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Sliding Between Layers in 2-Layer Reinforced Concrete Beams and Shell

Thanh Quang Khai Lam, Thi My Dung Do

ABSTRACT--- In the study of bending components such as multilayer beams, with a upper and lower layer of steel fiber concrete compared with the normal concrete layer, there will be a sliding process between layers in the process of loading and the sliding between the layers will be different due to depending on the position of the steel fiber concrete layer, thereby the study proposes the suitable position of steel fiber concrete layer to the working process of bending beam so that the sliding between the layers is minimal. In the tension-compression component such as multilayer doubly curved shell roof, the sliding between the layers will depend very much on different boundary conditions such as: the boundary is the joint frame, the boundary is on the single column, rigid constraint, etc. Therefore, in this study, the authors will study the sliding between the layers in 2-layer beams when the steel fiber concrete layer is in upper and lower positions comparing the normal concrete layer and 2-layer doubly curved shell roof with the steel fiber concrete layer under the normal concrete layer with the boundary is rigid constraint by experiment method and ANSYS numerical simulation method to elucidate the sliding ability of the layers during the work of the component.

Keywords: steel fiber concrete, sliding between the layers, doubly curved shell roof, multilayer shell, multilayer beam.

I. INTRODUCTION

In 1990; M. Saiidi et al [18] experimentally studied the reaction model of reinforced concrete beams strengthened by concrete coating in the compression zone and tension zone. In 2013; Iskhakov et al [7] conducted a 2-layer beam test with a high strength concrete layer above the normal concrete layer; In 2016, Iskhakov et al [8], experimented with high strength concrete beams in the compressive zone of 2-span beams. In addition, there are experimental 2-layer beam study of Khai [13]… In these studies, it was not clear that sliding between layers in beams.

Besides, in the reinforced concrete thin shell theoretical studies of Ambarsumian [6] [20], Huan [21] and Khai et al [10] [11] [12] and the empirical study of Khai et al [14] [15] [16] mentioned experimental study of shells. However, it is unclear for the sliding between the layers of the shells.

On the basis of the above studies, the target is to consider the possibility of separating the sliding of the layers of each other with 2 types of concrete as the normal concrete layer and steel fiber reinforced concrete layer on both types of bending and tension-compression structures such as 2-layer beams and multilayer doubly curved shell roofs.

II. EXPERIMENTAL STUDY

A. Design standards

- Design standards for reinforced concrete structures TCVN 5574-2012 [5]
- Standard steel fiber reinforced concrete structure of Russia: СП 52-104-2009 [3]

B. Materials used for manufacturing

The material used for making sample is:

- Vicem Bim Son Cement PCB40, TCVN 6260-2009, TCVN 6067-2004
- Durable concrete B20 for the normal concrete layer and B30 for dispersed steel fiber reinforced concrete layer.
- Australia and Vietnam Steel, CB300V Steel grade corresponding steel bar group AII for diameter types ϕ10, ϕ12 and ϕ22 meeting TCVN 1651-2-2008
- Australia and Vietnam Steel, CB300T steel grade – ϕ6 meeting TCVN 1651-1-2008
- Stone (D_{max}=10mm, floor sliding content 0.14: 10-20%), yellow sand (size 1.5-5mm)
- Steel fiber (ϕ0.5-L30mm): Steel fibers meet standards ASTM A820-01 [2], fiber direction rate from 50 to 100 meeting ACI 544.1R-1996 [1]

Fig. 1. Dramix steel fibers ϕ0.5-L30mm in experiment

C. Design of 2-layer beams and shell

Design of 2-layer beams

Casting 6 concrete beams of size15×30×220cm, the B30 fiber concrete layer with thickness of 10cm, the B20 normal concrete layer with thickness of 20cm.

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In particular: casting 2 beams with the upper fiber concrete layer with linked horizontal latches (SFC upper - link), casting 2 beams with the upper fiber concrete layer without linked horizontal latches (SFC upper - wlink), casting 2 beams with the lower fiber concrete layer with linked horizontal latches (SFC lower - link).

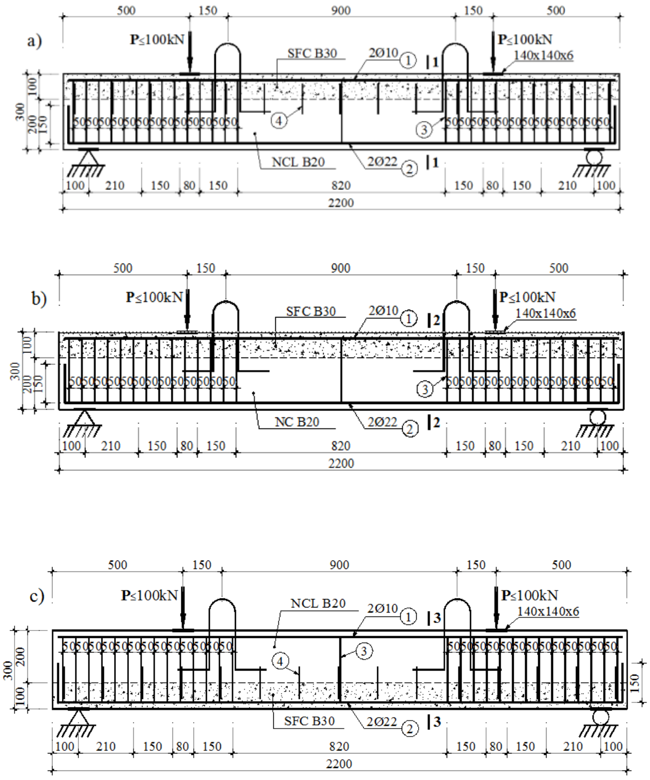

Fig. 2. 2-layer concrete beams in experiment

Design of 2-layer doubly curved shell roof

In terms of using the shell roof in Vietnam, the under layer of the shell roof is the main force bearing layer, the waterproof and insulating concrete layer has a lower level of durability above the shell. Therefore, arrangement of the fiber concrete layer (SFC) with higher strength under the normal concrete layer (NCL) with lower strength.

Due to complicated construction conditions and shell experiments by concrete materials with non-convertible materials, so: casting a 3×3m concrete shell with layer 1 (lower layer) is B30 SFC with 2cm thickness, layer 2 (upper layer) is B20 NCL with 3cm thickness bearing load itself and the live load used on the shell P=500kG/m^2.

Curvature equation: $z = f_1\left(\frac{x}{a}\right)^2 + f_2\left(\frac{y}{b}\right)^2$

Where: f is the largest camber at the top of the roof: $f = f_1 + f_2$; f_1, f_2 are the camber of the curved lines sliding in two directions; a, b are half the length of the side of the rectangular base of the shell.

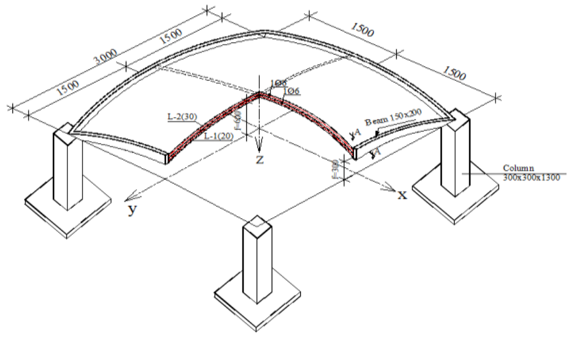

Fig. 3. Model of 2-layer doubly curved shell roof

D. Construction of 2-layer beams and 2-layer shell

Processing formwork and reinforcement for beams and shell. Pour concrete layer by layer with distance of 48 hours after the each layer.

Fig. 4. Pouring the concrete layer by layer in the beams

Fig. 5. Creating formwork and pouring the concrete layer by layer in the shell

E. Layout diagram of experimental equipment [9]

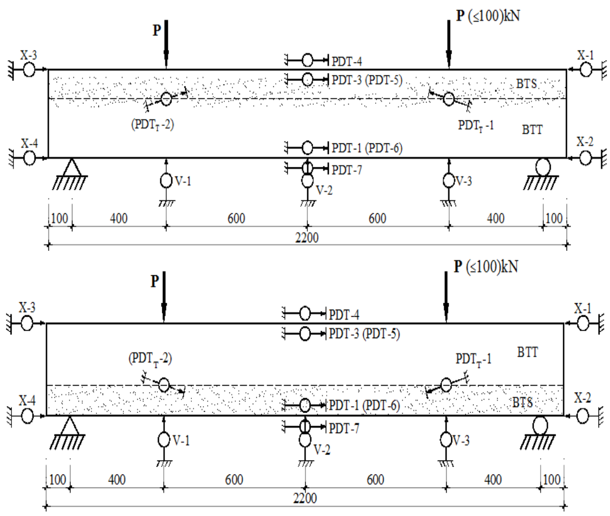

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Fig. 6. Layout diagram of experimental equipment on beams

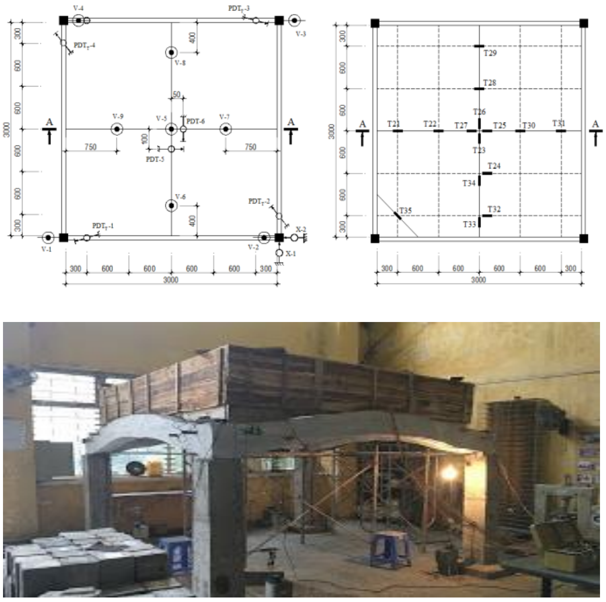

Fig. 7. Layout diagram of experimental equipment on shell

F. Experimental results of beams and shell

Line of load- sliding deformation relationship in beams:

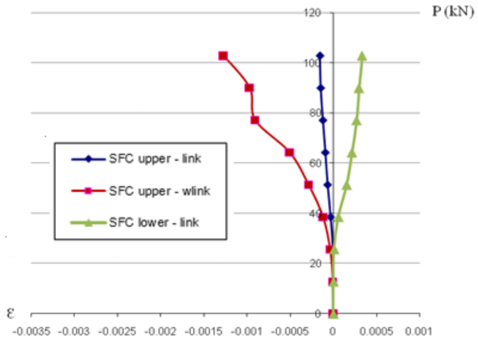

Fig. 8. Load- sliding deformation relationship in beams

Comments: For the upper fiber concrete beam without latches, it slides much more than the other beams and the upper fiber concrete beam with latches is the least sliding, which means that in the bending beam, the upper SFC layer with latches is more effective than the lower SFC layer with latches in the working process.

Line of load- sliding deformation relationship in shell:

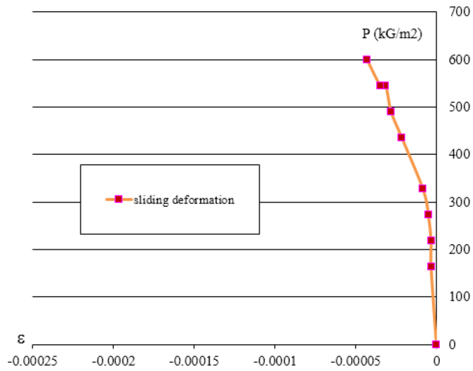

Fig. 9. Load- sliding deformation relationship in shell

Comments: In multilayer curved shell roof, sliding is very small (P=600kG/m^2, $\varepsilon<5\times10^{-5}$). Comparing to the upper SFC beams without latches ($\varepsilon\approx5\times10^{-4}$), the sliding in the shell is 10 times less.

To elucidate the sliding between the inner shell layers, the authors implements to simulate shell roof with ANSYS software. After having the results of shell experiment, the authors completes the finite element model in ANSYS.

III. SIMULATION &RESULTS OF 2-LAYER DOUBLY CURVED SHELL ROOF BY ANSYS

To examine the sliding ability of the inner layers, the authors investigates the case of the upper and lower SFC layer comparing to the NC layer.

Model selection: Finishing the finite element model by adjusting the input parameters from the experimental results of normal concrete, steel fiber concrete and steel fibers, including:

- Selection of steel fiber model in concrete: three models are used: smeared model, embeded model and discrete model. Thus, in this study, steel fiber was dispersed in concrete so using the smeared model was reasonable.
- Cracking modeling in concrete: Cracks in concrete are modeled in two basic forms: discrete model and smeared model. In this study, we are interested in the behavioral relationship between load and displacement without regard to crack shape, local stress. Therefore, in the study, select the smeared model for crack in concrete.
- Choice of contact pattern between two concrete layers: In the calculation can be used interface element or thin-layer element to simulate the sliding contact between the two concrete layers. Model building:
- Element selection for the model: Concrete simulator element: SOLID65 element, Contact element: ANSYS offers "hard surfaces with soft surfaces" contact elements. The hard surface is called the "target" surface and is modeled with the TARGE170 element type for 3D contact. The surface of the deformation (soft surface) is called the "contact" surface, which is modeled by the CONTA173 element type.

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- The meshing of the model: divided by the thickness of the shell is equal to the thinnest layer (ESIZE, ALL, h_{min}) and free mesh (MSHKEY, 0) with the 3D mesh geometry (MSHAPE, 1.3D).
- Boundary and load condition of the modeling: Hard bonding with boundary beam. The distributed load on the upper surface of the casing at the nodes of the tetrahedron cubic grid (NSLA, R, 1), by P-weight distribution (SF, ALL, PRES, P).
- Selection of normal concrete and steel fiber concrete models: using the Kachlakev model. Willam and Warnke's destructive standards.

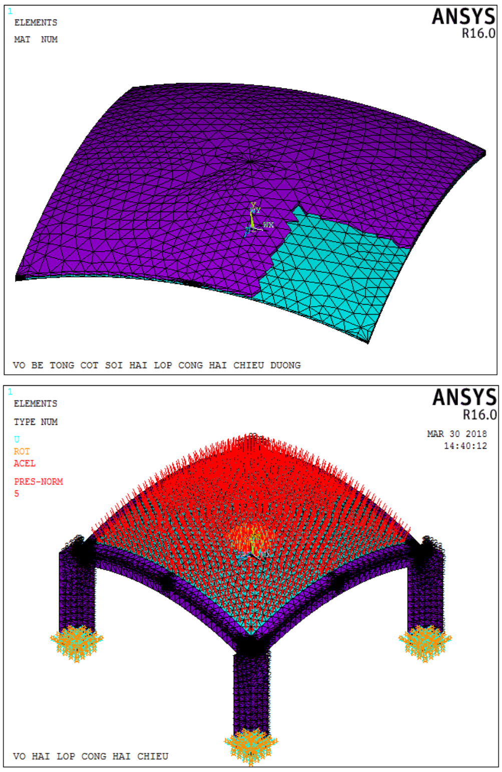

Fig. 10. Finite element model of each layer, boundary condition and load on the shell

Table 1. The result of the largest tangential stress calculation

Components of stress	2cm fiber concrete layer under 3cm normal concrete layer	3cm fiber concrete layer above 2cm normal concrete layer
Maximum tangential stress	0.094MPa	0.069MPa
Respective normal stress	0.346MPa	0.276MPa

Comments: When the shell is affected by the load evenly distributed on the top of the shell perpendicular to the shell surface, there is a phenomenon of the sliding between the layers in the shell roof. After being affected by the load, at the contact position between the two layers, there is a relative deformation difference between the two layers which is 1×10^{-3} and is still much smaller than the limited relative deformation of concrete $\varepsilon_{cu} = 3.5\times10^{-3}$

According to the EN 1992-1-1:2004(E) [4] the tangential stress at the contact surface between the concrete layers needs to meet the following requirements to have no sliding at the contact surface:

$$V_{Edi} \leq V_{Rdi} \quad (1)$$

$V_{Rdi} = 0.35\times0.9+0.6\times0.346+0 = 0.52$ MPa $< 0.5\times 0.24 \times11.5 = 1.38$ MPa

$V_{Edi} = 0.094$MPa $\leq V_{Rdi} = 0.52$MPa. So it can be considered that the two layers have not lost the cohesion effect and the two layers of the shells still seem to not slide on each other.

IV. CONCLUSION

1. Through experiment of 2-layer beams, it shows the effectiveness of attaching steel latches in reinforcing and repairing beams, thereby creating multilayer beam structure.
2. With the load itself and the live load of repair on the curved shell roof P=500kG/m^2, the layers of the shell roof stick together, working together.
3. The experiment shows that the effectiveness of the dispersed steel fiber concrete layer in multilayer structure. It is possible to use the steel fiber concrete in structures of plates and shells, etc.

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