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Experimental Study on Mechanical Property of Corner Columns Supported Reinforced Concrete Honeycombed-core Girderless Floor

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Abstract. In order to study the basic mechanical property of the new honeycombed-core girderless floor in cast-in-place reinforced concrete, and similarities and differences of the structural performance compared with traditional floor, we carried out the destructive stage loading test on large-scale corner columns supported reinforced concrete honeycombed-core girderless floor. And the thesis conducted finite element analysis in virtue of ANSYS software for solid slab floor, rib floor and honeycombed-core floor. The experiment indicates that honeycombed-core modules cement well with concrete around and participate in the load-carrying; the developing process, distribution and failure mode of crevice in honeycombed-core floor are similar to that of general solid girderless floor. The honeycombed-core girderless floor has higher bearing capacity and better plastic deformation capacity. The finite element analysis manifest that compared with solid slab floor, honeycombed-core floor's dead load decreases on greater level while deformation increases little, and that compared with rib floor, honeycombed-core girderless floor has higher rigidity. So reinforced concrete honeycombed-core girderless floor is particularly suitable for long-span and large-bay building structure.

Keywords: honeycombed-core module; reinforced concrete honeycombed-core girderless floor; mechanical property; experiment study; finite element analysis (FEA).

1. INTRODUCTION

The cast-in-place girderless hollow floor is a new floor endowed with merits of small structural height, light deadweight, convenient construction, etc. In the past, study on the hollow floor in China is mainly concentrated in the hollow floor with circular hollow tube inside [1~6]. With the thin tube as filling component, the hollow girderless floor will form the one-way channel like the hole-hollow plate, which causes the differences in aspects of shape and momento finertia between plate cross-section perpendicular to pore canal and that parallel to pore canal, and the later plate cross-section will change with the different positions of the cross section. The column grids of girderless floors are usually square or close to the square. Under the action of vertical load, the plates appear compound bending, and flexural capacity in both directions is roughly the same. As a result, the method of one-way pore-forming with thin-walled tube is conflictive to the property of biaxial bending of girderless floors. Then, hollow ratio of floor slab obtained in such situation is lower. If solid section around floor is taken into consideration, the hollow ratio of the whole floor is even less than 20%.

In allusion to the defect that round-tube girderless floors have different mechanical properties of bending and shearing in both span directions, China has independently developed a bi-directional orthogonality ribbed I-shaped girderless floor-technique of honeycombed-core girderless floor in cast-in-place reinforced concrete [7, 8]. This technique adopts honeycombed-core series of internal molds to form inner-space load carrying unit in the cast-in-place concrete slab, and to configurate a clear-load-transmission horizontal structural system of bidirectional gridding ribbed hollow floor, which can form a space structure system assorting with hidden beam, flat beam or visible beam, shown as Fig. (**1**). [9, 10]. At present, studies on such floor system are still relatively poor, and its mechanical property and analytical method are

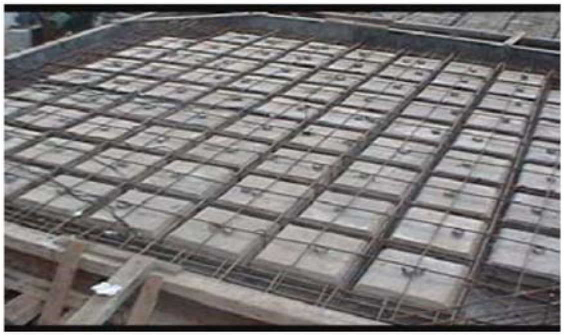

Fig. (1). Reinforced concrete honeycombed-core girderless floor.

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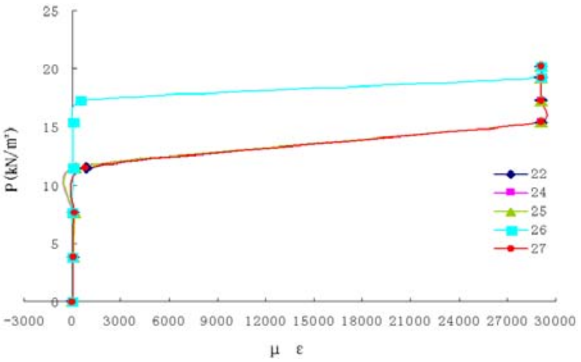

Fig. (11). Load - strain curve of concrete.

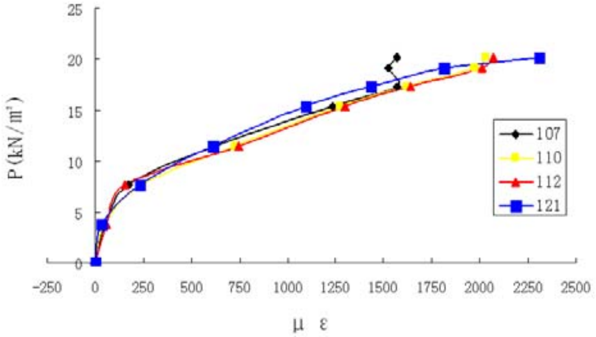

Fig. (12). Strain trends of reinforced midpoint.

column is a little complicated. There exists the phenomenon of stress concentration. So a range of solid area and more reinforcing steel should be adopted around the columns in designing. Reinforced strain data obtained from test demonstrate that the reinforcing steel bars contribute more to the tension of the floor, but little to the pressure. On the whole, the strain distribution is basically agreeable with that of solid girderless floor, and the strip division can apply strip division theory of common solid girderless floor mechanically.

4. FINITE ELEMENT ANALYSIS OF THE HONEYCOMB-CORE FLOOR

4.1. Finite Element Model

In virtue of ANSYS software, the finite element model of honeycomb-core floor, which is identical to the test model from aspects of structure and size, is established to carry out the finite element analysis to shape a compression with the test results. Meanwhile, to compensate for the trial deficiencies caused by limited conditions, solid floor model and ribbed floor model, both of which has the same support conditions and external dimensions, are set up, by which contrastive analysis with honeycomb-core floor can be conducted in order to obtain a deep knowledge of mechanical properties of honeycomb-core floor. The plane size of the finite element model is 4250mm×4250mm; slab thickness is 160mm. The mandrel size of honeycomb-core floor is 350mm×350mm×120mm, with bottom-slab thickness of 10mm, rib spacing of 50mm, the upper solid plate thickness of 40mm. The ribbed floor has no bottom-slab. In order to make clear observation, it only presents part of structure of finite element models of honeycomb-core floor, solid floor and ribbed floor, shown in Figs. (**13-15**). The 8-node isoparametric element, SOLID45, is adopted as its element type, with elasticity modulus $EX=EY=EZ=2.8\times10^{10}$Pa, Poisson's ratio $\mu=0.2$. To facilitate

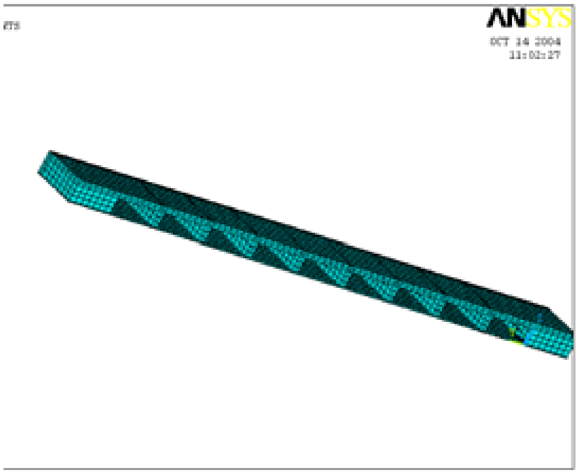

Fig. (13). Honeycombed-core floor.

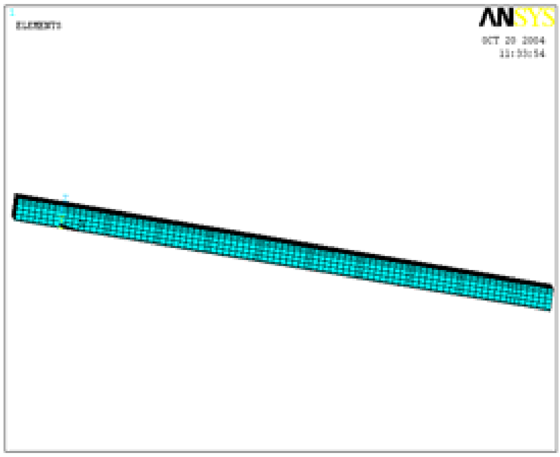

Fig. (14). Solid floor.

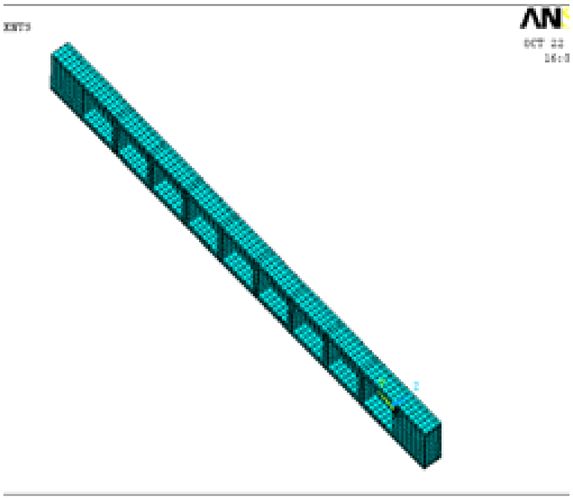

Fig. (15). Multi-ribbed Floor.

the description, there forms a unified convention: the face slab is x-y geometric plane surface, and the direction of plate thickness is Z-axis direction.

4.2. Results of Finite Element Analysis

(1) Deflection Analysis

Table **3** is the comparison between test deflection values and finite-element deflection values under the uniform load of 2.4kN/㎡. In the process of test, since the dial test indicator is installed up after finishing casting and removal of frame, the deflection value measured does not include the deflection under the influence of deadweight of floor. As a consequence, finite-element calculated value in Table **3** is the deflection under the uniform load of 2.4kN/㎡ without consideration of deadweight.

From Table **3**, the deflection from finite element calculation of honeycomb-core floor is very close to experimental value, with the average error of 9.9%. In addition, the deflection of honeycomb-core floor is smaller than that of ribbed floor in evidence. So it is safe to calculate the deflection of honeycomb-core floor according to theories of ribbed floor, but can cause large waste [10]. The box-type section improves the rigidity of floor greatly. If the finite-element deflection of solid floor is regarded as a benchmark, the deflection of honeycomb-core floor presents a difference of only 31% compared with that of the same thickness of the solid floor. However, rigidity of the rib floor with the T-shape section is small, and its deflection differs by 77.8％ compared with that of solid floor with the same thickness. This fully reflects the advantage of the honeycomb-core floor.

Considering the deadweight of the floor, Table **4** shows the reduced value of deflection of honeycomb-core floor, rib floor, and solid floor under the external load of 2.4kN/m^2. From the table, deflection of the honeycomb-core floor declines much more with a very small increase of the deadweight, compared with rib floor, which indicates that this structural style has good rigidity. In comparison with solid floor, the deadweight of honeycomb-core floor decreases sharply while deflection does not increase much. Therefore, such structure form has obvious advantages in the project.

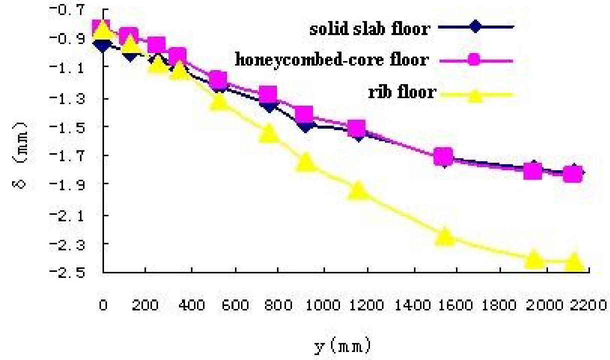

Fig. (16). Comparison of deflection alteration of crossing-section of three floors.

And then, Table **5** and Fig. (**16**) is comparison of deflection alteration of crossing-section of three floors. Through Fig. (**16**), the deflection change of honeycomb-core floor along span is rather close to that of solid floor; merely, its deflection in midspan area increase more rapidly than that of solid floor, but presents uniform change on a whole, which reflects that the honeycomb-core floor shows good overall distortion performance, and has higher rigidity. However, the deflection inboard of rid floor grows extremely rapidly. It indicates that the bending rigidity of such floor is smallest among these three floors.

(2) Stress Analysis

Fig. (**17-20**) are the stress nephogram of the honeycomb-core floor after finite element model is loaded. It is clear that the stress in X-direction is identical to that in Y-direction, but they are observed from different directions. Therefore, we can just study the stress from only one direction.

Some key sections are chosen to analyze the stress distribution. The key sections include crossing-section, hidden-beam section, hollow part of 1/4-span, and solid rib of 1/4-span, shown as Fig. (**21-24**).

Table 3. Comparison of Experimental Values and Finite Element Values of Deflection

Deflection Values (mm)	Test Value	Results of Finite Element Analysis		
		Honeycombed-Core Floor	Solid Slab Floor	Rib Floor
midspan	0.83	0.748	0.571	1.015
hiding-beam midspan	0.45	0.416	0.368	0.47
1/4-span	0.69	0.621	0.544	0.813

Table 4. Deflection Values Comparison Considering Dead Load

Types	Maximum Deflection Value（mm）	Ratio
solid slab floor（7.6 kN/㎡）	1.807	1.000
honeycombed-core floor（5.884 kN/㎡）	1.833	1.014
rib floor（5.716 kN/㎡）	2.417	1.338

Table 5. Comparison of Deflection Alteration of Crossing-Section

Location	Deflection Value of Midspan（x=2125mm）		
	Solid Slab Floor	Honeycombed-Core Floor	Rib Floor
y=0mm	0.939	0.831	0.839
y=130mm	0.994	0.895	0.930
y=250mm	1.050	0.958	1.071
y=350mm	1.107	1.023	1.120
y=525mm	1.223	1.192	1.325
y=750mm	1.338	1.291	1.540
y=925mm	1.475	1.420	1.745
y=1150mm	1.551	1.523	1.937
y=1550mm	1.713	1.724	2.240
y=1950mm	1.799	1.823	2.400
y=2125mm	1.807	1.833	2.417

From Figs. (**21**, **23**), it is clear that the top-slab of crossing-section bears largest stress, and presents a gradual transition to tension to both sides, and that the middle part of bottom-slab stands maximum tension, and gradually transit to pressure to both sides. This trend is the same with the solid floor. As can be seen from Fig. (**22**), pressure gradually becomes tension from top-slab to the bottom-slab, which is identical to the solid floor. But there exists uneven change of stress at the junctures between rids and top-slab and between rids and base plate. From Fig. (**24**), it shows that the overall trend of rids is the same as that of the solid floor.

5 CONCLUSION

After integrating the experimental study with the finite element analysis, the following conclusions can be obtained about the honeycomb-core floor:

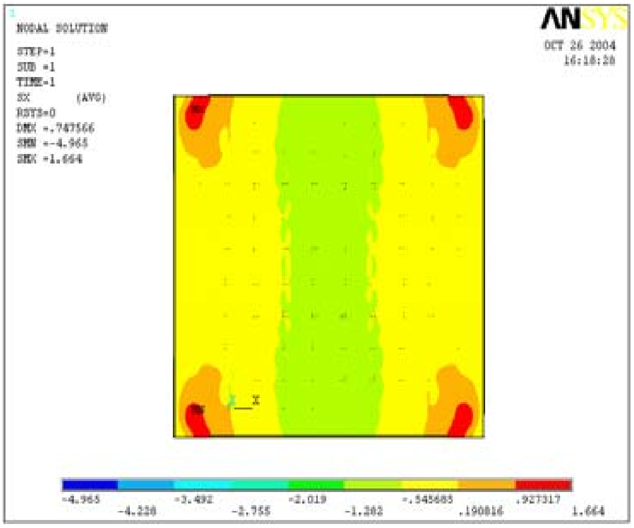

Fig. (17). σ_x nephpgram of top-slab.

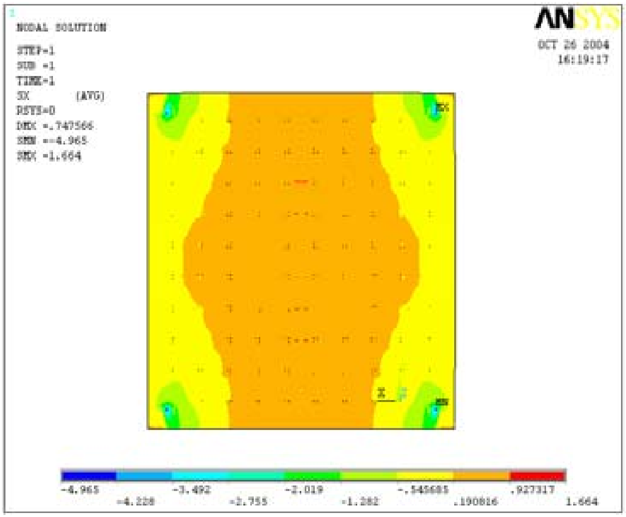

Fig. (18). σ_x nephpgram of bottom-slab.

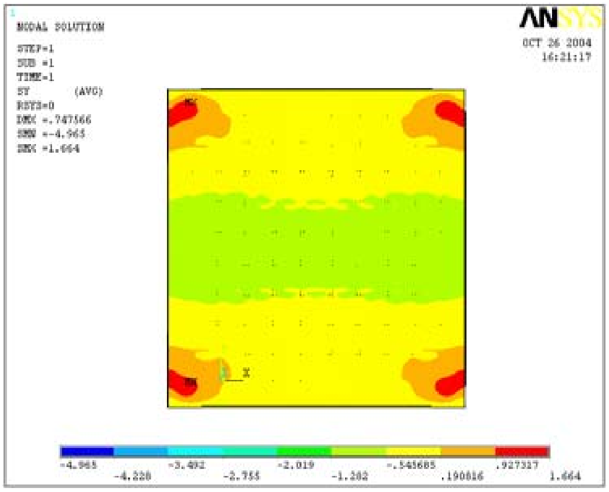

Fig. (19). σ_y nephpgram of top-slab.

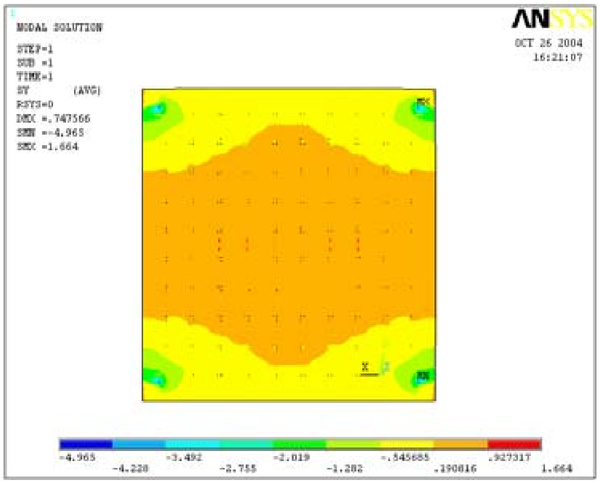

Fig. (20). σ_y nephpgram of bottom-slab.

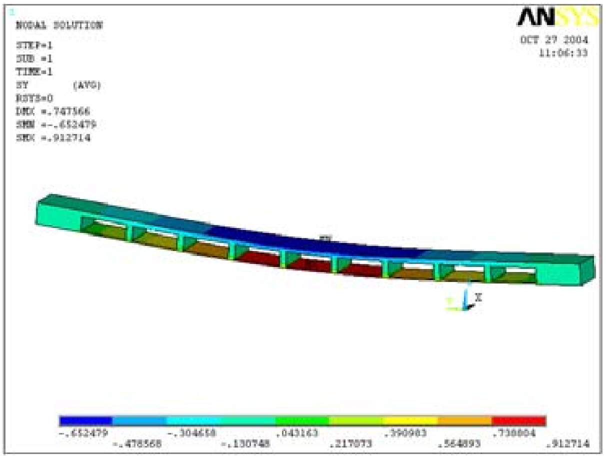

Fig. (21). Stress nephpgram of crossing-section.

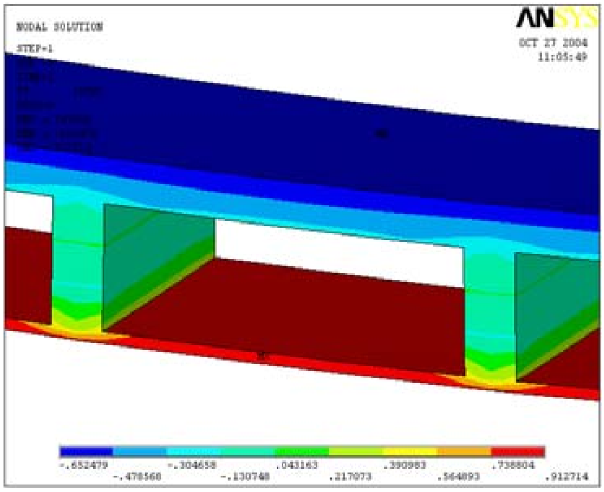

Fig. (22). Amplifier- stress nephpgram of crossing-section.

(1) Under the effect of vertical load, the bottom-slab of the honeycomb-core floor appears penetrating cracks vertically and horizontally intersected. Cracks pass through honeycombed-core module, which manifests that honeycombed-core module participates in the structure stress before cracking, and its adhesive property with concrete is quite good. The integrity of such floor is favorable. Therefore, in the design and analysis of the structure, it is essential to take the influence of mandrel into account.

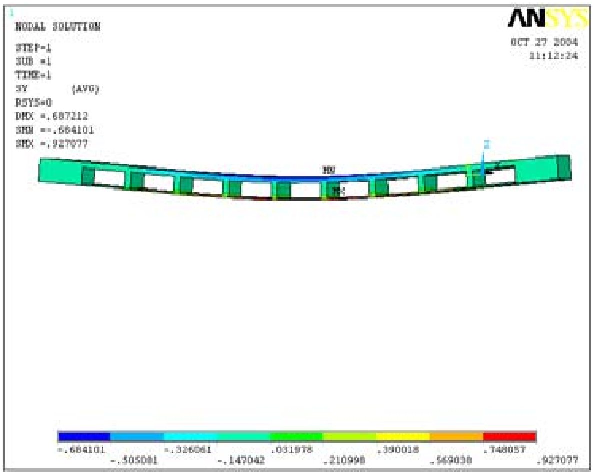

Fig. (23). Stress nephpgram of hollow part of 1/4-span.

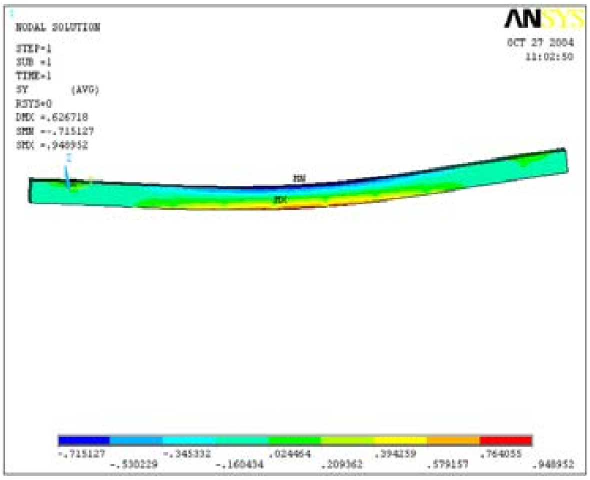

Fig. (24). Stress nephpgram of solid rib of 1/4-span.

(2) The development process of cracks, distribution, and the overall mechanical property of the honeycomb-core floor are identical to those of common solid girderless floor; its failure mode is similar to that of common solid girderless floor, as well as its biaxial bending property.

(3) From the strain value of concrete and reinforcing steel bar, the slab division of the honeycomb-core floor is in line with the method of division of typical girderless floor.

(4) Compared with the common RC floor system, the honeycomb-core floor is endowed with greater safety reserves and favorable capacity of plastic deformation. In comparison with solid floor, the deadweight decreases sharply under the circumstance that the deflection increases little, which saves the application amount of concrete greatly. Although the structural style of honeycomb-core floor is quite similar to that of the ribbed floor, the deflection of the former declines much with little increase of deadweight, which indicates that this structure has better rigidity. The design calculation of the honeycomb-core floor can not be carried out following the design method

of ribbed floor, and otherwise it will bring about the waste of materials.

(5) The honeycomb-core floor is a floor system with light deadweight and high rigidity. As a result, it is particularly suit for large-span and large-bay building structures. And such floor structure has a wide application prospect in the architectural engineering.

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