Hindawi
Advances in Civil Engineering
Volume 2023, Article ID 4711699, 17 pages
https://doi.org/10.1155/2023/4711699

Research Article

The Behavior of RC Beams Strengthened with Steel Fiber Concrete Layer by ANSYS Simulation

Thanh Quang Khai Lam and Thi My Dung Do

Faculty of Civil Engineering, Mien Tay Construction University, 20B Pho Co Dieu Street, Vinh Long, Vietnam

Correspondence should be addressed to Thanh Quang Khai Lam; lamthanhquangkhai@gmail.com

Received 24 August 2022; Revised 27 September 2022; Accepted 10 October 2022; Published 2 March 2023

Academic Editor: S. Mahdi S. Kolbadi

In this study, a double-layer reinforced concrete beam structure was created for the purpose of repairing reinforced concrete beams by pouring a layer of concrete on top of the reinforced concrete beam and then adding fibers to the concrete. Take into consideration the bearing capacity of these double-layer concrete beams as well as the effects that the input parameters have on the stress strain, the propagation of cracks in reinforced concrete beams. The study looks at double-layered reinforced concrete beams, with the steel fiber concrete placed on top of the one containing the normal concrete. This investigation led to the following relationships: load-compressive stress, tensile stress, and vertical displacement at the midpoint of the beam span, as well as a diagram showing how cracks spread in the beams. After getting the experimental results and comparing them with an ANSYS simulation, the diagram was used to figure out the loads at which the beams start to look cracked and the loads at which the beams are damaged. This study investigated the following six cases: how the addition of SFs affects the properties of concrete, the spacing of the stirrups at the ends of the beam should be looked into to see what effects it might have, how the number of tensile steel bars in the beam affects its properties, how the diameter of tensile steel bars affects their properties, how the diameter of compressed steel bars affects the results, and how the thickness of the SFC layer affects the properties of the material. Also, the things that were mentioned would have a big effect on how these double-layer beams in the design work.

1. Introduction

Steel fiber concrete is used quite commonly because they have increased load capacity, reduced the number of cracks, increased construction life, and have good impact resistance. A few studies on nanoconcrete with steel fibers (SFs) looked into the effects of concrete aggregation on increasing concrete tensile strength [1], the enhanced plasticity of concrete with SFs [2], and an observation design was also carried out to consider nanosilica effects on HPC strength at an early age [3], the fracture features of SFs' reinforced concrete beams [4]. A number of scholars have started referring to a series of studies on the RC beams with and without SFs; these studies have constructed a stress strain of the reinforced concrete (RC) beams with SF contents in concrete of 0%, 4%, and 8% by volume. This state determines the load of concrete beams at which the beams begin to appear cracked and the load at which they begin to be damaged [5, 6].

A multi-layer reinforced concrete structure was created for the purpose of repairing reinforced concrete structures by pouring a layer of concrete on top or at the bottom of the reinforced concrete structures and then adding fibers to the concrete, such as multilayer shells, these studies investigated experimental and simulation analyses on stress strain, vertical displacement [7, 8]. In addition, the studies either looked at how cracks spread in composite beams with SFs' reinforcement or how strong composite beams are when bent [9, 10].

Both theoretical and practical investigations into the properties of layered reinforced concrete beams have been carried out by Iskhakov et al. Both a layer of SFs and a layer of HPC were used in the beams over the period of the study; however, neither material was prioritized over the other.

These studies have shown the formation and growth of cracks in concrete beams, the stress strain of the RC beams, and the practicability of two-layer concrete beams made of normal and fibered high-strength concrete [11, 12]. After these studies, continuous experimental analysis of full-scaletwo-layer RC beams [13, 14] and experimental investigation of continuous two-layer RC beams [15] were conducted, respectively.

Many studies and FEM analyses of the bending moment of the double-layered RC beam are also interested [16]. Based on the studies of Iskhakov et al., material modeling of SFs' reinforced concrete [17–19], and in which [20] the input parameters in the design of RC beams affecting the work of SFs' reinforced concrete beams were investigated. The authors of this research [21] conducted experiments on beams made of two layers of SFs' concrete. A layer of SFs' concrete was placed both below and on top of the layer of normal concrete in these beams. After that, a simulation of the beams using dimensions of 15 by 30 by 220 centimeters had to be carried out. The investigation into the impact on beams built of three layers of concrete of the same size will continue even with these findings. These three-layer beams each feature one layer of SFs' concrete on the top, one layer of SFs' concrete on the bottom, and a normal concrete (NC) layer that is ten centimeters thick in the middle of the beam. According to the results, the beams made of two layers of SFs' concrete degraded the least quickly, but the beams made of three layers of SFs' concrete degraded quite quickly. Studies of two-layer beams, laminated beams, and three-layer beams are included here. Some case studies of these studies are the following: the influence of geometrical cross-sectional parameters, strength, and deformability of the materials used on the stress strain of three-layered RC beams [22], FEM analysis of a three-layer concrete beam with composite reinforcement [23–28].

Flexural behavior of RC beams having various layers of conventional concrete and steel fiber reinforced concrete were investigated in [29]. The behavior of concrete beams strengthened with a SFRC layer was studied by the nonlinear finite element analysis using ANSYS software [30].

According to the research that was done on the multilayer beams that were previously discussed, double-layer concrete beams that have SFs' concrete layers placed on top of the NC layer are commonly used in the repair of damaged concrete beams. However, there are still a great number of factors that need to be investigated. Within the scope of this article, the following factors should be investigated: the effects of modifying the beam's tensile steel bar number, diameter of steel bars in the tension zone, diameter of steel bars in the compression zone, the thickness of the SFs' concrete layer, and so on. It is important to take into account the effect that these factors have on the following relationships: load-compressive stress; tensile stress; vertical displacement (VD) in the middle of the beams' span; the propagation of cracks of beams, which determine the load at which the beams begin to crack; and determine the load at which the beams are damaged with beam dimensions of $15 \times 30 \times 220$ cm.

2. Materials and Methods

2.1. Design Model of Beam. The steel fiber concrete (SFC) layer that is a part of the double-layer SFs' reinforced concrete beam that is located in the compression zone indicates that it is placed on top of the NC layer. The dimensions of the beam are 15 by 30 by 220 cm. The concrete grade for the layer containing SFC is B30 (TCVN 5574-2018, Vietnamese standards), whereas the grade for the layer containing NC is B20. The thickness of the layer of SFC is 10 centimeters, the stirrups are spaced at ϕ6a200, the tensile steel bars are 2ϕ22, and the compression steel bars are 2ϕ10, and the volumetric percentage of SFs in the concrete is 2%. Concentrated stresses are applied to steel plates with dimensions of 10 by 14 by 6 centimeters.

The designs for the models of the double-layer concrete beams may be seen in Figure 1.

The strain gauge and VD measuring devices are shown in the diagram that may be seen in Figure 2.

2.2. Conducting Tests on Beams Made of Double Layer of RC. After the beams have been designed according to Section 2.1 and Figures 1 and 2, we go on to the next step, which is the creation of a 2-layer beam structure.

We construct the beam formwork and pour the concrete for the layers of the double-layer RC beams; after pouring the bottom layer, which is the NC layer, let the beams set for 24 hours before continuing to pour the SFC layer, as shown in Figure 3.

The concrete beams that were placed on top of the test pedestal are seen in Figure 4.

We set up ten tensiometers to measure strain, four devices to measure sliding strain between two layers of concrete, and three devices to measure vertical displacement, as shown in Figure 2.

We perform the beam bending test using two concentrated forces, draw the crack propagation diagram in the beam, and record both the strain values and the vertical displacement measurement value on the computer. In the process of this investigation, two beams were examined. Starting at 0 kN, the load was slowly increased until the beams were completely broken. The observations were then written down.

2.3. Modeling of a Double-Layer Concrete Beam Using Finite Element. Figure 5 shows the model of a double-layer RC beam that was constructed using ANSYS.

2.3.1. Element Types

Concrete: concrete simulation element—SOLID65 element

Steel reinforcement: used element of beam188

Choose the steel fiber model: a smeared model was used

Choose concrete cracking model: the smeared model for cracks in concrete

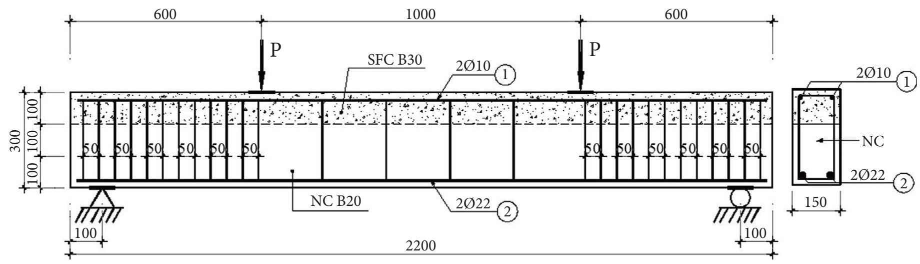


Figure 1: In the design, a double-layer concrete beam model is used.

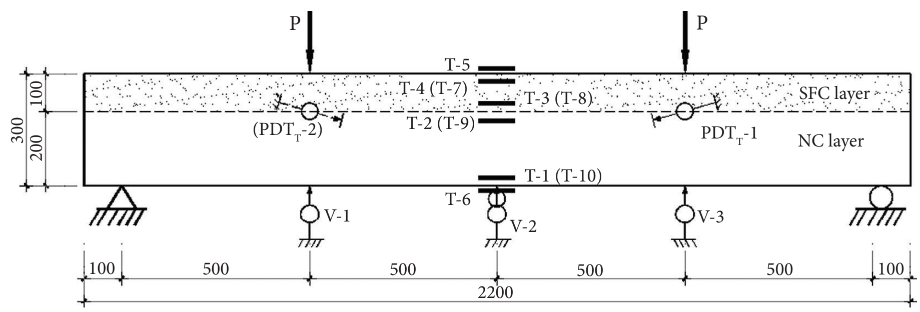


Figure 2: Double-layer beam measuring devices.

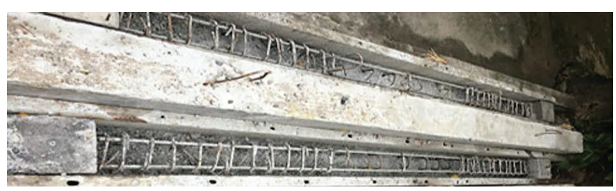
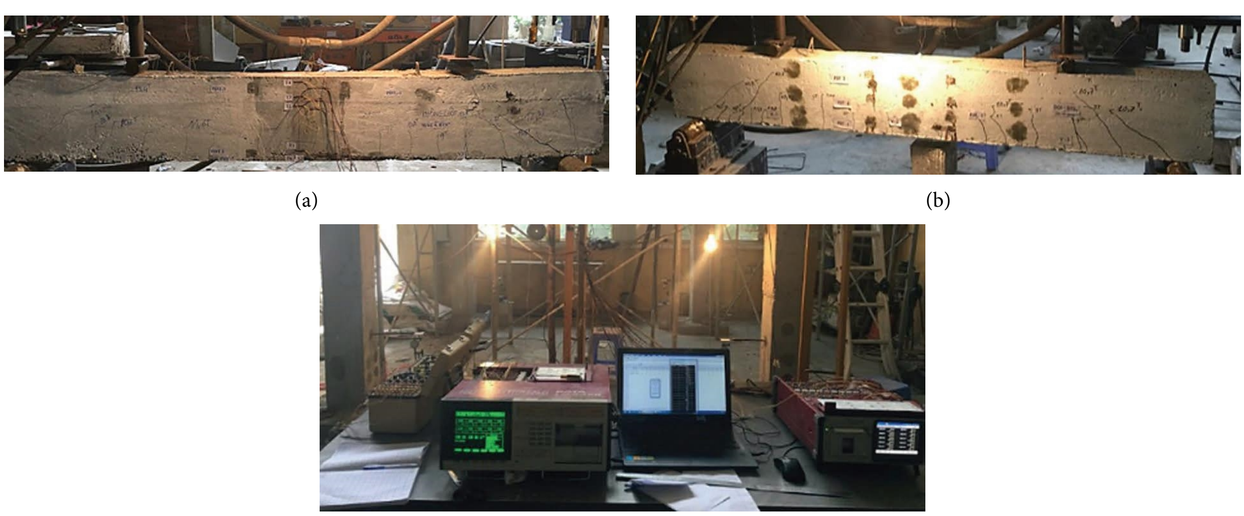


Figure 3: The design of the formwork and the beam concrete layers.



(a)

(b)

(c)

Figure 4: Test pedestal with measuring equipment and concrete beams: (a) measurement instruments for beams; (b) beams made of concrete were placed on the test pedestal; (c) connection of the measuring devices to the computer.

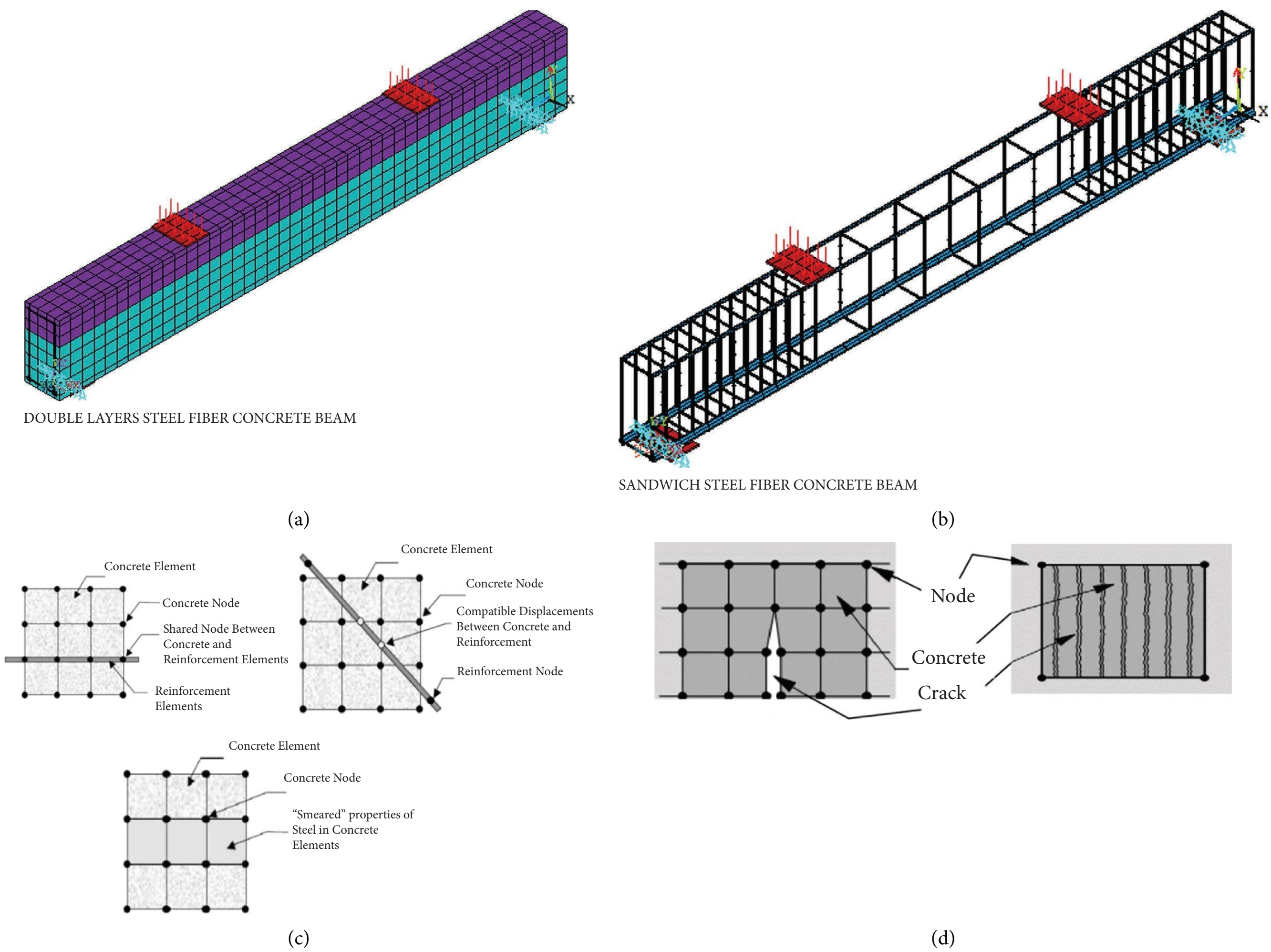
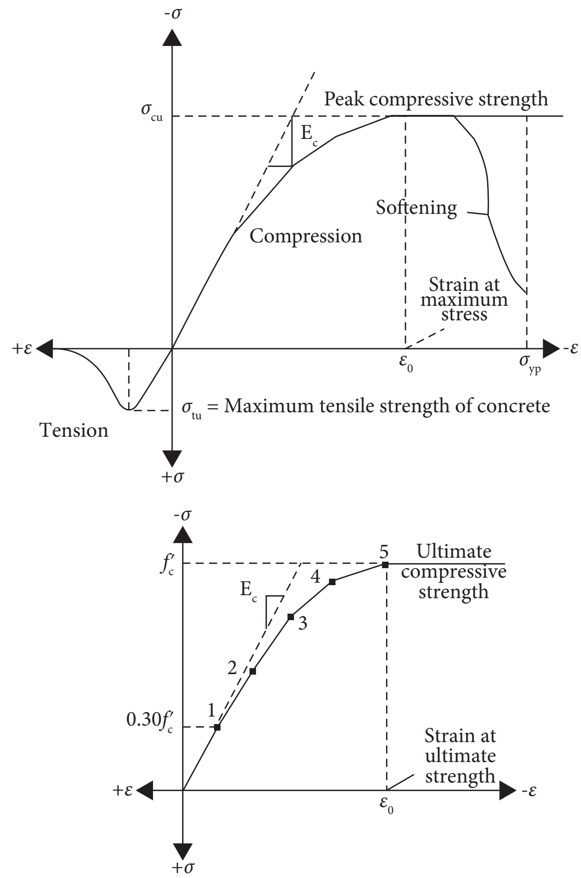


Figure 5: Continued.



(e)

Figure 5: ANSYS model of a beam constructed with two layers of concrete: (a) a model of a beam made of double-layered concrete; (b) the model of the steel bars including the boundary condition and the load; (c) steel fiber model in concrete [25]; (d) concrete cracking model [25]; (e) typical uniaxial compressive and tensile stress-strain curve for concrete [25].

Concrete stress-strain model through tensile and compression: Kachlakev model was used

Destructive standards: the destructive standard of Willam and Warnke was used

3. Results and Discussion

In Figure 6, the results of crack formation and development in tested concrete beams (EXP) are presented for each load level that was applied to the beam. These results may be observed for each individual load level.

Using ANSYS software, we were able to model the effect of crack formation and development in a concrete beam, and the results are shown in Figure 7.

Figure 8 shows the results of the simulation carried out by ANSYS, which examined the VD that occurred in the midpoint of the RC beams' span.

In Figures 6 and 7, the experimental and ANSYS simulation methods both produce cracks in beams in a way that is similar in terms of how they start and how they progress. The VD value in the midpoint of the span of the beam in Figure 8 is 2 millimeters different, which is a very small difference between two different calculation methods. This is due to the fact that the experimental method is also affected by the conditions of the measuring equipment, environment, and so on, and the test value is typically 30–50% higher than other analytical methods. As a result of this, it is possible to conduct more studies into the input factors that affect the stress strain in RC beams.

The following are the input parameters of a double-layerSFs' RC beam. These values will have an effect on the stress strain as well as the cracks in the beams.

3.1. Investigating How the Addition of SFs Affects the Properties of Concrete. In ANSYS, nonlinear materials are taken into consideration when the SFs' content in concrete is increased from 0% to 2% and 5%, the stirrup spacing at the ends of the beam is ϕ6a50, and the stirrup spacing in the middle of the beam is ϕ6a200. In addition to this, the tensile steel bars are 2ϕ22, while the compressed steel bars are 2ϕ10; the thickness of the layer made of steel fiber concrete is 10 centimeters, while the thickness of the layer made of normal concrete is 20 centimeters.

Color spectra of beam stresses and vertical displacement are shown in Figure 9.

(a)

(b)

Figure 6: Observed cracks in the concrete beams: (a) there were cracks in the concrete beam (Beam 1); (b) there were cracks in the concrete beam (Beam 2).

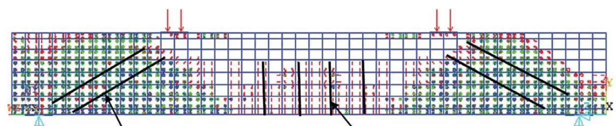


Figure 7: ANSYS simulation showing cracks in a concrete beam.

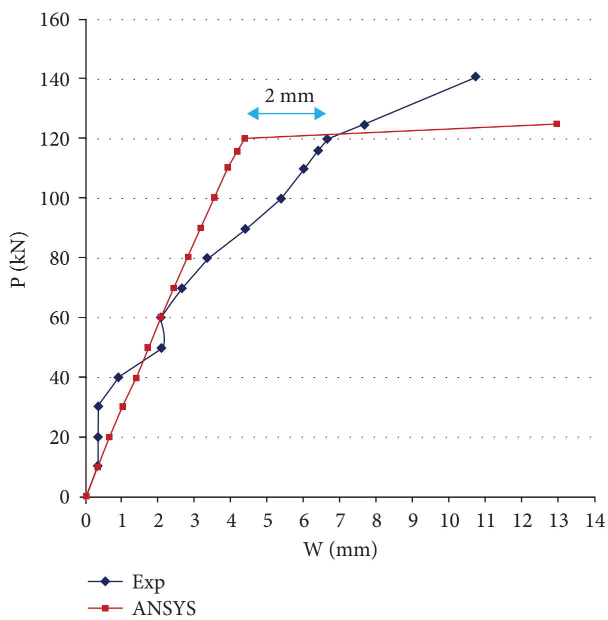


Figure 8: A vertical displacement could be seen in the middle of the span where the beam was installed.

As seen in Figure 9(a), the highest VD occurs in the midpoint of the beams' span and decreases as it reaches the supports. The color spectrum of stresses in Figure 9(b) reveals that the tensile stress is located below the beam, with its maximum value in the middle of the span; the compressive stress, on the other hand, is located at the top section of the beam, as well as the influence zone between the two concentrated forces. This shows that the ANSYS element model is suitable for the working conditions of a beam.

Figure 10 shows how beams start to crack when there is a change in the SFs' content of the concrete.

When the SFs' content in RC is zero, all of the concrete layers that make up the beam are NC layers. As a result, cracking occurs first in the area with the highest tensile stress, which is under the beam, and then spreads to the compressive zone. The load starts to break even if its value has not changed when the percentage of SFs' content in the concrete is raised by 2%. When the percentage of SFs in concrete is raised by 5%, the load starts to crack and goes from 8 kN to 9 kN. Because of this, when bending concrete beams with SFs' concrete layers in the compression zone, the effect of reducing the number of cracks and making the beam stronger has not been seen.

As can be seen in Figure 11, the percentage of SFs in the concrete starts to change, which ultimately leads to the failure of the beams.

According to what is represented in Figure 11(a), when there is no SFs' content in the concrete at all, the beam starts to fail at a load of 116 kN, and fractures occur practically

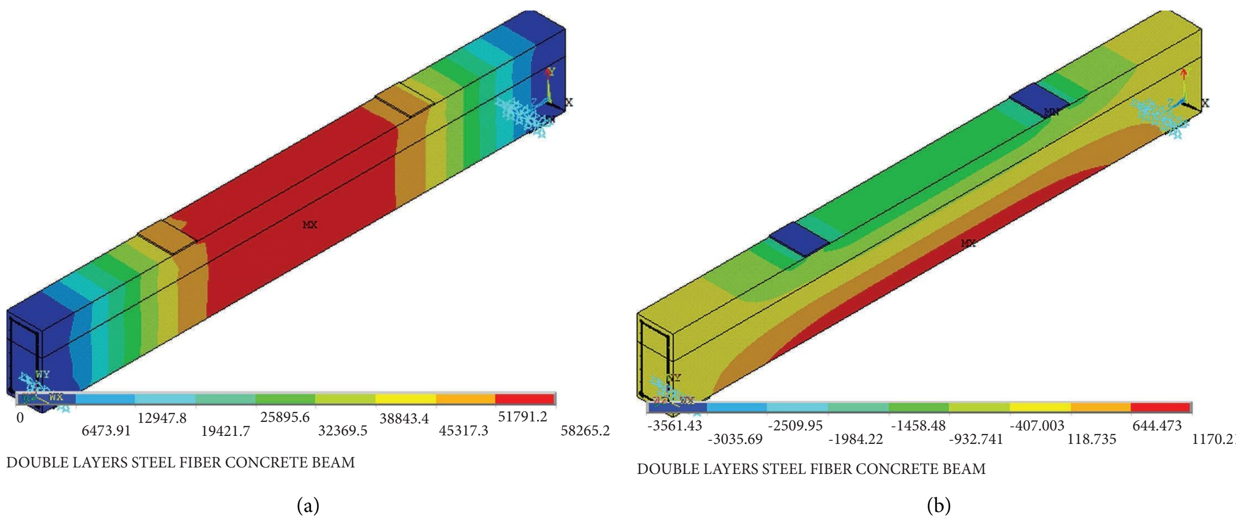


Figure 9: ANSYS's color spectrum of the beam's vertical displacement and stresses: (a) spectrum of color showing vertical displacement; (b) the spectrum of colors showing the stresses.

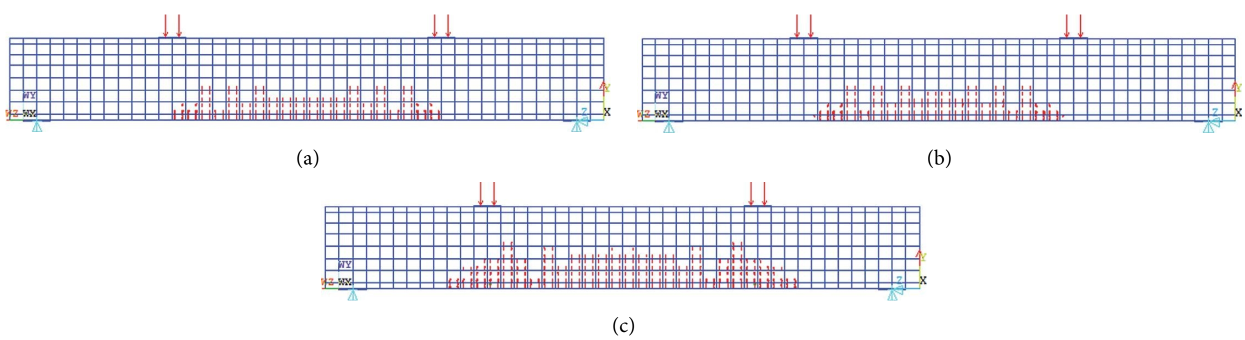


Figure 10: In ANSYS, cracks appear in the beams: (a) cracks begin to appear in the beam ($P_{crack} = 8$ kN), $\mu = 0$; (b) cracks begin to appear in the beam ($P_{crack} = 8$ kN), $\mu = 2\%$; (c) cracks begin to appear in the beam ($P_{crack} = 9$ kN), $\mu = 5\%$.

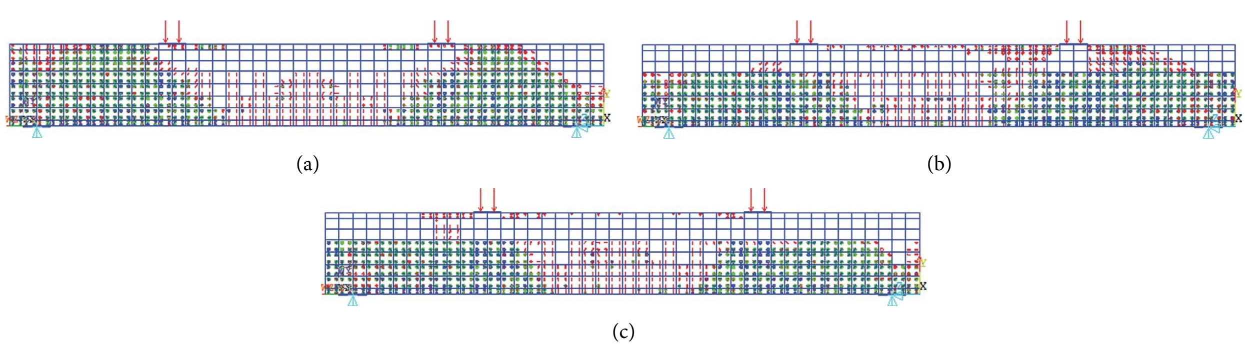


Figure 11: In ANSYS, beams quickly start to suffer from damage: (a) damage to the beam begins to appear ($P_{max} = 116$ kN), $\mu = 0$; (b) damage to the beam begins to appear ($P_{max} = 125$ kN), $\mu = 2\%$; (c) damage to the beam begins to appear ($P_{max} = 116$ kN), $\mu = 5\%$.

everywhere throughout the concrete beam. The beam damage load also increases to 125 kN as the SFs' content increases up to 2% (Figure 11(b)), and the cracks reduce in comparison to beams with 0% fiber content. However, fractures largely occurred in the NC layer, although they were not entirely fractured in the up direction. When the SFs content is increased to 5% (Figure 11(c)), the beam's bearing capacity does not keep going up compared to the concrete with 0% SFs' content. Instead, it just reduces the number of cracks that happen; large cracks have not yet formed in the top SFs concrete layer.

At the middle of the span of the RC beam, the relationships between: load and compressive stress, tensile stress, and VD are shown in Figure 12.

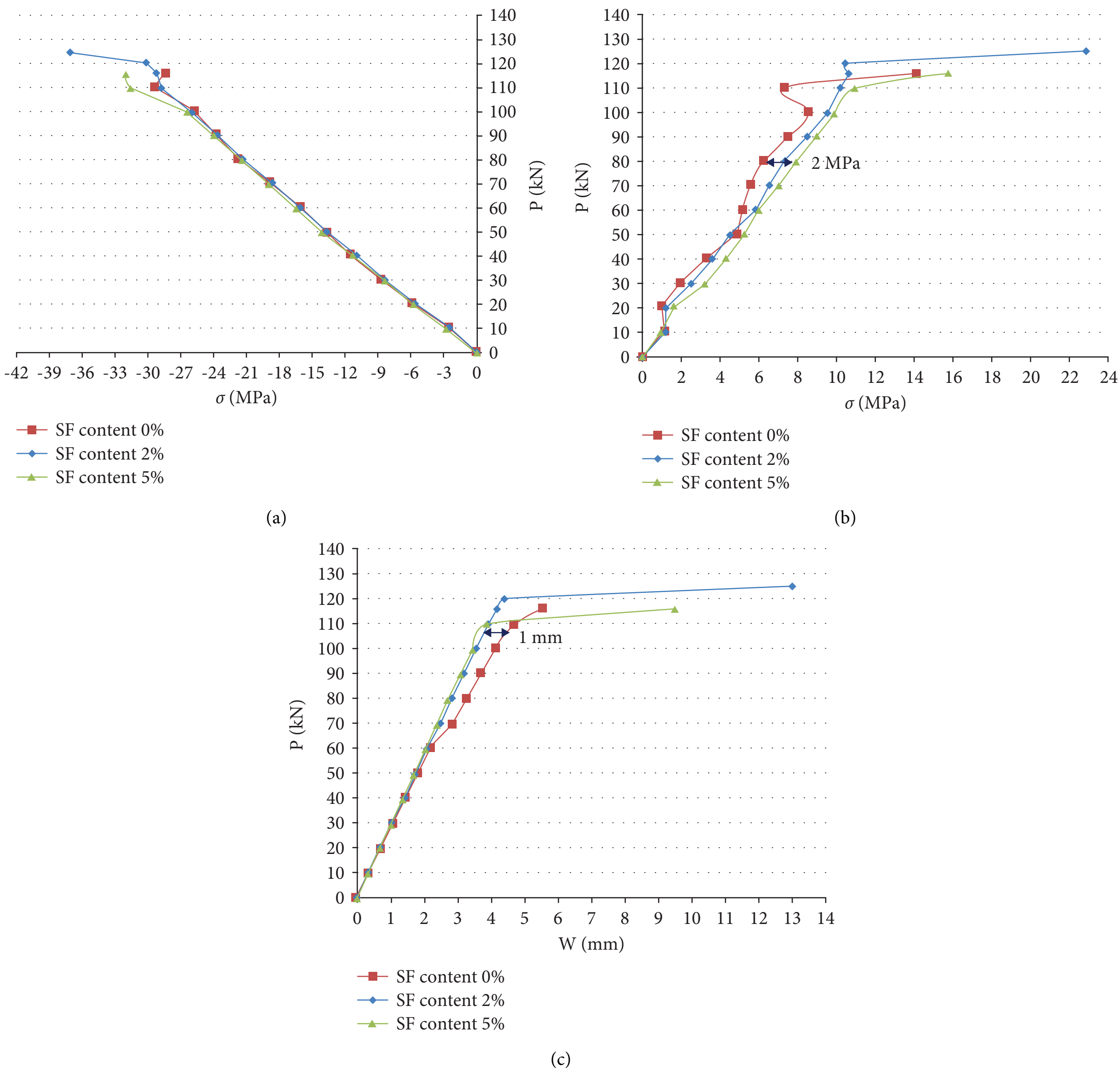


Figure 12: Relationship between load and stress, as well as between load and vertical displacement (effect of SFs): (a) relationship between load and compressive stress, (b) relationship between load and tensile stress. (c) the relationship between load and VD.

The SF content in the concrete is changed in Figure 12(a). However, this does not have any effect on the compressive stress of the beam. There is, nonetheless, a change in the tensile stress; however, this variation is around 2 MPa in magnitude (Figure 12(b)). The VD in the middle of the beam span will begin to grow when the applied load on the beam is greater than 60 kN. In addition, the vertical displacement is greater than the other fiber content by approximately one millimeter when the SFs' content in the concrete is zero. At the same load level of 116 kN, the beam is damaged by the NC layer below the SFs' content of 0% and 5% when the SFs' content in the concrete is too high. This causes the SFC layer to have a high strength, which in turn results in the high strength of the SFC layer. The percentage of SFs that can be included in concrete ranges from 0% to 4%.

3.2. The Spacing of the Stirrups at the Ends of the Beam Should Be Looked into to See What Effects It Might Have. A beam with a SF content in the concrete of 2%, stirrup spacing at beam ends modified from ϕ6a50 to ϕ6a100, stirrups spaced at ϕ6a200 in the middle of span, tensile steel bars are 2ϕ22, and compression steel bars are 2ϕ10. The use of nonlinear materials in ANSYS's numerical simulation analysis reveals that the thickness of the SFC layer is $H = 10$ cm, whereas the thickness of the NC layer is 20 cm. This information is presented in Figure 13.

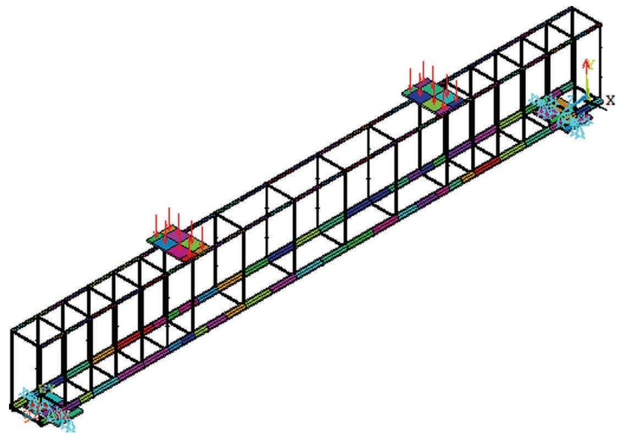


Figure 13: The distance between the stirrups at the ends of the beam has been increased to 100 millimeters.

When the distance between the stirrups at the ends of the beam is increased to 100 millimeters, as shown in Figure 14, beams will begin to crack and will be destroyed.

Increasing the stirrup spacing at the ends of the beam to 50 millimeters causes the beam to begin cracking at 8 kN in Figure 10(b), increasing the stirrup spacing to 100 millimeters causes the beam to crack but does not affect the load level in Figure 14(a), the beam begins to deteriorate at 125 kN in Figure 14(a), and the beam begins to deteriorate at 125 kN in Figure 10(b) (Figures 11(b) and 14(b)). On the other hand, there are less than fifty millimeters worth of fractures in the beam that has stirrup spacing of one hundred millimeters. In none of these beams did cracks show up in the layer of SFC that was being used.

Within the middle of the span of a SFC beam, Figure 15 shows the load-compressive stress, tensile stress, and VD relationships.

When compared to stirrup spacing of 50 mm, the results of Figure 15 show that increasing the stirrup spacing at the ends of the beam from ϕ6a50 to ϕ6a100 results in a compressive stress that is greater than 1.5 MPa (Figure 15(a)) and a tensile stress that is less than 1.5 MPa (Figure 15(b)). As a result of this, it is not recommended to install an excessive number of bars at the ends of beams. There is also no influence from the VD that occurs in the midpoint of the beams' span (Figure 15(c)). Based on the results of this study, the best distance between stirrups is 100 millimeters, and the design ϕ6a100 is used to study a number of other parameters in double-layer RC beams.

3.3. Conducting Research on How the Number of Tensile Steel Bars in the Beam Affects Its Properties. Beam with a 2% SFs' content in concrete, stirrup spacing at the ends of the beam is ϕ6a100, stirrup spacing in the middle of span is ϕ6a200, tensile steel bars are changed from 2ϕ22 to 3ϕ22, compressed steel bars are 2ϕ10, SFC layer thickness is $H = 10$ cm, NC layer thickness is 20 cm, and nonlinear materials are considered in the ANSYS numerical simulation analysis. This information is presented in Figure 16.

As shown in Figure 17, when the number of tensile steel bars is reduced or increased, the beams begin to crack and sustain damage.

The beam begins to fracture when the number of tensile steel bars in the beam is raised to 3ϕ22, and it starts to be damaged later on. When the number of tensile steel bars in the beam is 2ϕ22, the beam begins to crack at 8 kN, which increased to 1 kN later, and when the beam began to be damaged, it was 125 kN and 135 kN for the 3ϕ22 beam, an increase of 10 kN. When the number of tensile steel bars in the beam is 3ϕ22, the beam begins to crack at 135 k The crack gets smaller as the number of tensile steel bars in the beam gets higher; in Figures 14 and 17, the beams only begin to crack in the NC layer of the beam without developing cracks in the SFC layer. This is because the SFC layer is stronger than the NC layer.

Figure 18 shows the load-compressive stress, tensile stress, and VD relationships in the midpoint of the span of a SFC beam.

The compressive stress between 2ϕ22 and 3ϕ22 does not change much when the load is raised from 0 to 60 kN in the zone of compressive stress (Figure 18(a)). However, when this 60 kN load is reached, the difference is 1.5 MPa. At a load of 110 kN, the difference in stress in the tensile zone is equal to 4 megapascals (MPa). This difference is larger when the applied load is increased (Figure 18(b)). The difference in VD is growing; the value of the difference in VD is 1.1 mm when the force is set at 120 kN (Figure 18(c)). Because of this, the fact that there are more steel bars in the tensile zone shows that these elements work to lower the tensile stress.

3.4. Conducting Research on How the Diameter of Tensile Steel Bars Affects Their Properties. The stirrup spacing is ϕ6a100 at both ends of the beam, and it is ϕ6a200 in the middle of the beam. When nonlinear materials are included in the ANSYS numerical simulation analysis, the tensile steel bars are changed to 2ϕ18 and 2ϕ28, the compression steel bars are changed to 2ϕ10, the thickness of the SFC layer is $H = 10$ cm, and the thickness of the NC layer is 20 cm.

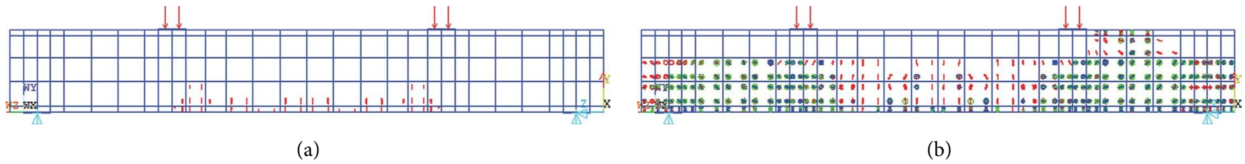


FIGURE 14: When the stirrup spacings are modified, cracks begin to appear in the beams, and the beams suffer damage: (a) cracks begin to appear in the beam ($P_{crack} = 8$ kN), ϕ6a100; (b) damage to the beam begins to appear ($P_{max} = 125$ kN), ϕ6a100.

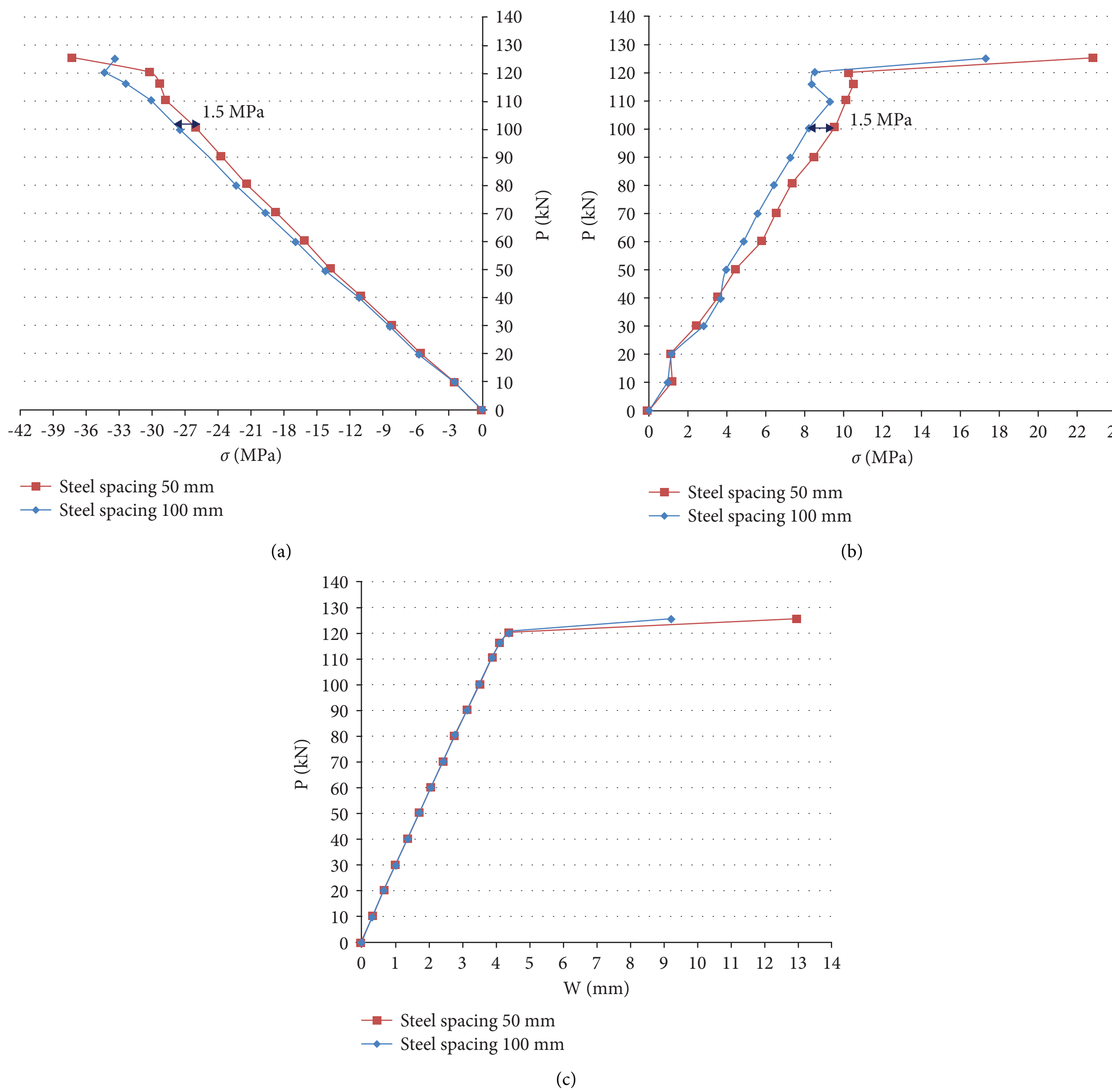


FIGURE 15: Relationship between load and stress, as well as between load and vertical displacement (effect of stirrups): (a) relationship between load and compressive stress, (b) relationship between load and tensile stress. (c) the relationship between load and VD.

Beams will begin to crack and get damaged if there is a change in the diameter of the tensile steel bars, as shown in Figure 19.

In Figures 14(a), 19(a), and 19(b), cracks form first in the NC layer, and the value of the cracking load does not vary much when there is not a significant change in the diameter

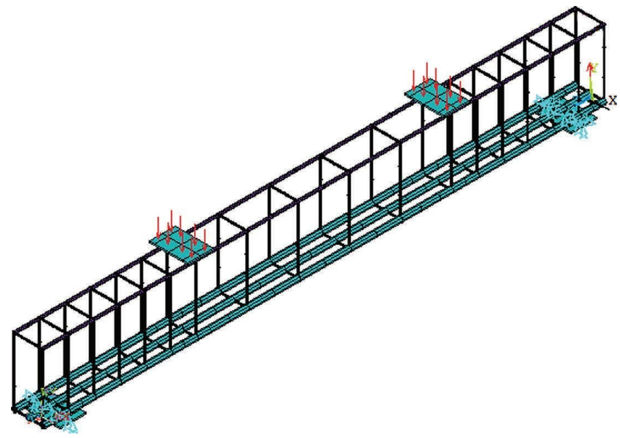
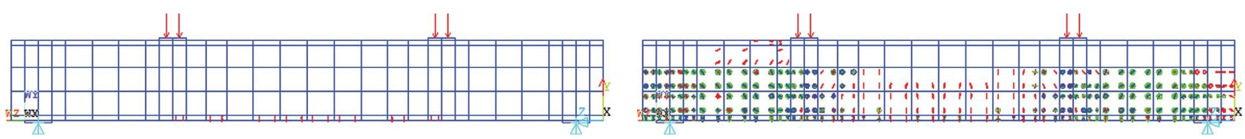
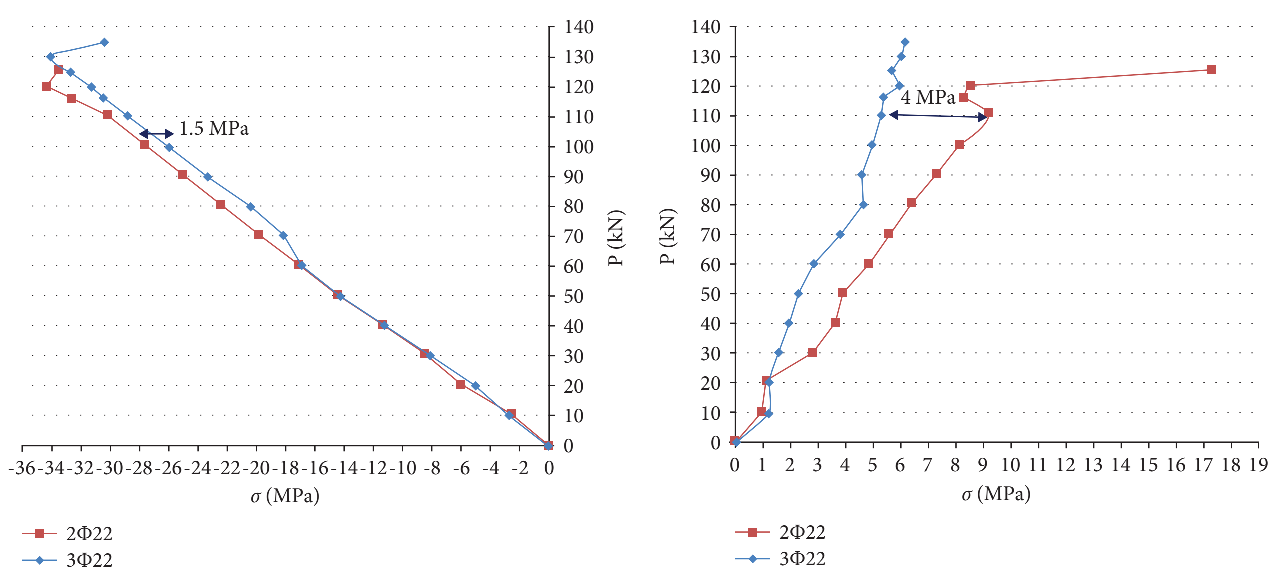


Figure 16: Beam that has had the number of tensile steel bars dropped to 3ϕ22.



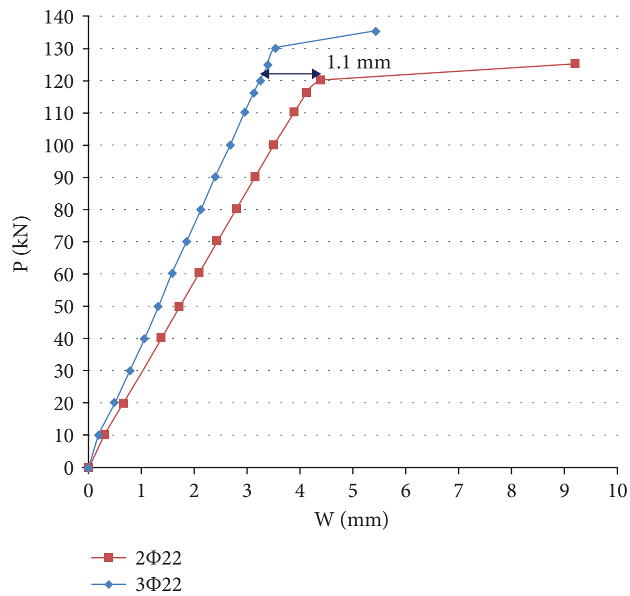
(a) (b)

Figure 17: When the number of tensile steel bars was increased, the beams began to break and suffer damage as a result: (a) cracks begin to appear in the beam ($P_{\mathrm{crack}} = 9$ kN), 3ϕ22; (b) damage to the beam begins to appear ($P_{\max} = 135$ kN), 3ϕ22.



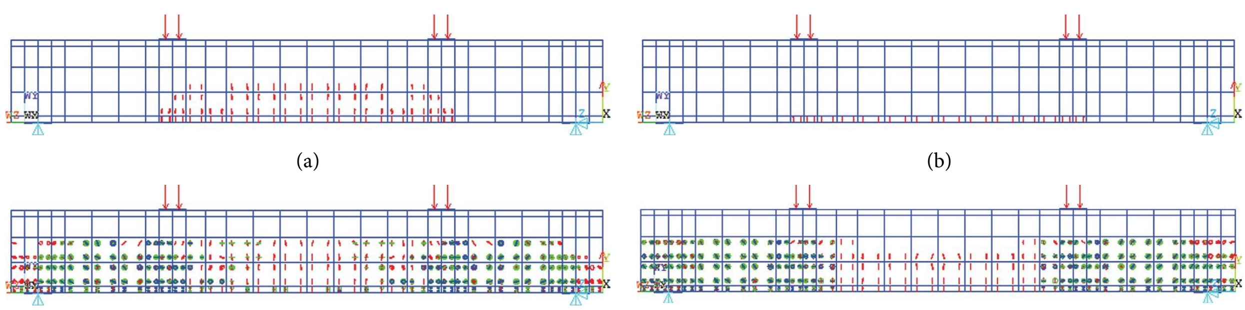
(a) (b)

Figure 18: Continued.



(c)

Figure 18: Relationship between load and stress, as well as between load and vertical displacement (effect of the number of tensile steel bars): (a) relationship between load and compressive stress, (b) relationship between load and tensile stress. (c) the relationship between load and VD.



(a) (b) (c) (d)

Figure 19: Because of a change in the diameter of the tensile steel bars, beams have begun to crack and have been damaged: (a) cracks begin to appear in the beam ($P_{crack} = 8$ kN), 2ϕ18; (b) cracks begin to appear in the beam ($P_{crack} = 10$ kN), 2ϕ28; (c) beam beginning to show signs of damage (Pmax = 90 kN), 2ϕ18; (d) beam beginning to show signs of damage (Pmax = 130 kN), 2ϕ28.

of the tensile steel bars. Beam 2ϕ18 has a limit of 90 kN, beam 2ϕ22 has a limit of 125 kN, and beam 2ϕ28 has a limit of 130 kN. However, the limit of damaged beams varies (Figures 14(b), 19(c), and 19(d)). But when the beams are broken, only the NC layer cracks and not the SFC layer that is on top of it.

In the midpoint of the span of a SFC beam, Figure 20 shows the load-compressive stress, tensile stress, and VD relationships.

Although there is a difference in tensile stress of 3.2 MPa between 2ϕ18 and 2ϕ28, the stress in the compression zone does not vary much when the diameter of the tensile steel bars is modified (Figure 20(a)). When the diameter of the tensile steel bars is modified, however, the tensile stress dramatically rises (Figure 20(b)). The difference in tensile stress between 2ϕ22 and 2ϕ28 is 3.2 MPa, and the difference in tensile stress between 2ϕ18 and 2ϕ22 is 5.3 MPa. As a direct result of this, when the diameter of the tensile steel bars is made bigger, the stress works better.

3.5. Conducting Research on How the Diameter of Compressed Steel Bars Affects the Results. Taking into consideration nonlinear materials in ANSYS numerical simulation analysis, the beam with a SF content in concrete of 2%, stirrups spacing at the ends of the beam is ϕ6a100, stirrups spacing in the middle of the beam is ϕ6a200, tensile steel bars are 2ϕ22, compressed steel bars modified from 2ϕ10 to 2ϕ16, the thickness of the SFC layer is $H = 10$ cm, and the thickness of the NC layer is 20 cm.

As shown in Figure 21, as the diameter of the compressed steel bars varies, cracking and damage to the beams begin to occur.

When the diameter of the compressed steel bars is increased in Figures 14 and 21, the bearing capacity of the

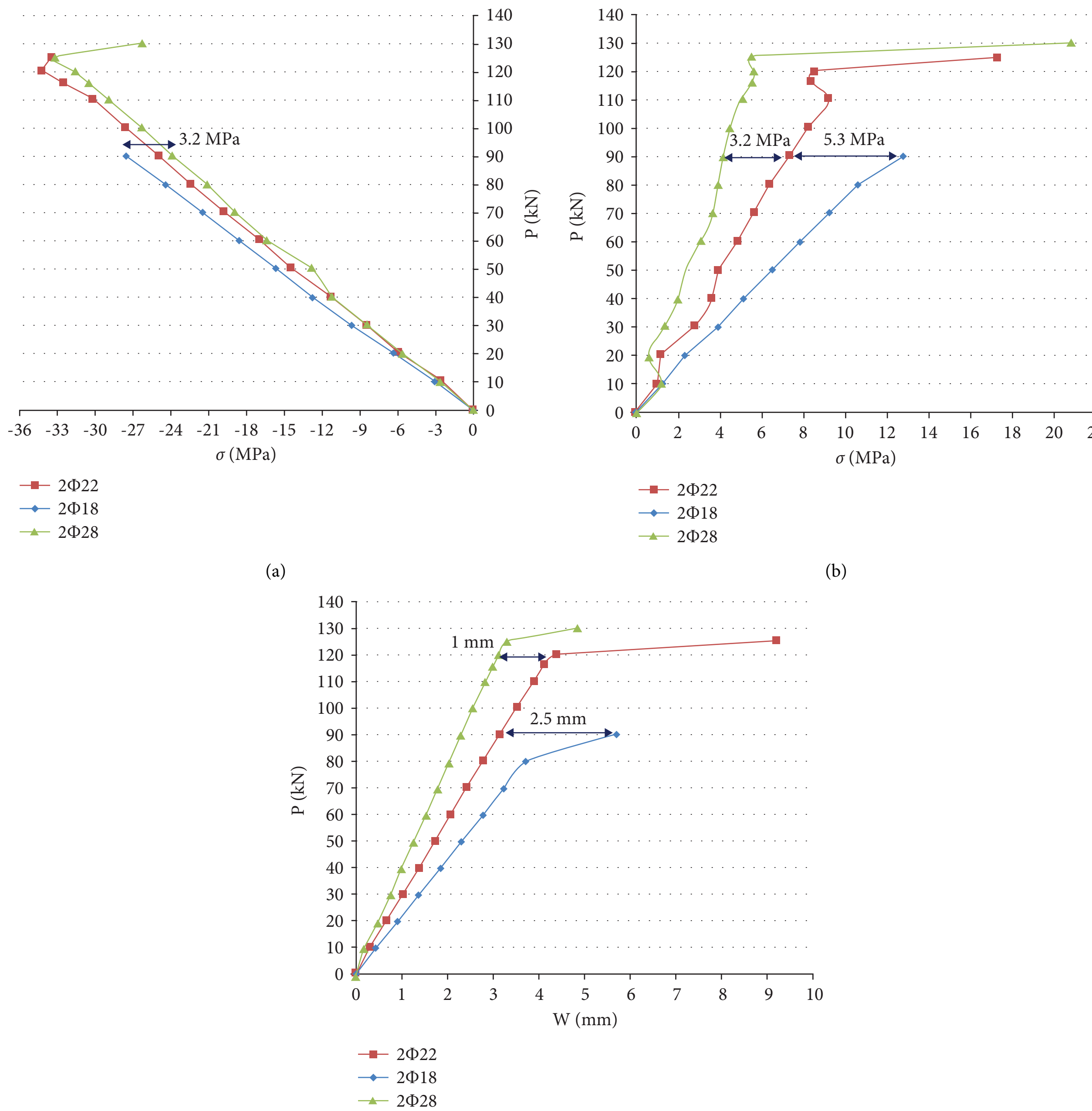


Figure 20: Relationship between load and stress, as well as between load and vertical displacement (effect of the diameter of tensile steel bars): (a) relationship between load and compressive stress, (b) relationship between load and tensile stress. (c) the relationship between load and VD.

beam also increases. Furthermore, when the load is increased from 2ϕ10 to 2ϕ16, the beam begins to crack at 8 kN to 9 kN and begins to damage at 125 kN to 131 kN. The layer of SFC that is located above the one being worked on is still in its early stages.

The relationships between load and compressive stress, tensile stress, and VD are shown in Figure 22 for a SFC beam in the middle of the span of the beam.

When the diameter of the compressed steel bars in Figure 22 is modified, there is a smaller change in the compressive stress and VD. However, there is a modification in the tensile stress. However, the difference in tensile stress is relatively small, having a value of 0.8 MPa. Because of this, when the diameter of the compressed steel bars in a bending beam is changed, it is less likely to change the amount of stress and the vertical movement of the beam.

3.6. Conducting Research on How the Thickness of the SFC Layer Affects the Properties of the Material. The beam with 2% SFs' content in concrete, stirrup spacing of ϕ6a100 at the ends and ϕ6a200 in the middle, 2ϕ22 tensile steel bars and 2ϕ10 compressed steel bars, SFC layer thickness of $H = 10$ cm

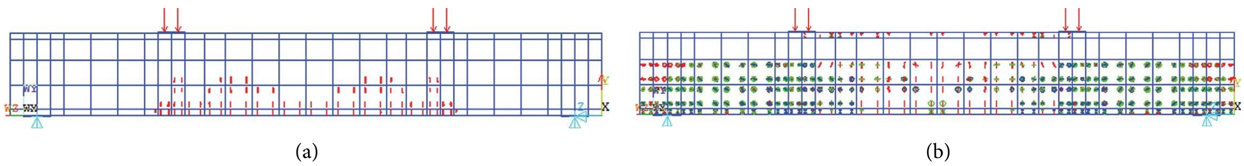


Figure 21: When the diameter of the compressed steel bars varied, cracking and damage began to appear in the beams: (a) cracks begin to appear in the beam ($P_{crack} = 9$ kN), $2\phi16$; (b) damage to the beam begins to appear ($P_{max} = 131$ kN), $2\phi16$.

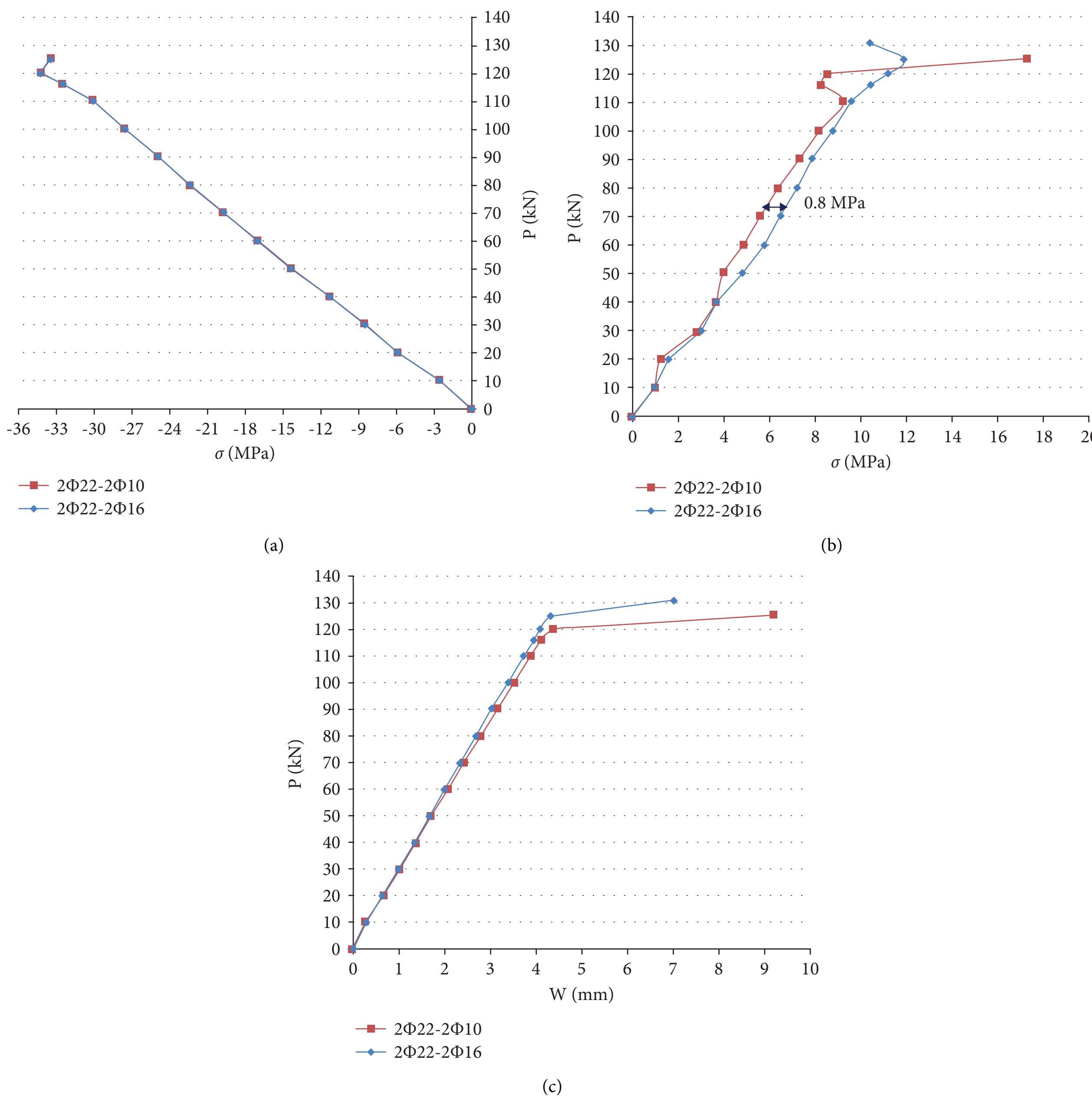


Figure 22: Relationship between load and stress, as well as between load and vertical displacement (effect of the diameter of compressed steel bars): (a) relationship between load and compressive stress, (b) relationship between load and tensile stress. (c) the relationship between load and VD.

modified to $H = 7$ cm and $H = 14$ cm, and nonlinear materials taken into account in an ANSYS numerical simulation analysis.

Beams start to crack and suffer damage if there is a modification in the thickness of the SFC layer, as shown in Figure 23.

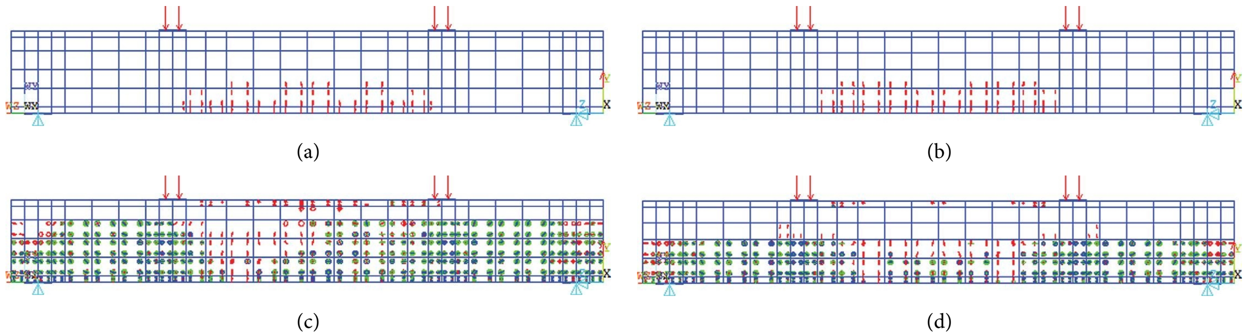


FIGURE 23: When the thickness of the steel fiber layer changed, the beams immediately began to crack and were damaged: (a) cracks begin to appear in the beam ($P_{crack} = 8$ kN), $H = 7$ cm; (b) cracks begin to appear in the beam ($P_{crack} = 8$ kN), $H = 14$ cm; (c) beam beginning to show signs of damage ($_{Pmax} = 125$ kN), $H = 7$ cm; (d) beam beginning to show signs of damage ($P_{max} = 128$ kN), $H = 14$ cm.

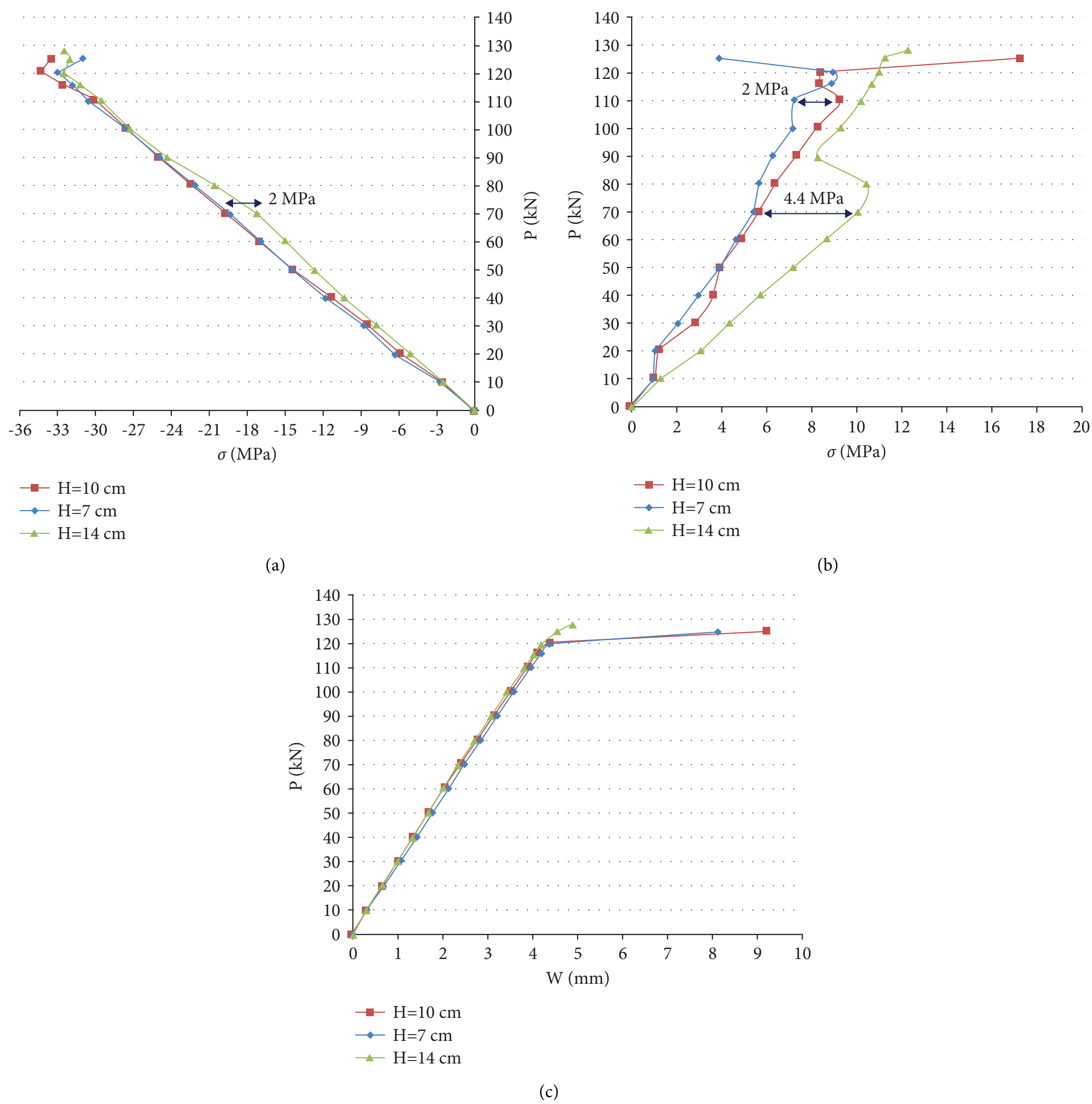


FIGURE 24: Relationship between load and stress, as well as between load and vertical displacement (effect of the thickness of the SFC layer): (a) relationship between load and compressive stress, (b) relationship between load and tensile stress. (c) the relationship between load and VD.

In Figure 23, increasing the thickness of the SFC layer from 7 centimeters to 14 centimeters results in no change in beam section size, an increase in beam bearing capacity from 125 kN to 128 kN and a significant reduction in the number of cracks in concrete beams; in both cases, the most cracked beams are in NC layers. Layers of SFC have been shown to cut down on the number of cracks in RC beams by a lot.

Figure 24 shows the load-compressive stress, tensile stress, and VD relationships in the midpoint of the span of a SFC beam.

Changing the thickness of the SFC layer in Figure 24 has little effect on compressive stress; the difference between beams is 2 MPa (Figure 24(a)). However, the tensile stress changes with stress, with the highest difference being 2 MPa between the beams with $H = 7$ cm and $H = 10$ cm, 4.4 MPa between the beams with $H = 10$ cm and $H = 14$ cm, and a smaller change in the VD in the middle of the span.

4. Conclusions

The following are some of the conclusions that may be derived from the results of the study:

(1) We were able to show that the number of cracks in bending beams may be greatly decreased by using a RC layer reinforced with SFs. Because it is affected by the maximum allowable steel content in the concrete, the beam will be damaged at the very least when the SFs' content of the concrete is raised by 5%. This is because the beam is affected by the maximum allowable steel content.

(2) When the distance between the stirrups at the ends is modified, it is found that the beam works more effectively when the distance between the stirrups grow to 100 millimeters. This is because the amount of steel in the concrete has reached the legal limit.

(3) The ability of the beams to support weight greatly improves when both the number of tensile steel bars and the diameters of those bars are increased, which also reduces the risk that cracks will form. The influence of tensile stress is large in this case as a result of an increase in the number of steel bars in the tensile zone as well as the diameter of those steel bars.

(4) The figures for compressive stress and VD do not vary much when the thickness of the SFC layer is modified, but the tensile stress does rise.

(5) It has been shown that the input parameters of double-layer SFC beams have an effect on the performance of the beams. Because of this research, the important parameters could be changed to either limit or encourage certain values that are better for building SFC beams with multiple layers.

Abbreviations

FE: Finite element
NC: Normal concrete
NCL: Normal concrete layer
SFC: Steel fiber concrete
SFCL: Steel fiber concrete layer.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

[1] V. T. Ngo, T. Q. Khai Lam, T. M. Dung Do, and T. C. Nguyen, "Nano concrete aggregation with steel fibers: a problem to enhance the tensile strength of concrete," *E3S Web of Conferences*.vol. 135, Article ID 03001, 2019.

[2] V. T. Ngo, T. Q. K. Lam, T. M. D. Do, and T. C. Nguyen, "Increased plasticity of nano concrete with steel fibers," *Magazine of Civil Engineering*, vol. 1, no. 93, pp. 27–34, 2020.

[3] V. T. Ngo, T. T. Bui, T. Q. K. Lam, T. T. N. Nguyen, and V. H. Nguyen, "Experimental evaluation of nano silica effects to high performance concrete strength in early age," *IOP Conference Series: Materials Science and Engineering*, vol. 869, no. 3, p. 869, Article ID 032011, 2020.

[4] S. Anandan, S. Islam, and R. A. Khan, "Effect of steel fibre profile on the fracture characteristics of steel fibre reinforced concrete beams," *Journal of Engg. Research*, vol. 10, no. 2, pp. 105–124, 2019.

[5] T. Q. Khai Lam, D. D. Thi My, V. T. Ngo, T. Chuc Nguyen, and T. Phuoc Huynh, "Numerical simulation and experiment on steel fiber concrete beams," *Journal of Physics: Conf. Ser*, vol. 1425, no. 1, Article ID 012007, 2019.

[6] A. Fatih, K. M. Metin, Y. Canan, A. Kamuran, and D. Adem, "Experimental investigation of reinforced concrete beams with and without steel fiber under explosive loading," *Indian Journal of Engineering and Materials Sciences*, vol. 14, pp. 419–426, 2007.

[7] T. Q. K. Lam and T. M. D. Do, "Analysis of nonlinear material and steel fiber content in the double layers concrete shell," *AIP Conference Proceedings*, vol. 2283, p. 2020, Article ID 020008, 2020.

[8] T. M. D. Do, T. Q. K. Lam, T. T. N. Nguyen et al., "Initial parameters affecting the multilayer doubly curved concrete shell roof," *Advances in Civil Engineering*, vol. 2021, Article ID 7999103, 18 pages, 2021.

[9] A. Gokmen, "Buckling analysis of delaminated composite beams," *Indian Journal of Engineering and Materials Sciences*, vol. 20, pp. 276–282, 2013.

[10] A. Soto and F. M. Tehrani, "An investigation of crack propagation in steel fiber-reinforced composite beams," *Periodica Polytechnica: Civil Engineering*, vol. 62, no. 4, pp. 956–962, 2018.

[11] I. Iskhakov and Y. Ribakov, "A design method for two-layer beams consisting of normal and fibered high strength concrete," *Materials & Design*, vol. 28, no. 5, pp. 1672–1677, 2007.

[12] I. Iskhakov and Y. Ribakov, "Two-layer beams from normal and fibered high strength concrete," *Modern Methods and Advances in Structural Engineering and Construction(ISEC-6)*, vol. 21, 2011.

[13] I. Iskhakov, Y. Ribakov, K. Holschemacher, and T. Mueller, “Experimental investigation of full scale two-layer reinforced concrete beams,” *Mechanics of Advanced Materials and Structures*, vol. 21, no. 4, pp. 273–283, 2014.
[14] I. Iskhakov, Y. Ribakov, and K. Holschemacher, “Experimental investigation of continuous two-layer reinforced concrete beams,” *Structural Concrete*, vol. 18, no. 1, pp. 205–215, 2017.
[15] I. Iskhakov, Y. Ribakov, K. Holschemacher, and S. Kaeseberg, “Experimental investigation of prestressed two layer reinforced concrete beams,” *Structural Concrete*, vol. 22, pp. 238–249, 2019.
[16] M. M. A. Pratama, R. K. Suhud, P. Puspitasari, F. I. Kusuma, and A. B. N. Rahma Putra, “Finite element analysis of the bending moment-curvature of the double-layered graded concrete beam,” *IOP Conference Series: Materials Science and Engineering*, vol. 494, p. 494, Article ID 012064, 2019.
[17] B. Thomee, K. Schikora, and K. Bletzinger, “Material modeling of steel fiber reinforced concrete,” *Computers and Concrete*, vol. 3, no. 4, pp. 197–212, 2006.
[18] T. L. Teng, Y. A. Chu, and B. C. Shen, “Penetration resistance of steel fiber reinforced concrete containment structure to high velocity projectile,” *Computers and Concrete*, vol. 5, no. 6, pp. 509–524, 2008.
[19] P. Ramadoss and K. Nagamani, “A new strength model for the high-performance fiber reinforced concrete,” *Computers and Concrete*, vol. 5, no. 1, pp. 21–36, 2008.
[20] T. M. D. Do and T. Q. K. Lam, “Nonlinear analysis of multilayer steel fiber reinforced concrete beams,” *Journal of Construction, Vietnam.*vol. 4, pp. 58–63, 2021.
[21] T. M. D. Do and T. Q. K. Lam, “Design parameters of steel fiber concrete beams,” *Magazine of Civil Engineering*, vol. 2, no. 102, 2021.
[22] V. D. Tho and E. A. Korol, “Influence of geometrical parameters of the cross section, strength and deformability of the materials used on stress-strain state of three-layered reinforced concrete,” *IOP Conference Series: Materials Science and Engineering*, vol. 661, no. 1, p. 661, Article ID 012121, 2019.
[23] D. T. Vu, E. Korol, Y. Kustikova, and H. H. Nguyen, “Finite element analysis of three-layer concrete beam with composite reinforcement,” *E3S Web of Conferences*, vol. 97, Article ID 02023, 2019.
[24] A. Ayman and M. Sayed, “Nonlinear static analysis of reinforced concrete framed buildings - a case study on Cairo earthquake,” *Journal of Engg. Research*, vol. 4, no. 4, 2016.
[25] T. Q. K. Lam, T. M. D. Do, V. T. Ngo, T. T. N. Nguyen, and D. Q. Pham, “Concrete grade change in the layers of three-layer steel fibre reinforced concrete beams,” *Journal of Achievements in Materials and Manufacturing Engineering*, vol. 1, no. 102, pp. 16–29, 2020.
[26] T. M. D. Do and T. Q. K. Lam, “Design parameters of double layers steel fiber concrete beams,” *Lecture Notes in Civil Engineering*, vol. 130, pp. 299–321, 2021.
[27] T. M. D. Do, T. Q. K. Lam, V. T. Ngo, and T. T. N. Nguyen, “Two-layered steel fiber concrete beam with concrete grade change in layers,” *Resilient Infrastructure*, vol. 202, pp. 427–443, 2021.
[28] T. M. Dung Do and T. Q. Khai Lam, “Cracks in single-layer and multi-layer concrete beams,” *Transportation Research Procedia*, vol. 63, pp. 2589–2600, 2022.
[29] H. Mertol, “Farklı gçlbksbked,” *Journal of Polytechnic*, vol. 25, no. 1, pp. 273–280, 2021.
[30] N. Elmezaini and M. Ashour, “Nonlinear analysis of concrete beams strengthened with SFRC layer,” *Journal of Engineering Research and Technology*, vol. 2, no. 3, pp. 181–188, 2015.