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Nonlinear analysis of multi-layer steel fiber reinforced concrete beams

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ABSTRACT

This paper presents the results of an experimental study involved testing of double-layer reinforced concrete beams in two cases: steel fiber concrete layer is located below, and is located above of the normal concrete layer. The size of the beams is 15×30×220cm, in which the steel fiber concrete layer is 10cm thick, all the beam samples were tested under two-point loads. ANSYS has simulated experimental beams as load-vertical displacement relationship, load- compression strain relationship, load-tensile strain relationship at the middle of the span of the beams. Experimental results and numerical simulation of ANSYS of double-layer steel fiber concrete beams were compared with three-layer steel fiber reinforced concrete beams of the same size. In three-layer steel fiber reinforced concrete beams, the 10cm thick steel fiber concrete layer is located below, and is located above, a middle layer is the normal concrete layer. Concrete of beams is B30 for all layers, all types of beams with steel fiber content in concrete is 2% by volume, with nonlinear material analysis in ANSYS numerical simulation. The data are compared with each other results show that the two-layer steel fiber reinforced concrete beams are damaged the slowest, the three-layer fiber concrete beams are damaged very early in other beams. Experimental results also show that the vertical displacement, tensile strain and compressive strain values are 30-40% larger than the simulated 2-layer and 3-layer beams.

Keywords: steel fiber, stress-strain, crack, multi-layer beam, ANSYS, experiment, testing

1. Introduction

In the study of steel fiber concrete, many studies have used nano concrete aggregation with steel fibers to enhance the tensile strength of concrete [1], increased plasticity of nano concrete with steel fibers [2], experimental evaluation of nano silica effects to high performance concrete strength in early age [3]. Steel fiber concrete is applied in the shell roofs as a way to repair damage in the shell, the research has built the load-vertical displacement, load-strain relationships by experimental research methods and ANSYS numerical simulation [4-5], sliding study between layers by both experiments and simulations have also been studied [6].

In particular, steel fiber concrete is widely used in bending beam structures, adding steel fibers into concrete has created concrete beams to reduce cracks, enhance bearing capacity for beams, significantly improve some properties of concrete [7], through experiments studies have investigated design parameters affecting steel fiber concrete beams such as survey the effects of steel fiber content in concrete, survey the influence of the number of tensile steel bars, study the impact of the diameter of tensile steel bars, etc. on fiber concrete beams with the size of 15×20×220cm beam [8].

When reinforced concrete beams are reinforced, repaired and need to add one layer of concrete (usually high-strength concrete layer) or add one layer of steel fiber the concrete is located below or is located above of the old concrete layer, forming multi-layer steel fiber concrete beam structures which to enhance bearing capacity for tensile concrete areas. It can be said that the studies of Iskhakov and his colleagues have studied quite a lot about this type of multi-layer fiber reinforced concrete, such as studies on the experimental study of full scale two-layer concrete beams [9], two-layer beams from normal and fibered high strength concrete [10], experimental investigation of prestressed two layer reinforced concrete beams [11-12], experimental investigation of continuous two-layer reinforced concrete beams [13], studies by Iskhakov et al. has built the process of forming and developing cracks in beams, stress-strain state of beams. In addition, there are also studies of two-layer beams on finite element analysis of the bending moment-curvature of the double-layer concrete beam, the use of periwinkle shell aggregate concrete, cost efficiency, flexure Behavior [14-17], etc.

Besides, there are many other finite element analysis methods of three-layer concrete beams with composite reinforcement, the influence of geometrical parameters of the cross-section, strength, and deformability of the materials used on the stress-strain state of three-layered reinforced concrete [18-20]. And studies of the prefabricated concrete frame, analysis of axial stiffness reduction factors, quality of construction works, analysis of structural failures and remedial measures, improve the quality of concrete construction, etc. [21-27].

Through the analysis of the multi-layer steel-fiber reinforced concrete beams of the authors who mentioned above, studies have shown the influences on cracks formation and cracks development, load-strain relationships, etc. of the layers when the fiber concrete layer is located below of the normal concrete layer, steel fiber concrete layer is located above of the normal concrete layer, located both below and above of the normal concrete layer (three-layer beams).

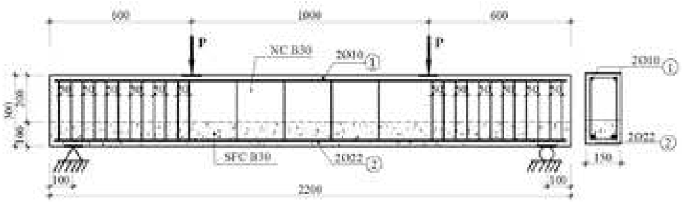
In this paper, the authors have experimented on two-layer steel fiber reinforced concrete beams, with a 10cm thick steel fiber concrete layer is located below of the normal concrete layer and is located above of the normal concrete layer. Then simulate the tested beams with the dimensions of 15×30×220cm beams. These results continue to investigate the influences in three-layer concrete beams of the same size, in these three-layer beams, a layer of 10cm thick steel fiber concrete is located above, one layer of 10cm thick steel fiber concrete is located below, the middle layer is a normal concrete layer of 10cm thick. The results showed that two-layer steel fiber concrete beams were damaged the slowest, three-layer steel fiber concrete beams were damaged very soon. Experimental results also show that the vertical displacement, tensile, and compressive strain values are 30-40% larger than the simulated two-layer and three-layer beams.

2. Materials and Methods

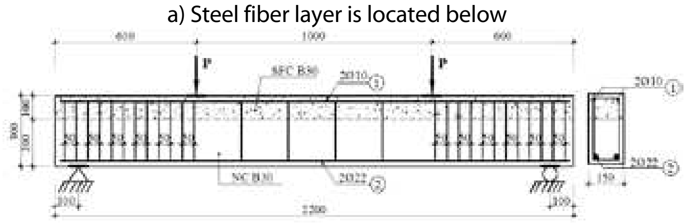
2.1 Designed model and testing of beams

Beam of 15×30×220cm size, shear steel stirrups spacing at the ends of the beam is ϕ6a50, shear steel stirrups spacing at the middle of the beam is ϕ6a200. Tensile steel bars are 2ϕ22, compression steel bars are 2ϕ10.

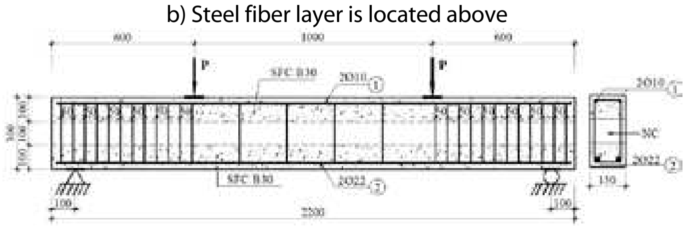
Concrete beam is B30, all beams, fiber steel content were studied with 2% by volume. Loads P are applied to the steel plate 140×140×6mm, increased from 0kN until the beam is damaged, are shown in Fig.1



a) Steel fiber layer is located below



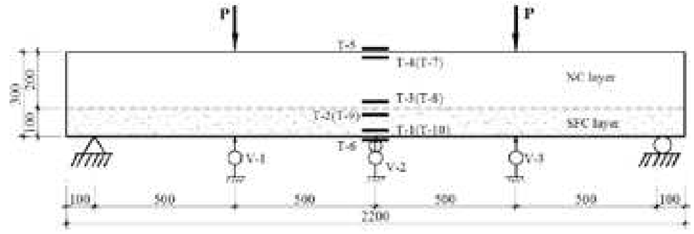
b) Steel fiber layer is located above



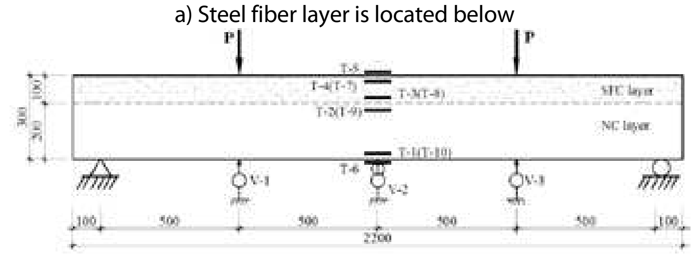
c) Three-layer steel fiber concrete beam

Fig. 1 Model of two-layer and three-layer concrete beams

Diagram of placement of measurement positions: strain measurement, vertical displacement measurement (testing only two-layer steel fiber reinforced concrete beams with steel fiber concrete layer is located below and steel fiber concrete layer is located above of the normal concrete layer, not testing three-layer steel fiber reinforced concrete beams), are shown in Fig. 2



a) Steel fiber layer is located below



b) Steel fiber layer is located above

Fig. 2 Diagram for placing strain and vertical displacement measuring devices in beams

In which: NC: normal concrete, SFC: steel fiber concrete, T-1 to T-10: measure the strain by strain gauges (front and back of beams), V-1 to V-3 measure the vertical displacement at middle of the beam span.

Concreting beams in layers are shown in Fig. 3

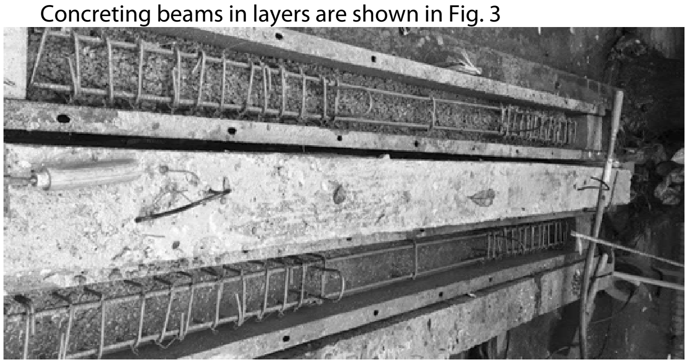


Fig. 3 Concreting beams in layers

Tested beams on the experimental pedestal, are shown in Fig. 4

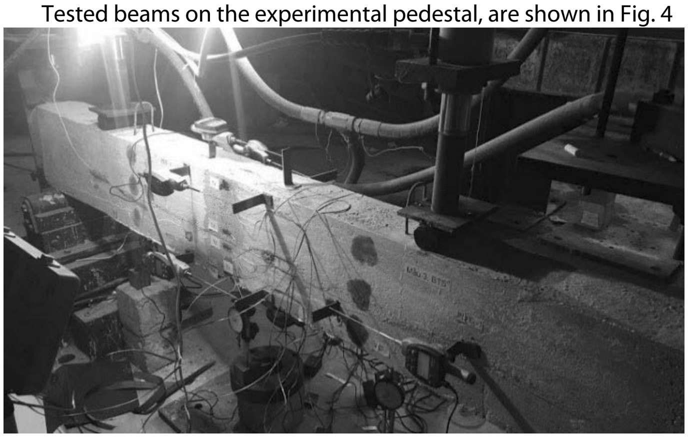
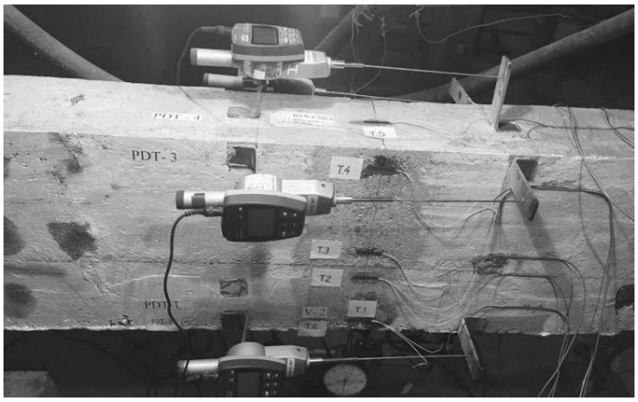
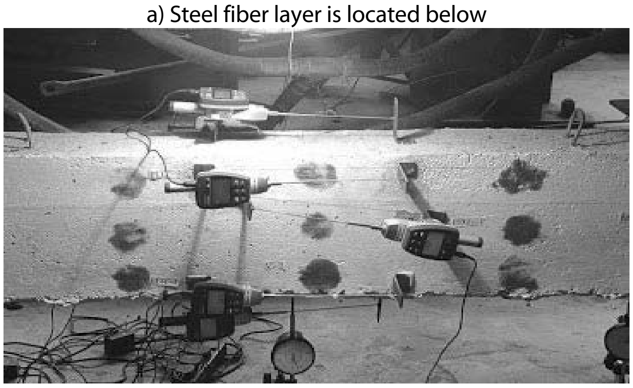


Fig. 4 Tested beams on the experimental pedestal

Measuring devices are placed on the beams, are shown in Fig. 5



a) Steel fiber layer is located below



b) Steel fiber layer is located above

Fig. 5 Measuring devices are placed on the beams

2.2 Finite element model in ANSYS

Two-layer steel fiber reinforced concrete beams, both concrete layers are B30 concrete, the fiber content in concrete is 2%, shear steel stirrups spacing at the ends of the beam is ϕ6a50, shear steel stirrups spacing at the middle of the beam is ϕ6a200, tensile steel bars are 2ϕ22, compression steel bars are 2ϕ10, considering nonlinear materials in ANSYS numerical simulation analysis.

three-layer steel fiber concrete beams with fiber concrete layer is located below, 10cm thick and steel fiber concrete layer is located above, 10cm thick, and the middle layer is 10cm thick concrete layer, all three concrete layers are B30 concrete.

Selecting the model of steel fibers dispersed in concrete: to model steel fibers in concrete, three models are used: smeared model, embedded model, and discrete model. In this study, steel fibers that are dispersed in concrete should use a smeared model.

Modeling cracking in concrete: Currently, cracks in concrete are modeled in two primary forms: discrete model and smeared model. In this study, we are interested in the behavior relationship between load and displacement without being too concerned about crack shape, local stress. So in the survey, choose the smeared model for cracks in concrete.

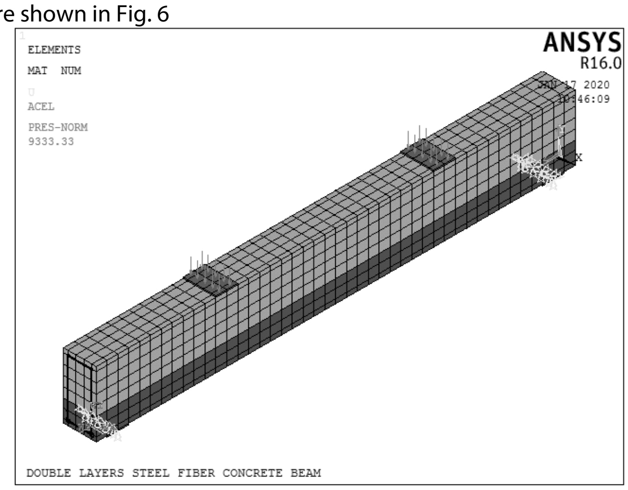
Modeling of reinforcement bars: using BEAM188 element with two-node.

Finite element model in beams: Concrete simulation element: SOLID65 element, which is a specialized simulation of concrete materials, can simulate reinforcement in concrete with the phenomenon of cracking and compression, nonlinear material definition. This is a 3D element with eight buttons.

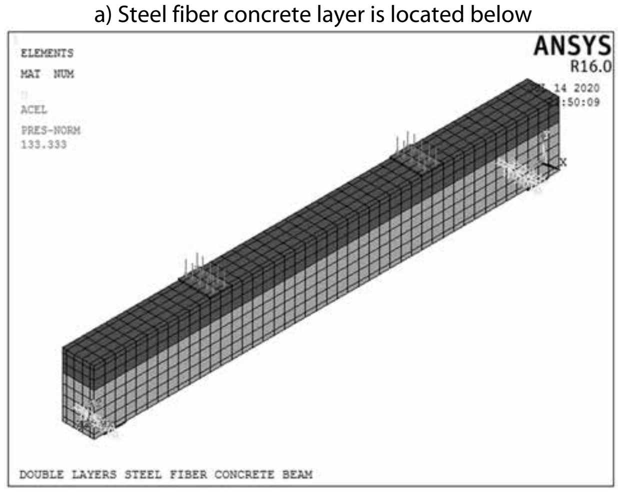
Meshing for models, boundary conditions, and loads: due to the simple beam structure, mesh shapes are divided by 3D blocks available in ANSYS and optimized element size.

Input parameters in the model: In ANSYS to enter the input parameters for SOLID65 concrete element, we must enter the following eight basic parameters: shear force transmission coefficient when the crack is opened, shear force transmission coefficient when cracking is closed, cracking stress when tensile, compression stress, weak reduction coefficient due to cracking when tensile, modulus, Poisson's coefficient, stress-strain relationship (considered the nonlinearity of the material).

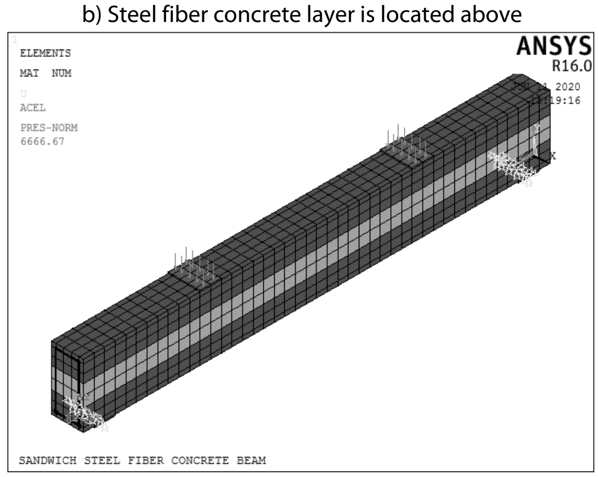
Two-layer concrete beam model, three-layer concrete beam model, boundary conditions in ANSYS, loads applied to the beam are shown in Fig. 6



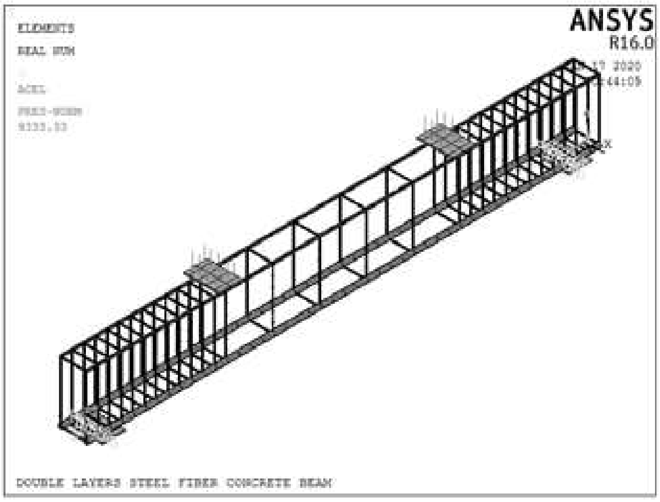
a) Steel fiber concrete layer is located below



b) Steel fiber concrete layer is located above



c) Three-layer beam model



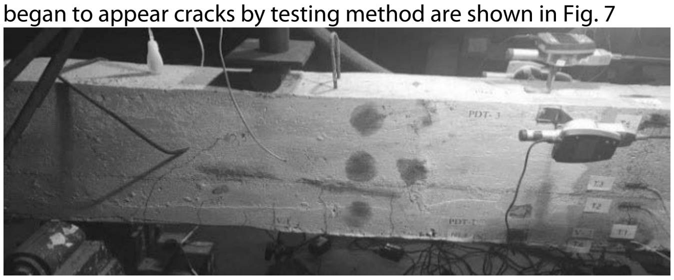
d) Model of steel bars in beam

Fig. 6 Multi-layer concrete beam model in ANSYS

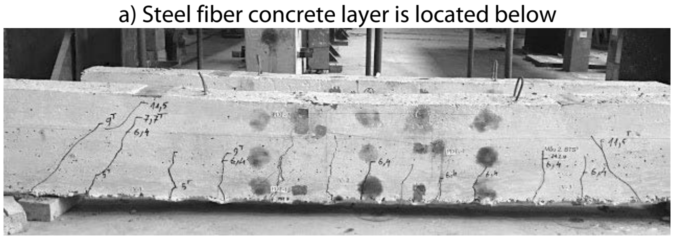
3. Results and Discussion

3.1 Results between experiments (EXP) and ANSYS

Two-layer concrete beams with steel fiber concrete layer is located below and is located above of the normal concrete layer began to appear cracks by testing method are shown in Fig. 7



a) Steel fiber concrete layer is located below

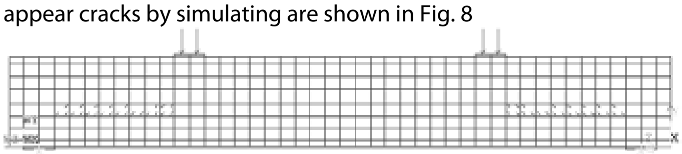


b) Steel fiber concrete layer is located above

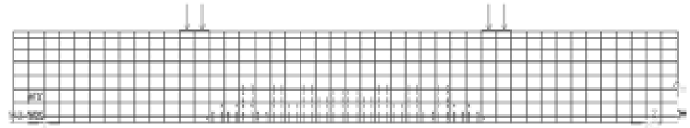
Fig. 7 The beams began to crack in the experiment method

Comment: In Fig. 7, we observed that the steel fiber concrete layer is located below will make the concrete beams reduce the number of cracks and cracks development compared to the steel-fiber concrete beams, which is located above of the normal concrete layer. For concrete beams with steel fiber layer is located below, concrete beams cracked at 87kN and damaged at 103kN. In contrast, the steel fiber concrete layer of beams above, concrete beams started to appear cracks at 50kN, damaged at 113kN. This means that the steel fiber reinforced concrete layer is on top will increase the bearing capacity to 10kN when they are damaged.

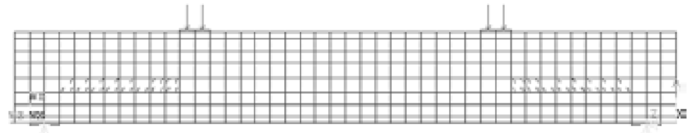
Two-layer concrete beam and three-layer concrete beam begin to appear cracks by simulating are shown in Fig. 8



a) Steel fiber concrete layer is located below, (P_{crack}=54kN)



b) Steel fiber concrete layer is located above, (P_{crack}=8kN)



c) Cracks in three-layer concrete beam, (P_{crack}=24kN)

Fig. 8 The beams started to appear cracks in ANSYS

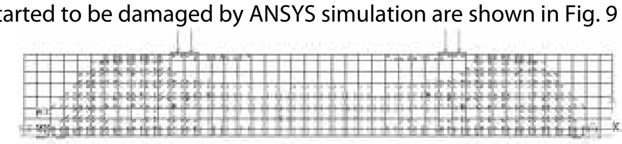
Comment:

- In Fig. 8a, and Fig. 8c, when the concrete beams began to appear cracks, the cracks appeared first at the normal concrete layer for both cases of two-layer beams with steel fiber concrete layer is on the bottom and three-layer beams. In Fig. 8b, due to the steel fiber concrete layer on top, the concrete layer on bottom of the normal concrete layer, so the beams appear quickly with cracks at the bottom of the middle of the span of the beams, meaning the steel fibers have made the steel fiber concrete layer increases the bearing capacity, reducing cracks in the beams.

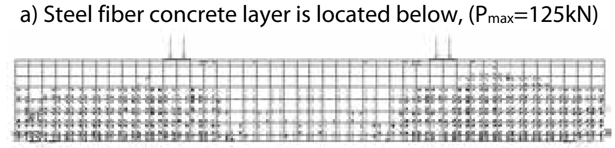
- In Fig. 8b, the lower layer is a normal concrete layer, so the cracked beams at P_{crack}=8kN, and the three-layer beams, the cracks at P_{crack}=24kN. In contrast, two-layer beams with the steel fiber concrete layer is located below, the cracks appear later and crack at P_{crack}=54kN. That is, at this stage, the two-layer beam with the steel fiber concrete layer is below work effectively in the bending beams. The three-layer beam has not yet exerted its bearing capacity because the upper layer and the lower layer are steel-fiber concrete layers, so the bearing capacity is high, but the middle layer is the normal concrete layer, so the layers have the same hardness should cracks occur occur earlier. In two-layer beams of the experiment, by visual observation combined with the crack display device, cracks appear and can be observed at later load when numerically simulated.

- In Fig. 8a, Fig. 8c, the cracks don't appear first in the tensile zone at the center of the beam span, but the crack appears at the position from the supports to the concentrated loads, these cracks are investigated at an angle of 45^0, because in this section, the shear in beams does not change values, and moment diagrams change according to the first order.

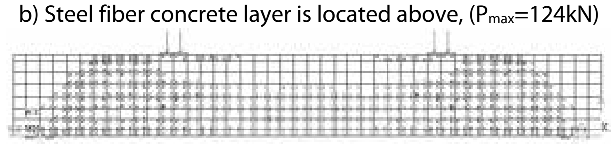
Two-layer concrete beams and three-layer concrete beams started to be damaged by ANSYS simulation are shown in Fig. 9



a) Steel fiber concrete layer is located below, (P_{max}=125kN)



b) Steel fiber concrete layer is located above, (P_{max}=124kN)



c) Three-layer beam, (P_{max}=64kN)

Fig. 9 Concrete beams started to be damaged in ANSYS

Comment:

- In Fig 9a, we see that, cracks appearing continuously and slope 45^0 from supports to loads, and the load starts to be damaged at P_{max}=25kN. Also, in Fig. 9b, the cracks develop from supports to the steel fiber concrete layer, the cracks do not develop further, while in three-layer concrete beams in Fig 9c, the cracks also develop to the steel fiber concrete layer on top and before if the beams are damaged, at the upper compression area and from between the two concentrated forces, the cracks have developed most of this compressive layer, so the beams are damaged very early at the load level of P_{max}=64kN, nearly ½ of the value of two-layer concrete beams.

Load–vertical displacement relationship at the middle of concrete beam span as shown in Fig. 10

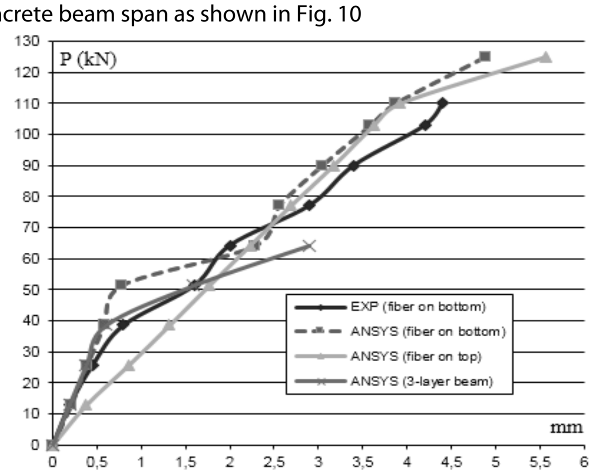


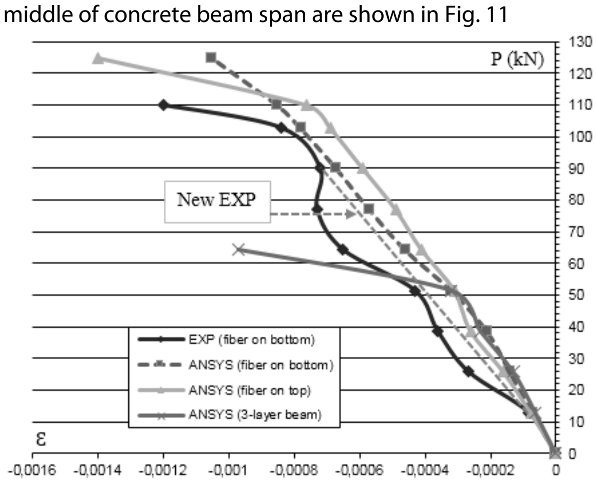
Fig. 10 Vertical displacement at the middle of the beam span

Comment:

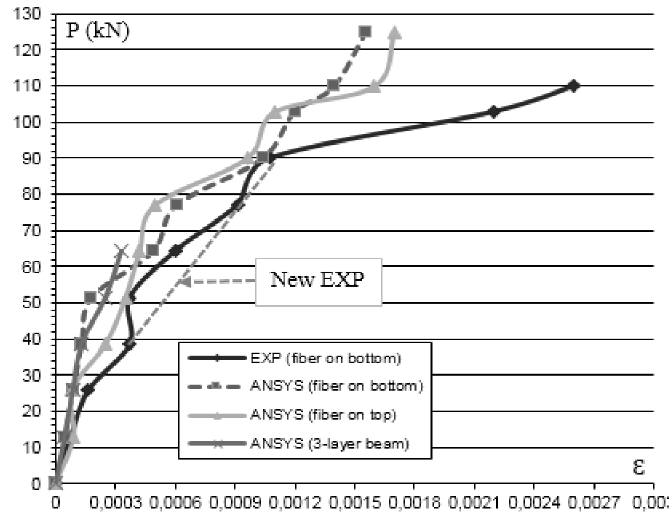
- In Fig. 10, we see that, the load is increased from 0kN to nearly 40kN, all 3 concrete beams are linear displacement, all 3 concrete beams have the same maintenance cost, however concrete beams with steel fiber layer on top which have variable values and values than other types of beams surveyed. When the load exceeds this value, the two-layer and three-layer concrete beams are nonlinear.

- However, the alignment of layers in multi-layer concrete beams will greatly affect the working of the structure. Therefore, in fact reinforcing and repairing multi-layer beams need to ensure that the layers have to link well, otherwise the components will be destroyed very soon.

Load - compressive strain and load - tensile strain relationship at the middle of concrete beam span are shown in Fig. 11



a) Load - compressive strain relationship



b) Load - tensile strain relationship

Fig. 11 Load-strain relationships of concrete beam

Comment:

- In Fig.11a, the process of testing bending beams has a change in compressive strain value with a higher amplitude than the simulation method, because in the experiment will be greatly influenced by measuring equipment, human level measured and affected by the weather etc., however, the load-compression strain relationship of the experimental method will be adjusted as line (New EXP). We see these values little change, except for the three-layer beam near to damage, when passing the 50kN load, the large change in compressive strain value.

- At the tensile strain area, the experimental line diagram will be adjusted to a line (New EXP), but the value varies. The compression strain value of the experiment is larger than that of three-layer beams (Fig.11b).

4. Conclusion

Based on the results of the study lead to the following conclusions:

1. In the process of reinforcing and repairing multi-layered concrete beams, we can use a high strength concrete layer in other areas of the concrete beams, in order to increase the bearing capacity of the beams. However, attend the connection between layers to ensure normal working for the multi-layered beam structure.

2. Experimental results and simulation of steel fiber concrete beams, showed that when adding steel fibers into concrete will significantly improve the properties of concrete such as: increasing bearing capacity, limiting cracks, etc. .

3. The load-vertical displacement relationship, the load-compression deformation relationship between two-layer concrete beams and three-layer concrete beams does not change much. However, the load-tensile strain relationship is variable.

4. With the use of ANSYS simulation software, it is possible to accurately simulate the real work of the component, so with limited funding, testing equipment or complexity in experimental research, the model ANSYS simulation is the optimal solution in research. However, the experimental results are almost 30-40% larger than simulation values due to the influence of many different impact factors.

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