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Application and Research Status of Nonlinear Finite Element Analysis in Composite Floor

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Abstract

As the most widely used building material in the field of current construction, reinforced concrete is very important to the study of its own performance, especially to the numerical analysis of the nonlinear relationship between various materials. The nonlinear analysis of reinforced concrete composite floor slab by using finite element analysis software is of great significance to practical engineering application. In this paper, the development status of composite slabs and the analysis of their performance by finite element method are introduced, and the expectation of enlarging the application of nonlinear finite element method in engineering is put forward.

Keywords

Finite Element Analysis; ABAQUS; Composite Floor Slabs; Reinforced Concrete.

1. Introduction

Reinforced concrete is the basic material and structure in civil engineering construction. It is composed of two materials with completely different mechanical properties - concrete and steel bar. The concrete unit is mainly used to bear the pressure, and the steel bar unit is mainly used to bear the tension. The mechanical properties of reinforced concrete composites are very complex, and there are obvious linear and nonlinear stages. In the elastic stage, it can be approximated that various materials work together and work together. However, in the nonlinear working stage, various nonlinear characteristics of concrete and steel bar are shown in the composite material of reinforced concrete. In the 1960s, American scholars A.C.Scordelies and D.Ngo first applied the finite element analysis method to reinforced concrete composite structures, and achieved ideal analysis results. Since then, with the application of nonlinear finite element method in reinforced concrete structures by scholars from various countries, many remarkable achievements have been made, which promotes the wider and deeper development of nonlinear finite element analysis method in the field of reinforced concrete[1].

As the main direction of the development of the construction industry at this stage, the prefabricated building urgently needs new materials and new technologies related to it to provide reliable support. With the development of prefabricated buildings, the production process of prefabricated components is becoming more and more mature. Prefabricated walls, prefabricated columns, prefabricated beams and so on gradually show great advantages in the application of prefabricated buildings. Due to the cumbersome and inefficient construction of cast-in-place components in prefabricated buildings, a composite structure is proposed to solve this problem. The composite structure is a new product that combines the factory prefabricated components with the cast-in-place construction technology. For example, the application of the composite floor slab can effectively reduce the support of the formwork during the construction process, accelerate the construction progress, and effectively promote the development of prefabricated buildings.

Due to the special structure of the composite floor, the mechanical performance is different from that of the ordinary concrete cast-in-place floor, and there are phenomena such as "two-stage stress" [2] and "stress lag" [3]. In recent years, the introduction of prestressed systems into prefabricated components has increased the uncertainty of the stress of the composite floor. For this reason, many domestic scholars have carried out experimental research and finite element analysis on the mechanical properties of composite slabs[4].

2. Development Status of Composite Floor

In the prefabricated structure, the composite component can ensure the integrity of the floor structure and minimize the use of the construction site template and support. Therefore, from the end of the 1970s, experts and scholars at home and abroad began to study the composite floor. The initial purpose is to solve the construction problem of high-altitude formwork support for cast-in-place buildings[5]. In recent years. With the innovation of technology and the improvement of industrialization, more and more scholars at home and abroad pay attention to the research of composite floor, and have achieved relevant research results in the structural form of prefabricated floor and the design and calculation method of composite floor.

Zhou Xuhong and Wu Fangbo et al[6] summarized the seismic damage of the floor in Wenchuan earthquake and the problems existing in the floor system commonly used in post-earthquake reconstruction, and proposed a prefabricated prestressed ribbed floor composite floor. This prefabricated floor has large bearing capacity and stiffness, and there is no need to set temporary support in construction. At the same time, this kind of floor can also meet the needs of two-way force. Rectangular holes can be reserved according to the design requirements, and transverse reinforcement can be configured between rectangular holes to achieve the purpose of two-way force. Liu Wenzheng et al[7] proposed a kind of prefabricated floor composite slab with steel truss upper chord, and carried out experimental research. The results show that the steel truss can significantly improve the flexural performance of the concrete prefabricated floor. Considering the influence of span factors, Qi et al[8] made six prefabricated truss composite slab specimens with different spans, and compared the mechanical properties of steel bar truss and grouting steel pipe truss in the construction stage. Within a certain range, with the increase of span, the cracking load, yield load and peak load of prefabricated truss composite slab decreased. Compared with steel bar truss specimens, grouting steel pipe truss composite slab has greater initial stiffness and deformation resistance.

After the completion of the traditional composite floor construction, the overall thickness of the floor is too large, which increases the weight of the building structure. In order to reduce the weight of the composite slab itself, the weight of the slab is reduced by reserving rectangular holes in the prefabricated ribbed concrete slab under the condition of satisfying the bearing capacity. Or arrange lightweight filling materials on the solid precast slab, which is also called precast concrete hollow composite slab. Yavuz Yardim et al[9] proposed ribbed precast steel wire mesh floor-autoclaved aerated concrete (AAC) composite floor, as shown in Figure 1. Wu Liwei et al[10] proposed to arrange polystyrene board sandwich layer on the prefabricated floor of reinforced truss concrete (Figure 2), and the replacement rate of floor concrete was 35%. The uniform loading test of simply supported flexural members was carried out. By studying the bearing capacity, crack distribution and steel strain development of polystyrene sandwich panels at different stages, it was found that the arrangement of polystyrene board sandwich layer on the prefabricated floor can effectively reduce the self-weight of the composite floor formed by post-casting. The flexural bearing capacity meets the requirements of the relevant specifications for the construction and use stages ; at the same time, the experimental study found that under the action of load, multiple cracks appeared in the mid-span of the floor, and the maximum crack width reached 0.17mm. It is suggested that temporary support should be set up in the use of prefabricated hollow floor in large-span structure.

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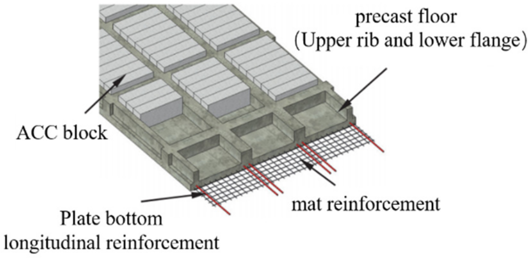

Fig 1. Steel mesh cement floor-autoclaved aerated concrete composite floor

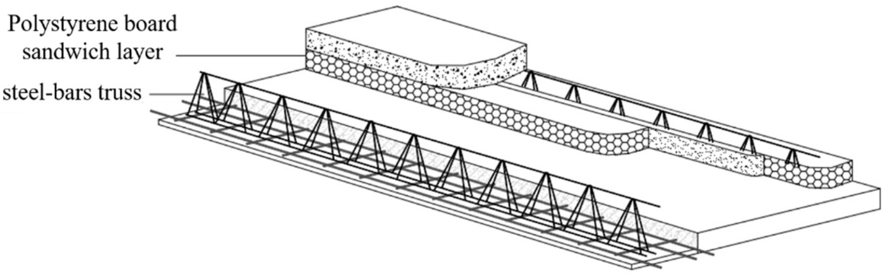

Fig 2. Polystyrene sandwich precast composite floor

3. Finite Element Analysis

As a large general-purpose finite element analysis software at this stage, ABAQUS has a good pre- and post-processing program and a powerful nonlinear solver [11], which has been widely used in various engineering fields. In the finite element modeling analysis, separate and integral modeling methods can be adopted according to different needs. In the aspect of composite structure, separate modeling is more commonly used. After modeling steel and concrete respectively, material definition and component assembly are carried out. After the modeling of the part module of ABAQUS, the material properties need to be defined. In addition to the basic material properties, the plastic damage model (CDP) of concrete is also used. According to the existing research experience, the material parameters of the CDP model can be set according to Table 1.

Table 1. Parameter values of CDP model

expansion angle	eccentricity	f_{b0}/f_{c0}	K	Viscosity parameter
30°	0.1	1.16	0.667	0.005

The definition of contact and the division of element mesh is a crucial link in the finite element analysis. The contact between various materials should be as much as possible in line with the actual contact situation of the components, such as the friction type contact between the prefabricated layer and the cast-in-place layer of the composite floor, which is realized by setting the friction coefficient ; the definition of contact between steel and concrete is completed by embedding regional constraints without considering bond slip between steel and concrete. Whether the meshing of various components in ABAQUS is accurate or not will directly determine the accuracy and convergence difficulty of the calculation model. The meshing should not be too coarse or it will affect the calculation accuracy. If the meshing is too fine, the calculation time will be greatly increased and the model calculation may not converge. Therefore, in the nonlinear analysis, it is necessary to consider the actual situation to carry out the necessary meshing of the components.

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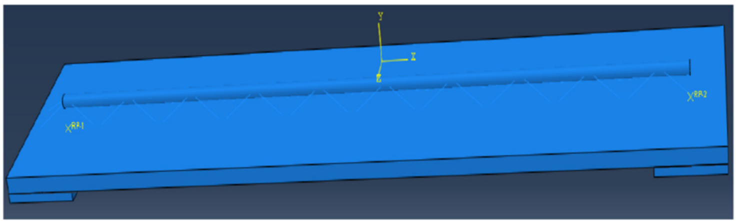
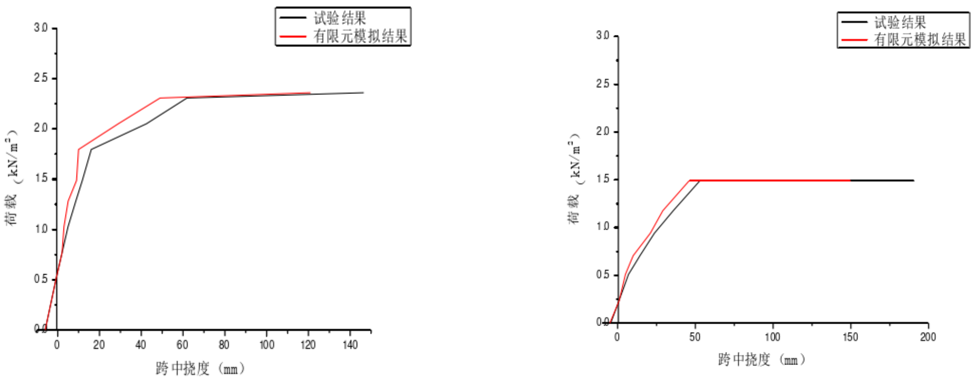
4. Application of Finite Element Analysis of Composite Floor

Wang[12] simulated and analyzed the mechanical properties of prestressed concrete steel tube truss composite slab, and established the analysis model shown in Fig.3(a)[12]. The most concerned mid-span deflection of plate members is compared with the test results, and the analysis results shown in figure 3(b)[12] are obtained. It can be found that the finite element numerical analysis can better simulate the stress characteristics of structural members. It shows that ABAQUS has a good fit between the nonlinear analysis of composite slabs and the actual engineering. The conclusions can provide a basis for the construction and design of composite slabs in practical engineering. Inevitably, there is a small error between the finite element simulation results and the test. The main reason is that ABAQUS considers the performance of various materials too perfectly, and the defects generated in the actual component production process are not considered.



(a) ABAQUS modeling diagram



(b) Load-deflection comparison

Fig 3. Specimen model and simulation comparison diagram

The joint problem between adjacent components needs to be considered in the design and construction process of prefabricated composite floor. Bing et al[13] proposed three kinds of reinforced dense joint construction measures, and carried out static loading tests on three kinds of composite floors with different joints. The nonlinear finite element analysis of the test specimens was carried out by ABAQUS software, and the results were compared with the test results. The specimen model shown in Fig.4(a)[13] was established by finite element software. The CDP model of ABAQUS was used to analyze the stress of the model plate, and the damage comparison diagram of the composite surface shown in Fig.4(b)[13] was obtained. The simulation and experimental results show that the finite element model considering material nonlinearity can better simulate the crack distribution, failure mode and bending performance of the composite slab. It is found that one of the key factors affecting the flexural bearing capacity of the composite floor is the thickness of the composite layer concrete. By increasing the thickness of the composite layer concrete, the ultimate bearing capacity of the composite floor has been greatly improved.

Through the existing experiments and finite element simulation analysis of many scholars, it is not difficult to see that the results of crack distribution, damage and load-deflection curve of the composite floor obtained by ABAQUS nonlinear analysis are in good agreement with the

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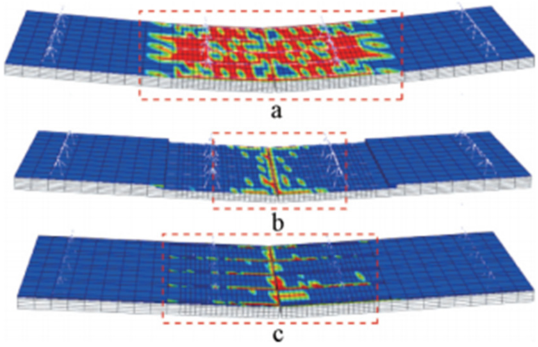
experimental results. ABAQUS can be used to effectively predict the stress and failure of the composite floor.

(a) ABAQUS modeling diagram



(b) Comparison of damage of composite surface of specimens

Fig 4. Specimen model and simulation comparison diagram

5. Conclusion

The nonlinear study of concrete structures is not limited to ABAQUS analysis software. The use of relevant theories combined with analysis software can make the research work achieve twice the result with half the effort. It can not only simulate and analyze the nonlinear relationship between various materials, but also clearly obtain the stress-strain situation of the working state of the component and the whole process of structural damage under load. At the same time, the use of software for nonlinear analysis can greatly save test funds and provide a lot of data and support for the design of the specimen.

The nonlinear theory of reinforced concrete structures is in the research stage in the world, and there is no mature theory. We must firmly grasp this opportunity and further improve and develop the application of nonlinear analysis in reinforced concrete.

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