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REVIEW OF RESEARCH ON SHEAR LAG IN CIVIL ENGINEERING STRUCTURES

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Abstract: This paper introduces the phenomenon and basic characteristics of shear lag in civil engineering structures, and summarizes the research on shear lag problems of bridge structures and house structures at home and abroad. method, the applicability of various theories and methods and the research results on shear lag in civil engineering structures so far are reviewed, providing a basis for further research in the future. The research provides a basis and provides an outlook on the research prospects of shear lag.
Keywords: Thin-walled box beam; Shear lag; Variation method; Finite element method; Cylinder structure

1. RESEARCH STATUS OF SHEAR LAG IN THIN-WALLED BOX GIRDER STRUCTURES

In terms of the development and application of bridges, the box section is the most common section used in bridges. The main reason is that the box section The cross-section bridge has good mechanical performance and stiffness. The mechanical properties and stress modes of tube structures and box beams in high-rise buildings are similar. Similarly, under the action of a horizontal load on a cylinder structure, the lateral force-resisting structure parallel to the load direction and the lateral force-resisting structure perpendicular to the load direction are the same. function, so that the structure forms a spatial overall resistance. Because this building structure system can withstand relatively large loads in all directions The load, space stiffness and mechanical performance are relatively good, and it is most used in super high-rise buildings. Cantilever thin-walled box girder structure under lateral load Similar to the frame-tube structure affected by horizontal wind force, the difference is that the frame-tube structure needs to withstand relatively large axial force. Relevant studies have been Ming [1- 2] , the influence of axial force on shear lag in the cylinder structure can be ignored. Although thin-walled box girder structures and cylinder structures have outstanding mechanical properties, due to the existence of shear lag, they must be considered when designing engineering structures. Otherwise, safety incidents will be more likely to occur Therefore, many accidents of tube structures and bridges are caused by shear hysteresis. Therefore, strengthening the box-section structural system The study of shear lag is not only a need for the development of civil engineering analysis theory, but also has important practical significance and application value.

1.1 Research Methods

1.1.1 Elasticity theory solution

Among the shear lag analysis research methods, the elastic theory solution method is a relatively classic theoretical method, which mainly includes the following three methods:
1) Folding plate theory method. Based on the elastic plane theory and combined with the plate bending theory, the box beam is discretized into rectangular plates, and then based on the equilibrium conditions at the junction of the rectangular plates, a system of equations is established and solved. GOLDBERG et al. [3] proposed the elastic folding plate theory for the first time, and VAN et al. [4] Plate theory is applied to the shear lag problem of wide and low box beams. 2) Tuning function method. Rib structures are widely used in bridges, and the tuning function method is as the research object. Taking the ribs and wing plates as isolation bodies, the wing plates use the inverse solution method to solve the stress function for plane stress analysis. For the ribs The plate is analyzed using elementary beam theory, and then a system of equations is established based on the displacement coordination and static equilibrium conditions between the wing plate and the floor plate and the unknowns are obtained. The stress and deflection of the wing plate can finally be substituted into the unknowns to obtain. According to the literature [5] , Karman used the tuning function method in the 1930s to solve problems such as effective width distribution. 3) Orthotropic plate method. It is a commonly used method. The main idea is to compare the rib structure to an orthotropic plate and then use the elastic thin plate theory to solve it. REISSNER This method was first used to solve some shear lag problems [6]. COULL et al. [7] applied this method to high-rise tube structures to analyze the shear lag of the frame tube.

1.1.2 energy functional variation method

The energy variation method is a common method for solving shear lag problems. When using the energy variation method to solve the shear lag problem, it is usually necessary to It is necessary to assume in advance that the longitudinal displacement function on the box girder wing plate is closer to the real solution, and then apply the principle of minimum potential energy to solve it. Normal situation In this case, the deflection function of the beam and the longitudinal displacement function describing the shear lag of the flange plate are unknown variables, more complex problems will introduce more parameters numbers, then establish the governing differential equations, and solve the equations simultaneously to obtain the stress and deflection solutions. Many scholars have shown that the effects of different longitudinal displacement functions The selection will have a certain impact on the obtained results, and the difficulty of solving the system of differential equations will also be different. REISSNER [8] First Proposed

the energy functional variation method. Based on the principle of minimum potential energy, he used the quadratic parabola as the longitudinal displacement mode and derived the biaxially symmetric rectangle. The differential equation of the beam is the first successful example of applying energy method to analyze and solve the shear lag problem.

1.1.3 Analogue rod method

The analog rod method is often used by scholars to analyze shear lag. This method uses a combination of thin plates to bear shear force and stiffening bars to bear axial force. To compare the bending thin-walled box girder structure, and then according to the deformation coordination conditions at the intersection of the stiffening rod and the connecting thin plate and the static force balance between them Establish a system of differential equations based on equilibrium conditions, and solve the equations simultaneously to obtain the required analytical solution. Usually, the number of analog rods needs to be determined according to the requirement Determine the accuracy of the solution. The analog rod method was first developed by the British scholar EVANS [9] proposed it on the basis of improving the previous stiffening plate theory. literature [10] used the three-bar analogy method to analyze the shear lag of long-span continuous rigid frame box girder, and compared the static load test of the actual bridge.

1.1.4 Numerical solution

five main methods of numerical solution. 1) Finite difference method. Based on the energy variation method, a system of shear lag differential equations is obtained and the corresponding finite difference format is given, which can be applied to the shear lag analysis of variable-section box girder bridges. Literature [11] used this method to conduct a linear variable cross-section cantilever beam. Shear lag analysis. 2) Finite element method. The essence of the finite element method is to divide the complex continuum into a limited number of simple units, eliminating the The limited degree of freedom problem is a problem with limited degrees of freedom. It is widely used in various fields such as civil engineering and machinery. It is a powerful numerical analysis method. This method can be used to obtain results that meet engineering needs for many very complex problems, as well as problems that are difficult to solve using other methods. fruit. Commonly used finite element analysis software include ANSYS, ABAQUS, MIDAS, etc. CLOUGH [12] named this method as "finite element method" for the first time. KWAN [13] proposed a simple method to calculate the shear lag coefficient, and conducted a shear lag analysis on the shear walls of high-rise buildings. Literature[14] Using finite element software ANSYS For a certain height in the 8 degree area exceeding 200m Conducted shear lag correlation analysis on super high-rise buildings, and provided valuable suggestions on the selection and optimization of structural solutions. Literature [15] used the SOLID45 solid element in ANSYS software to study the shear lag distribution rules of different longitudinal and transverse parts of steel box girder. 3) Limited article method. The finite strip method is developed from the finite element method. Compared with it, there are The limit method requires less calculations. This method is more effective in analyzing simply supported girder bridges with equal cross-sections. Many domestic and foreign scholars like to use this method when analyzing the shear lag of box girders. For example, Luo Banqi [16] derived the finite strip method of curved box girder based on the geometric equation of the conical shell, and compiled a calculation program for simply supported curved box girder. Cheng Xiangyun et al. [17] proposed the "three combined analysis method" when analyzing the shear lag effect of variable-height box girder bridges, which further broadened the application scope of the finite strip method. 4) Finite segment method. This is a semi-analytical method. As a one-dimensional finite element method, the accuracy of this method is It is highly efficient and requires less calculation, and is also suitable for analyzing shear lag problems of various box girder structures. Some scholars proposed an improved finite segment method [18] in the early days to analyze the shear lag effect. This method combines analytical theory and ordinary numerical methods to establish a semi-analytic finite segment model of a plane beam element. The function of automatically accounting for shear lag effects is implemented in structural analysis. 5) Spline function method. Use the spline function to establish the corresponding displacement field, and Interpolate over the entire solution domain. Then the principle of minimum potential energy is used to establish a system of linear equations that is easy to solve. Spline element method, finite spline element method, etc. are developed by combining the principle of minimum potential energy with spline functions. WANG [19- 20] Based on Vladisov's classic method of thin-walled structures, the influence of shear deformation on the mid-surface of the rod wall is taken into account to reflect the shear lag phenomenon, and the warpage displacement field of the rod cross-section is adopted as a transformation spline function. Simulation and analysis of the shear lag problem of cantilever beams and simply supported beams.

1.1.5 Experimental research

Experiment is an important method of scientific research. This method can reflect scientific phenomena more truly. Different types of experiments require different equipment and experimental cycles, depending on the purpose of the research. Structural model testing does not require the assumption of mathematical models like theoretical analysis and numerical analysis, so it is not affected by simplifying assumptions and can more truly reflect various physical phenomena and laws of the structure. Literature [21] takes 1/5 According to the proportion, a reinforced steel fiber high -strength concrete box girder model was made, and the mechanical performance and shear lag phenomenon under bending load were analyzed. Zheng Haocheng [22] made a reinforced concrete box column model and studied the shear lag effect of box columns under low-cycle repeated loading.

1.2 Current Research Results

Luo Banqi [23] believed that shear lag effect also exists in variable-height box beams, and he found that when the width - to-span ratio becomes larger, the beam height ratio changes the shear force The influence of stagnation becomes more

prominent. Chen Yuji [24] considered the shear lag effect when studying the elastic-plastic problem of thin-walled curved box beams and believed that the bending The nonlinear characteristics of the shear lag coefficient are more significant relative to the deflection and torsion angle. Pan Danguang [25] used the energy functional variation method to establish the differential equation and corresponding boundary conditions of the box beam under nonlinear temperature gradient, proposed a two-parameter displacement function, analyzed the longitudinal displacement of the upper and lower wing plates, and believed that in Under nonlinear temperature gradient, shear lag effects occur in both the upper and lower flanges of the box girder. Huang Xianguo [26] used the finite element method to analyze long-span box girders under temperature load and believed that the shear lag phenomenon of long-span cantilever box girders and continuous box girders was severe under temperature load. Heavy. REZA Masoudnia [27] summarized previous research on the shear lag phenomenon and effective flange width of steel, concrete, and wood composite T-beams and concluded that In order to study the influence of various aspects of single-span and multi-span steel-concrete T-beam structures on the effective flange width of negative and positive bends, still need to consider important required structural details. Wei Chenglong [28] combined with the analysis of the shear lag effect of box beams, proposed a new finite segment element of plate and truss combined beams, and established a mechanical model and finite element equation. The analysis shows that the shear hysteresis phenomenon is more prominent in the deck of the plate-truss combined beam cable-stayed bridge and needs to be taken into consideration during structural design. Zhou Xuhui [29] believed that as the width-to-span ratio and natural vibration order increase, the shear lag effect has a more prominent impact on the natural frequency. Li Guifeng [30] used ANSYS to establish a full-bridge solid model and analyzed the forces between the webs of the flat ultra-wide box girder. The results showed that the middle web and the side The maximum stress difference in the web reaches 40%, and the shear lag phenomenon in the transverse direction of the entire section is considered to be significant. Zhu Shifeng [31] based on finite element method Using finite element software, the influencing factors of the shear lag effect of corrugated steel web box beams were analyzed. It is considered that the shear lag coefficient increases with the supporting length of the box girder. decreases as the thickness of the roof increases; decreases as the number of diaphragms in the box girder increases; changing the cantilever ratio has no obvious effect on the maximum shear lag coefficient. Based on the principle of minimum potential energy, Xia Wenqiang [32] discussed the influence of uniformly distributed load and concentrated load on shear lag of simply supported box beams, and believed that under the action of concentrated load in the mid-span and uniform load across the full span, the maximum deflection is affected by shear lag. Increased by 2% ~ 2.5%.

2. RESEARCH STATUS OF SHEAR LAG IN HIGH-RISE TUBE STRUCTURES

2.1 Displacement Function Along Height Direction

COULL [33] in In 1975, he assumed a longitudinal warping displacement function distributed quadratically along the horizontal direction, and first proposed the idea of continuity. Liu Kai Guo [34] adopted a quadratic parabolic displacement distribution method in the flange frame along the horizontal direction, solved the variational equations, and obtained various cylinder Analytical solution of structural displacement. LEE When Kang - Kun [35] et al. studied the tube-in-tube structure, the vertical displacements of the tube web frame and flange frame of the outer frame were all in the form of cubic distribution functions.

Among them, ω is the horizontal displacement of the frame-tube structure, a is half the length of the web frame, b is half the width of the web frame, v 1 (z), v 2 (z) are the wings Maximum difference in shear angle between edge and web frame.

Some scholars regard the floor as a rigid connecting rod, and the role of the floor is continuous along the height direction, resulting in a completely different structure composed of cosecant functions and so on. into the displacement distribution form. At this stage, these displacement forms are mainly used. What displacement form should be more appropriate along the height direction? Awaiting further research.

2.2 Current research results

Wang Mengfu [36] used the nonlinear finite element analysis software ABAQUS to analyze and study the reinforced concrete core tube with hybrid concealed supports and the ordinary reinforced concrete core tube. He believed that the core tube with concealed supports has better integrity than the ordinary tube, shear lag effect Significantly less than ordinary cylinders. Chen Bing [37] conducted a study on the mechanical properties of reinforced concrete double-chamber cylinder and believed that in the reinforced concrete core cylinder Adding hybrid dark supports can greatly reduce the shear hysteresis effect of the core tube. Among them, adding profiled steel dark supports has the most significant effect. Xu Jianye [38] based on equivalent continuum method and ANSYS Finite element software was used to study the tube-in-tube structure, and it was considered that the continuum method was used to analyze the shear force. When considering the lag effect, there is a lack of consideration of the impact of the negative shear lag effect on the structure. Yao Shudian [39] is based on the finite element method and uses ABAQUS software vs. steel After analyzing the reinforced concrete tube-in-tube structure, it is believed that within an appropriate span-to-height ratio range, increasing the height of the window skirt can significantly reduce the structural stress. Shear lag effect. Li Jiabao [40] used the force method to directly solve Airey's stress equation based on the continuous model when analyzing the frame tube, and obtained the analytical solution of the frame tube. He believed that the frame tube structure has extremely obvious shear lag phenomenon. Based on the principle of continuity, Feng Bo [41] introduced the piecewise linear interpolation function of longitudinal displacement, considered the deformation caused by torsion under the influence of

shear lag effect, analyzed the beam tube structure of super high-rise buildings, and concluded that the structure is more consistent with Actual force deformation. Gao Yan [42] analyzed the cylinder structure based on the equivalent continuum method and the principle of minimum potential energy, and believed that only the top is subject to concentrated The frame-tube structure under load will not produce a negative shear lag effect, but only a positive shear lag effect. Zhao Feng [43] based on finite element software to calculate the oblique Conducted research on the internal forces of the cross-grid tube structure and pointed out that the shear lag effect of the diagonal cross-grid tube structure is different from that of the frame tube, and defined the "bias-cross net tube structure" "Structural shear lag ratio", it is believed that the shear lag ratio of traditional frame and tube structures is much higher than that of diagonal mesh tube structures. Ma Xinli [44] took a different approach and analyzed the shear lag effect of the frame-tube structure based on the spline function method. He believed that the stiffness of the corner columns had little effect on the shear lag effect, and the effect increased with the increase of the aspect ratio of the frame-tube. The shear lag effect at the same height is reduced. Wang Haibo [45] analyzed that the greater the stiffness ratio of the inner and outer cylinders, the more obvious the shear lag effect of the structure will be. Factors such as aspect ratio and corner column stiffness will have a certain impact on the shear lag effect of high-rise cylinders.

3. CONCLUSION AND OUTLOOK

In summary, through the efforts of many scholars, more and more useful results have been achieved in the research on the shear lag effect. Whether it is a box Shear lag exists in both high-rise bridges and high-rise tube structures. If this phenomenon is ignored in the design of engineering structures, it will leave potential safety hazards. Therefore, only by conducting more in-depth research on shear lag can we fully understand the working performance of the structure and optimize the structural design.

Since the research on shear lag effects on bridges is relatively sufficient, the following prospects are made for the research on shear lag on high-rise tube structures:

1) In view of the fact that some cylinder structures are now designed as variable cross-section structural systems, different shear modulus and shear modulus can be considered in the energy equation. Wall thickness to further realize temperature analysis of variable cross-section frame tubes. 2) The frame tube can be further analyzed under the nonlinear temperature gradient along the section height direction. Structural shear lag effect. 3) The tube-in-tube structure is a common structural system in high-rise buildings. The tube-in-tube structure can also be analyzed in the horizontal direction. Shear lag effect under load and temperature load. 4) The role of the floor can be taken into account in the shear lag analysis process. 5) Also You can choose a more complex and reasonable longitudinal displacement function to analyze the shear force of the beam tube structure under the action of temperature load and transverse load. hysteresis effect. 6) In engineering, the characteristics of many materials are nonlinear, and the deformation is also nonlinear, which will lead to many problems encountered during structural analysis. There are many nonlinear problems, but there are relatively few studies on the shear lag effect in the nonlinear field. Therefore, the analysis and discussion of the nonlinear shear lag problem are carried out. It should be a meaningful new topic.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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