Optimization design of F-type Traffic Signage based on ANSYS Finite Element Analysis

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Abstract. F-type traffic sign structure is a common cantilever traffic sign structure, its structural stability and durability in the life cycle is closely related to traffic safety. For the design and production of F-type traffic sign poles, a fully mature design theory has not been established, and favorable guidance cannot be given to the structure, material and cost. In this paper, ANSYS finite element analysis method is used to analyze the stress characteristics of round tube and square tube and the structural optimization of column reinforcement plate. The calculation results show that the mechanical effect of circular tube is better than that of rectangular tube, and the theoretical weight of circular tube of 203x6 is 36% smaller than that of rectangular tube of 200x120x8. The eight-bar flange of the base can ensure that it does not fail under the limit working condition, and can prevent the column from breaking under the limit working condition. Through the optimization calculation of the key parts of the F-type traffic sign posts, the design and production of the F-type traffic sign posts have a certain guiding effect.

Keywords: Traffic Engineering, ANSYS, F-type traffic sign structure, traffic safety.

1 Introduction

With the rapid development of China's highway and road traffic, by the end of 2022, the total mileage of China's highways has reached 5 million kilometers, and the total mileage of expressways has exceeded 160,000 kilometers, both ranking first in the world. Traffic signage is an indispensable device for road infrastructure, conveying road traffic information to road users, clarifying road traffic prohibitions, restrictions, compliance conditions, and informing real-time road and traffic conditions [1-3]. Under normal circumstances, the number of signs set up also reaches an average of 8 to 12 blocks per kilometer, and the setting is huge, therefore, the safety, long durability and cost of traffic signs are particularly important.

In order to ensure the durability of traffic signs in different environments while meeting their functional requirements, researchers and engineers fully consider their mechanical strength, stiffness and stability under load in designing [4-5]. Park [6] et al. studied and proposed common fatigue damage locations of signboards through test

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and simulation methods. Multi-segment fatigue cracks mainly occur at the welded corner joints of pipe end plates. The elasticity, number of edges and bend radius of the end plates are important parameters affecting the fatigue resistance of multi-barrel structures, which may have occurred sometimes during transportation and installation. Somchai [7] et al. analyzed the effect of road vehicle cyclone on the size of the bottom stiffening ribs of the F-type signage, and the results show that the traffic sign structure is acted by gravity, vehicle cyclone, and wind loads, and that the use of rectangular shear plate is the best type of bottom stiffening ribs for the traffic sign structure. Qu [8] et al. conducted a simulation analysis of the L-shaped sign composed of a column, a cantilever and connected by bolts under the coupled action of gravity and wind loads, gave the stress and displacement fields under different loads and their combinations, extracted the stress and displacement values of key parts and compared them with the theoretical calculation values, and verified the theoretical calculation method and the finite element calculation method. Barodi [9] studied the recognition of traffic road signs with the goal of demonstrating link optimization and powerful elements for easy-to-use computer vision algorithms in image and video processing, and proposed that signage size, color, etc. have an effect on the accuracy of some recognition methods, and optimizing the recognition algorithms can improve it. Fang [10] et al. proposed a penalty function theory combined with ANSYS optimization method. The results show that, under the same volume, F-type traffic signs with circular section have a larger structural optimization space and can reduce the amount of steel used. When the column is the same and the cross section size is the same, the shorter the length of the beams corresponds to a larger space for structural optimization. The current traffic sign structure design theory has not been perfected, but the traffic signs are located in different environments, the geological conditions and climatic conditions of different regions vary greatly, such as cold areas needed to consider frost, coastal areas needed to resist wind, snow and corrosion, which is difficult to develop a unified standard for different regions of the geological conditions. Most areas are designed according to experience, the design based on different norms, various methods only have a certain reference significance.

Therefore, this paper will optimize the structural design of the F signboard to achieve better durability in extreme weather while saving materials and mechanical properties. F-type sign plate is taken as the design object and uses Ansys Workbench platform to optimize the design of the key position of F-type sign plate, round tube and square tube of rear beam, flange structure topology optimization, plate reinforcement structure. That is to strive for lighter weight under long life, maximize the use of mechanical properties of materials and reduce costs.

2 Modeling and Simulation

Most of the existing signage structure consists of sign plate, crossbeam, column, flange between crossbeam and column, flange between column and foundation, according to the existing signage structure, the size of the sign plate, the specification of the crossbeam and the structure of the flange between the column and the foundation are parametrically modeled for the subsequent simulation parameter drive. Ansys Workbench platform is used to simulate and analyze this structure, the steel of this traffic sign structure is made of Q235, with a density of 7.85x103 kg/m^3 and poisson's ratio of 0.3.

The model is simplified without affecting the simulation analysis:

(1) Loads. Consider only weight and wind loads, ignoring other loads.

(2) Flange connection. For the column simulation analysis of the beam and column flange connection can be ignored in order to simplify the calculation.

(3) Calculation of sign board load. Consider the local maximum wind pressure w=1.3kN/m in the last 50 years, and calculate the wind load according to the formula:

$$v = \sqrt{1600w} \tag{1}$$

$$F_{wh} = \gamma_0 \gamma_Q [(\frac{1}{2}\rho C v^2)\sum_{i=1}^{n} W_b \times H_b]/1000 \tag{2}$$

Where: F_{wh} represents the wind load on the sign board; γ_0 represents the structural importance coefficient, and γ_Q represents the variable load coefficient, $\gamma_0 = 1.0$, $\gamma_Q = 1.4$; ρ represents the density of air, generally take 1.2258g/m^3; C represents the wind coefficient, C=1.2; v represents the basic wind speed; W_b represents the width of the wind-blocking surface; H_b represents the height of the wind-blocking surface.

(4) Restraint. The components are rigidly connected to each other. The components are grounded and secured by fixed restraints.

(5) Mesh. For this welded steel structure, due to the constraints are rigidly connected and there is no very complex structure, in order to save the amount of calculations, the grid is set as the default tetrahedral mesh. In the connection of the flange steel plate it is done local grid encryption, so that its calculation is more accurate. The number of nodes in the statistical grid division is 126935 and the number of cells is 63824.

3 Simulation results and analysis

3.1 Analysis of the force characteristics of the round tube and square tube of the rear crossbeam of the signboard

In the modeling stage, the diameter and wall thickness of the round pipe are taken as the driving size, and the seamless steel pipe specifications are found according to the national standard GB/T17395-2008, and several specifications of round pipes are selected as shown in table 1. Under the premise of constant wind pressure, constant sign size and constant distance between round pipes, the end faces of the two round pipes are fixed, and the maximum equivalent stress of the round pipe structure is taken as the driving result. Static analysis of the structure. Figure 1 shows the simulation analysis results under the round tube F of 219mm. Other specifications of the round tube are analyzed according to the same method, and the following table 1 shows the simulation analysis results of the round tube with different diameters.

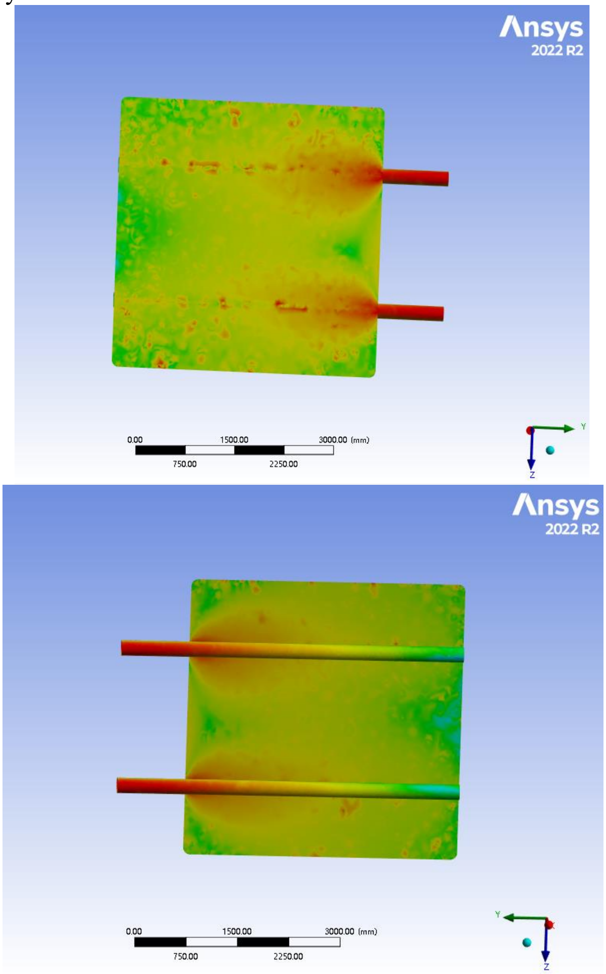

Fig. 1. Cloud view of stress distribution on the front and back of the circular pipe Φ 219

Table 1. Force analysis of circular tubes of different diameters

Round tube diameter (mm)	Wall thickness (mm)	Theoretical weight per unit length (kg/m)	Maximum equivalent force (MPa)
203	6	29.15	177.36
203	6.5	31.50	173.89
203	7	33.84	175.86
203	7.5	36.16	155.28
203	8	38.47	150.86
219	6	31.52	152.27
219	6.5	34.06	145.53
219	7	36.60	144.36

219	7.5	39.12	139.64
219	8	41.63	127.79
232	6	33.44	156.27
232	6.5	36.15	145.65
232	7	38.84	126.27
232	7.5	41.52	123.11
232	8	44.19	116.00
245	6	35.36	140.62
245	6.5	38.23	123.76
245	7	41.09	117.09
245	7.5	43.93	108.79
245	8	46.76	108.33

In order to compare the steel pipe and rectangular tube under the same load conditions, modeling will be replaced by a rectangular pipe, according to the national standard cold-drawn profiled pipe, the selection of standard specifications rectangular tube simulation analysis, simulation process parameter settings with the same round tube settings. Figure 2 is the rectangular tube 200x100mm simulation analysis of stress distribution results. Other specifications of the round tube were simulated according to the same method of analysis, and the following table 2 is different specifications of the maximum equivalent stress of the rectangular tube.

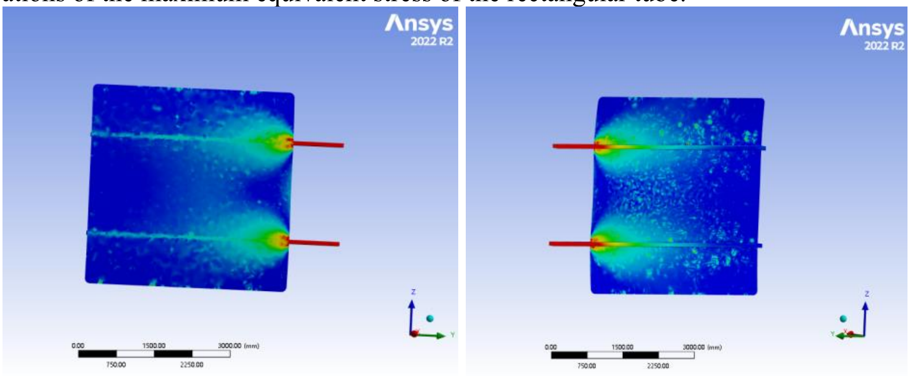

Fig. 2. Stress distribution cloud of rectangular tube 200x100mm front and back side

Table 2. Force analysis of rectangular tubes with different diameters

Rectangular tube specification(mm)	Wall thickness (mm)	Theoretical weight per unit length (kg/m)	Maximum equivalent force (MPa)
200x100	6	27.95	239.66
200x100	7	37.26	192.59
200x100	8	46.58	184.13
200x120	6	29.84	232.46
200x120	8	39.78	175.84
220x200	6	39.26	194.31
220x200	8	52.34	171.82
250x150	6.5	40.48	151.01
250x150	8	49.82	125.72
250x200	8	56.1	124.34

When the length of the round tube and rectangular tube is certain, the simulation is set up. The theoretical weight per unit length is the greater, and material consumed is the more, which unit length theory and the maximum equivalent force correlation with a graphic display is more intuitive. Fig. 3 shows the unit length theory and the maximum equivalent force correlation. From the figure, it can be seen that the theoretical weight per unit length is between 35-40kg/m, and round pipe of F 203x7.5-8, F 219x7-7.5, F 232x6.5-7, F 245x6-6.5 are smaller than the maximum equivalent force of rectangular pipe of 200x100x7, 200x120x8, 220x200x6.

According to the simulation analysis of round tube and rectangular tube, under the same load, the maximum equivalent stress of round tube of 203x6 and rectangular tube 200x120x8 and 220x200x8 is around 175Mpa. However, the circular tube of 203x6 is 36% smaller than the theoretical weight of the rectangular tube of 200x120x8, and 79% smaller than the theoretical weight of the rectangular tube of 220x200x8, that is, the circular tube is more material saving, and the circular tube has more specifications to choose from than the rectangular tube. From the manufacturing point of view, the round tube is more conducive to the welding of the flange plate than the rectangular tube. In summary, compared with the rectangular tube, the circular tube has good force effect and less material used, and is more suitable for being the rear beam of the sign plate.

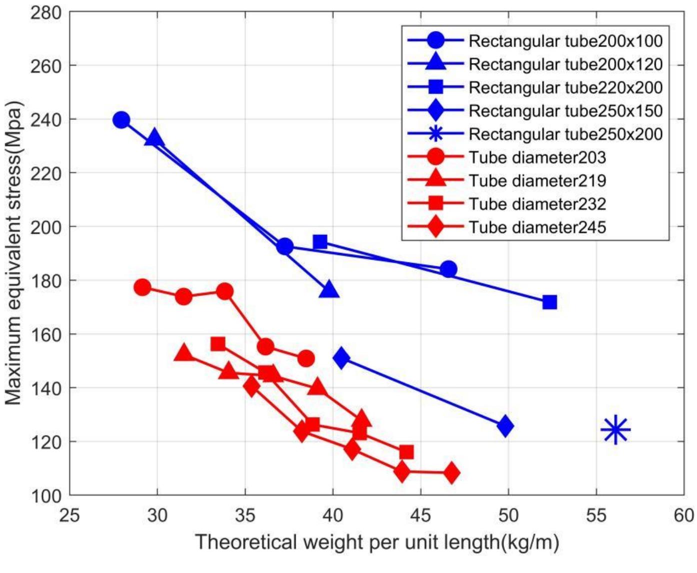

Fig. 3. Unit length theory and maximum equivalent force correlation

3.2 Optimization of column fascia structure

According to the preliminary static analysis, it can be seen that the column and foundation connection flange equivalent force is larger. To ensure that under the thickness of the fascia plate, the original four-bar plate flange is dimensionally driven. The height of the fascia plate is set to be the driving size, and the maximum equivalent force is taken as the output. The results are shown in Table 3, and Figure 4 shows the results of static analysis under four-bar plate 700mm height.

Table 3. Force analysis for each dimension of four-reinforced plate

Height (mm)	Maximum equivalent force (MPa)
600	281.82
650	279.52
700	275.81
750	273.33
800	270.19
850	262.35
900	260.86
950	255.33
1000	254.15

From the simulation and analysis results of four-bar plate, it can be seen that increasing the height of the bar plate cannot solve the stress concentration problem. Then eight-bar plate is used, and the simulation results are shown in Figure 5. And the simulation is continued to use the height as a driver to get the maximum equivalent stress under different heights, as shown in Table 4, and the relationship between the height and the maximum equivalent stress is plotted in Figure 6.

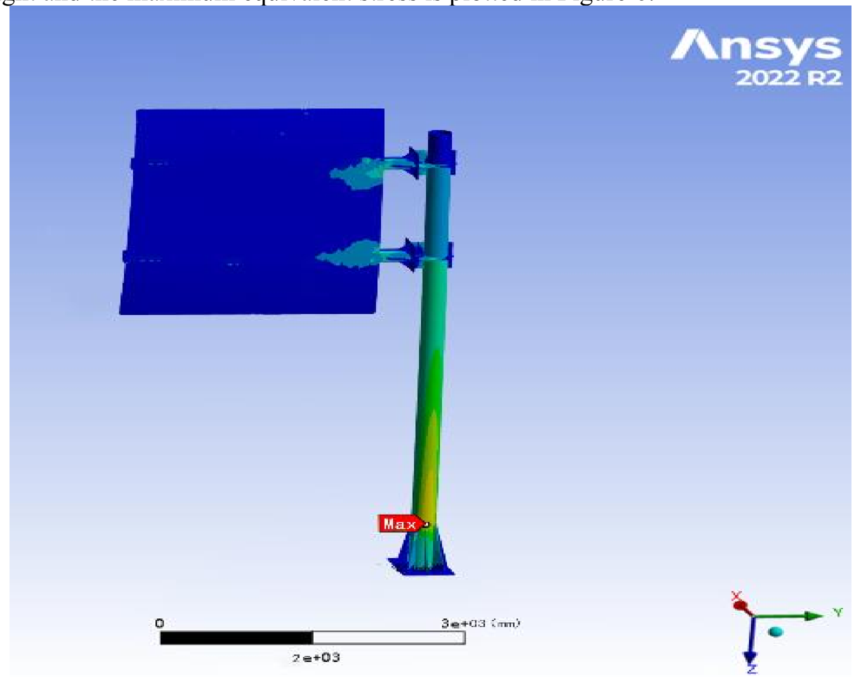

Fig. 4. Four-reinforced plate Stress distribution at height 700 mm

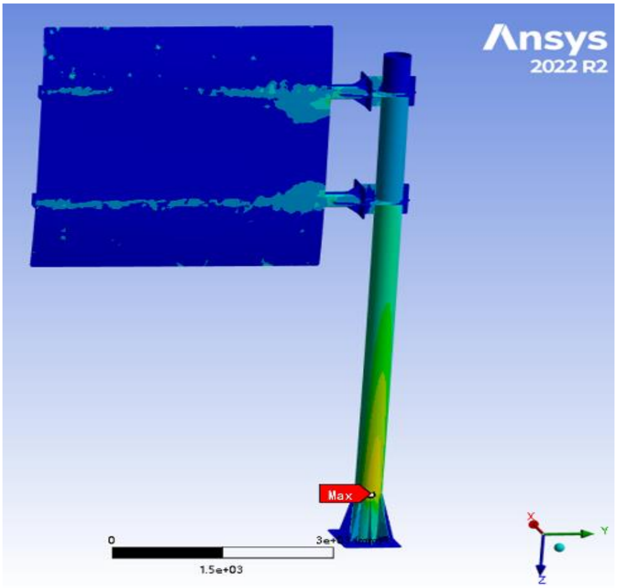

Fig. 5. Stress distribution of eight-bar plate height 800mm

Table 4. Force analysis for each dimension of eight-reinforced plate

Height (mm)	Maximum equivalent force (MPa)
600	212.67
650	212.59
700	210.55
750	208.44
800	203.28
850	193.58
900	192.35
950	191.74
1000	186.57

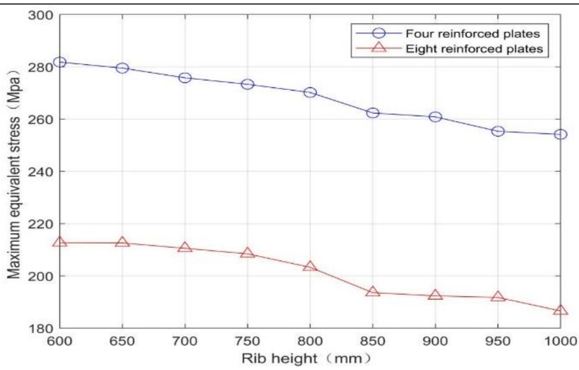

Fig. 6. Maximum equivalent stresses for different heights and number of fascia plates

From the four-bar plate flange results, it can be seen, only by increasing the height of the bar plate, that can not control the maximum equivalent force in the material yield strength of 235Mpa, that is, it can not solve the problem of stress concentration at the bottom of the column. Increase the flange fascia, drive the fascia height as a variable again, the maximum equivalent force are less than 212.67Mpa. Within the material yield strength, it can be seen that eight fascia flange in the limit of the working conditions to ensure that no failure, both to prevent the column in the limit of the working conditions of the fracture.

Based on the idea of topological structure, structural optimization and evaluation on the reinforcing ribs and crossbeams of F-type signboards are conducted. It is a supplement to the overall structural optimization goal, saving materials and increasing the safety of F-type signboards under extreme loads.

4 Conclusion

In this paper, the structural optimization design of the critical structure of F-type traffic signage was carried out by using Ansys Workbench platform, and the main research conclusions are as follows:

(1) Round tube F 203x6 is 36% smaller than the theoretical weight of rectangular tube of 200x120x8, and 79% smaller than the theoretical weight of rectangular tube of 220x200x8. Round tubes are more effective in stressing and saving materials than rectangular tubes;

(2) The base four-bar plate flange can not control the maximum equivalent force within the yield strength of the material only by increasing the height of the bar plate. The base eight-bar plate flange can ensure no failure under the extreme working condition, and can prevent the column from fracture under the extreme working condition.

This study provides an optimized design method for F-type signs with better mechanical properties, durability, and material savings. It is more suitable for the reliability design of signage in areas with frequent extreme weather and environmental conditions.

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