

# Overview of Research Methods for Shear Lag Effect of LVL-UHPC Composite Box Girder

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## Abstract

In the development and application of bridges, box section is the most common section used in bridges, mainly because the box section bridge has good mechanical performance and stiffness. Although the good mechanical performance of box girder structure is outstanding, it must be considered in the design of engineering structure because of the existence of shear lag. Otherwise, it is easy to have safety accidents, and many accidents of tube structures and bridges are caused by shear lag. Therefore, strengthening the research on shear lag of box-section structural system is not only the need of the development of civil engineering analysis theory, but also has important practical significance and application value.

## Keywords

**Box Girder; Shear Lag Effect; Theoretical Analytical Method; Numerical Simulation; Experimental Investigation.**

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## 1. Summary

The application of wood-concrete composite beam meets the requirements of green building materials and double carbon policy, and this composite structure maximizes the material properties of wood and concrete. Compared with traditional wooden bridge, the mechanical properties of wood-concrete composite bridge have been significantly improved. Compared with concrete bridge, the weight of wood-concrete composite bridge is smaller because of the combination of wood, and the seismic capacity of composite structure is stronger because of the existence of shear connectors. In order to promote the application of highway bridges in China to respond to the requirements of national policies and approach to green building materials such as saving resources, protecting the environment and reducing pollution, the wood-concrete composite structure bridge is a scheme with application prospects and engineering feasibility.

## 2. Research Background

In recent years, seven departments, including the Ministry of Housing and Urban-Rural Development and the National Development and Reform Commission, have issued the Action Plan for Creating Green Buildings[5], saying that by 2022, the proportion of green building area in new urban buildings will reach 70%, and it is required to promote the full implementation of green design and application of green building materials in new buildings and strengthen the research and development and promotion of green building materials technology. Secondly, in order to cope with the climate anomalies caused by greenhouse gas emissions, China has issued a number of policies to promote peak carbon dioxide emissions and carbon neutrality. In 2020, the total carbon emissions of China's construction process will be 5.08 billion tons, accounting for 50.9% of the national carbon emissions. It is an arduous task for the construction industry to achieve the goal of "double carbon". Wood is a

natural green building material, the only renewable building material, which has carbon fixation ability and adapts to the green development direction and carbon reduction requirements of the construction industry. Under the background of low-carbon development of the construction industry, the advantages of low-carbon, renewable and sustainable development of wood are prominent.

### 3. Research Significance

LVL is a laminated veneer lumber with uniform material, high strength and stable mechanical properties. Ultra-high performance concrete (UHPC) has the characteristics of high elastic modulus, high tensile and compressive strength, small shrinkage and creep in the later period, and good durability. In this paper, LVL and UHPC are introduced into the wood-concrete composite box girder to form a new type of composite box girder structure-LVL-UHPC composite box girder, which solves the long-term problems of traditional wood-concrete composite structure, such as heavy weight, long-term deformation and insufficient durability.

Because of the shear lag effect of box girder, the stress distribution of box girder section is uneven, and the part with greater stress is unstable and partially destroyed because it exceeds the design strength and local unstable bearing capacity of box girder, which weakens the overall bearing capacity of the whole structure and causes the overall strength or unstable failure of the structure. This kind of damage caused by local failure is very worthy of designers' attention. Therefore, the research on shear lag effect of box girder is the need of box girder development theory, and also has important practical significance and practical value[3-4].

### 4. Research Method

In the last twenty years, many scholars at home and abroad have done a lot of research work on the shear lag effect of box girder, and systematically studied and summarized the shear lag effect of box girder from theoretical analysis, numerical solution and model test respectively[6-10]. The analysis methods of shear lag effect of box girder are mainly divided into three categories as follows[1-2]:

#### (1) elastic theory solution

The analytical method of elastic theory is based on classical elastic theory, which can effectively solve simple mechanical models and obtain accurate results of shear lag effect. Most of these theories can only theoretically analyze simply supported beams with equal cross-section, but the solution system of elastic mechanical equations has not changed fundamentally, which leads to complicated analysis and calculation formulas and is difficult to be used in engineering practice. Therefore, the elastic theory solution can only be used to solve a few problems, and it is no longer applicable to some complex stress structures. It is divided into tuning function method, orthotropic plate method and elastic folded plate theory.

#### ① Tuning function method

Based on the structural characteristics of rib plate, the rib plate and flange plate are calculated separately, and the rib plate is analyzed and calculated according to the elementary beam theory. The flange plate is regarded as a plane stress problem, and the stress function of the flange plate is solved by inverse method. Then, the equations are established according to the static balance and deformation coordination conditions between the rib plate and flange plate, and then the analytical solutions of stress and deflection of the flange plate are derived.

#### ② orthotropic plate method

In this method, ribs are compared to orthotropic plates perpendicular to each other, and then the area of ribs is assumed to be evenly distributed on the whole plate. Based on the elastic thin plate theory and the boundary conditions of elasticity, the formulas of normal stress and deflection of rib structure are derived, and the analytical solution of shear lag problem is obtained. The orthotropic plate method considers the whole box girder, treating the box girder as a whole, not a single slab, and the applied load is expressed by Fourier series, so it is complicated and limited in application.

### ③ elastic folded plate theory

Based on the elastic plane stress theory and the bending theory of plates, this method divides the box girder into several rectangular plates, and establishes equations according to the deformation coordination conditions and static equilibrium conditions at the junction of the plates, which can be solved by matrix method.

### (2) Energy Variational Method

The energy variational method is based on energy. First, the displacement field of box girder is established. Taking the vertical displacement of beam and the longitudinal warping displacement function of flange plate as unknowns, the strain field is deduced according to the constitutive relation, and then the total potential energy of the whole box girder structure is obtained. Then, based on the principle of minimum potential energy, the warping differential control equations of box girder are established, and the closed solutions of stress and deflection are solved, thus the analytical solutions of shear lag problems under various loads are obtained. Energy variational method is a common method to solve shear lag problem. When using variational method to solve shear lag problem, it is usually necessary to assume the longitudinal displacement function on the wing plate of box girder which is close to the real solution in advance, and then apply the principle of minimum potential energy to solve it. Therefore, whether the solution of shear lag effect obtained by this method is reasonable depends mainly on the assumed deformation conditions. The remarkable advantage of energy variational method is that it can not only determine the transverse stress distribution in the wing plate, but also calculate the deflection of the beam after considering the shear lag. Therefore, this method has been adopted by many scholars to solve the shear lag problem of box girder with equal cross section.

The closed solution can be obtained by the energy variational method, which can not only describe the function image of shear lag effect of any section, but also qualitatively analyze the influence of each different parameter. This method assumes the plane stress of the wing plate, although there is still some error at the free end of the wing plate, the maximum stress obtained is close to the actual stress, which can meet the requirements of engineering accuracy. However, this method is generally applicable to the box girder with equal cross section, and the closed solution can not be obtained in the solution of the box girder with variable cross section.

The finite segment method based on energy variational method has good adaptability and can be used to solve the general multi-span box girder with variable cross section.

### (3) analogy rod method

When analyzing the structure, the analogy bar method adopts reasonable basic assumptions, and compares the simply supported box beam under symmetrical load to cantilever beam structure, thus dispersing the structure into two ribbed plate structures composed of stiffening ribs and thin plates, thus simplifying the structure. That is to say, the box-section beam structure under bending can be regarded as the combination of the thin plate which only bears the shear force and the bar which only bears the axial force. Then, according to the deformation compatibility condition between the plate and the bar and the stress balance condition, the internal force of the stiffening rib can be obtained by solving the equations. The shear lag effect produced in each wing plate can be determined by the internal force of idealized stiffener, which is equal to the actual stiffener area plus the area provided by adjacent thin plates. Usually, the number of comparable stiffeners needs to be determined according to the accuracy of solution. The analogy bar method simplifies the mechanical model through basic assumptions, so it has advantages in solving the problem of box beams with equal cross section. However, there are still many difficulties in calculating the shear lag effect of structures with relatively complex mechanical models.

### (4) Numerical analysis method

Numerical analysis can solve various mechanical problems. With the rapid development of computer technology, numerical analysis plays an important role in the analysis of shear lag effect. Finite

element method is an effective numerical analysis method to solve various complex engineering problems. The numerical analysis methods mainly include finite element method, finite strip method and finite segment method.

① finite element method

The finite element method is a numerical analysis method developed in the 1970s, which can be used to analyze complex engineering structural problems. Its essence is to divide a complex continuum into a finite number of simple units, and turn an infinite degree of freedom problem into a finite degree of freedom problem. It can be used to analyze large-scale complex spatial structures, and can also make uncontrollable elements in the experiment be realized by numerical simulation, and finally an accurate and comprehensive stress distribution map can be obtained. Therefore, many scholars use the finite element method to analyze the shear lag effect of box girders. Commonly used finite element analysis software includes ANSYS, ABAQUS, MIDAS, etc. Finite element method can obtain a more comprehensive and accurate stress distribution map, which can be used as a good method for numerical verification and comparison, and can also test the sensitivity and rationality of various assumptions and approximations made in analytical theory, and at the same time, it can make the elements that cannot be simulated and controlled in the experiment realized by numerical simulation.

② finite strip method

The finite strip method was first proposed by Zhang Youqi [75], which is a semi-analytical method developed by introducing the principle of minimum potential energy on the basis of the finite element method. Compared with the finite element method, this method combines the advantages of the finite element method and the analytical method of elasticity. The finite strip method reduces the degree of freedom, improves the calculation efficiency, and has stronger applicability, which is widely used in the shear lag effect of box girders with equal cross section under any boundary conditions. The finite strip method is developed from the finite element method, and compared with it, the finite strip method has less calculation. This method is effective in analyzing simply supported beam bridges with equal cross-section, but it is still difficult to analyze box beams with variable cross-section.

③ Finite segment method

The finite segment method is a semi-analytical and semi-analytical method of finite element, which combines analytical theory with ordinary numerical method. The beam is cut into many sections along the longitudinal axis of the beam, and the variation law of the beam element in the cross section is expressed by a specific shape function. According to the continuous control conditions of deformation between sections, the stiffness matrix of the element is obtained from the basic differential equation of box girder shear lag. As a one-dimensional finite element method, this method has high accuracy and less calculation. It is also suitable for analyzing the shear lag problem of various box girder structures and the shear lag effect of variable cross-section beams, thus making up for the shortcomings of the finite strip method.

(5) Model test

Model test is a scaled physical model made according to similarity principle and similarity criterion, which is used to predict the working state of the original structure and verify the design and calculation results. It is an indispensable link in major engineering construction, one of the main means to provide data and conclusions for structural analysis, and also the main basis to test the correctness of numerical theory and analytical theory. For some important projects, in order to check the accuracy of calculation results, model tests are often used. The model test can simulate the boundary conditions, load conditions and some details of the actual structure, and more importantly, it is not affected by the simplified assumptions used in theoretical calculation. Experiment is an important method of scientific research, which can truly reflect scientific phenomena. Different types of experiments need different equipment and experimental periods, depending on the research purpose. Structural model test does not need to assume mathematical models like theoretical analysis

and numerical analysis, so it is not affected by simplified assumptions and can more truly reflect various physical phenomena and laws of the structure.

## 5. Conclusion

To sum up, through the efforts of many scholars, more and more useful achievements have been made in the study of shear lag effect. Both box bridges and high-rise tube structures have shear lag phenomenon. If this phenomenon is ignored in the design of engineering structures, it will leave hidden dangers. Therefore, only by studying the shear lag more deeply can we fully understand the working performance of the structure and optimize the structural design. For this reason, theoretical analysis, experimental research and numerical simulation are usually combined to carry out in-depth research on the shear lag effect of box girder.

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