will undertake the combined action of the bending moment, shearing force and axial force, so in order to really reflect the forced state of the truss member as close as possible, this paper does not use plane link element and beam element, but adopts three-dimensional beam element which can not only undertake tensile force and stress, but also can undertake the combined shear force and bending; the stayed-cables can just bear axial force, no stress and bending moment, so the link element is adopted to simulate cables; bridge deck undertakes the combined action of the bending moment and tension force, so the shell element is used to simulate it.

(2) Establishing the finite element modes: According to the differences of structure size, mechanical properties and research purposes, it often adopts bar system element, shell element and solid element to establish modes. While using solid element, the structure is often complex, so the process of modeling is difficult too. Compared with the solid element, bar element system is relatively simple, so the author adopts bar system element and shell element to establish the finite element models.

(3) Load selection: According to standards: Design Code for Garage, Loading Code for Design of Building Structures and Code for Design of Steel Structures, this paper adopts 3.5KN/m² (considering certain safety stock) as the design load. Because of the limit of the length of the paper, this paper just discusses two working conditions as follows: ① self weight of the full bridge; ② full load on the whole deck.

Based on the several points above, this paper utilizes spatial beam element and cable element to establish the finite element models of steel trussed girder bridge and steel trussed cable-stayed bridge, and analyses the mechanical properties of the two structures under the two different working conditions.

**Scheme Selection**

Through establishing the finite element models of steel trussed girder bridge and steel trussed cable-stayed bridge with the finite element program, stress nephograms of structures can be obtained, which are shown separately in the figure 3 and figure 4:

![Figure 3. Stress nephogram of the first scheme.](image-url)
Compared with the two stress nephograms, it is obvious that the two structures have the similar deformation tendency. The force transfer systems of the two schemes both transfer the bridge floor system load into stringer and crossbeam, then transfer the load to the truss members(cables), and transfer the load from the truss(cables) to the tower(pier) and foundation. From these two figures, it is showed that the vertical displacement of midspan of steel truss girder bridge is smaller than steel trussed cable-stayed bridge, and the stress value is also smaller.

In order to choose a better type of construction, further work is done to analyse the mechanical properties of the structures, which is shown in table 1.

Table 1. Mechanical characteristics of the steel truss girder bridge and the steel trussed cable-stayed bridge.

<table>
<thead>
<tr>
<th>Type</th>
<th>Dead load</th>
<th>full span load</th>
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<tbody>
<tr>
<td></td>
<td>steel truss-girder bridge</td>
<td>steel truss cable-stayed bridge</td>
</tr>
<tr>
<td>Maximum Deflection (cm)</td>
<td>1.24</td>
<td>1.11</td>
</tr>
<tr>
<td>Axial Force(KN)</td>
<td>63.57</td>
<td>54.73</td>
</tr>
<tr>
<td>Shearing Force (KN)</td>
<td>4.736</td>
<td>4.723</td>
</tr>
<tr>
<td>Bending Moment (KN·m)</td>
<td>3.256</td>
<td>3.255</td>
</tr>
<tr>
<td>Von-Mises Stress(MPa)</td>
<td>5.865</td>
<td>5.415</td>
</tr>
</tbody>
</table>
Discussions on the Effect of Stay Cables

Comparing the analysis results under the circumstance of two structure types with or without stayed-cables (fig.4 and fig.5), it is obviously that the mechanical characteristics of the two structure types are similar without prestressed cable tension. The choice of truss cable-stayed bridge mainly bases on the following considerations:

1) To improve structural stiffness and strength. From the mechanical analysis of the two structure types, table 1 showed that after adding stay-cables, the maximal displacement, axial force and stress of the bridge have a certain decrease in the dead load and full span load, for instance, the deflection of cable-stayed bridge with steel truss decreased 13.3% compared to steel truss girder bridge under the full span load. Therefore, stay-cables can improve the stability and carrying capacity of the structure.

2) Half-span can be self-balanced in the process of construction. Stay cables can be used as a series of elastic bearings in the installation process, so the half-span bridge needs no other supporting structure, which can overcome the disadvantage of full framing scheme and enhance symmetrical construction.

In order to further research the stress of stayed-cables structure in the construction process, this paper used finite element model to analysis construction process. For the structure and method of construction are symmetrical, only the right bridge model was been established. In the mid-panels construction, because of the truss is in the cantilever condition, the displacement is 2.1cm. After the installation completed, stay cables provided a series of flexible girder supporting and tensile deformation happens under the flexural deflection of main girder. The tension of cables is shown in table 2

Table 2. the tension of stay cables.

<table>
<thead>
<tr>
<th>Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable tension(KN)</td>
<td>5.581</td>
<td>6.331</td>
<td>4.785</td>
<td>3.249</td>
<td>3.493</td>
<td>2.417</td>
</tr>
</tbody>
</table>

From table 2, the value of maximum cable tension is 6.331KN, which is far less than failing load 102KN. For the overall right-span bridge, the biggest stress locates in the connecting point of frame pylon and deck. The maximum value is 6.76MPa, which is smaller than design value of load-carrying capacity of members. Therefore, the bearing capacity of cable structure completely satisfy the requirements in the construction.

The stay cables temporarily support the main girder in the construction. While installing the girder, the truss girder should be assembled out of the site, and then be carried to the spot and erected. Using the cables as elastic struts can avoid problems of support machinery and trestle platforms, which can decrease the space during the erection of the bridge effectively. Also, the cables simplify the construction process and save the construction time. All of these advantages minimize the impact of the car overpass construction.

3) Ensure adequate safety margin. The stay-cables play the role of stress reserves. Because of the limited traffic space and because of the limited traffic space and heave vehicular traffic, there may be some emergencies, such as the vehicle crash the car overpass, which will cause parts of the truss damaged in the service period. In this case, the force reserves can be fully stimulated, so that it will participate in load-bearing system timely and prevent the instability of the structure.
4) Strong adaptability of the structure. From calculations above, it can be seen that, in the circumstances of cables not being stretched, the cable-stayed steel truss bridge still has large surplus capacity. If the cables are tensioned, the capacity of the whole structure system will be larger, which makes the study of larger span bridge possible. So the car overpass may be used in more locations to improve traffic jams.

Based on force analysis and comparisons of the two structure types, steel trussed grid-bridge and steel trussed cable-stayed bridge, especially the analysis of construction process, it can be found that the cable-stayed bridge has good mechanical properties and the cables have certain advantages in construction process. So the steel trussed cable-stayed bridge is an ideal structure form of car overpass. Meanwhile, under the construction of the bridge, unlike other structures it is not need to excavate huge foundation, for the car overpass is lightweight. The frame bridge tower can mount on the road and anchor with the frame pier. Also, stay-cables can improve the bearing capacity and stability of the bridge. At the same time, the deck pavement of the bridge pavements uses light steel plate to reduce self-weight. Because the car overpass assembles with standardized structural element, it can be disassembled quickly and carried to another point for reuse. The advantages of the structure, such as convenience assembly and disassembly convenience, small influence to construction and low cost, make it be a kind of ideal solution to the traffic congestion and the structure can be promoted.

Conclusions

By directly defined the car as the target of traffic dispersion, the car overpass can solve the urban traffic congestion effectively. This paper proposes a structure type of steel trussed cable-stayed bridge as the car overpass, which has the advantages of reliable structure, simple construction, economical cost, and little influence on traffic. The car overpass can remarkably relieve the traffic pressure and substantially lower even can cancel the cost of provisional traffic diversion, especially fit for the rail construction in large and medium-size city.

References


