# Stress-strain in multi-layer reinforced concrete Doubly curved shell roof

**Lam Thanh Quang Khai, Do Thi My Dung**

***Abstract*— This paper presents a result of stress-strain in double-layer reinforced concrete doubly curved shell roof by experimental method and simulated by ANSYS. In the analytical method of multi-layer shell by the authors as Ambarsumian, Huan T. Le...with assuming that the layers in shell are stick together, work together, in addition to the analytical solution, there are also limitations in the choice of approximation functions as: the stress function φ and the displacement function w, selection of boundary conditions of the shell...The study of double-layer reinforced concrete shell roof by experimental method and ANSYS show the real work of the shell, as well as the real work of the double-layer shell with the use of normal concrete layer and steel fiber concrete layer in shell, experimental method and ANSYS in the reinforced concrete shell roof model with a square size is 300×300cm.***

***Keywords: Doubly curved shell roof, experimental method in shell multi-layer, reinforced concrete shell roof, steel fiber concrete layer, stress-strain in shell.***

## I. INTRODUCTION

In stress-strain analysis of multi-layer reinforced concrete doubly curved shell roof with a square size is 300 · 300cm, Ambarsurmian [5][13] was based on Vlasov's equations, Vlasov [12] gives equations with two functions: the stress function φ and the displacement functions w. However, solving the high-order differential equations are complex because of chosing two functions: φ, w and the different boundary conditions of the reinforced concrete shell. To solve the problem, many authors have used approximation functions in the form of single and double trigonometric series, or common polynomials, differential methods, differential variables...In it, Huan T. Le [15] used the point method to solve the multi-layer shell equations of Ambarsurmian.

Solving the problems by the analytical method on multi-layer reinforced concrete shell that has many problems to solve such as the ability to slip between layers of the shell...With experimental method and simulated by ANSYS to determine the stress-strain in double-layer reinforced concrete doubly curved shell roof with the real work of the shell, consider the possibility of slipping between reinforced concrete layers.

The experiment was carried out in double-layer reinforced concrete doubly curved shell roof, steel fiber concrete layer under normal concrete layer, a square size is 300 x 300cm, the bottom layer is a steel fiber concrete layer, B30, thickness is 2cm; the upper layer is normal concrete layer, B20, thickness is 3cm. The itself load and the used load are 5kN/m$^2$= 500kG/m$^2$ under conditions of use shell roof in Vietnam.

## II. DOUBLE-LAYER EXPERIMENTAL SHELL

### *A. Sample design*

Fig. 1 is the double-layer reinforced concrete doubly curved shell model, with a square size is 300×300cm. The bottom layer is a steel fiber concrete layer, B30, thickness is 2cm, μ=2% volume concrete. The upper layer is normal concrete layer, B20, thickness is 3cm. Boundary beam size is 15×20cm, 4 corners of the shell on the columns. The itself load and the used load are 500kG/m2.

The equation of the shell is:

$$z = f_1\left(\frac{x}{a}\right)^2 + f_2\left(\frac{y}{b}\right)^2 \qquad (1)$$

With: f is the highest elevation at the top of the shell roof: $f = f_1 + f_2 = 60cm$ ; $f_1 = 30cm$ , $f_2 = 30cm$ are the height of the boundary curves in two directions; a=150cm, b=150cm is half the length of the rectangular size of the shell.

The materials used to make the sample are: Vicem Bim Sơn cement PCB40; rock (Dmax = 10mm); sand (size: 1.5-5mm); Dramix steel fiber (ϕ0.5-L30mm): with ASTM standard A820-01 [2], rate 50 to 100 with ACI standard 544.1R-96 [1].

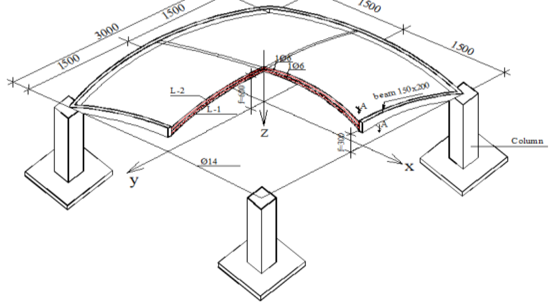


**Fig. 1 Double-layer reinforced concrete doubly curved shell roof model, size: 300 X 300cm**

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**Lam Thanh Quang Khai**, Department of Civil Engineering, Mien Tay Construction University, 20B Pho Co Dieu street, Ward 3, Vinh Long town, Vinh Long province, Vietnam
(email : lamthanhquangkhai@gmail.com)

**Do Thi My Dung**, Department of Civil Engineering, Mien Tay Construction University, 20B Pho Co Dieu street, Ward 3, Vinh Long town, Vinh Long province, Vietnam (email : dothimydung1983@gmail.com)


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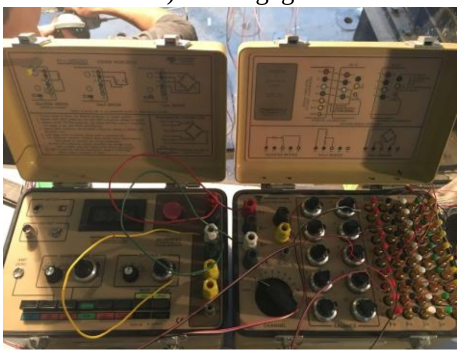
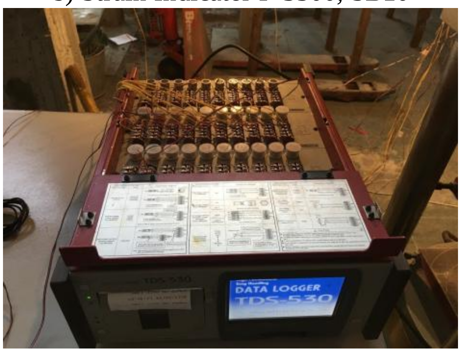
Design standards: Vietnamese standard: TCVN 5574 [4] and Russian standard: СП 52-104-2009 [3].

Strain gage type and strain gauges: BX120-30AA, long 30mm, wide 3mm, Rgage=120Ω, gage coefficient =2.08±1%. Data loger TDS-530 (30 channels), Data loger TDS-601 and Strain Indicator P-3500, SB10 (10 channels) (Fig. 2)

a) Strain gage



b) Strain Indicator P-3500, SB10

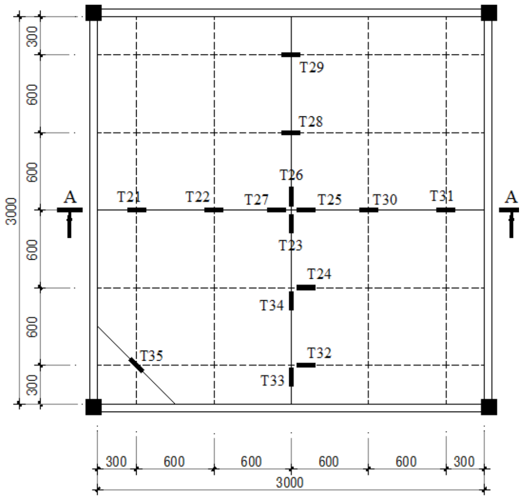



c) Data loger TDS-530

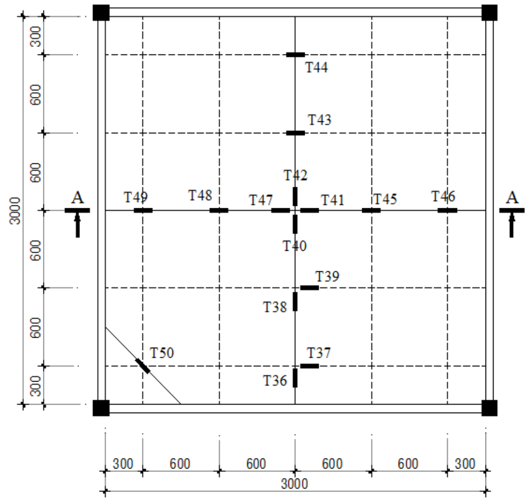
d) Data loger TDS-601

**Fig. 2 Strain gage type and strain gauges**

Location of strain gages: from results calculated by Huan T. Le [15] and ANSYS R16 (Fig. 3)

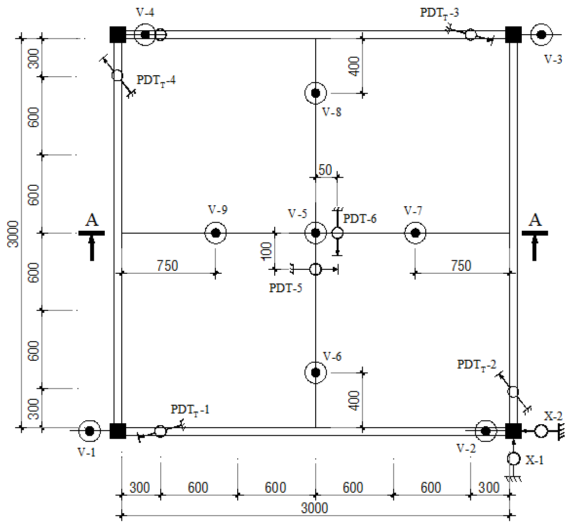



a) Location of strain gages on bottom surface




b) Location of strain gages on upper surface

**Fig. 3 Location of strain gages**




a) Vertical displacement and slip strain



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b) Dramix steel fiber

**Fig. 4 Vertical displacement, slip strain and Dramix steel fiber**

*B. Make the modeling*

- Step 1: Make the mold in the right shape
- Step 2: pour concrete bottom layer
- Step 3: pour concrete upper layer, upper layer was poured after bottom layer with 48 hours

a) Make the mold

b) Pour concrete

**Fig. 5 Make the mold and pour concrete**

*C. Test the shell roof*

a) The measuring device

b) Strain gages on shell surface

**Fig. 6 Test the shell roof**

## III. SIMULATION OF DOUBLE-LAYER SHELL ROOF

*A. 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.

*B. 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.
- The meshing of the model: divided by the thickness of the shell is equal to the thinnest layer (ESIZE, ALL, hmin) 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).



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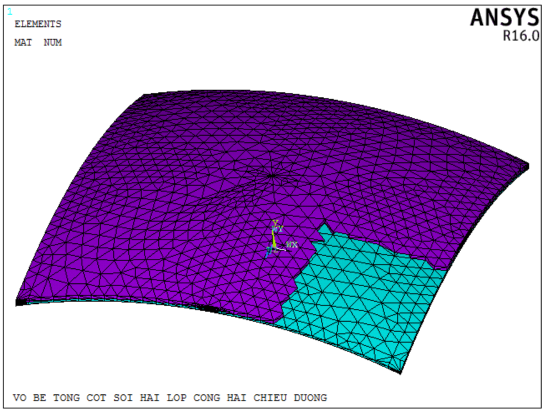
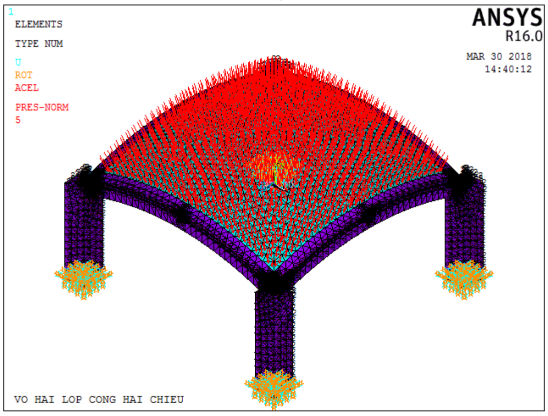
- Selection of normal concrete and steel fiber concrete models: using the Kachlakev model. Willam and Warnke's destructive standards.




a) The meshing of the model



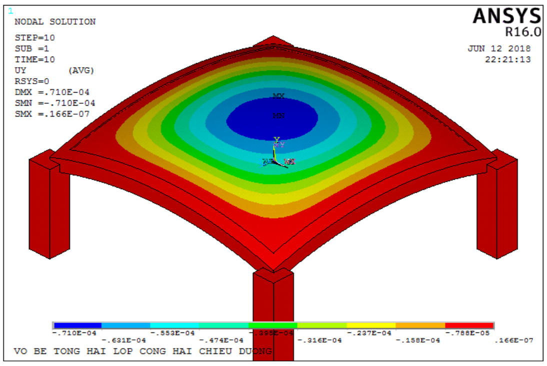

b) Boundary beam and load of the model

**Fig. 7 The meshing of the model, boundary beam and load of the model**

## IV. RESULTS OF RESEARCH METHODS

The itself load and the used load are $5kN/m^2 = 500kG/m^2$ under conditions of using shell roof in Vietnam.

Relationship of load and displacement between methods: P=500kG/m2:



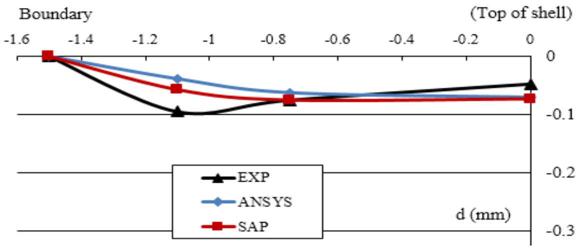
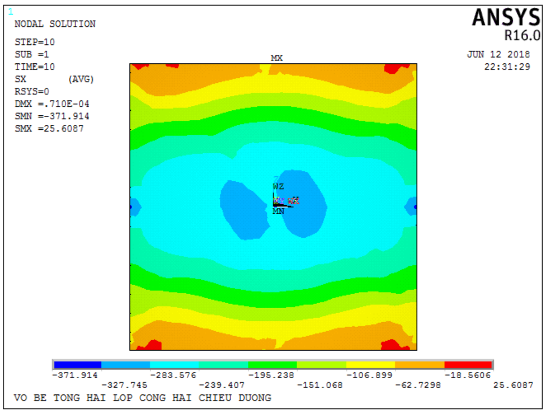



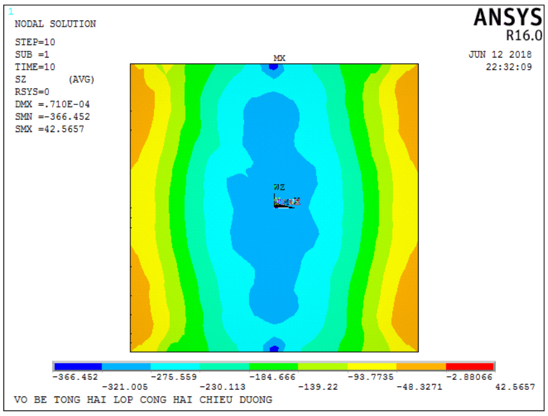

**Fig. 8 Relationship of load and displacement between methods**

Comment: The results show that near the boundary there is a difference between the experimental result and ANSYS, Sap2000, showing the influence of boundary condition between theory and experiment. In addition, the results of ANSYS and Sap2000 are nearly identical, suggesting that the simulation model in ANSYS is appropriate.

Relationship of load and strain between methods, $P=500kG/m^2$:




a) Strain with x direction on bottom surface




b) Strain with y direction on bottom surface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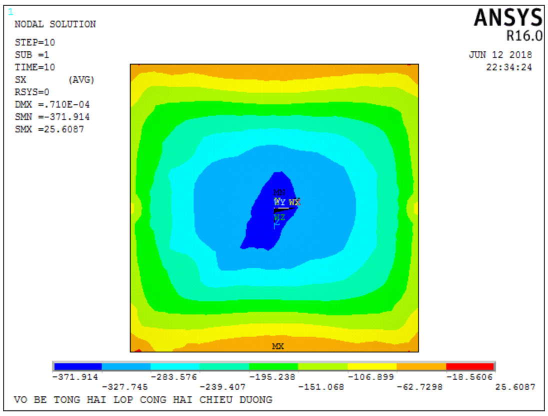
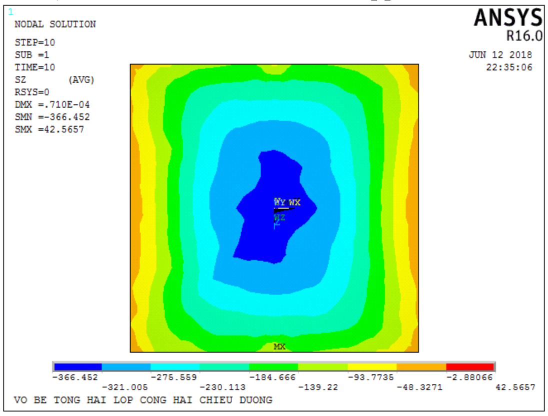
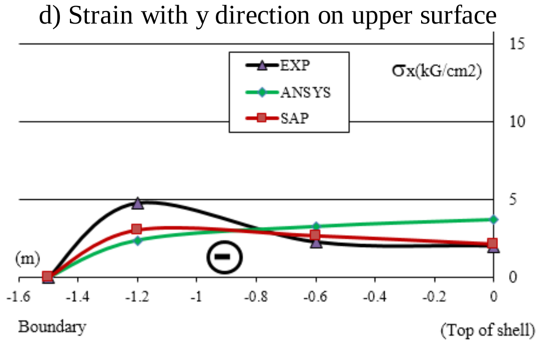


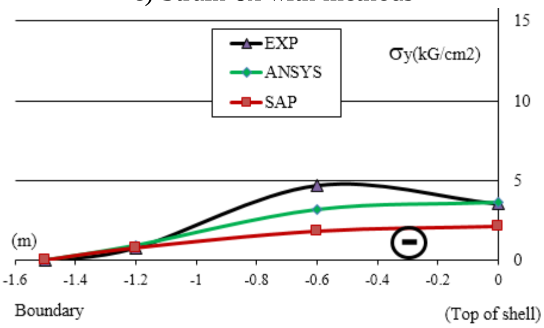
c) Strain with x direction on upper surface



d) Strain with y direction on upper surface



e) Strain σx with methods



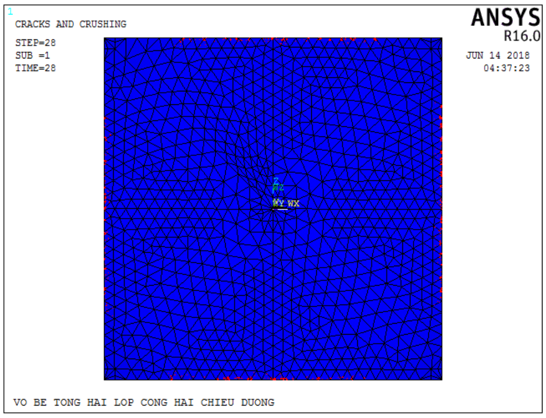
f) Strain σy with methods

**Fig. 9 Relationship of load and strain between methods**

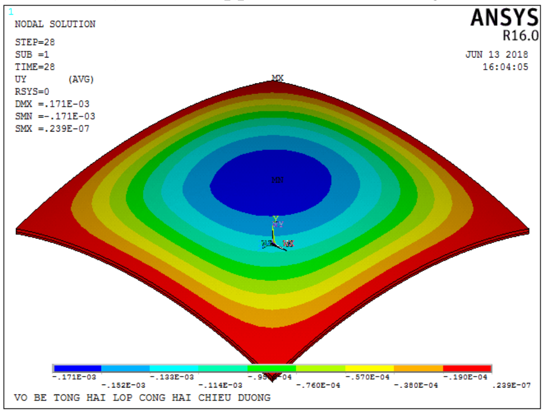
Comment: Stresses in experimental method are more valuable than ANSYS and Sap2000 results.

The itself load and the used load are 5kN/m$^2$ = 500kG/m$^2$, the shell roof has not appeared cracks.

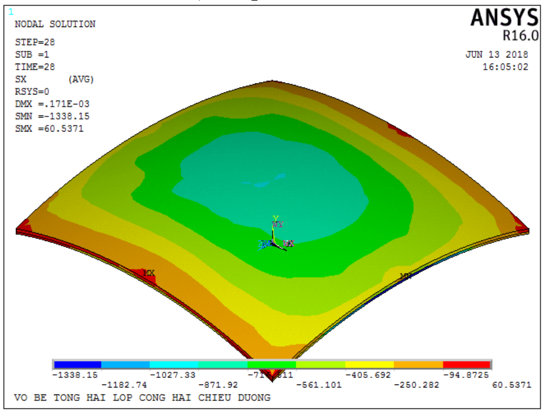
Concrete period begins to appear cracks: load is P=14kN/m$^2$=1400kG/m$^2$, stress is 13.38kG/cm$^2$, the first crack appeared in the shell along the steel fiber concrete layer on the underside, max displacement at the top of the shells is 0.17mm.



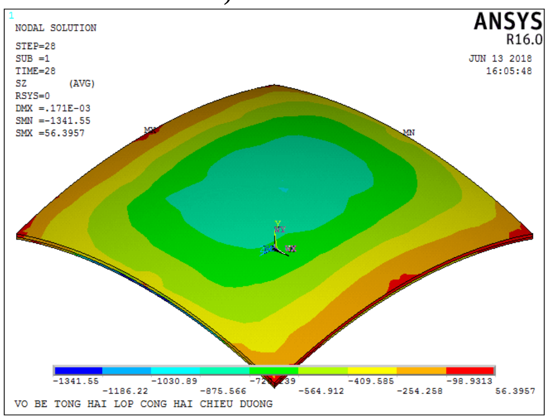
a) Cracks appeared in boundary



b) Displacement



c) Strain σx



d) Strain σy

**Fig. 10 Displacement and strain in shell, P=14kN/m2**

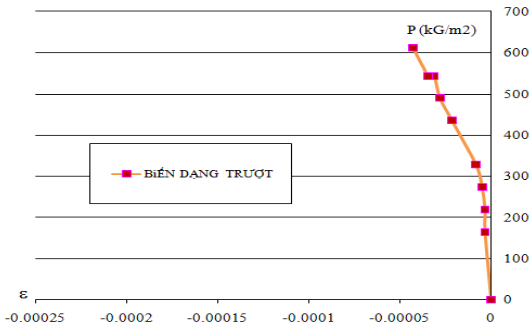



**Fig. 11 Relationship between load and slip deformation of the shell**

## CONCLUSIONS

- The itself load and the used load are P=5kN/m2, concrete period begins to appear cracks: P=14kN/m2. Therefore the bearing capacity of the shell is very large

- Between experiment and ANSYS, Sap2000 has a difference in value. However, that is the difference between absolute theory and practice. This is also the error of the instrument in practice.

- The results of the shell roof analysis are through load-stress relation, load-deflection relation, FEM model in ANSYS which is suitable for experiment and Sap2000. ANSYS model can be used to investigate the effect of layer thickness, fiber concrete placement, fiber content...on the stress-strain in the shell and the ability to slip between layers.

- The layers in the shells do not slip together, work together as a multi-layer structure. Therefore, it is possible to use the equivalent class model with load and experimental boundary condition.

- Structural simulation capabilities in ANSYS are still large, consistent with large structures, complex structures that can not be tested.

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