__Minireview Article__

Review on mechanical performance of concrete laminated slabs

Abstract：
Prefabricated structures meet the requirements of industrialized construction production and are increasingly used in the field of construction. Among them, the laminated slab is widely used in practical projects as a new type of component. In prefabricated buildings, the laminated slab can not only significantly increase the prefabrication rate, but also has the advantages of good integrity, saving templates, flat bottom surface, and efficient construction. Applied to a variety of prefabricated structural systems. This article summarizes the mechanical performance of concrete laminated slabs by using the literature survey method, and elaborates in detail on the indirect lap joint performance of concrete laminated slabs and additional reinforcement at the wall or beam support, the shear performance of concrete laminated slabs, and the overall performance of laminated slabs And the research status of the seismic performance of different joints of the composite structure, and the development trend of the concrete composite structure prospects.
Keywords: Laminate；Force performance；Seismic performance；Connection part

Introduction

The laminated structure is a new type of assembled integral structure. The laminated slab is an important laminated component. The research on the laminated slab at home and abroad includes the shear performance of the laminated slab surface, the overall performance of the laminated slab and the seismic performance at different nodes. Precast concrete laminated slabs can be classified in various ways according to the construction method, stress process, contact surface treatment method, and the difference between the precast floor and the post-cast layer materials. In addition, the laminated slab has obvious advantages such as good integrity, high construction efficiency and saving construction formwork materials, and has a good development prospect.

In the 1920s, foreign countries began to widely use concrete composite structures in bridge structures, and then concrete composite structures began to develop greatly in the field of housing construction. In China, relevant research on laminated components has been carried out since the 1950s, and the research on reinforced concrete laminated slabs is the most. Research on shear performance of superimposed surfaces, etc. The node connection between the laminated slab and the wall or beam is a relatively weak part of the structure, but the specific definition, design method and construction measures of the indirect lap joint at the wall or beam node connection have not been stipulated in the code. Therefore, in the laminated slab, the safety and efficiency of the connection structure between the prefabricated slab and other prefabricated components, and between the prefabricated slab and the cast-in-place component have become the top priority of the research work.

1 Research On The Mechanical Performance Of Laminated Slabs

At present, scholars at home and abroad have conducted a lot of research on the shear performance of new and old concrete horizontal superimposed surfaces. For example, Liu Hanchao et al. [1] found that when the rib area of the inverted T-shaped slab is appropriate and the roughness of the superimposed surface meets the requirements of the concrete structure design code, Its superimposed surface has a strong bonding and shearing resistance, which can ensure that the two parts of concrete work together effectively. Nie Jianguo et al. [2] discussed the interface shear capacity of laminated slabs with different interface roughness and found that no matter whether it is a high-strength concrete laminated slab or an ordinary concrete laminated slab, under different roughness degrees, the interface has been roughened and no shear reinforcement is provided, there is no shear failure phenomenon at the superimposed surface, which shows that the bonding and friction ability of the superimposed surface of the laminated plate can ensure the overall working performance of the laminated plate. Tang Lei et al. [3] found that the shear resistance of the laminated surface through the combined action of sweeping and truss webs can ensure that the laminated slab will not slip relative to the prefabricated layer and the laminated layer during the entire loading process. Hou Hetao et al. [4] believed that the bonding and anchoring performance of the prefabricated floor and the post-cast concrete in the test is the key factor affecting the flexural performance of the prestressed concrete laminated slab and the basis for ensuring the effective work of the two. Therefore, in actual engineering, it is necessary to roughen the surface of the prefabricated floor.

Foreign scholars have also found similar conclusions on the shear performance of the new and old concrete horizontal superimposed surfaces. For example, Kumar et al. [5] found that when the upper limit of the average horizontal shear stress of the new and old concrete joint surfaces of precast bridge decks is 0.8MPa, there is no need to set the shear resistance. For steel connectors, only the surface of the prefabricated slab joint surface needs to be brushed to make the old and new concrete interface have sufficient shear strength. Gohnert et al. [6] conducted 90 horizontal shear tests on composite beam specimens and found that surface roughness can significantly affect the horizontal shear strength of the interface. Ibrahim et al. [7] studied the shear capacity of composite slabs under different roughness. It was found that concrete slabs with rough HCU surfaces had greater pre-crack stiffness, greater load-bearing capacity, smaller ultimate loads and interfacial slip at failure than concrete slabs with smooth HCU surfaces, and at a more ductile Way to destroy. The above studies on the shear performance of the new-old concrete horizontal superimposed surface by domestic and foreign scholars have found that the roughness of the interface is an important factor affecting the shear performance of the new-old concrete superimposed surface, and scholars [2,5] believe that the interface When the roughness of the concrete meets certain requirements, the interface between old and new concrete can be guaranteed to have sufficient shear strength.

The mechanical performance of laminated slabs with joints has always been the focus of research on laminated slabs. Regarding the difference between the mechanical properties of laminated slabs with joints and the mechanical performance of cast-in-place laminated slabs, scholars [8] found that the two were in the standard Under the action of load and design load, there is not much difference in deflection, crack width and bearing capacity, but the failure form is different. Zhu Wenzheng et al. [9] also found that the cracking deformation, cracking load, yield displacement and yield load of the assembled composite beam-slab joints are close to those of the cast-in-place components with equal strength design; and the assembled composite beam-slab joints designed according to the equal strength conditions The failure modes, characteristic loads and displacement values of the composite beam-slab joints in this study are the same as those of the cast-in-place components. It is considered that the composite beam-slab joint connection structure in this study meets the requirements of bearing capacity and normal service limit state, and shows good mechanical properties.

Some scholars believe that through a series of strengthening and transformation measures, the bearing capacity of laminated slabs with joints can be close to that of cast-in-place laminated slabs. For example, Ye Xianguo et al. [10] found that the jointed laminated slabs can ensure the effective transfer of internal forces (bending moment and shear force, etc.) through the joints after strengthening the reinforcement at the joints. Further strengthening the reinforcement and anchorage measures at the joints or changing the position of the steel bars to increase the effective height can also increase the bearing capacity of the joint slab to make it close to the resistance of the monolithic slab. Yu Yongtao et al. [11] found that the bearing capacity of laminated slabs with joints was significantly lower than that of monolithic slabs, but when the number and spacing of truss reinforcements in laminated slabs and the diameter and length of additional reinforcements met certain structural requirements, the dense joints overlapped The mechanical performance of the plywood can be close to that of the two-way board. Yan Feng et al. [12] believed that laminated slabs with joints exhibited obvious unidirectional slab stress characteristics under vertical loads, and shear force could be transmitted at the joints, but the transmitted bending moment was small; for laminated slabs without steel trusses, in the later stage of loading, the horizontal superimposed surface slips and suddenly loses bearing capacity, which belongs to brittle failure. Effective measures should be taken, such as configuring reinforced trusses and setting shear reinforcement at the interface, to prevent shear failure of the horizontal superimposed surface of the laminated slab.

Many scholars have also conducted research on improving the performance and bearing capacity of laminated panels with joints. For example, Xu Tianshuang et al. [13] thought that the steel bars protruding laterally from the edge of the prefabricated slab are lapped at the joint and then bent and anchored in the post-cast concrete layer, so that the force transmission of the steel bars on both sides of the joint can be realized, thereby transferring the bending moment. A two-way slab stress state is formed, thereby improving the bearing capacity of the laminated slab. Ding Yongjun et al. [14] found that when the post-cast slab bottom extension longitudinal reinforcement adopts 90° hook anchorage, the bearing capacity of the laminated slab is better than that of 30° and 45° hook anchorage. In addition, the use of 90° hooks for anchoring is easier to accept in actual engineering, easy to promote, and saves materials. Ye Xianguo et al. [10] believed that increasing the reinforcement amount and anchorage length of the connecting reinforcement at the joint can improve the bearing capacity of the spliced slab. Weng Chuanyang, Chen Xudong et al [15,16] analyzed the effect of different lengths of additional reinforcement on the performance of laminated slabs, and found that: when the additional reinforcement is longer, it is beneficial to prevent the development of cracks at the joints, and at the same time increase the bearing capacity of the component. The integrity of the laminated board is improved.

2 Study on Seismic Behavior of Laminated Slabs

The node connection between the laminated slab and the wall or beam is a relatively weak part of the structure. After experiencing the reciprocating action of the earthquake, it is very easy to cause serious damage to this part due to insufficient bearing capacity of the building or poor connection of the node [17]. Therefore, some scholars have studied the seismic performance of laminated slabs and joints. For example, Chen Zhonghan et al. [18] analyzed the variation law of the in-plane shear capacity and in-plane shear stiffness of the laminated slab through the experimental study of low-cycle repeated loads in the plane of the prestressed laminated slab and established the in-plane shear stiffness of the slab. Stiffness degradation expression. The test results show that the in-plane stress and deformation characteristics of the slab are close to those of the cast-in-place slab, and it has better seismic performance. Regarding the research on the connection performance of composite slabs and walls or beams, scholars [18-20] conducted related research on the seismic performance of precast concrete beam-column-laminated slab edge nodes and middle nodes and found that: Under repeated repeated loads, compared with cast-in-situ specimens, the two have comparable seismic performance. As for the joint specimens in precast beam-column-laminated slab assembly under the action of low cycle reciprocating load, it is found that the connection mode of laminated slab, precast beam longitudinal reinforcement and prefabricated column longitudinal reinforcement has an important influence on the seismic performance of the overall joint; For the middle joints of precast beam longitudinal reinforcement anchored connection, the steel bar has slippage phenomenon, and for the middle joint of prefabricated beam longitudinal reinforcement through connection, it has the same energy dissipation capacity and comprehensive seismic performance as the cast-in-place middle joint. To sum up, there has been sufficient research on the related properties (bending resistance, shear resistance, and seismic performance) of laminated slab members at home and abroad, but for the node connection between the laminated slab and the wall or beam and the joint connection of the laminated slab, There are few studies on the function, construction measures and mechanical properties of the additional reinforcement.

3 Research Status of Indirect Lap Splices of Reinforcement Bars at Home and Abroad

Lap splices are the easiest form of rebar connection. On the whole, the two steel bars pass the force of one steel bar to the other through the grip of the concrete at the overlapping position. From the perspective of each steel bar, it is equivalent to an anchoring problem. From the perspective of each steel bar, it is equivalent to an anchoring problem. They transmit the tension to the cladding concrete respectively, and at the same time complete the tension transmission between the two bars[21]. The stress mechanism of the indirect lap joint of steel bars is not completely the same as that of the binding lap joint.

With the rise and widespread use of prefabricated buildings in China in recent years, research related to indirect lap joints has also begun to appear. At the same time, indirect lap joints of this type of reinforcement widely exist in various structural systems, such as lap joints of longitudinal bars at the bottom of reinforced concrete beams, indirect lap joints between longitudinal bars at the bottom of precast slabs and additional steel bars, and single-row joints for shear walls. The additional connecting reinforcement forms an indirect overlap with the vertically distributed reinforcement. Therefore, scholars at home and abroad have conducted relevant research on the performance and structural requirements of indirect lap joints of steel bars.

As for the specific definition, design method and construction measures of indirect lap joints, there are no clear regulations in our country codes. Therefore, different scholars have different selections for the value of the indirect lap length that meets the standard. The mechanical performance of indirect lap joints is not the same as that of traditional lashing lap joints, and the research results of different scholars are quite different.

Zhou Jian et al. [22] carried out unidirectional tensile tests on 6 indirect lap joint specimens with different steel bar diameters and lap lengths and stipulated that the standard for reliable lap joints is that the steel bars can yield under tension until they reach the ultimate strength, and The free end does not slip before yielding, and the free end slip does not exceed 0.04 times the diameter of the steel bar at the limit. According to this standard, it is judged that the specimens with lap lengths of 1.0La and 1.2La do not meet the lap requirements. It is recommended that the design lap length be 1.5 times the design anchorage length.

And Liu Shuo et al. [23] studied the mechanical properties of the spiral stirrup restrained lap joints poured with C30 fine stone concrete through 12 uniaxial tensile tests, in which the diameters of the steel bars were 10 mm and 14 mm, and the strength grades of the steel bars were HRB400. and HRB500 grade, the lap length of steel bars is taken as 1.0La. The results show that when all the specimens are finally destroyed, the steel bars have reached yield, and the steel bars have not been pulled out. The lap joint with spiral stirrup restrained by fine stone concrete pouring in the lap area has good mechanical performance and deformation capacity and can Realize the reliable connection of steel bars. When the spiral stirrup takes the minimum reinforcement ratio specified in the code, the lap length of the steel bar is 1.0La to ensure the reliable connection of the steel bar. When it is used for the connection of large-diameter steel bars, the lap length of the steel bar is recommended to be 1.2La.

Scholars at home and abroad have also conducted relevant research on the performance of contact lap joints and non-contact lap joints, and different scholars have different conclusions on the performance of the two.

Zhang Tian et al. [24] conducted experimental research on five reinforced concrete beams with different lap joints (contact lap, non-contact lap, and steel bar penetration). The force distribution of the steel bar at the joint is similar to that of the contact lap joint, and the yield of the steel bar at the lap joint occurs before the bond failure between the steel bar and the concrete, so it is determined that the non-contact lap joint is effective. In addition, the comparison and analysis of the data of mid-span deflection and lap joint deflection shows that the form of the lap joint and whether the lap joint has little effect on the stiffness of the mid-span section, but has a greater impact on the stiffness of the lap joint.

Song Xuchuan [25] conducted a comparative analysis of the working performance and data of five reinforced concrete beams combined with the finite element analysis method and found that the non-contact lap joints are safe and reliable. It is a practical and effective lap joint, and it can better realize the joint work of concrete and steel compared with contact lap.

Jiang Debao et al. [26] conducted pull-out tests on 36 specimens with different lap joints (contact lap and non-contact lap), and compared and analyzed the force transmission performance of steel bar contact lap and indirect lap according to specific experiments. It was found that the non-contact lap joint connection of steel bars can also effectively and reliably transmit force, but under the same reinforcement ratio and lap length, the force transmission performance of steel bars connected by contact lap joints is better than that of non-contact lap joints.

Foreign scholars such as Ismael et al. [27] analyzed four different indirect lap joint test schemes and selected the optimal scheme (the steel bars are all arranged on the same plane) for improvement, and tested the two diameters of 12mm and 16mm through 14 test pieces. Experimental research was carried out on the contact and non-contact lap joint properties of steel bars at a lap length of 5d. The results showed that the average ultimate bond stress τB, max of non-contact lap joints was lower than that of contact lap joints, and the free end slippage was also smaller big.

The indirect overlap of steel bars not only exists in horizontal components but also vertical components. For example, in shear walls, additional connecting steel bars are often used to form indirect Some scholars have also carried out related research on lap joint performance.

Zhang Weijing et al. [28] found that the relationship between the vertically distributed reinforcement and the connecting reinforcement of the prefabricated shear wall was found to be The indirect connection form of the lap joint that can effectively transfer the stress of the steel bar.

Qian Jiaru et al [29] introduced the quasi-static test of four prefabricated reinforced concrete shear wall specimens with a shear-span ratio of 2.25. way to connect. Through the research on the performance of indirect lap joints, it is found that indirect lap joints can effectively transfer the stress of steel bars.

4 Development Trend and Prospect

To sum up, in recent years, some achievements have been made in the research and design methods of laminated structures, especially laminated slabs, in terms of mechanical mechanism and seismic performance. Reasonable interface treatment measures have been proposed for the laminated surfaces of different prefabricated slabs and cast-in-place slabs. The bearing capacity calculation and deformation calculation models of the secondary stressed members of the laminated slab are constantly maturing, and the design of the beam-slab joints of the laminated slab is safe and reliable, which can meet the needs of the project and greatly promote the development of prefabricated structures and long-span structures in my country. Although the research results of concrete laminated slabs are remarkable, there are still many problems that need further research. At present, the research on laminated slabs is mostly designed according to the one-way slab, and the design results are too large, resulting in waste of resources and high cost. Stress laminated slabs are more common, and the calculation model needs to be improved. The low-cycle repeated loading test method is often used in the research on the seismic performance of composite structures. It is essentially a static loading test, which cannot fully reflect the dynamic performance of plywood slabs under earthquakes. The test method needs further study. The force calculation and economical issues of the new laminated slabs with the application of new smart materials and new structural forms are also important directions for future research.

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