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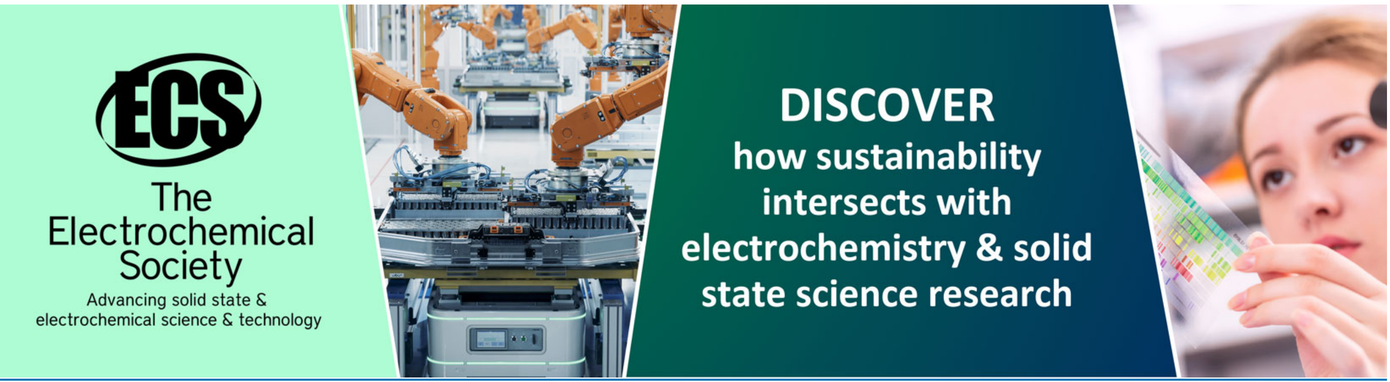

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Finite Element Analysis of Displacement and Vibration Characteristics of Cantilevered Plate

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Abstract. The cantilever structure will produce a large dynamic response under the vertical load, which will cause the user's discomfort. Therefore, the vibration characteristics of the structure caused by the vertical load are an important part of the comfort design of the cantilever structure in the normal use limit state. This article takes the vertical displacement of a cantilevered balcony slab on one side of a project under load as an example, and builds a model in the nonlinear finite element software to calculate the structural displacement and the factors of the cantilever length and the tensile reinforcement, and the corresponding comfort evaluation is carried out, which provides a reference for the vibration comfort evaluation of the house cantilever structure.

Keywords: Cantilever Plate, Nonlinear Finite Element, Displacement, Natural Frequency, Comfort.

1. Introduction

With the demand of large space structure and diversity of building use, the floor structure is developing towards the direction of large span and light weight, which makes the damping and natural frequency of the structure reduce. In the engineering structure, the external balcony, awning, bay window, canopy, and porch are often directly implemented by cantilevered boards. In the process of structural design, the seismic performance of small components such as cantilevered slab is ignored, while the overall seismic requirements of beams and columns are generally emphasized. However, the vertical natural frequency of these components in the structure is relatively low, which will produce obvious vibration under the live load, making people uncomfortable. The vibration comfort has increasingly become a problem to be considered in the normal use of the structure [1-3].

At present, there are different evaluation standards for the vibration comfort of floor slabs at home and abroad, but they can be divided into two categories: one is based on the dynamic characteristics of floor vibrations, so that the natural frequency of the floor structure can avoid the sensitive frequency range of the human body. ; Another type is based on the vibration response of the floor structure under external load as the standard for comfort evaluation. The first type of evaluation standard considers

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that the normal frequency of people walking is between 1.45-2.5Hz. In order to avoid the resonance phenomenon of floor slabs under the action of pedestrians, China stipulates pedestrian bridges in ("Technical Specifications for Urban Footbridges and Underpasses" CJJ69-95) The first-order vertical frequency must be greater than 3 Hz [4]. Another type of evaluation method mainly uses a certain vibration response index of the floor structure under the external load to evaluate the comfort [5].

The problem studied in this article comes from a practical project, which involves a large overhanging balcony with a width of more than 5m. For the construction effect, the overhang length is planned to reach 2m. In order to study the vibration frequency of the overhanging structure, this paper uses ABAQUS software performs nonlinear finite element analysis of the cantilever structure, obtains the main factors affecting the vibration frequency of the cantilever structure, and gives reasonable suggestions for design [6].

2. Model Establishment and Parameter Selection

First, choose a small overhang size of the cantilever balcony board for modeling analysis. The length of the fixed side of the cantilever board is 5.32 meters, the cantilever length is 1.35 meters, the board thickness is 120mm, and the concrete protective layer thickness is 25mm. The section size and reinforcement are shown in Figure 1.

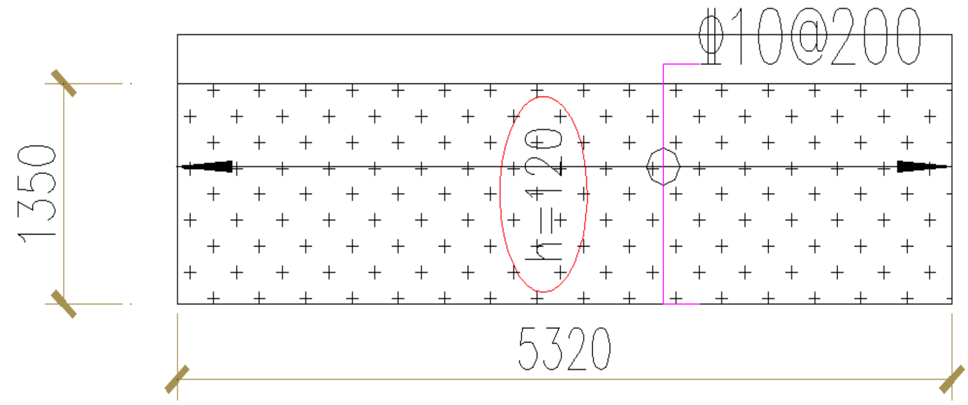


Figure 1. Sectional dimensions and reinforcement of balcony panels

When meshing with ABAQUS, an 8-node three-dimensional hexahedral reduced integral solid element (C3D8R) was used to simulate the concrete slab, and a 2-node three-dimensional truss linear element (T3D2) was used to simulate the reinforcement [7]. The diameter of the reinforcement was achieved by changing the cross-sectional area of the Turss element. The force steel bar φ10 @ 200, and the distribution bar is set to φ8 @ 200.

The connection between the reinforcement and the concrete is realized through the interaction of the built-in area settings, with the boundary condition being fixed at one end and free at the other edges. The finite element ABAQUS model is shown in Figure 2.

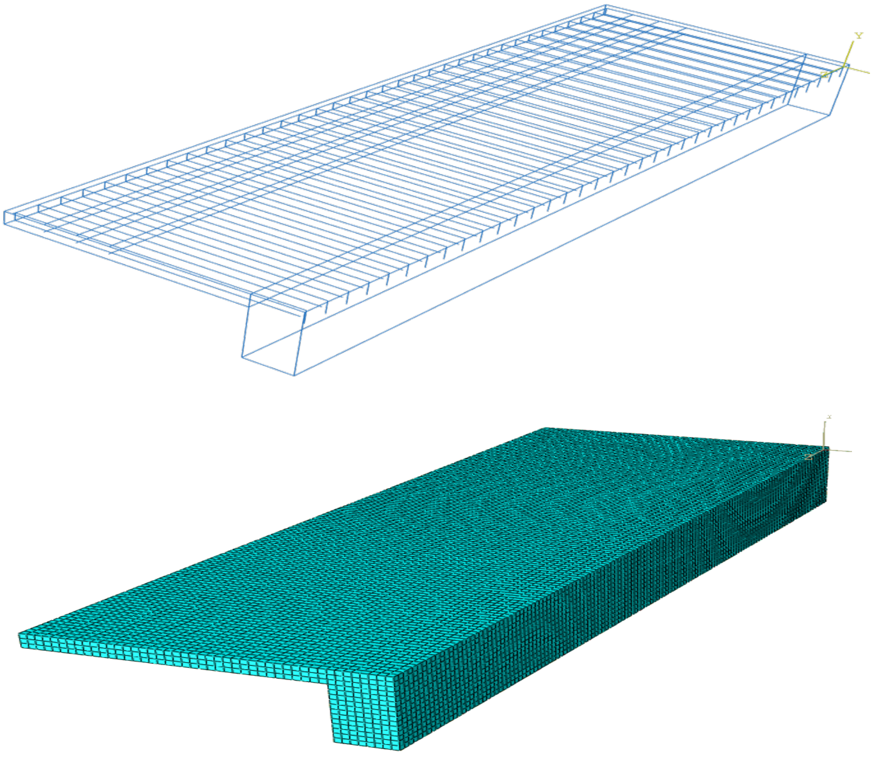


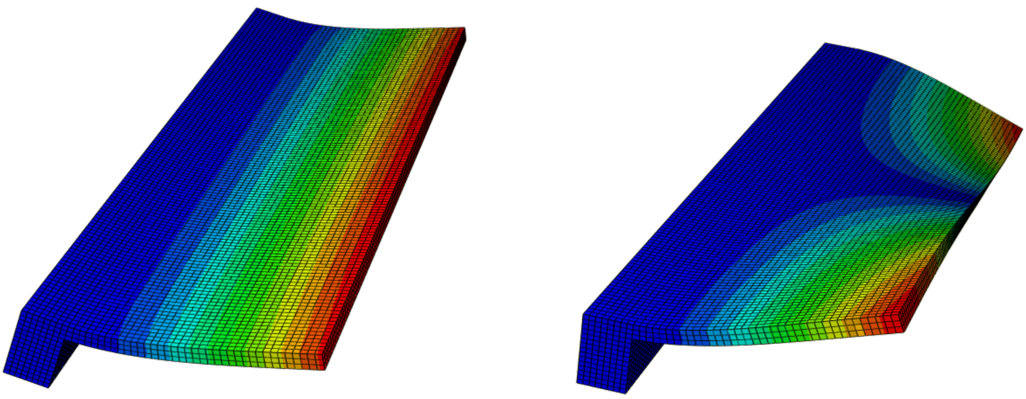
Figure 2. Finite element model of a plate built in ABAQUS

The properties of the steel and concrete materials used in this model are shown in Table 1

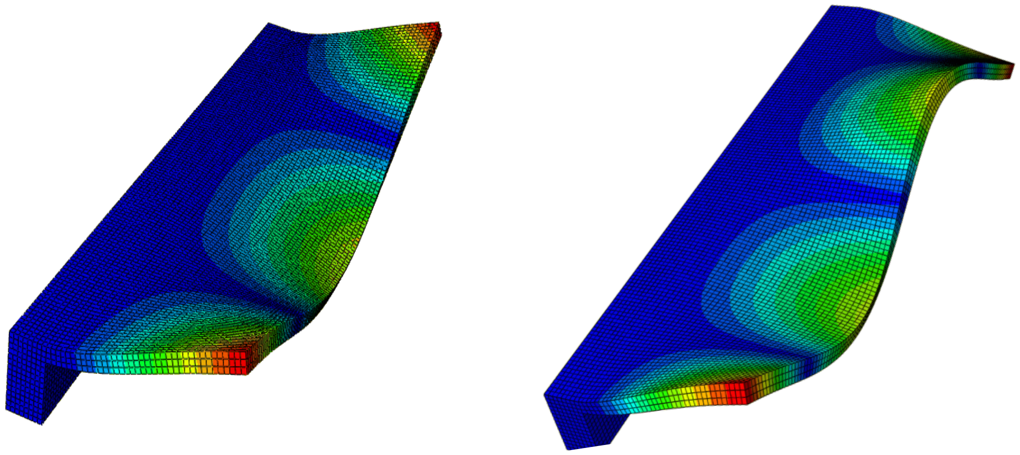
Table 1 Material properties of concrete and steel

Material	Elastic modulus N/mm²	Poisson's ratio	Density N/mm^3	Tensile strength N/mm^2	Compressive strength N/mm^2
Reinforced	2.0×10^5	0.25	7.85×10^{-9}	360	360
Concrete	2.55×10^4	0.2	2.5×10^{-9}	1.54	13.4

Apply uniform load: Apply a uniform load of 2.5KN / ㎡ on the surface of the cantilever plate, set the built-in interaction between concrete and steel bars, and perform calculations to obtain the vibration frequency diagram of each step of the cantilever balcony plate. The first four order vibration frequencies are shown in Figure 3.



(a) First-order frequency 29.24Hz (b) Second-order frequency 34.35Hz



(c) Third-order frequency 48.46 Hz (d) Fourth-order frequency 72.04Hz

Figure 3 Fourth-order vibration frequency diagram of a cantilevered balcony board

As can be seen from Figure 3, the first-order frequency of the structure is 29.24Hz, and the main deformation is upward bending; the second-order frequency is 34.35Hz, which generates bending deformation around the fixed edge; the third-order frequency is 48.46Hz, which is mainly twisted around the fixed plate Deformation; the fourth-order frequency is 72.04 Hz, and a combination of deflection and torsion occurs [8].

3. Analysis of Influential Factors of Vibration Frequency and Displacement of Cantilever Plate

Change the length, thickness, and reinforcement of the cantilever plate, and analyze the factors affecting the vibration frequency of the cantilever plate. The finite element simulation process is the same as described above [9].

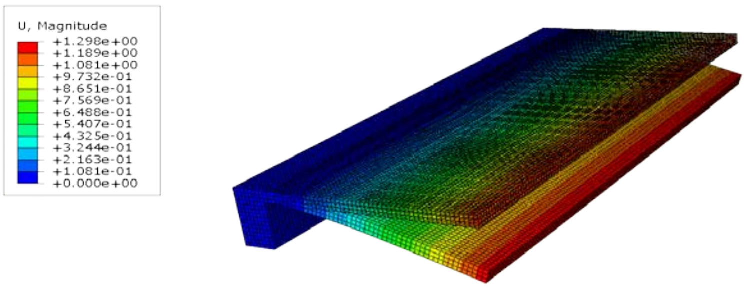
The finite element analysis conditions are established. The cantilever length of the variable cantilever plate is 1.35m, 1.8m, and 2.0m, the thickness of the variable cantilever plate is 100mm and 120mm, and the reinforcement of the variable cantilever plate is φ10@150 and φ10@200, φ8@200, get the maximum displacement and natural frequency of the cantilever plate under different working conditions. Among them, the comparison results of the maximum displacement and natural frequency of various working conditions are shown in Table 2, and the maximum displacement of the balcony plate overhanging 2 meters is shown in Figure 4.

Table 2 Maximum displacement and four-stage frequency of the structure under different overhang lengths

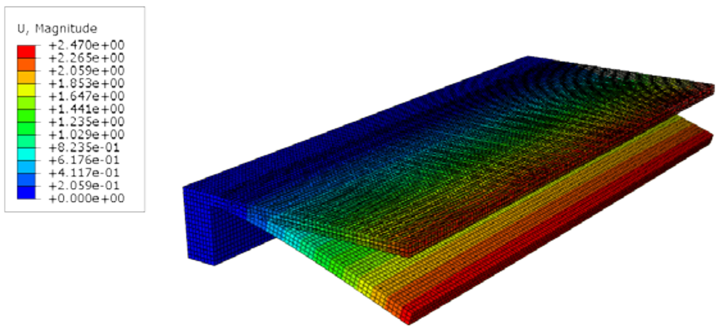
group number	Test piece number	Cantilever length /m	Plate thickness /mm	Stress bar	Displacement /mm	First order frequency Hz	Second-order frequency Hz	Third-order frequency Hz	Fourth-order frequency Hz
1	1	2.0	120	φ10@150	1.16	16.82	21.60	34.61	57.69
	2			φ10@200	1.30	16.21	21.11	34.27	57.43

2	3	2.0	100	φ10@150	2.24	13.94	17.98	28.91	48.14
	4			φ10@200	2.47	13.48	17.62	28.65	47.94
3	5	1.8	120	φ10@150	0.78	20.57	25.43	38.76	61.92
	6			φ10@200	0.84	19.82	24.81	38.32	61.59
4	7	1.35	120	φ8@200	0.42	27.82	33.13	47.56	71.35
	8			φ10@200	0.41	28.39	33.62	47.92	71.63
	9			φ10@150	0.38	28.52	33.73	48.00	71.69

From the data obtained in Table 2, it can be known that as the overhang length increases, the maximum vertical displacement of the structure increases. After reducing the cantilever length of the plate, the natural frequency of the structure increases and the stiffness of the plate increases. With other conditions unchanged, the higher the reinforcement ratio of the plate, the smaller the vertical displacement of the plate, the higher the natural frequency of the structure, and the higher the stiffness of the plate [10].



(a) Cantilever 2m, h = 120 displacement map



(b) Overhang, h = 100 displacement map

Figure 4 Comparison of the maximum displacement of a cantilevered 2m balcony board

As can be seen from Figure 4, the maximum displacement of the balcony plate is 2.47mm when the thickness of the cantilever plate is 100mm; the maximum displacement of the balcony plate is

1.298mm when the thickness of the cantilever plate is 120mm, the thickness is increased by 20%, the displacement is reduced by 47%, The effect of structural thickness on structural displacement is very significant.

4. Conclusion
This paper uses ABAQUS non-linear finite element software to analyze the effects of stiffness, reinforcement ratio, overhang length and plate thickness on the vibration frequency and vertical displacement of the cantilever balcony slab structure [11]. It is concluded that the structure displacement under different overhang lengths with the change law of vibration frequency. The natural frequency of the structure indirectly affects the user's perception of the comfort of the house. The calculation in this paper provides a certain range of references for the optimal design of the cantilever structure and the study of comfort. Calculations prove that:

(1) The cantilever length in the cantilever structure has a certain effect on the vibration characteristics of the structure. As the cantilever length increases, the plate's natural frequency decreases.

(2) The smaller the cantilever length of the cantilever plate, the smaller the maximum vertical displacement of the plate is.

(3) The higher the reinforcement reinforcement ratio of the cantilevered plate, the higher the natural frequency of the plate and the smaller the vertical displacement.

(4) Among the influencing factors considered, the thickness of the cantilever plate has a relatively large impact on the cantilever structure. When the thickness of the plate is reduced, the vertical displacement of the structure increases significantly, and the natural frequency of the plate decreases with.

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