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Concrete grade change in the layers of three-layer steel fibre reinforced concrete beams

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ABSTRACT

Purpose: Determine the state of stress-strain, formation and development cracks, three-layer beam diagrams of load-compression stress, load-tension stress, load-vertical displacement relationships with a change in concrete grade.

Design/methodology/approach: This paper presents the results of an ANSYS numerical simulation analysis involving stress-strain state and cracking of the steel fiber concrete layers of three-layer reinforced concrete beams with the upper and lower layers. With a cross-section of 150x300 mm, a total span of 2200 mm and an effective length of 2000 mm, the middle is a normal concrete layer. Under two-point loads, all the beam samples were tested. The research simulated three-layer concrete beams in different layers of beams with a change in concrete grade, and compared with and without the use of steel fibers in layers of concrete beams, including the nonlinearity of the material considered.

Findings: A diagram of the formation and development of cracks in three-layer concrete beams has been constructed by the study results, determining the load at which the concrete beams begin to crack, the load at which the concrete beams are damaged. In the middle of three-layer steel fiber reinforced concrete beams, load-compression stress, load-tension stress, load-vertical displacement relationships are established. Study results show that these three-layer concrete beams appear to crack earlier than in other cases in cases 2 and 3, but the beam bearing capacity is damaged at 67 kN, the earliest in case 3. And case 6 at 116 kN is the latest. The effects of case 1 and case 3 are small compared with and without the use of steel fibers in cases, while the effects of case 5 and case 6 are very high.

Research limitations/implications: The research focuses only on the change of concrete grade in the layers, but the input parameters affecting three-layer steel fiber concrete beams have not been researched, such as the number of tensile steel bars, tensile steel bar diameter, steel fiber content in concrete, thickness variation in three-layer concrete beam layers, etc.

Practical implications: Provides a result of experimental study and ANSYS numerical simulation in multi-layer steel fiber concrete beams.

Originality/value: The analysis of multi-layered steel fiber concrete beams using experimental and simulation methods shows that other parameters influencing the beams will continue to analysis the working stages of three-layer beams.

Keywords: Steel fibre concrete, Stress-strain, Crack, Material nonlinear, Multi-layer beam, Concrete grade

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ANALYSIS AND MODELLING

1. Introduction

Concrete, made of sand, aggregate, cement and water, is a composite material. Steel fiber concrete is widely used in concrete researches because it has the potential to greatly enhance some of concrete 's properties, such as making the concrete increase its load capacity, strong impact resistance, and decrease cracks, increase building life, etc. In addition, it is also possible to combine steel fiber concrete with nano to form steel fiber nano concrete. In combination with nano, studies of steel fiber concrete have shown that they significantly increase the tensile strength of steel fiber concrete as well as increase the ductility of steel fiber concrete when nano [1,2] is included.

Fiber concrete is also used in damaged concrete beams for surface repair. To form a two-layer steel-fiber reinforced concrete beam, this steel fiber concrete layer may be above or below the damaged concrete layer or use both the upper and lower layers of steel-fiber concrete to form three-layer steel fiber reinforced concrete beams, the aim of this repair is to increase the structure's long life.

The ANSYS computational simulation and experimental method for the analysis of steel fiber reinforced concrete beams was used in the study [3], with the use of steel fibers in the concrete, the concrete was made to reduce cracking, improve the structure's bearing strength, The initial design parameters such as the effect of the fiber, the effect of the diameter and the number of tensile steel bars, etc. have also been investigated in study [4] and the effect of the concrete grade on beams has not been studied in this study.

In a large number of studies, Iskhakov et al. high-strength concrete (HSC) on two-layer concrete beams is made of the compressed zone of such a beam section, and the tensile one is made of normal strength concrete (NSC). It is known that the principal disadvantage of HSCs is their low ductility. In order to resolve the problem, fibers are added to the HSC layer. It addresses the effects on structural ductility of different fiber volume ratios. An upper limit of the necessary fiber volume ratio is found based on the compatibility equation of transverse tensile concrete deformations and fiber deformations [5].

Iskhakov's study also examined the steel fiber content in the compressive region of the beam, varying the fiber content and obtaining the required ductility level. Providing sufficient ductility is necessary to design structures for seismic, wind and other dynamic loadings. It has been shown that the content of fibers for such materials, such as reinforcing steel bars for normal RC beams, is important to calculate. The research focuses on finding optimal fiber content, producing as a result the highest Poisson coefficient and higher ductility of the beam section. The fiber weight ratio is used as an option to the fiber volume ratio, as the first is a more efficient parameter for evaluating the fiber content in the concrete mixture. In the context of this study, the experimental results obtained form the basis for general knowledge relating to the formation of two-layer beams [6].

The authors then proceeded to research based on previous studies theoretical studies and tests that showed such beams to be highly efficient, carrying very large bending moments. The study aims to experimentally verify data relating to the interaction of concrete layers in two-layer beams (TLB) and to demonstrate the efficiency of the two-layer bending element from the beginning of loading to the final stages of loading, including collapse [7].

The research is a further stage of these studies, focused on testing, as in the previous stages, a continuous two-span TLB with optimal steel fiber ratio. This is the first continuous TLB (CTLB) experimental investigation. The study aims to measure the behavior of the CTLB under positive and negative bending moments respectively in the span and above the middle support [8].

Pre-stressed two-layer reinforced concrete beams, experimental study and comparison of pre-stressed single-layer and repaired two-layer reinforced concrete beams was also empirically studied by Iskhaov [9,10].

Flexure behavior, the use of periwinkle shell aggregate concrete, experimental study of multilayer beams of lightweight concrete and normal concrete, nonlinear analysis of concrete beams reinforced with SFRC layer, organic element method, are also studied in the research on double-layer beams. Words, like simulation [11-17], are also studied. Simulation methods using ANSYS software were also performed on these multi-layered beams [18-20].

The authors studied the bond strength between concrete layers in the study of three-layer beams, the finite element analysis of three-layer concrete beams with composite reinforcement, the flexural behavior of functionally graded concrete beams, the analysis of the effects of lightweight concrete on the stress-strain state in the middle layer of multi-layered reinforced concrete structures [21-24].

Through the study of the above research authors, it is shown that the change of concrete grade in the layers of three-layer concrete beams should be studied and investigated in the three-layer beam structure, and the effects of steel fibers should be considered when adding layers, a diagram for the formation and development of cracks in three-layer concrete beams needs to be constructed when the load is gradually increased from 0 kN until the beam is damaged, with the concrete layer above and the concrete layer below becoming the concrete layer of steel fiber. Load-compression stress, load-tension stress, load-vertical displacement relationships in the middle of the span of three-layer concrete beams have been constructed from the research results.

2. Materials and methods

2.1. Design model of beams

In this analysis, the beam size is 150×300×2200 mm, concrete steel fiber content, μ=2 percent; spacing of shear steel stirrups at the ends of the beam, ϕ6a100; spacing of shear steel stirrups at the middle of the beam, ϕ6a200; 2ϕ16 tensile steel bars; 2ϕ12 compressed steel bars; three layers of concrete beams of steel fiber concrete layer (SFC layer) above and steel fiber concrete layer below the normal concrete layer with a thickness of 80 mm for these two layers of steel fiber concrete, and the middle layer is normally 140 mm thick for the concrete layer (NC layer).

Model of three-layer concrete beam in design is shown in Figure 1.

2.2. Finite element model for steel fibre reinforced concrete beam in ANSYS

<u>Element types</u>

Concrete: Concrete simulation element: the SOLID65 element, which is a specialized concrete material simulation, can simulate concrete reinforcement with cracking and compression effects, the definition of nonlinear materials. With 8 buttons, this is a 3D element. In SOLID65, as a percentage, steel fiber content can be declared constant by concrete reinforcement (Fig. 2a).

Steel reinforcement: Element of steel bars: used element of beam188: is an element used to model beam reinforcement, used as the basis for Timosenko beams, consisting of 2 nodes with 6 degrees of freedom at each node (Fig. 2b).

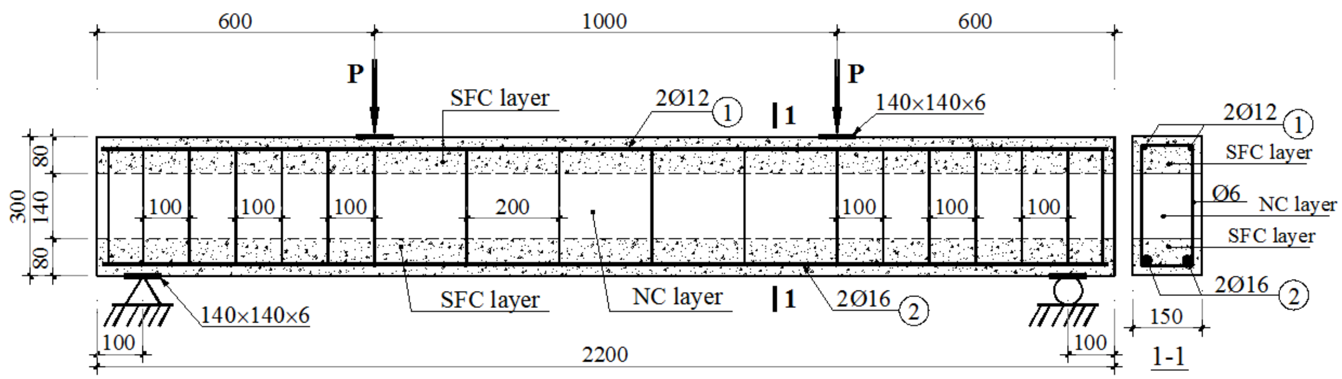


Fig. 1. Three-layer concrete beam model in design

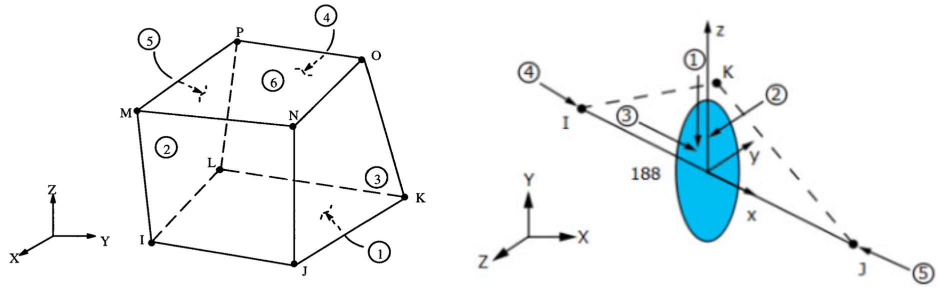


Fig. 2. Element types of beam: a) Solid65 element, b) beam188 element

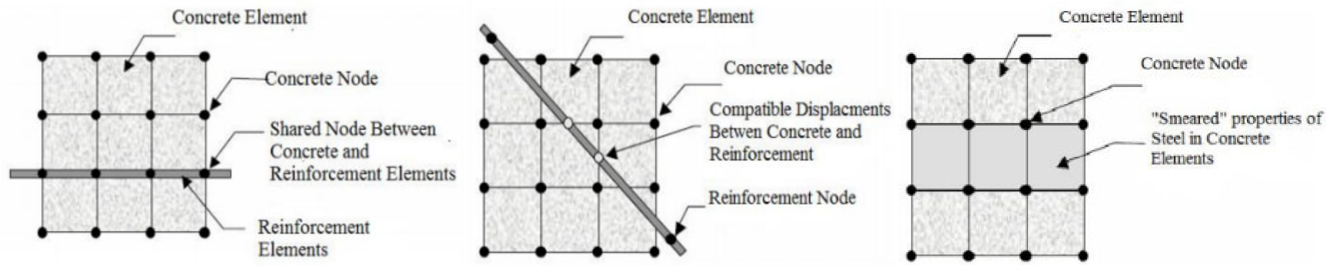


Fig. 3. Steel fiber model in concrete

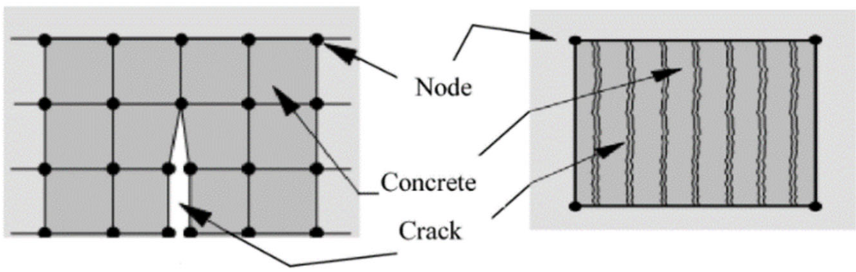


Fig. 4. Concrete cracking model

Choose the steel fiber dispersion model in concrete: Three models are used for the concrete steel fiber model: the smeared model, the embedded model and the discrete model. In this research, a smeared model should be used for steel fibers that are dispersed in concrete (Fig. 3).

Choose concrete cracking model: Currently, concrete cracks are modeled in two basic forms: a discrete model and a smeared model. In this research, without being too worried about crack shape, local stress, we are interested in the behavior relationship between load and displacement. So, choose the smeared model for cracks in concrete in this analysis (Fig. 4).

Material properties

Concrete stress-strain model through tensile and compression: we have a Hognestad model, a Todeschini model, a Kent and Park model, a Kachlakev model, etc. According to the Kachlakev model, we select the concrete model under compression based on the analysis of stress-strain models of compressive concrete presented above. This model has been predefined in ANSYS by the stress-strain model of concrete under tensile stress (Fig. 5).

Destructive standards: In this analysis, the destructive standard of Willam and Warnke is used and established in ANSYS (Fig. 6).

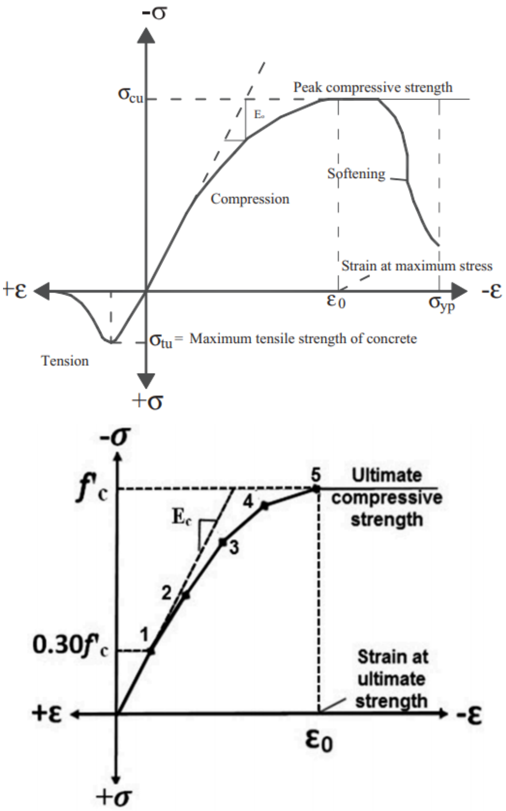


Fig. 5. Typical uniaxial compressive and tensile stress-strain curve for concrete

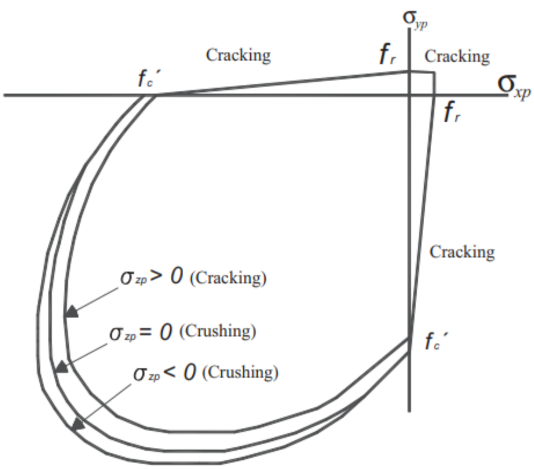


Fig. 6. Failure Surface for concrete

Meshing for models, boundary conditions and loads: meshing (VSWEEP, ALL) with mesh shapes is separated by 3D blocks available in ANSYS and optimized element size, shown in Figure 7, due to the simple beam structure.

a)

b)

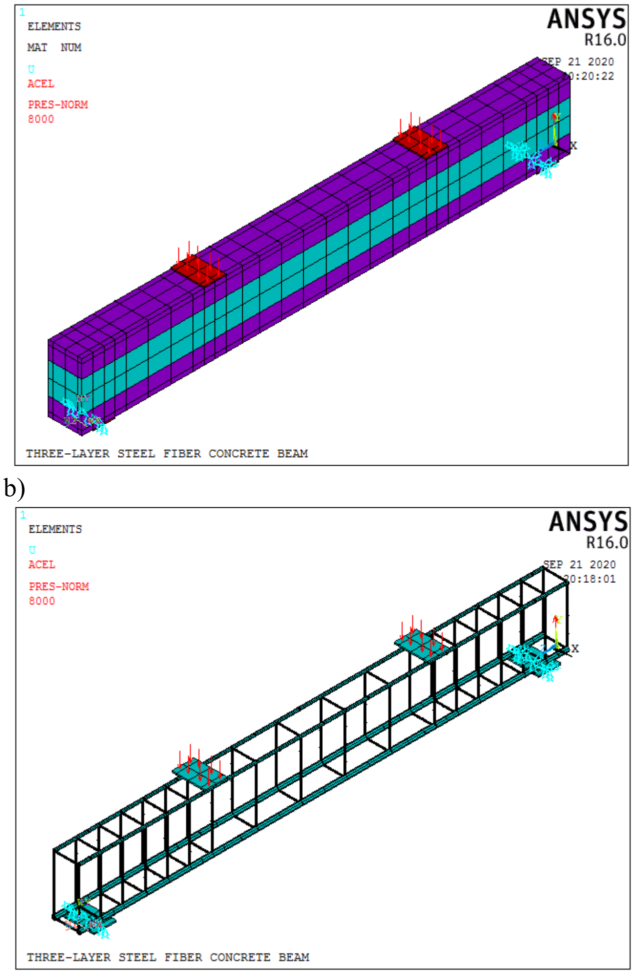


Fig. 7. Three-layer concrete beam model in ANSYS: a) model of three-layer concrete beam, b) Modeling of steel bars in concrete beams

Model input parameters: in ANSYS, in order to enter the SOLID65 concrete element input parameters, we need to enter the following 8 basic parameters:

1. The transmission coefficient of shear force when opening the crack (β_0);
2. The transmission coefficient of shear force when the cracking is closed (β_C);
3. Stress of cracking as tensile (f_r);
4. Stress Compression (f_C');
5. Weak coefficient of reduction as a result of cracking as tensile;
6. Module (E_C);
7. Coefficient of Poisson's: υ;
8. Stress-atrain relationship curve of concrete, the non-linearity of the material considered.

Model of three-layer steel fiber concrete beam in ANSYS is shown in Figure 7.

3. Results and discussion

3.1. Effect of concrete grade changes in layers of three-layer concrete beams

Table 1 presents the cases of investigating changes in concrete grades in the layers of three-layer concrete beams.

Table 1.
Concrete grade in all cases investigated

Case	Layer 1: SFC layer	Layer 2: NC layer	Layer 3: SFC layer
1	B20	B15	B20
2	B15	B20	B15
3	B15	B15	B15
4	B20	B20	B20
5	B20	B15	B15
6	B15	B20	B20

Where: The steel fiber concrete layer below is layer 1; the normal concrete layer in the middle is layer 2; the steel fiber concrete layer above is layer 3.

For three-layer concrete beams, the vertical displacement spectrum and stresses are shown in Figure 8.

Beams start to crack in cases, are shown in Figure 9.

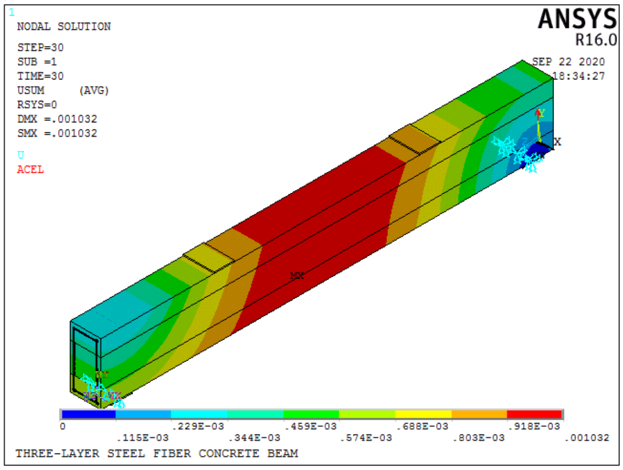
Comment: In Figure 9, in the steel fiber concrete layer below, the beams are all cracked, and they develop onto the normal concrete layer above it. The beams appear to become the earliest crack at 7 kN in case 2, case 3 and case 6, while crack occurs at 8 kN in other cases. Only in the tension area and in the middle of the two concentrated forces may cracks appear, and these are flexural cracks. Those with a steel fiber concrete layer below and a concrete grade of B15 are the three instances where the beams appear at a load of 7 KN.

Beams start to be damaged in cases, are shown in Figure 10.

Comment: In Fig. 10, beams damaged at the earliest load of 67kN in case 3 and beams damaged at the latest at 116kN in case 6. In Fig. 10a, the crack appears vertical in the middle of the two concentrated forces, which are vertical flexural cracks; and cracks appear inclined from the support to the concentrated forces with a slope of 450, which is inclined flexural shear cracks. The formation and development of cracks in the cases are consistent with the published research.

Load-compressive stress, load-tensile stress, load-vertical displacement relationships at the middle of span of concrete beam, are shown in Figure 11.

a)



b)

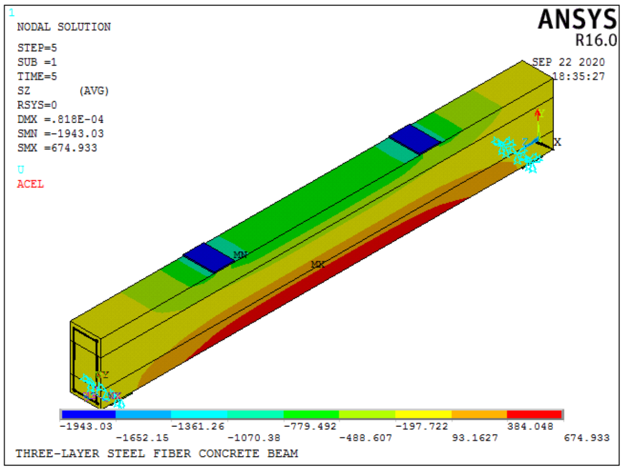


Fig. 8. Color spectrum of vertical displacement and stresses in three-layer concrete beams: a) the vertical displacement spectrum, b) the stresses spectrum

Comment:

- In the compressive stress area, case 1 has the smallest compressive stress value and case 6 has the largest compressive stress value, with a maximum difference of 3.2 MPa between these two cases at 60 kN, the stress value has a sudden change in value near the stage where the beams are damaged, then it is destroyed, and the two layers of steel fiber concrete with grade B20 and normal concrete with grade B15 are the most optimal in case 1 (Fig. 11a);

- Case 3 has the greatest value of tensile stress in the tensile stress area because all three concrete layers have concrete grade B15 (the lowest grade in the investigation cases), all three cases: case 1 and case 2 have the highest value and are nearly equal, and the difference in the tensile stress values of these cases is 1MPa compared to case 3 with a load of 60 kN (Fig. 11b);
- In Figure 11c, at the span middle of three-layer concrete beams, all 6 cases surveyed had the same vertical displacement, it can be seen from the diagram that case 6 damaged the slowest and damaged at 116 kN with a vertical displacement value of 15.2 mm.

a)

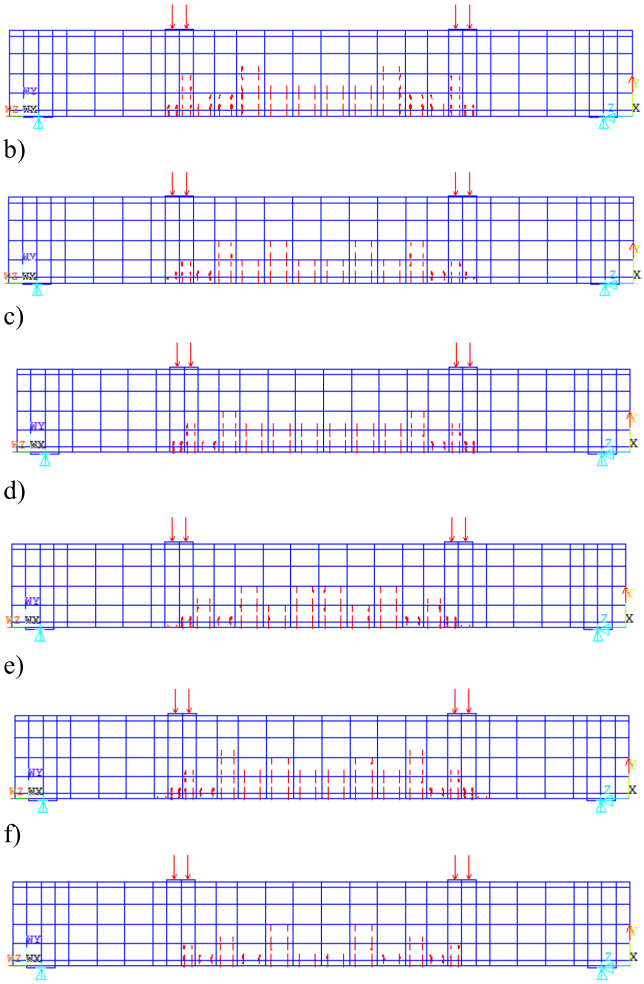


Fig. 9. Beams start to crack in cases, μ=2%: a) Case 1, P_{crack}=8 kN, b) Case 2, P_{crack}=7 kN, c) Case 3, P_{crack}=7 kN, d) Case 4, P_{crack}=8 kN, e) Case 5, P_{crack}=8 kN, f) Case 6, P_{crack}=7 kN

a)

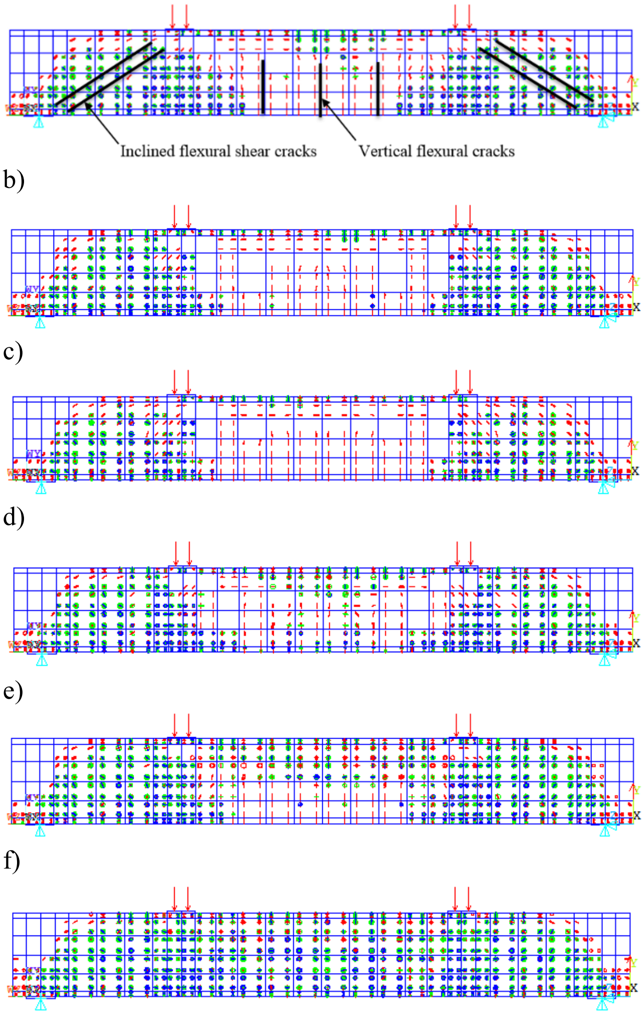


Fig. 10. Beams start to be damaged in cases, μ=2%: a) Case 1, P_{max}=94 kN, b) Case 2, P_{max}=93 kN, c) Case 3, P_{max}=67 kN, d) Case 4, P_{max}=102 kN, e) Case 5, P_{max}=93 kN, f) Case 6, P_{max}=116 kN

3.2. Effect of steel fibers when changing the grade of concrete in the layers of three-layer concrete beams

The concrete layer above and the concrete layer below are the layers of steel fiber concrete in the 6 cases surveyed above, the concrete layer in the middle is the normal concrete layer, with a volume of 2 percent of the steel fiber content in the concrete. All three concrete layers are normal concrete layers in the following case study (without using steel fibers in layers), we have the results.

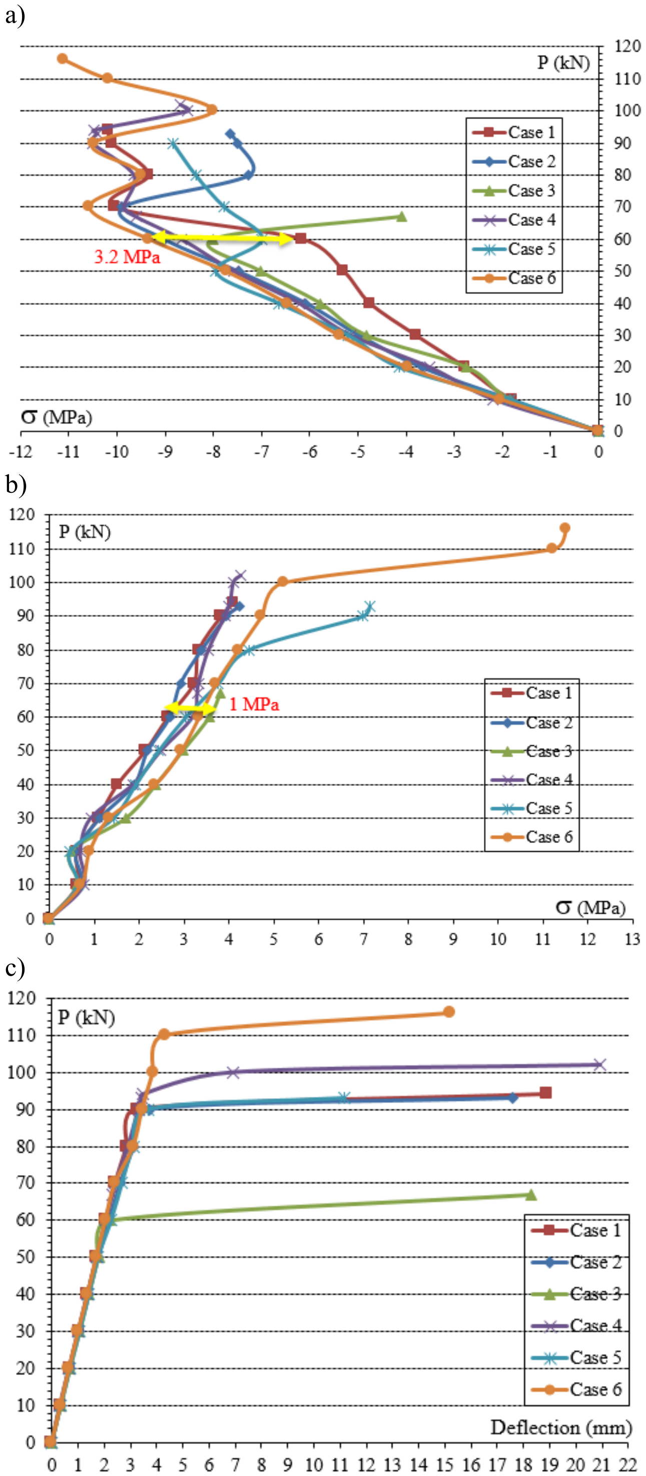


Fig. 11. Load-stress, load-vertical displacement relationships, μ=2%: a) load-compressive stress relationship, b) load-tensile stress relationship, c) Load-vertical displacement relationship

Beams start to crack in cases, are shown in Figure 12.

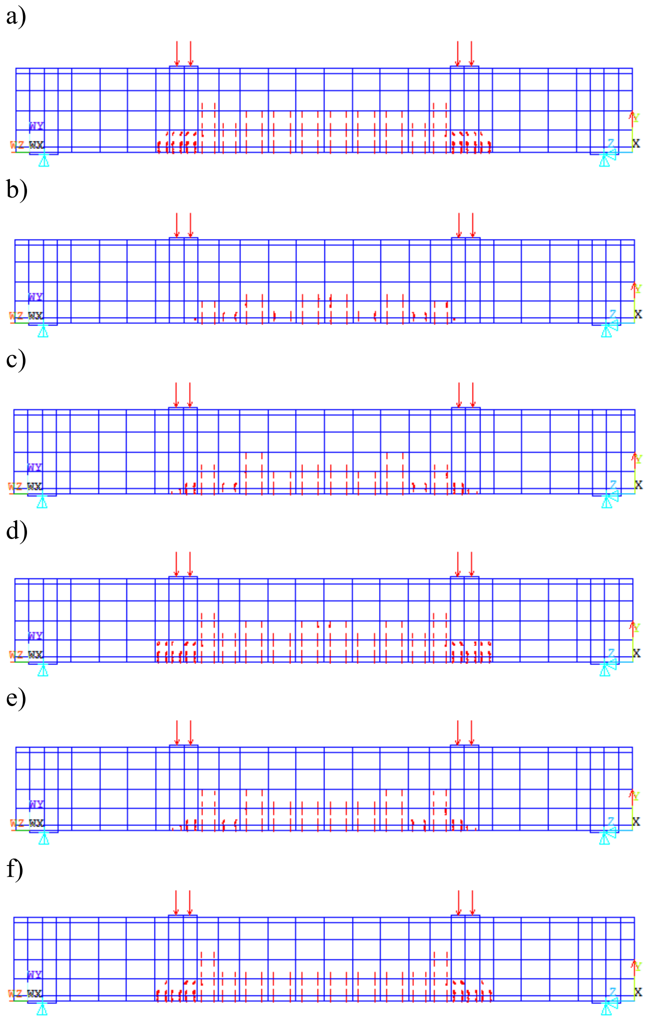


Fig. 12. Beams start to crack in cases, μ=0%: a) Case 1, P_{crack}=9 kN, b) Case 2, P_{crack}=7 kN, c) Case 3, P_{crack}=7 kN, d) Case 4, P_{crack}=9 kN, e) Case 5, P_{crack}=8 kN, f) Case 6, P_{crack}=8 kN

Comment: in Figure 12 and Figure 9, the beams start to appear cracks almost the same, the difference in the value of the cracking load between with and without the use of steel fibers in the concrete is very small, 1 kN. The crack appears only in the lower tension area between the two concentrated forces.

Beams start to be damaged in cases, are shown in Figure 13.

Comment: just in Figure 13 and Figure 10, the beam bearing capacity in case 1 and case 3 varies from 3 to 4 kN, which means that the effect on the layers of concrete beams when using steel fibers is not great. However, the beam bearing capacity is significantly reduced (reduced from 38 to 40 kN) in case 5 and case 6 with no steel fiber used in the layers, while case 2 and case 4 are reduced from 10 to 20 kN. It is also recommended to use steel fiber concrete layers in the beams in case 5 and in case 6.

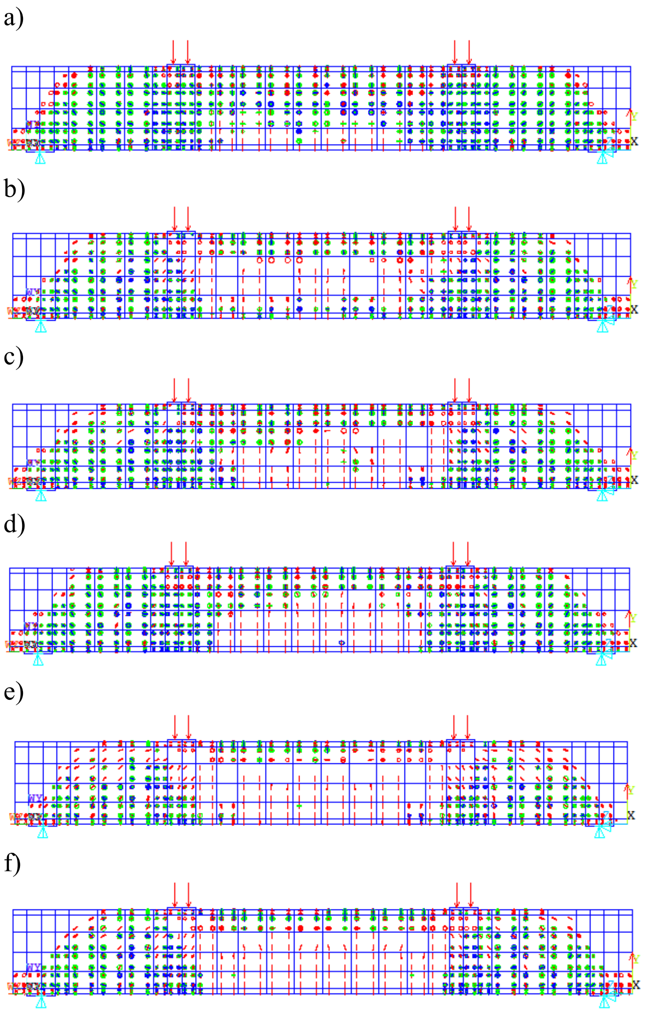


Fig. 13. Beams start to be damaged in cases, μ=0%: a) Case 1, P_{max}=98 kN, b) Case 2, P_{max}=73 kN, c) Case 3, P_{max}=70 kN, d) Case 4, P_{max}=92 kN, e) Case 5, P_{max}=55 kN, f) Case 6, P_{max}=76 kN

Load-compressive stress, load-tensile stress, load-vertical displacement relationships at the middle of span of concrete beam in case 1, with and without steel fibers in concrete, are shown in Figure 14.

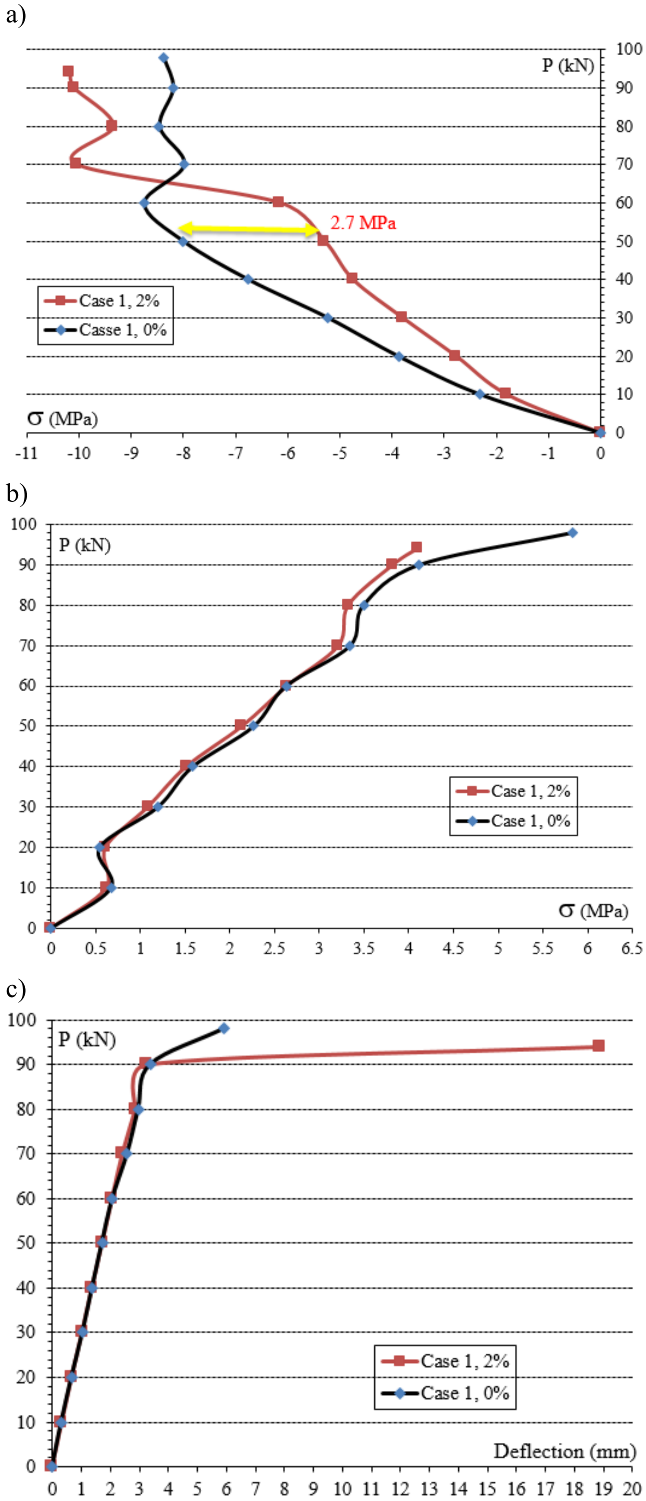


Fig. 14. Load-stress, load-vertical displacement, Case 1: a) load-compressive stress relationship, b) Load-tensile stress relationship, c) Load-vertical displacement relationship

Comment: In case 1 (Fig. 14), there is a very small difference in the tensile stress and vertical displacement at the middle of the beam span with and without the use of steel fibers in the layers, but the compressive stress varies, with a load of 50 kN, the difference is 2.7 MPa and 0 percent of the steel fiber content has a compression stress value of less than 2 percent steel fiber (Fig. 14a).

Load-compressive stress, load-tensile stress, load-vertical displacement relationships at the middle of span of concrete beam in case 2, with and without steel fibers in concrete, are shown in Figure 15.

Comment: Compressive stress, tensile stress and vertical displacement at the middle of the beam span do not significantly change in Figure 15. Just in Figure 15a, there is a change when the load reaches 60 kN, and the beam is damaged.

Load-compressive stress, load-tensile stress, load-vertical displacement relationships at the middle of span of concrete beam in case 3, with and without steel fibers in concrete, are shown in Figure 16.

Comment: In this case (Fig. 16), the values of compressive stress, tensile stress and vertical displacement at the middle of the span are considered unchanged.

Load-compressive stress, load-tensile stress, load-vertical displacement relationships at the middle of span of concrete beam in case 4, with and without steel fibers in concrete, are shown in Figure 17.

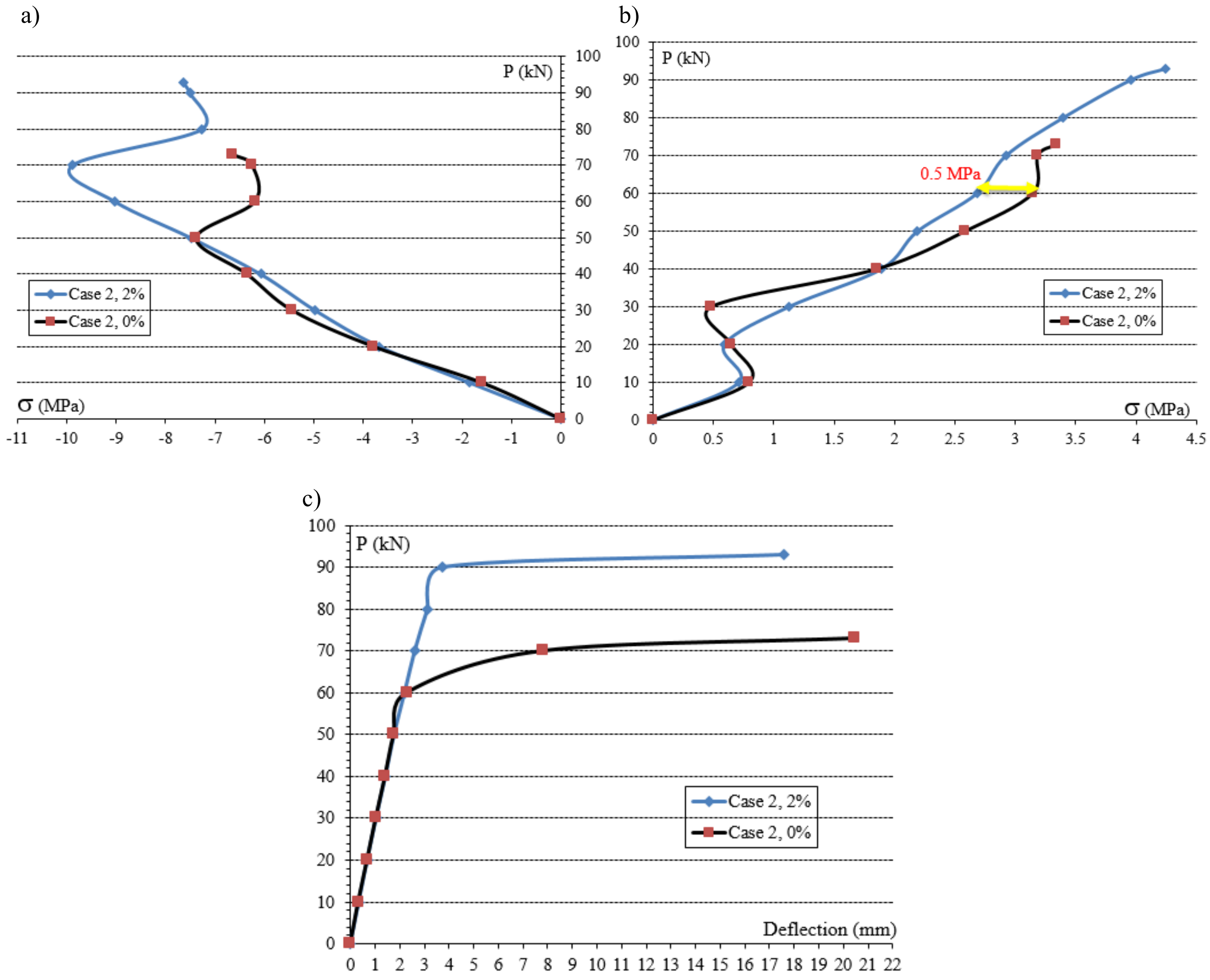


Fig. 15. Load-stress, load-vertical displacement, Case 2: a) load-compressive stress relationship, b) load-tensile stress relationship, c) load-vertical displacement relationship

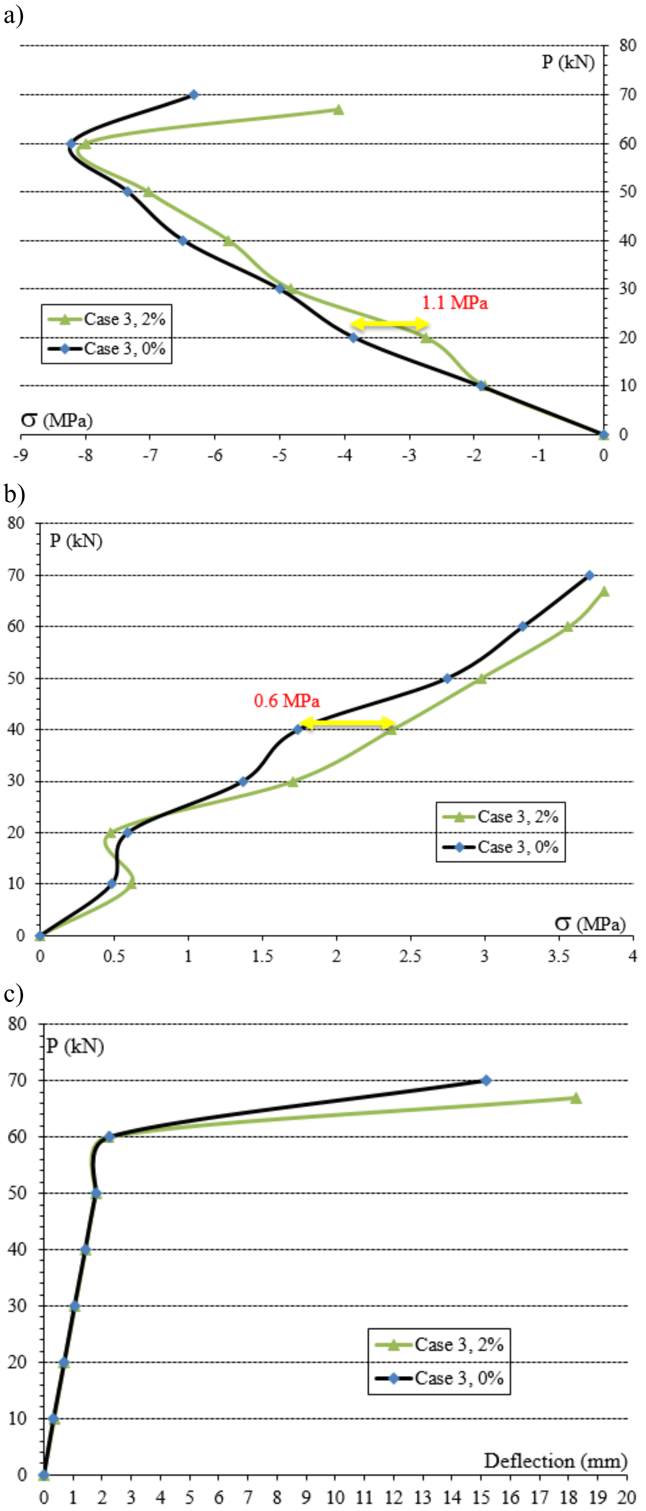


Fig. 16. Load-stress, load-vertical displacement, Case 3: a) load-compressive stress relationship, b) load-tensile stress relationship, c) load-vertical displacement relationship

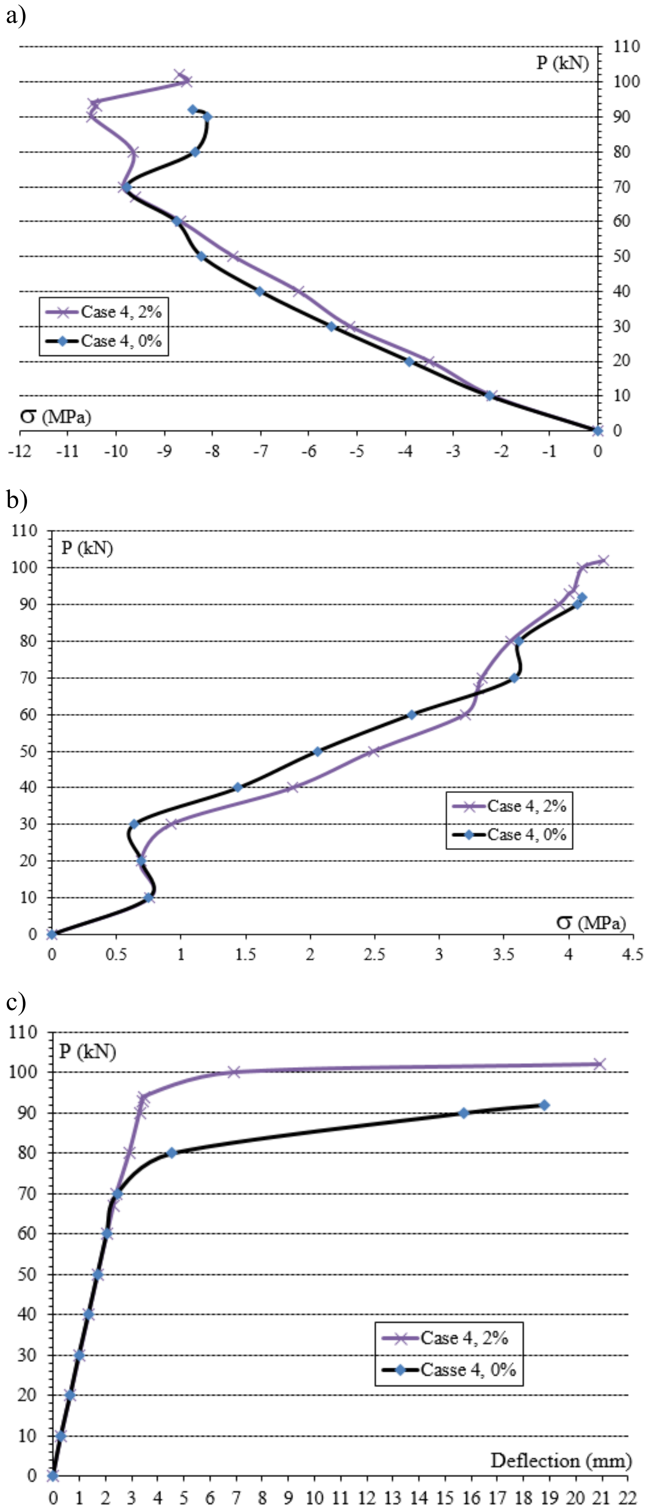


Fig. 17. Load-stress, load-vertical displacement, Case 4: a) load-compressive stress relationship, b) load-tensile stress relationship, c) load-vertical displacement relationship

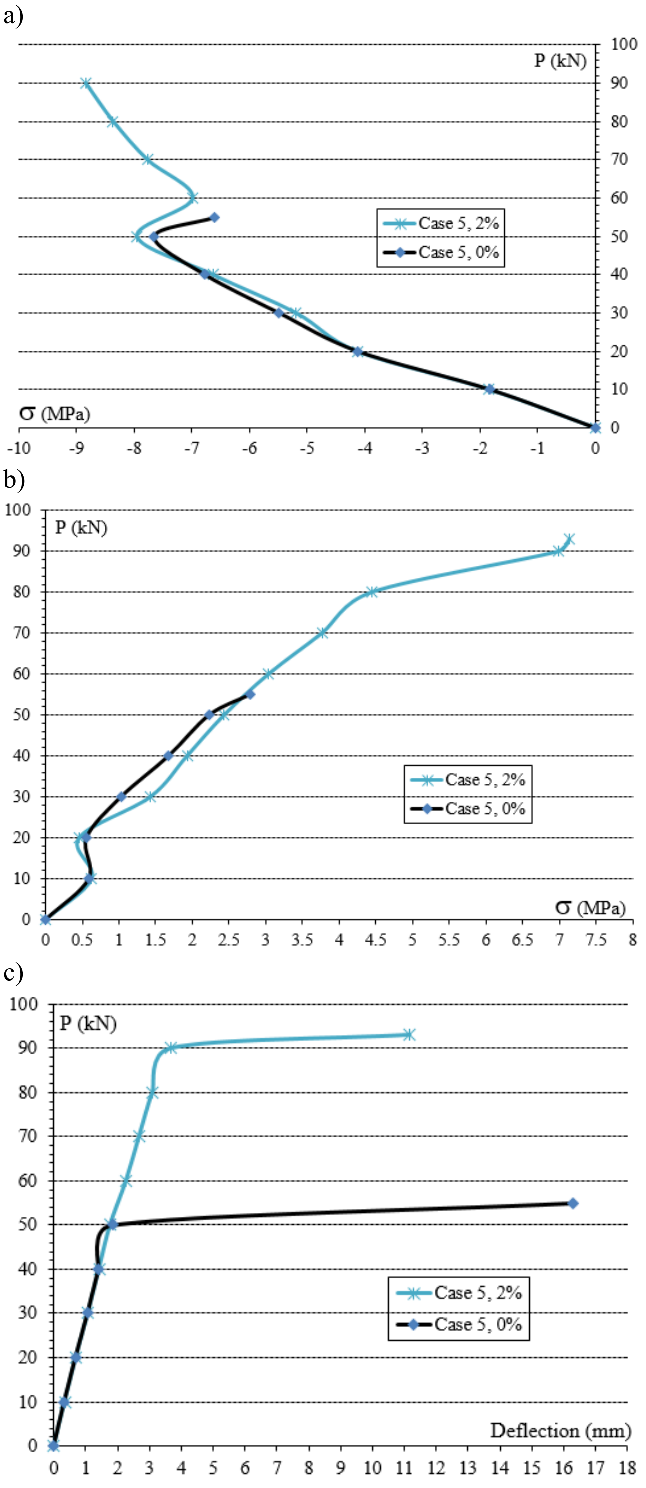


Fig. 18. Load-stress, load-vertical displacement, Case 5: a) load-compressive stress relationship, b) load-tensile stress relationship, c) load-vertical displacement relationship

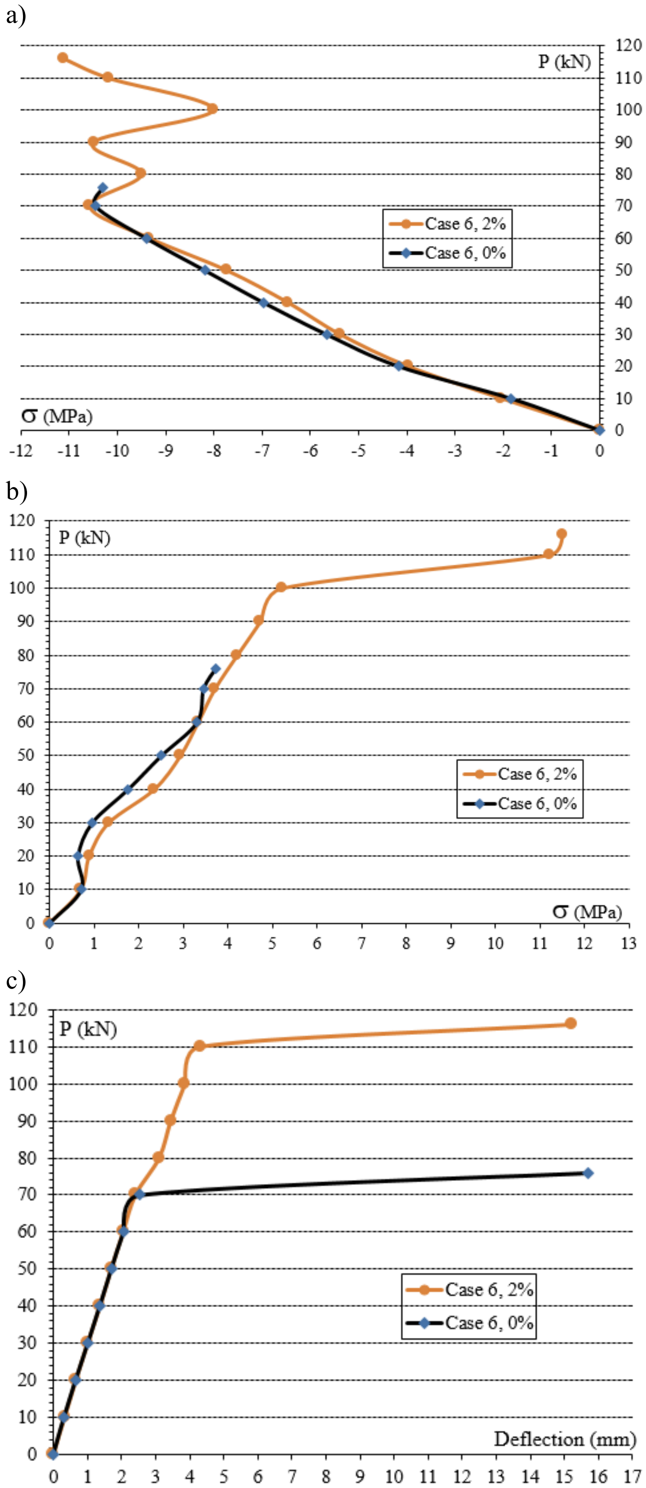


Fig. 19. Load-stress, load-vertical displacement, Case 6: a) load-compressive stress relationship, b) load-tensile stress relationship, c) load-vertical displacement relationship

Comment: Similarly, in Figure 17, case 4 the value change is small.

Load-compressive stress, load-tensile stress, load-vertical displacement relationships at the middle of span of concrete beam in case 5, with and without steel fibers in concrete, are shown in Figure 18.

Comment: Just in Figure 18, the beam bearing capacity significantly increased from 55 kN without use of steel fibers in layers to 93 kN with the use of steel fibers in layers. And the difference is very small in stress value and vertical displacement.

Load-compressive stress, load-tensile stress, load-vertical displacement relationships at the middle of span of concrete beam in case 6, with and without steel fibers in concrete, are shown in Figure 19.

Comment: In Figure 19, the beam bearing capacity increased to 40 kN when steel fiber was used. Of the studied cases, this is the most optimal case.

4. Conclusions

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

1. The analysis of concrete grade changes in the layers shows that the value of compressive stress is the smallest in case 1. Case 3 and case 6 have a higher value of tensile stress than the other cases investigated. And there is a very small value change in the vertical displacement in the middle of the span between cases.
2. Beam bearing capacity is the earliest damaged beam in case 3, while the latest damage is investigated in case 6.
3. In case 5 and case 6, the effect of steel fibers on the change in the grade of concrete in layers of three-layer concrete beams is very large; the use of steel fibers in layers of three-layer concrete beams is necessary. The effect with and without the use of steel fibers is very minimal in cases 1 and 3.

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