Comparison of Tunnel Options for Overhead Electrified Highways

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Abstract. To address the problems caused by the new energy overhead electrified highway, such as reduced normal driving lanes, susceptibility to extreme weather conditions, and inapplicability in inner cities, this paper takes Kunming, Yunnan Province as an example.This study examines three different tunnel structures: wall panel box structure, ribbed wall box structure, and combined box structure. The finite element modeling of these structures was performed using MIDAS GTS NX software. The study conducted a comparative analysis of force characteristics, economy, and construction difficulty. The results showed that 1) The maximum deformation of the wall-plate box structure occurs in the middle of the top plate between the side wall and the partition wall, with a maximum deformation value of 0.057 m. The economic impact is generally positive, the construction difficulty is relatively straightforward, and the top space is not optimally utilized;2) The ribbed wall plate type box structure is a cost-effective solution that utilizes less material, resulting in a more economical construction. However, the force characteristics at the center column are not optimal, with a maximum bending moment of 610KN.m; 3) The combined box structure exhibits the most favorable economic characteristics and the highest space utilization rate. However, it is more challenging to construct than the other two schemes. The maximum deformation is located in the middle of the top plate between the center column and the side wall, with a maximum deformation value of 0.058 m. After analyzing and comparing the three systems, it is clear that each system has its own advantages and disadvantages. However, they can provide useful reference points for the practical application of overhead electrified highways in China.

Keywords: New energy, Overhead electrified highway, Structural analysis, Force characteristics

1 Introduction

The rapid urbanization in China has intensified the conflict between the carrying capacity of the natural environment and energy. Additionally, the continuous population growth poses a significant challenge to the ecological balance. At the twentieth National Congress, the General Secretary emphasized that nature is the basic condition for human survival and development, and that we should promote the construction of a

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beautiful China and accelerate the green transformation of the development mode. One of the main drivers of economic development is the logistics and freight transport model, which is dominated by traditional fuel-guzzling trucks. However, this model is facing an extremely challenging transition to green alternatives.[1, 2] Currently, countries such as Europe are proposing to transform traditional fuel-polluting energy sources for heavy-duty trucks into clean electrical energy sources in order to solve this problem. [3-5]However, due to technical limitations, the traditional battery-powered system cannot meet the power needs of trucks required to travel long distances. Sweden has been the first country to propose the construction of electrified highways so that vehicles can be recharged while they are on the move. Maximize logistics efficiency while maintaining the original travel path. Swedish scholars have projected that only 25% of the original highways in Sweden need renovation for the economic benefits of electrified highways to reach their peak.[6] According to the Institute of Transportation Studies at Iowa State University in Ames, Iowa, United States, the application of electrified highways would reduce chemical fuel energy use and carbon emissions by more than 25%.[7, 8]The crisis of energy and environmental pollution poses a threat not only to European countries but also to china. To address the issues of energy consumption and environmental pollution. China has chosen to learn from the European experience and actively implement electrified highway planning and pilot projects. Three technical solutions are mainly involved: overhead, rail, and wireless. Among these, the overhead electrified highway is considered the most suitable solution for new energy heavy-duty trucks to pick up electric drive. [9]The principle is to install a pantograph above the vehicle and set up pillars on the side of the vehicle traveling road, along with an aerial conductive line. If the vehicle's power is low, it should be driven to the lane with the overhead conductive line and the pantograph should be raised to slide on the line and obtain electricity. Once the vehicle has enough power, it can leave the pick-up lane and move to other lanes. Although the application of overhead electrified highways and new energy heavy-duty trucks plays a significant role in the pollution energy transition, there are several challenges that must be considered. When applied to highways, overhead electrified highways will face a reduction in the number of lanes brought about by charging shelters along the road. Additionally, there are concerns regarding traffic safety hazards caused by overhead wires and the impact of extreme weather. Furthermore, due to the scarcity of land resources within the city and the resulting building density, traffic congestion problems occur frequently. This renders the installation of overhead wires and charging poles along city roads a challenging endeavour. The resulting congestion and safety concerns are further compounded by the difficulty of ensuring that trucks have access to electricity in a timely manner when entering the city. [10-16]

Generally, research on electrified highways is limited to technical solutions, implementation proposals, and other related aspects. There is very little targeted literature available. This paper aims to explore the practical application of overhead electrified highways in China by utilizing underground space. It proposes three new bridge and tunnel structural schemes and analyzes their force characteristics, economy, and construction difficulty in a comprehensive comparison. Given the necessity of implementing new energy heavy-duty trucks in the future and the significance of overhead electrified highways for their operation, exploring the practical application of such highways in China is of great practical significance.

2 Engineering Overview

Guangfu Road is located in the third ring road of Kunming City, Yunnan Province. It is a major corridor for logistics transportation due to its high traffic volume, surrounding shopping malls, and dense distribution of residential buildings. This paper uses the geological conditions of Guangfu Road in Kunming, Yunnan Province as an example. The site is situated in complex geological conditions, with layers of miscellaneous fill, plastic clay, powder sand, powder soil, and peaty soil from top to bottom. Table 1 displays the primary geological parameters.

Table 1. Table of main geological parameters

Ground Level	Densities /kN.m¯3	Cohesion /kPa	Internal friction angle/ (°)	Modulus of elasticity/MPa	Poisson's ratio
miscellaneous fill	18.0	15	10	4	0.35
plastic clay	18.0	28	16	5	0.33
siltstone	19.7	12.3	30	8.5	0.33
sand	19.5	12.2	30.8	7	0.36
peaty soil	15.0	15	5	3	0.34

3 Methods

Based on the analysis of the characteristics of overhead electric transmission lines, we propose three new types of bridges and tunnels.

3.1 Option 1: Wall Panel Box Structure

This paper focuses on utilizing underground space to address the issue of truck traffic restrictions in the short term. In the long term, the goal is to minimize problems caused by overhead electrified highways while retaining the logistics advantages of electrified new energy heavy trucks. To achieve this, Program 1 employs a wall plate box design. The bottom plate has a thickness of 0.9m, while the top plate, side wall, and partition wall have a thickness of 0.8m each. Please refer to Fig. 1 and 2 for the structural scheme.

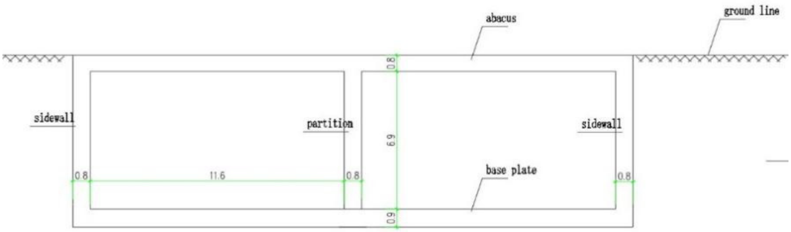

Fig. 1. Wall panel box structure cross section

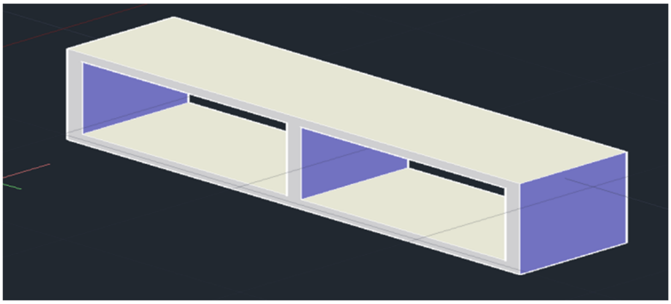

Fig. 2. Wall panel box structure elevation

3.2 Option 2: Ribbed Wall Box Structure

The design process for overhead electrified highways, which require wires in the air and pillars along the road, must consider the narrowing of lanes due to the location of pillars. To address this issue, the second option combines the traditional box structure of the side wall columns with the overhead electrified highway, requiring the columns on the side of the road to serve as both the side wall columns and the pillars. The partition wall between the right and left chambers has been replaced with columns to facilitate emergency access and maintenance.Structural Option 2 is displayed in Figures 3 and 4.

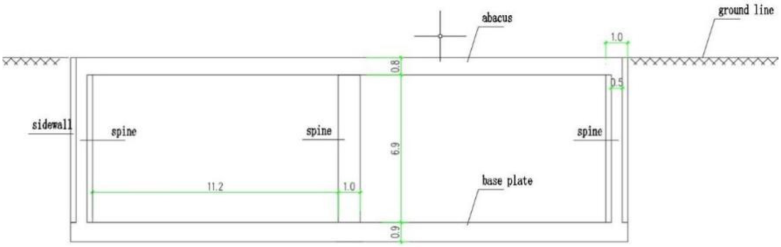

Fig. 3. Ribbed wall box structure cross-section

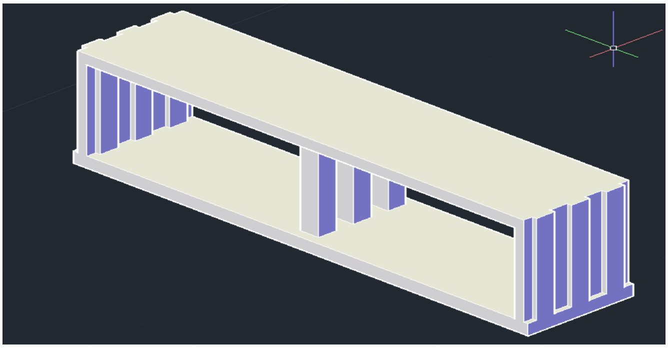

Fig. 4. Ribbed wall box structure elevation

3.3 Option 3: Combined Box Structure

Option 3 proposes to optimize the ribbed wall box structure to meet the challenges of constructing an overhead electrified highway above a city's main street. This involves reducing the thickness of the top slab and increasing headroom height by erecting longitudinal beams on the side wall columns in the direction of travel. Please refer to Figures 5 and 6 for a visual representation of Structural Option 3.

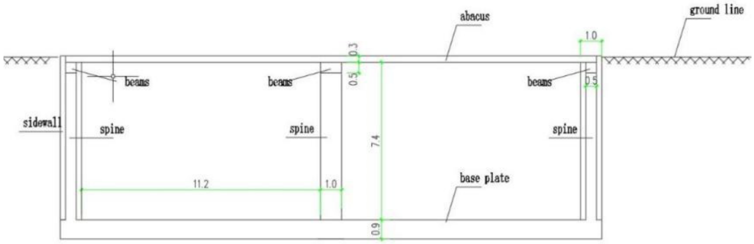

Fig. 5. Sectional drawing of combined box structure

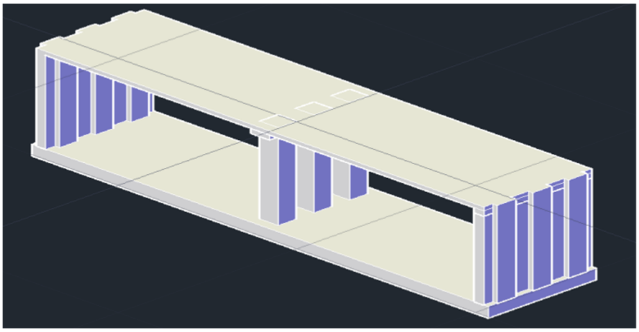

Fig. 6. Elevation of the combined box structure

4 Results and Discussion

4.1 Force Characteristics

For Scenarios 1, 2, and 3, spatial finite element models were created using MIDAS GTS NX, followed by computational simulation analyses. Scheme 1 simulates the top plate, bottom plate, side walls, and partition walls using plate units. Scheme 2 simulates the top plate, bottom plate, and side walls using plate units, and the columns using beam units. Scheme 3 simulates the top plate, bottom plate, and side walls using plate units, and the columns and longitudinal beams using beam units. The base of each scheme is located in the mud peat soil layer. After calculation, the force results and deformation diagrams for each scheme are presented below.

As shown in Figure 7, Figure 9 and Figure 11. Based on the internal force calculations, it is evident that the top slab forces in Scenarios 1, 2, and 3 are in better condition. Scenario 3 has the smallest reinforcement rate and a thinner top slab thickness compared to the other scenarios. As for the bottom plate forces, the forces in Schemes 1, 2, and3 are mostly similar. Scheme 2 has a maximum internal force of 610 KN.m at the columns in the top and bottom slabs. In Scheme1, the bending moment at the partition wall in the top and bottom slabs is relatively smaller than that of Scheme 2, with a maximum bending moment of 589.3 KN. In Scheme 3, the bending moment at the columns in the top and bottom slabs is the smallest; however, the internal force at the columns in the side walls increases more than in Scenarios 1 and 2, resulting in a maximum bending moment of 477.587 KN.m.

As shown in Figure 8, Figure 10 and Figure 12. Based on the simulation results, it is evident that the deformation of the bottom plate is similar for Scheme 1 and Scheme 2, while Scheme 3 exhibits the least deformation. The top plate of Scheme 1 experiences maximum deformation of 0.057 m at the midpoint between the partition wall and the side wall. Scheme 2, on the other hand, experiences maximum deformation at the midpoint between the center column and the side wall. However, its maximum deformation value is larger than that of Scenarios 1 and 3, and it is 0.069 m .The top plate of Scenario 3 is much thinner than that of Scenarios 1 and 2 due to the addition of longitudinal beams. Scenario 3 exhibits the most obvious deformation among the three scenarios. Based on the given premise, scheme 3 exhibits the most significant deformation among the three schemes. The maximum deformation of 0.058m is observed in the middle section of the roof slab, between the center column and the side wall.

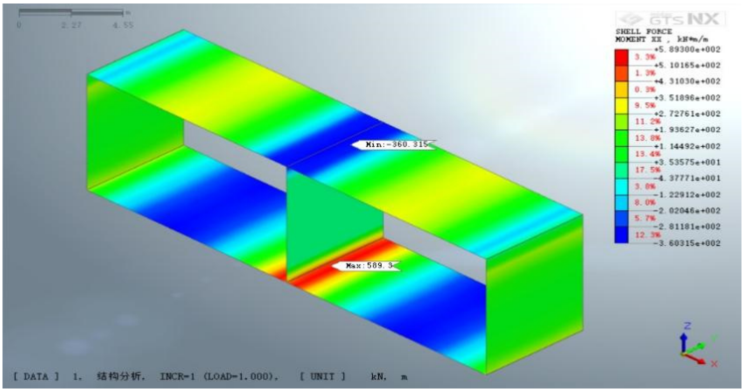

Fig. 7. Wall panel box structure bending moment diagram

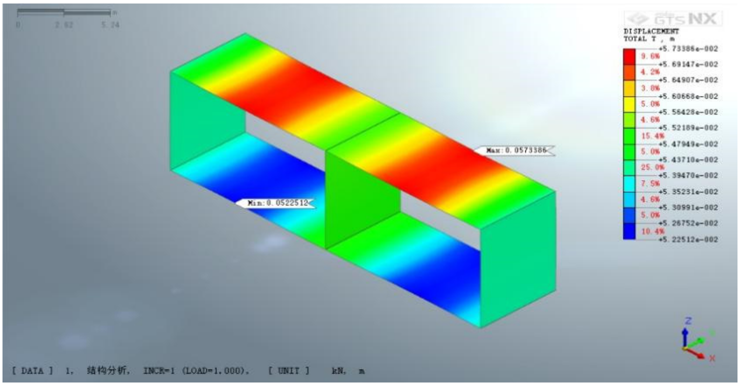

Fig. 8. Wall panel box structure deformation diagram

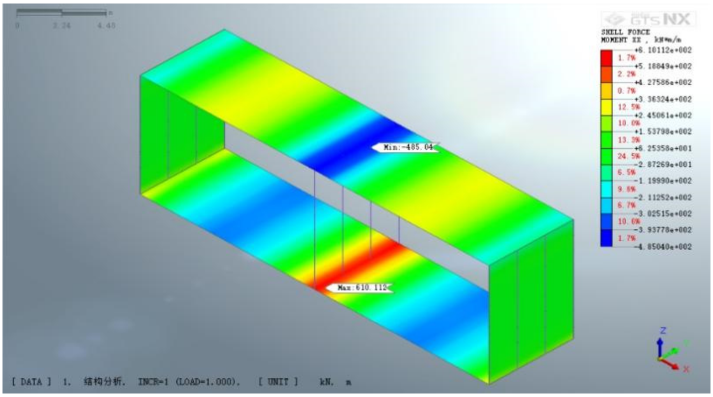

Fig. 9. Bending moment diagram of ribbed wall box structure

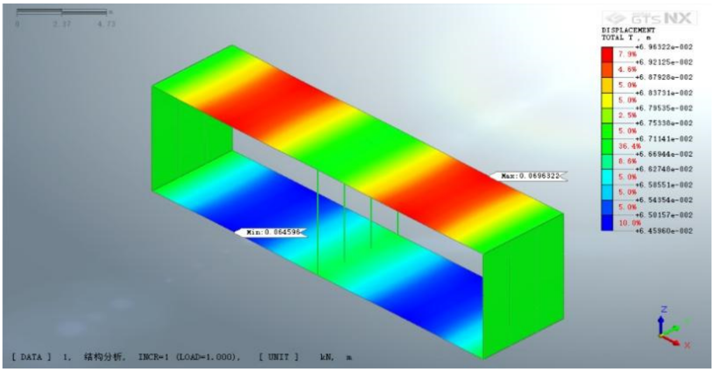

Fig. 10. Ribbed wall box structure deformation diagram

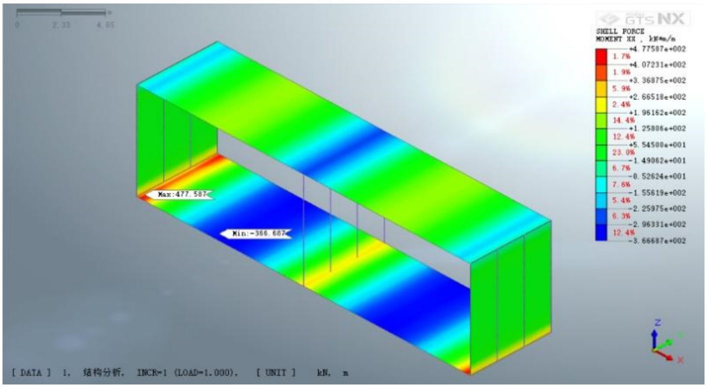

Fig. 11. Bending moment diagram of combined box structure

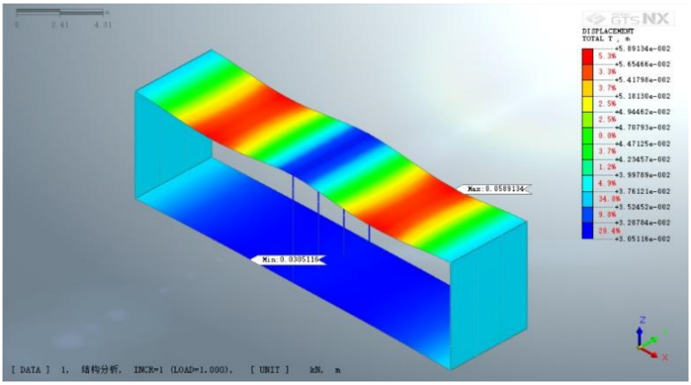

Fig. 12. Deformation diagram of combined box structure

4.2 Economy

This paper comprehensively compares the economics of each program based on the excavation volume, the volume of the main structure, and the cost.

1）Excavation volume:The excavation volume of each program in this paper is roughly equal. This is because all of the programs use the traditional box-type structural framework, resulting in minimal differences in excavation volumes.

2）Volume of main structural work:Program 3 utilizes a top plate with a thinner part thickness and reduced side wall ribbing to improve economy. However, due to the increased longitudinal beams and partition walls to columns, the total amount of main structural work is the largest among the three programs. Program 2 employs a ribbed wall box structure with thinner side walls and partition to columns, resulting in a slightly larger total amount of main structural work than the wall plate box structure used in Program 1. Program 1 has the minimum amount of main structural work among the three programs, as it uses a wall plate box structure.

3）Cost of construction:In terms of cost, Scheme 1 utilizes the traditional box structure, which requires the most materials and is the most expensive. Scheme 2 optimizes the partition wall of the traditional box structure into columns and adds ribs to the side walls to reduce wall thickness, resulting in a slight reduction in cost compared to Scheme 1. Scheme 3 takes it a step further by adding longitudinal beams to Scheme 2, resulting in a thinner top plate and even less material usage. As a result, Scheme 3 is the most cost-effective of the three options. Therefore, scheme 3 utilizes the most economical materials, resulting in the lowest cost among the three options.

4.3 Construction Difficulty

The order of construction difficulty for each scheme is as follows: Combined Box Structure > Ribbed Wall Box Structure > Wall Plate Box Structure. This ranking is determined by a combination of the structural characteristics of each scheme, supporting molds, the volume of the main structure, steel binding, and steel fabrication.

4.4 Comprehensive Comparison

Table 2 provides a comprehensive comparison of economics, construction difficulty, and force characteristics.

Table 2. Consolidated comparative summary table

Comparison Program	Wall panel box structure	Ribbed wall box structure	Combined box structure
Economy	general	preferably	best
Construction Difficulty	simplest	simpler	harder
Comparison Program	Wall panel box structure	Ribbed wall box structure	Combined box structure

Force characteristics	Better with components, worse with partitions	Better at all parts, worse at columns	best
Comprehensive performance	good	good	best

5 Conclusions

Following a comprehensive analysis and comparison of the force characteristics, economy, and construction difficulty of the three schemes, it can be concluded that all three provide a reference framework for the practical application of overhead electrified highways.

The specific characteristics of the three programs are as follows:

(1) The wall-plate box structure exhibits satisfactory force characteristics and a relatively straightforward construction. However, it is wasteful in terms of material and top space. It can be adopted under open site or unfavorable construction conditions. However, for the pantograph electrified highway, the actual adoption may encounter problems such as high cost or restricted top space and lane space.

(2) The ribbed wall box structure exhibits certain advantages over the wall plate box structure in terms of force characteristics and economy. However, these advantages are not readily apparent when the span and burial depth are relatively modest. In the case of a large span, it may be advantageous to consider the structure from the perspective of optimizing the force and economy.

(3) The combined box structure is optimal in terms of stress characteristics, and also has the advantages of high space utilization and low cost. However, its construction is more difficult. When this scheme is actually used, the waterproofing scheme can be further optimized according to the site conditions to further expand its advantages.

Problems and Recommendations:

1）The structural forms compared in this paper have limitations for the real-life application of electrified highways, despite their creativity.

2）The study is limited to exploring overall box-type structural solutions, and the number of solutions examined is also limited. Further research is necessary to explore other innovative structural solutions.

3）Each structural scheme can be optimized in practical applications by combining construction characteristics, such as anti-drainage, pit scheme, seismic resistance, and other factors.

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