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Initial factors impacting vertical displacement, stresses, and propagation of cracks in three-layered steel fiber concrete beams

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Abstract: The main aim of the study is to examine the input parameters of three-layered steel fiber concrete beams. Bending RC beams is studied by many different scientists. Multilayer RC beams using SF concrete are one way. In high compressive and tensile stress zones, this method improves beam load strength and reduces cracks. The main goal is to decrease beam stress. Repairing broken three-layered SF-reinforced concrete beams by adding more concrete on top or below the current layer is a benefit. Modifying input parameters during three-layered beam design greatly affects beam efficacy. In this paper, the authors conducted a study using ANSYS simulation and nonlinear material analysis. The objective was to investigate the behavior of three-layered bending RC beams subjected to two concentrated loads. Specifically, the study examined the impact of varying the content of SF in the RC, as well as the effects of stirrup at the ends of the beams. Furthermore, the study explored the influence of changes in the quantity and size of steel bars in the region of tensile strength, along with the effect of varying the SF concrete layer's thickness. The survey results on three-layered beams were used to create diagrams that depict the relationship between load and vertical displacement and load and stress area. These diagrams also help determine the initiation and progression of cracks in three-layered beams, starting from the application of load until the beams become damaged. Ultimately, this information allowed us to identify the specific load level that caused the beams to crack and become damaged.

Keywords: *Bending beam, Cracks, Fiber reinforced concrete, Multilayered beam, Numerical simulation, Reinforced concrete, Steel fiber, Stress-strain.*

1. Introduction

In research on new concrete materials, various types of concrete have been investigated, such as high-strength concrete, inorganic concrete, organic concrete, and steel fiber (SF) reinforced concrete. These materials were added to enhance the bearing capacity of concrete, improve its characteristics, and reduce the occurrence of cracks in RB beams. In order to create multilayer reinforced concrete beams (RCB), the process involved repairing damaged RCB by adding a new layer of concrete either above, below, or both above and below the existing concrete. Successfully repairing damaged RCBs was crucial, particularly in the case of three-layered SF RCBs. Numerous researchers have used nanosilica in their studies on SFRCB. Their aims were to enhance the tensile strength and plasticity of nano-concrete containing SFs. Consequently, these researchers have examined the impact of nanosilica on high-performance concrete that incorporates SFs [1, 2].

Numerous studies have been conducted on using thin multilayer shells to repair damaged shell roofs. These studies have focused on various aspects, such as investigating the formation and development of cracks in the shell through experimental and simulation methods. Furthermore, studies have been carried out to establish relationships between load, vertical displacement (VD), and stress when evaluating the thickness of the SF concrete layer (SFCL) in the compressible shell [3-5].

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Numerous studies have been conducted on SFRCBs. These studies have focused on investigating the cracking and stress-strain states of RCB by modifying the SF content in the concrete. For example, different SF contents, such as μ=0%, μ=2%, μ=4%, and so on, have been examined in these studies [6, 7]. Several researchers have conducted studies on delaminated composite beams, focusing on various aspects such as bending analysis, crack propagation, and bending of composite beams [8, 9].

2. Literature Review

Iskhakov studied multilayer RCBs. HSC was used in compression and NSC in tensile [10]. The paper discussed beam kinds and their difficulties in assigning layer levels. Connectivity between the HSC and NSC layers is established. The assumption was that shear deformations at layer boundaries in a section were equivalent, especially in the compression zone with the highest depth. This describes double-layer RCB applications, static systems, and charging circumstances. The main downside of HSCs is their low flexibility. This is addressed by adding fibres to the HSC layer. Fibre volume ratios affected structural ductility in the research. The top limit of the needed fibre volume ratio was determined using the equation of compatibility between transverse tensile concrete deformations and fibre deformations. The present research sought to determine the beam section's ideal fibre composition for highest Poisson coefficient and ductility. The fibre weight ratio was employed in concrete mixes to better measure fibre content than the fibre volume ratio. The results from this work provide the foundation for two-layer beam construction regulations [11, 12]. The experiment employed two-layer beams with high-strength SFRC in compression and normal-strength concrete in tensile. Calculating SF concentration for two-layer beams was crucial to determining RC element ductility. Full-scale, two-layer beam testing was the main research emphasis. This research showed that the two-layer bending element worked well during the whole loading process, even when it failed. It also looked at TLB concrete layer interaction data in an experiment. After the NSC layer solidified, the SFHSC layer was cast to test an independent casting procedure, which is more practicable for real-world TLB manufacture [13].

The authors performed tests on models of static two-layer full-scale beams [14]. These beams were constructed using high-strength SFRC in the compression zone and normal-resistance concrete in the tensile zone. The study represented the next phase of these investigations, which aimed to test a continuous two-span TLB with an optimal SF ratio, similar to the previous phases. The study's goal was to look at how the CTLB (Concrete T-Beam with Lateral Bracing) behaved in the span and above the middle support, specifically how it responded to both positive and negative bending moments. This study was part of a series of investigations on two-layer beams [15]. In this series, a two-layer beam concept was designed, SFHSC was tested, and materials for simple supported and continuous two-span two-layer beams were tested. The focus of the current research was testing prestressed, full-scale, simple, supported two-layer beams. The objective of this study was to examine the behavior of PTLBs (prestressed thin laminated beams) under four-point bending conditions and to compare it to the behavior of non-prestressed beams. No debonding has been observed between the SFHSC layers and the normal-strength concrete in the tested beams up to the maximum limit state. This indicated that there was a proper interaction between the layers. The results obtained from this study suggest that further investigation of PTLB is recommended for full-scale RC elements with longer spans (9-12m). This research also highlighted the potential practical application of PTLB as an effective and cost-effective bending solution.

In structural analysis, the concept of concrete rigidity is important since it indicates how well beam members can tolerate bending brought on by workloads. In the investigation, the behavior of the graded concrete beam was continually examined [16]. A graded RCB's bending moment-curvature connection was examined via numerical analysis. The nonlinear simulation program Strand7 was used to study a single-reinforced graded RCB. The Eurocode will be used as a basis for evaluating the research results. The graded RCB should have a constant curvature and bending moment behavior. Utilizing graded RCBs as structural components for cutting-edge applications was essential.

It was necessary to do numerical studies of the stress-strain states of these structures under various loading scenarios in order to build multilayer structures out of concrete that had a wide range of mechanical and physical properties [17]. The effect of concrete and cross-sectional materials on the stress-strain behavior of a three-layer RC structure was investigated in this research.

The research on three-layered beams investigated the impact of geometrical parameters of the cross-section, as well as the strength and deformability of the materials used in the stress-strain state and finite element method (FEM) analysis. This study specifically focused on the effect of these factors on the three-layered RCBs with composite reinforcement [18]. In addition, the study examined the design parameters of RCBs that impacted their bearing capacity [19]. A separate study on multilayer RCBs has been presented in references [20, 21].

Further research should be conducted on multilayer beams, with a specific focus on three-layered SF RCB. Including concrete SFL in the tensile zone and compressive area of the RCB has the potential to improve their bearing capacity and minimize cracks in the bending beams. Therefore, it is important to explore and expand upon the study of these multilayer beams. In this paper, the authors utilized simulations to examine the input parameters involved in the design of three-layered SFRCBs. These parameters had an impact on beams as well as on the formation and progression of cracks. The study specifically focused on factors such as the content of SF changing, the stirrups changing, the number of tensile steel (TS) bars changing, and the thickness of the concrete layer of SF changing. The authors constructed a diagram to look at how cracks in three-layered beams start and spread. The relationship between load-tensile stress (L-TS), load-compression stress (L-CS), and L-VD was shown in the diagrams. The authors worked with a non-linear material to run an analysis system (ANSYS) simulation, which allowed them to calculate the stress at which the beam begins to fracture and incur damage.

3. Materials and Methods

3.1. Design Model of Beams

The research involved studying a three-layered RCB made of steel fiber-reinforced concrete(SFRC). The beam had a layer of SFRC on both the top and bottom, with a standard concrete layer (NC) between. The dimensions of the beam were 15×30×220cm. The SFCL was of grade B30, while the NC layer at the center of the beam was of grade B20.

Figure 1 shows the design of the three-layered RCB model.

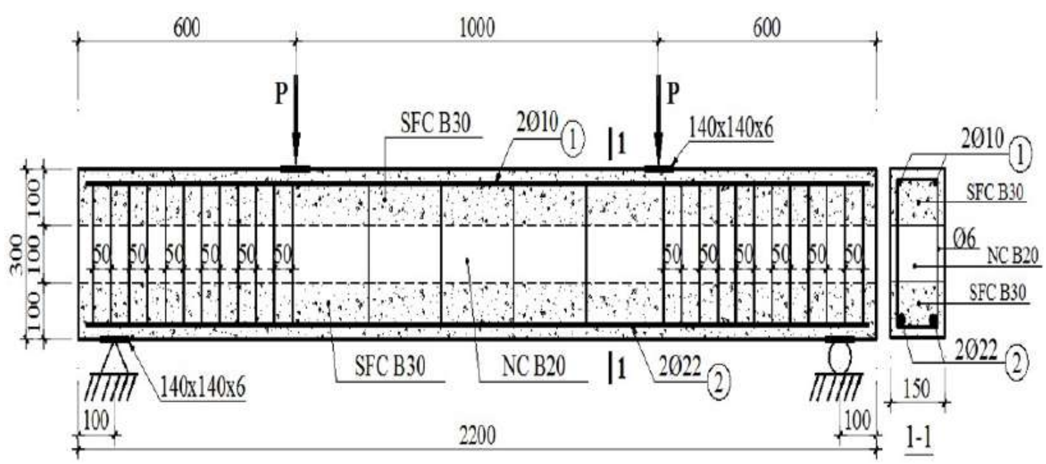


Figure 1.
The design of a three-layered RCB model.

3.2. Finite Element Model for Three-Layered RCBs

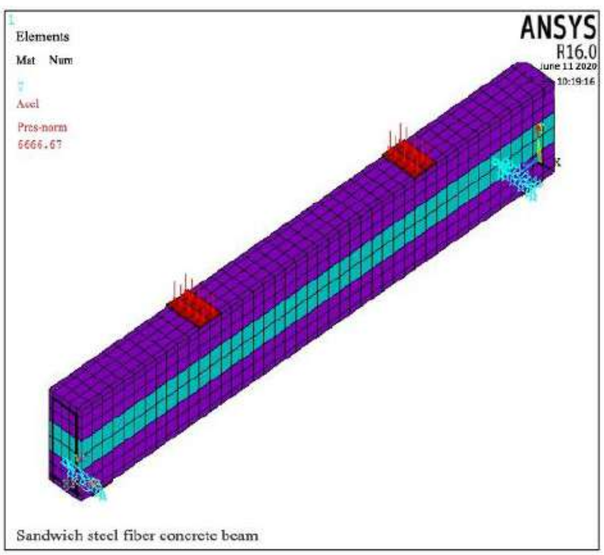
Choosing a suitable model of SF dispersed in concrete was a crucial decision. The smeared model was chosen to represent the dispersion of SFs in concrete in this study.

Modeling the phenomenon of cracking in concrete. Currently, two primary models are used to represent cracks in concrete: the discrete and the smeared models. In this study, our focus was on examining the relationship between L-VD. Therefore, the smeared model was selected to investigate cracks in concrete.

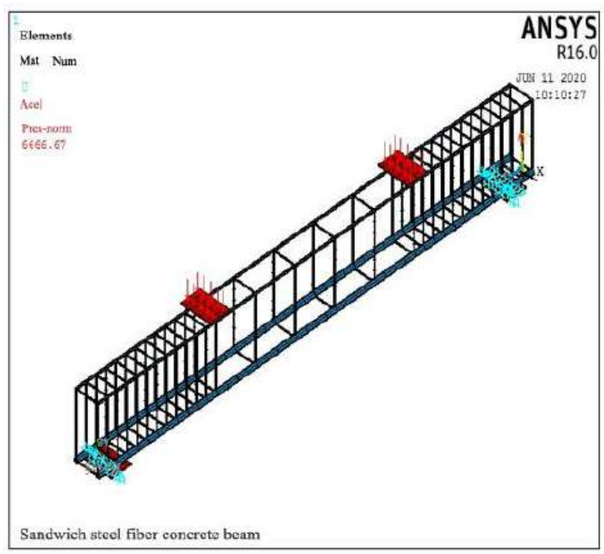
The BEAM188 element, which had two nodes, allowed for the modeling of reinforcement bars. Finite element modeling in beams was a technique used to analyze the structural behavior of beams. The SOLID65 element was a specialized simulation element that could accurately model concrete materials. It was capable of simulating the behavior of reinforcement in concrete, including phenomena such as cracking and compression. Additionally, it allowed for the definition of nonlinear material properties. This element was three-dimensional and consisted of eight nodes.

Provide information about the mesh used for the models, as well as the boundary conditions and loads applied. The mesh shapes in ANSYS were divided into 3D blocks because of the simple beamstructure. Additionally, the element size has been optimized for better performance. To input the parameters for the SOLID65 concrete element in ANSYS, we needed to specify eight essential parameters. The cracking stress in tension, the compression stress, the reduction coefficient for weakening due to cracking in tension, the modules, Poisson's ratio, and the stress-strain relationship (which accounted for the material's nonlinearity) were some of these.

Figure 2 shows the three-layered RCB model in ANSYS.



a) The three-layered RCB



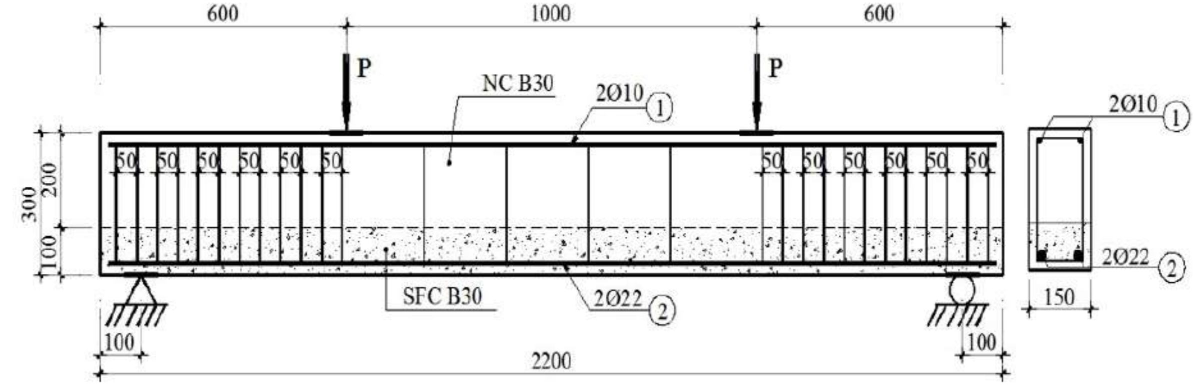
b) Steel bar model, boundary conditions and loads

Figure 2.
Model of three-layer RCB.

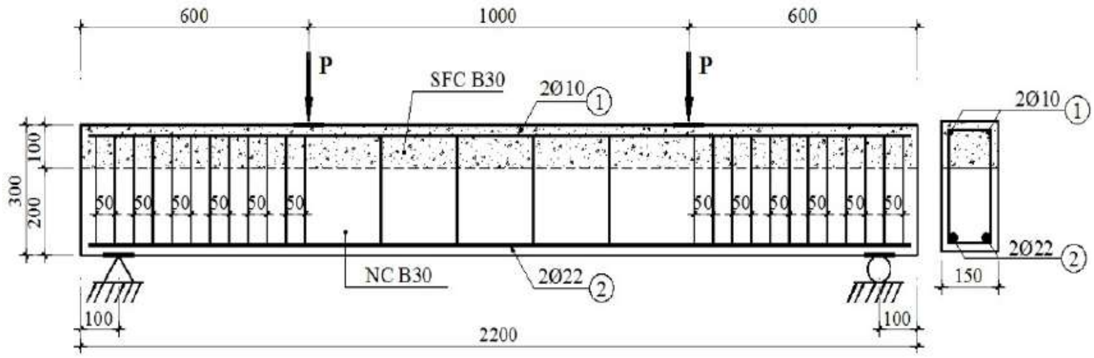
4. Results and Discussion

The authors compared the accuracy of the two-layer beam testing method with the three-layered beam (TLB) model constructed in ANSYS. The two-layer beam was constructed to be the same size as the TLB, since there were no experimental results available for the TLBs to serve as a basis for the beam survey.

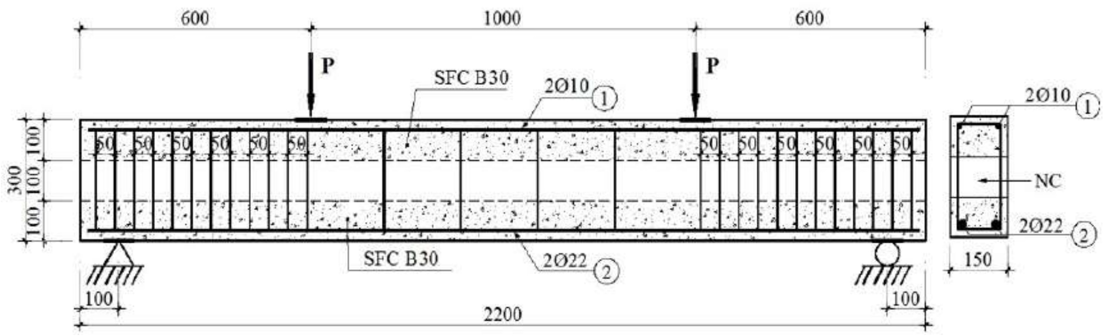
The design model in Figure 3 shows two-layer and three-layer RCBs.



a) The SFL is located at the bottom.



b) The SFL is located on top.



c) A three-layered SF RCB.

Figure 3.
Model of two-layer and three-layered RCBs.

Figure 4 shows the process of concreting beams in layers.

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Figure 4.
Concreting beams in layers.

Figure 5 shows the experimental beams.

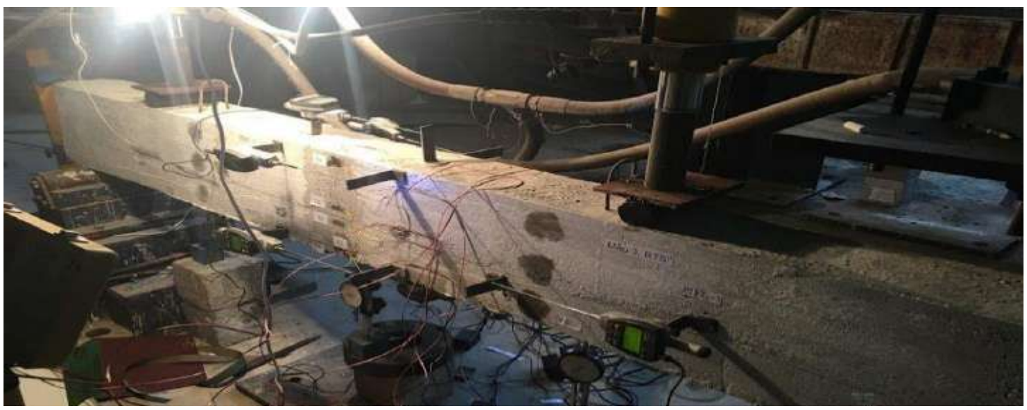

Figure 5.
Tested beams on the experimental pedestal.

Figure 6 shows the measuring devices.

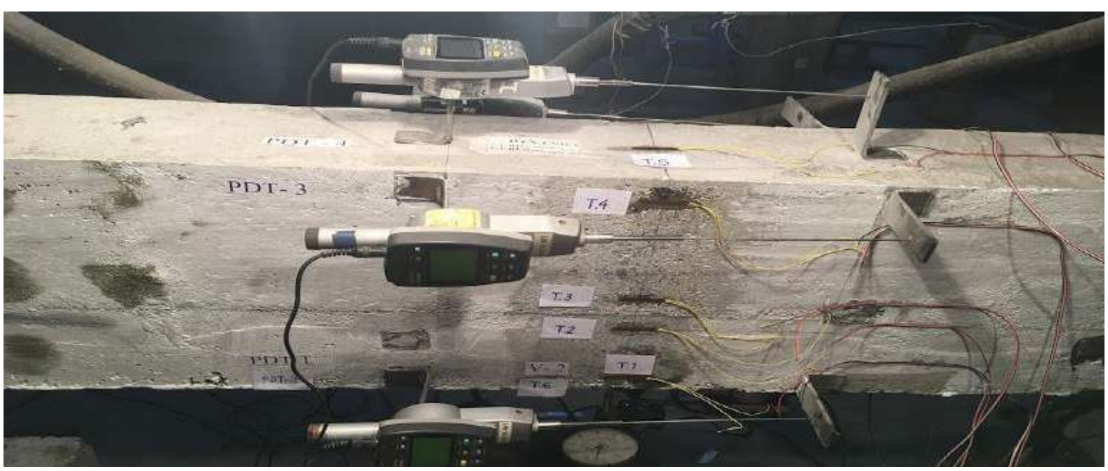

Figure 6.
The beams have measuring devices placed on them.

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The formation and development of cracks are shown in Figure 7.

Figure 7.
Formation and development of cracks in test beams.

Relationship between L-VD in the middle of the RCB span is shown in Figure 8.

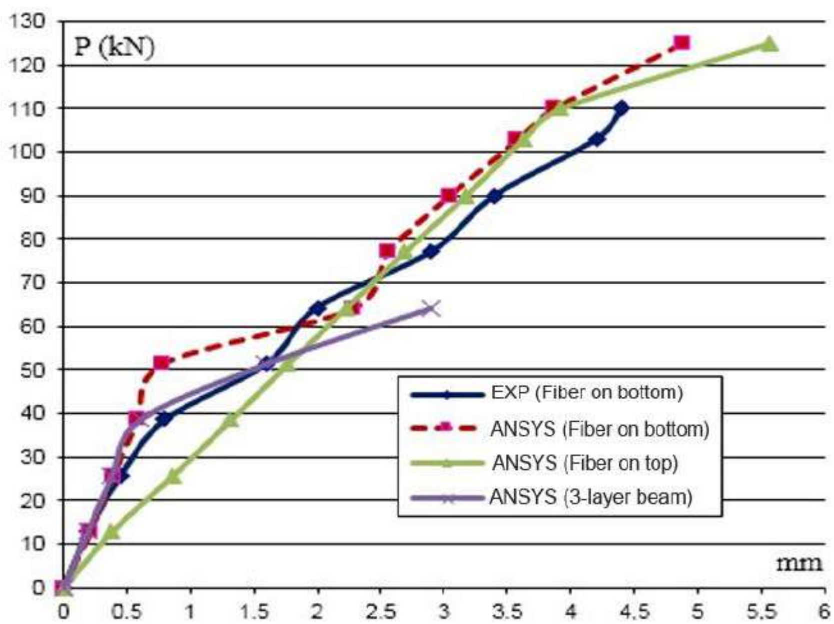

Figure 8.
VD at the middle of RCB span.

The relationship between L-CD, as well as the relationship between load and tensile deformation in the middle of a RCB can be observed in Figure 9.

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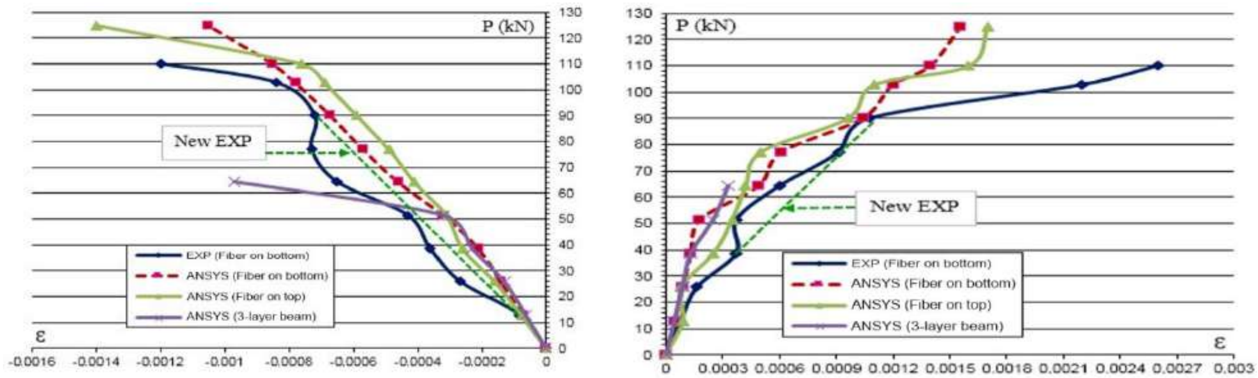


a) Load - compressive strain relationship

b) Load - tensile strain relationship

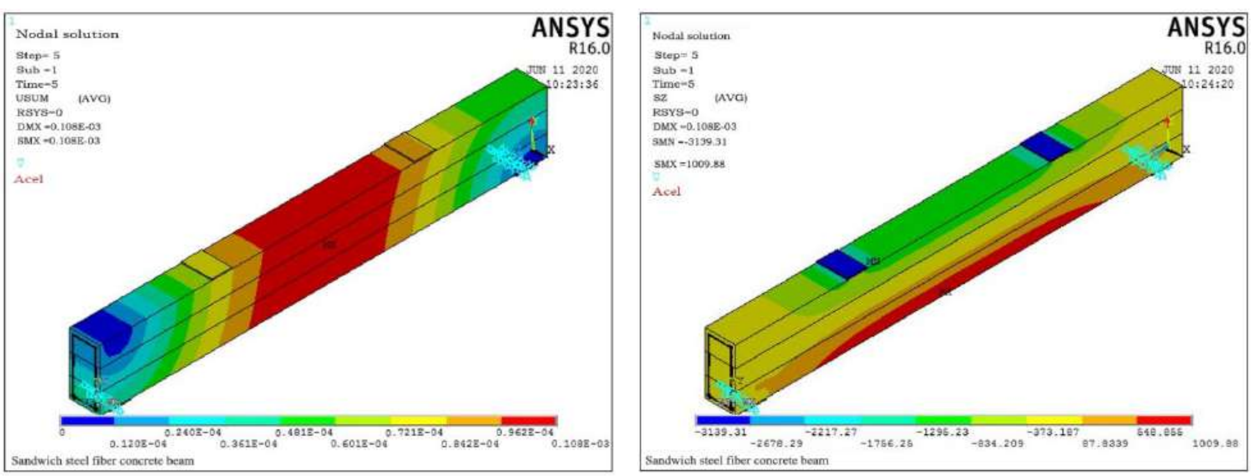
Figure 9.
Load - strain relationships of RCB.

Comment: After comparing the results of testing beams and simulations in ANSYS for the survey cases, it has been proven that the program has been constructed appropriately. It can be used effectively to assess changes in input parameters. The input parameters that affect the stress-strain state and VD in SF RCB are the following: the content of SF, the stirrups at the ends of the beam, the number of tensile steel bars (TSB), the diameter of the TSB, and the thickness of the SF concrete layer.

4.1. Investigate the Effects of SF Content on Concrete

The concrete SF content was adjusted to 2% and 4% from its initial 0%. Stirrups, with a diameter of ϕ6a50, were placed at the ends of the beam. In the middle of the beam, stirrups with a diameter of ϕ6a200 were used. TSB with a diameter of 2ϕ22 was employed, while compression steel bars with a diameter of 2ϕ10 were utilized. The thickness of the SF concrete layers, both at the bottom and at the top, was set at H1=H2=10cm. Furthermore, an NC layer with a thickness of H3=10cm was placed in the middle of the beam. It was important to note that the numerical simulation analysis in ANSYS considered non-linear materials.

Figure 10 displays the stress colour spectrum and VD.



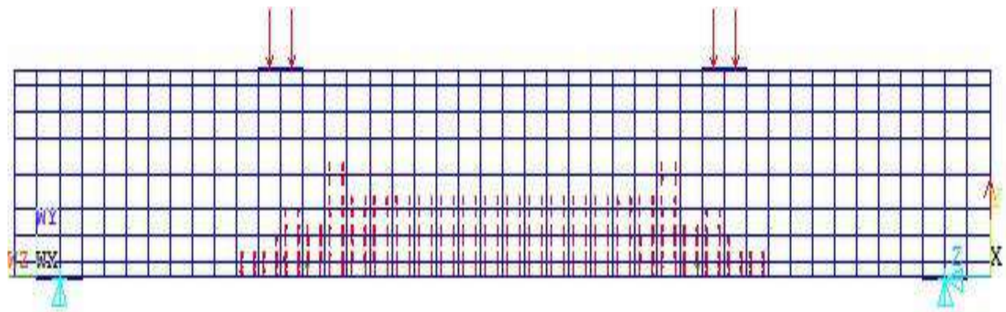
a) VD of RCB

b) Stresses of RCB

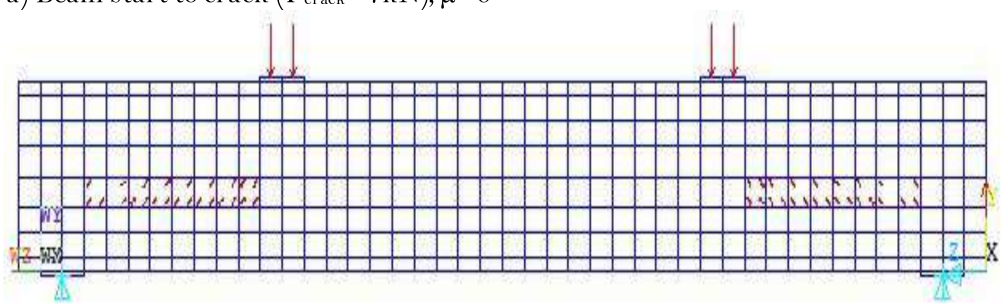
Figure 10.
VD and stresses on RCB.

Comment: In Figure 10a, the middle of the RCB span has the biggest VD; the value decreases as it gets closer to the supports. TS is centered around the bottom of the beam, with the maximum value occurring in the middle of RCB span, as indicated by the color spectrum of the prestresses in Figure 3b. Two concreted forces are exerting force on the CS, which is in the upper portion of the beam. This demonstrates that the ANSYS element model accurately models the beam's actual operating circumstances.

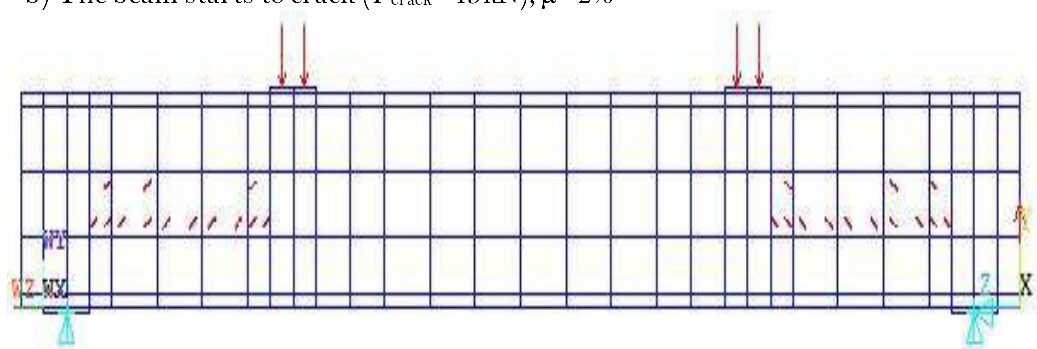
The beams began to crack when SF content changed, as shown in Figure 11.



a) Beam start to crack (P_{crack}=7kN), μ=0



b) The beam starts to crack (P_{crack}=19kN), μ=2%



c) The beam starts to crack (P_{crack}=62kN), μ=4%

Figure 11.
RCB start to crack in the ANSYS.

Comment: In Figure 11a, the three-layers consist of NC. As a result, cracks initially appear at the bottom of the RCB. These cracks then progress towards the compressive area. In Figures 11b and 11c, the lower layer consists of SFRC, which has a higher intensity compared to the NC layer in the middle. As a result, the cracks initially appear in the middle layer of the beam. By increasing the SF content in concrete from 2% to 4%, load-induced cracking increased from 19kN to 62kN. This is because the

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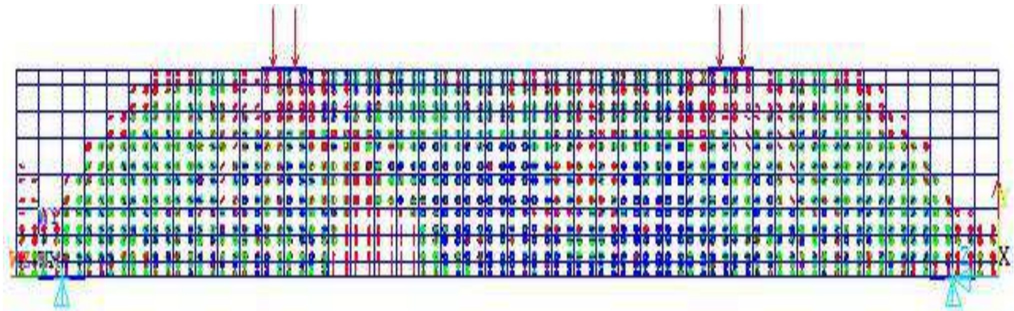
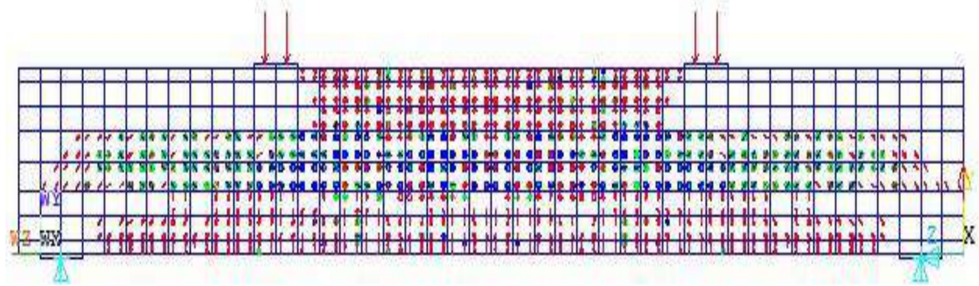
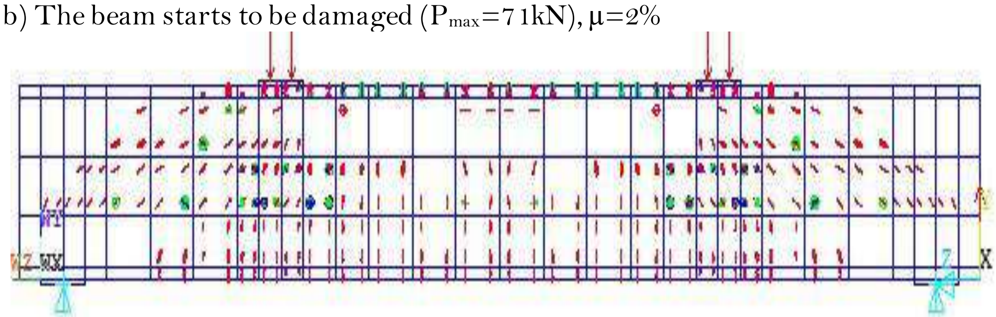
concrete layer in the tensile zone consists of SF concrete, resulting in fewer cracks and a higher bearing capacity for the beam.
The beams began to experience damage when SF content changed, as shown in Figure 12.



a) The beam starts to be damaged (P_{max}=56kN), μ=0



b) The beam starts to be damaged (P_{max}=71kN), μ=2%



c) The beam starts to be damaged (P_{max}=122kN), μ=4%

Figure 12.
RCB start to be damaged in ANSYS.

Comment: In Figure 12a, it was observed that RCB without any SF content began to show signs of damage at a load level of 56kN. Cracks were observed in the RCB. However, when the SF content was increased to 2%, the destructive load of the beams also increased to 71kN. Furthermore, the presence of SFs resulted in a decrease in the number of cracks compared to beams without any SF content. By increasing the content of SFs to 4%, the bearing capacity of the beam was further enhanced, reaching 122kN. Additionally, the presence of SFs in the concrete has significantly reduced the appearance of cracks in the beam. This demonstrates that the inclusion of SFs minimizes cracks and increases the beam's ability to withstand force.

The relationships between L-CS, L-TS, and L-VD are shown in Figure 13.

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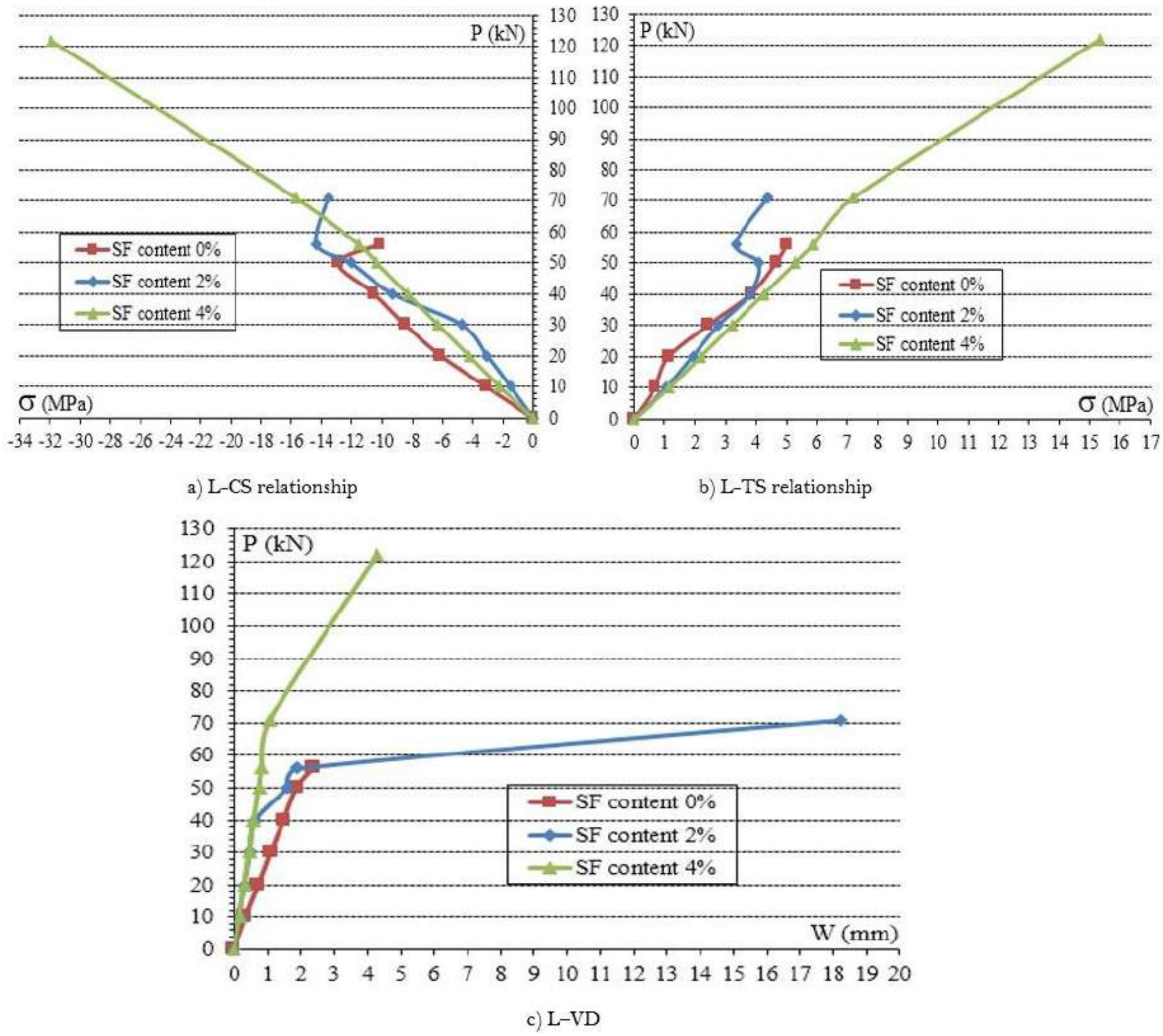

Figure 13.
Load-stresses, L-VD relationships in the beam.

Where: SF content refers to the SF content present in concrete.

Comment: In Figure 13a, it can be observed that normal RCB with a SF content of 0% shows the minimum compressive strain value. On the other hand, Figure 13b shows that beams with a SF content of 4% have the highest tensile strain. The VD of normal RCB is greater than that of other beams. When concrete contains 0% and 2% SFs, VDs are approximately equal under loads ranging from 0 to 56kN. However, the stress levels show significant variation once the limit is exceeded.

4.2. Investigate the Effects of Stirrups at the Ends of the Beam

The RCB has a SF content of 2%. The stirrups have been changed from ϕ6a50 to ϕ6a100. TSB has a diameter of 2ϕ22, while the compression steel bars have a diameter of 2ϕ10. The SF concrete layers are H1 =H2=10cm, and the NC layer is H3=10cm. The ANSYS simulation analysis considers non-linear materials, as shown in Figure 14.

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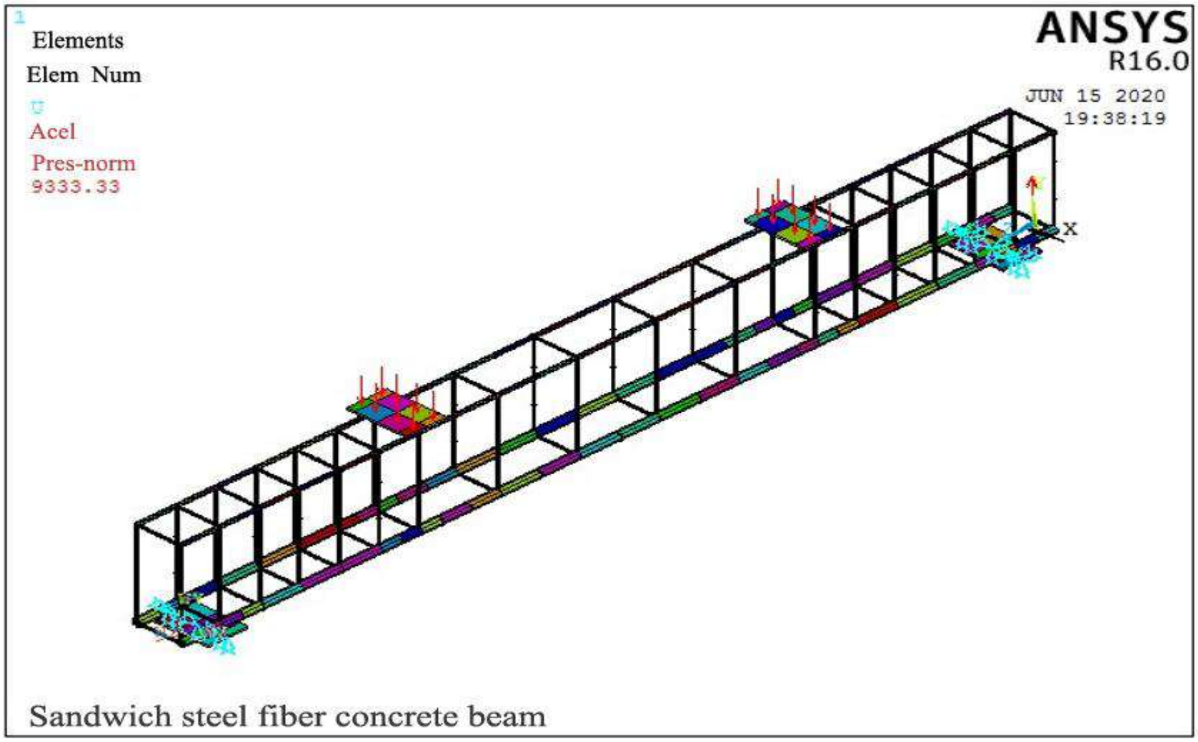
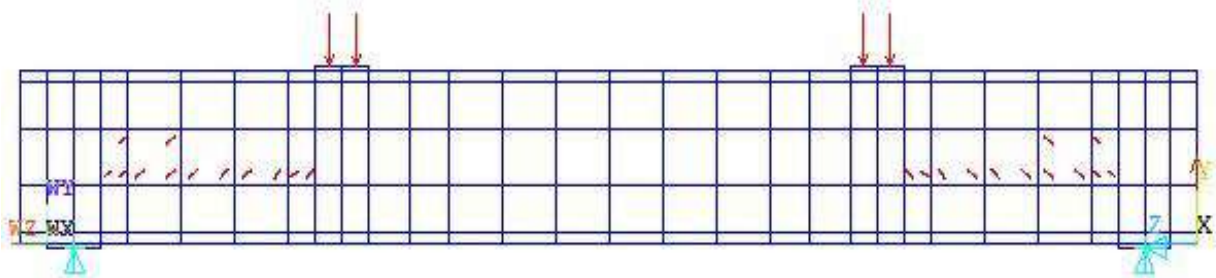
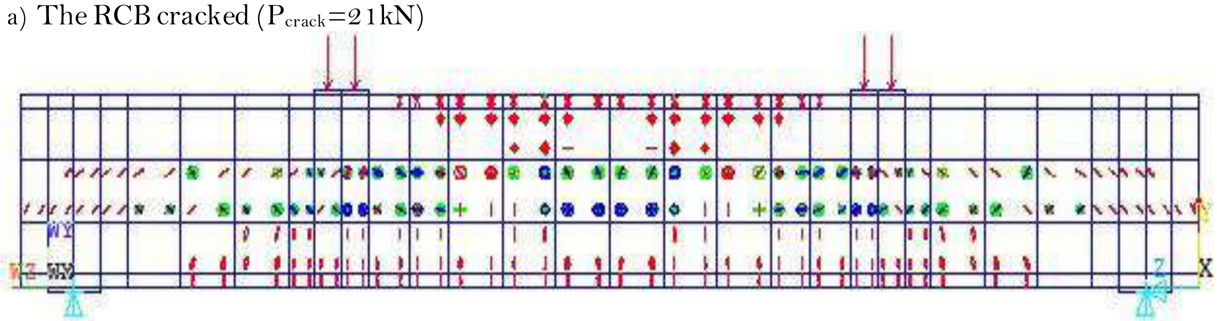


Figure 14.
Stirrups changed.

The RCB crack and damage when the stirrups changed, as shown in Figure 15.



a) The RCB cracked (P_{crack}=21kN)



b) The RCB damaged (P_{max}=72kN)

Figure 15.
Beams start to crack and be damaged when stirrups changed.

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Comment: In Figure 11b, the beam shows cracking at a load of 19kN when the stirrup at the ends of the beam is 50mm. When the stirrup is increased to 100mm, the beam experiences cracking at a higher load of 21kN. Furthermore, the beam begins to show signs of damage when the stirrup is 50mm, with a load of 71kN. Lastly, when the stirrup is 100mm, the beam begins to show damage at a load of 72kN. However, the number of cracks in the beams decreased significantly at 100mm. This is due to the stirrup being too thick and the SF content in concrete exceeding the allowed content value of steel in concrete.

The relationships between L-CS, L-TS, and L-VD, shown in Figure 16.

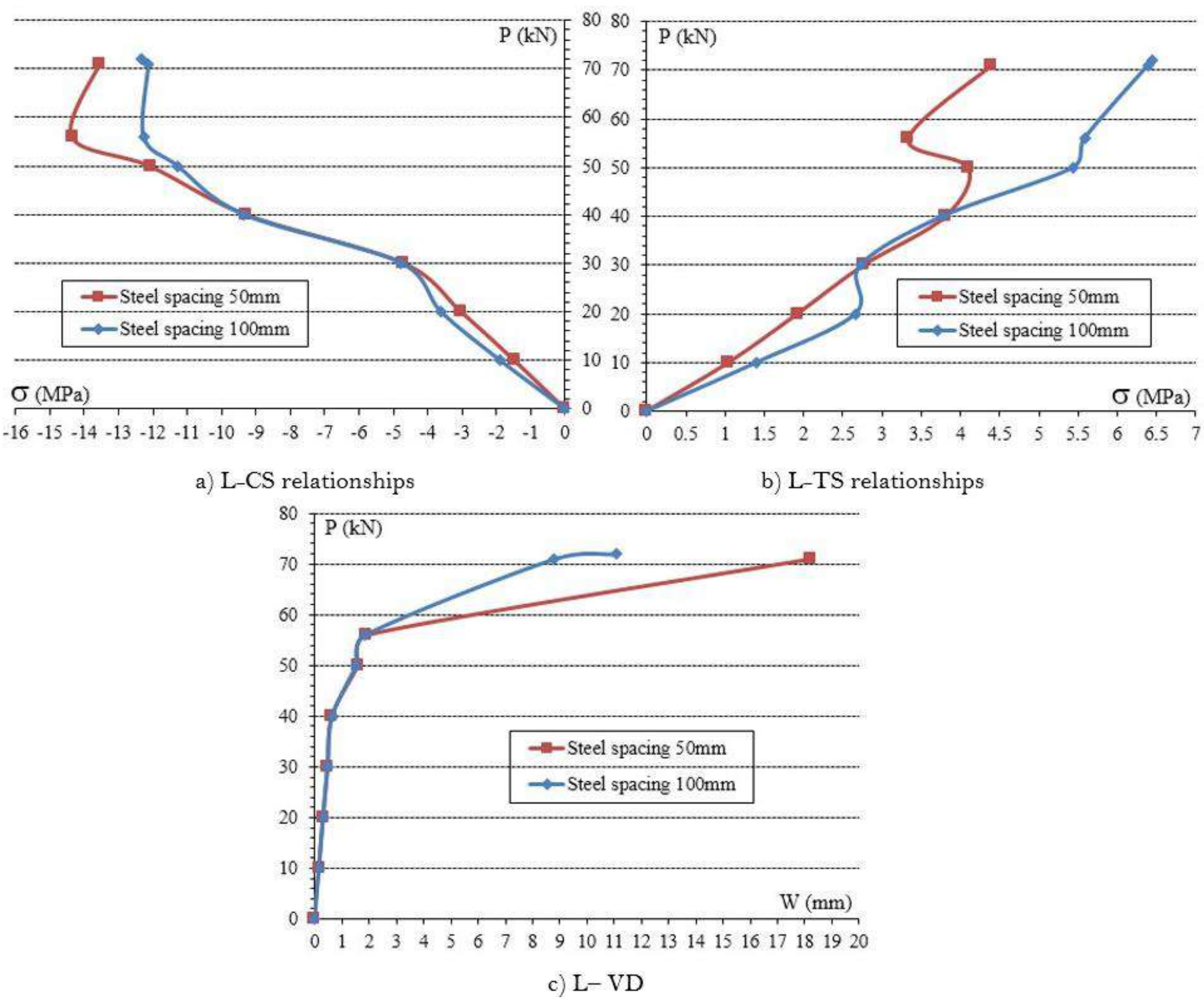

Figure 16.
Relationships of load - stresses, load – VD.

Comment: In Figures16a and 16b, as the load increases from 0kN to 40kN, both compressive and tensile stresses experience minimal changes. However, beyond 40kN, these stress values start to vary. It should be noted that the stirrup is 100mm, which is smaller compared to the stirrup of 50mm. Additionally, the tensile stress in the former is greater than that in the latter. The stirrups are placed at a spacing of 100mm, which is reduced to 50mm in situations where there is VD.

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4.3. Investigate the Effects of the Number of TSB on the Beam

The RCB has a SF content of 2%. The stirrups areϕ6a100. TSB has been changed from 2ϕ22 to 3ϕ22. The SF concrete layers are H1=H2=10cm, and the NC layer is H3=10cm. The ANSYS simulation analysis shown in Figure 17 takes into account non-linear materials.

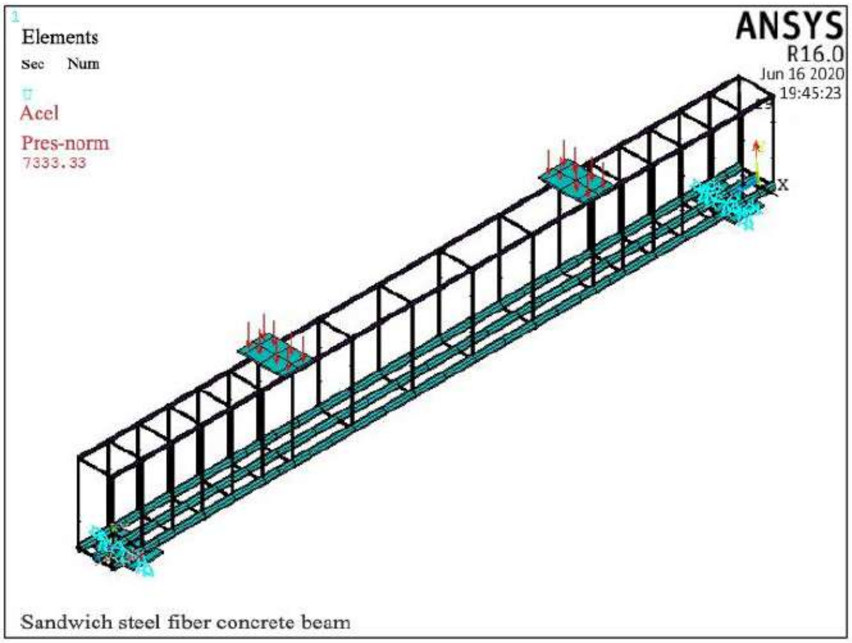
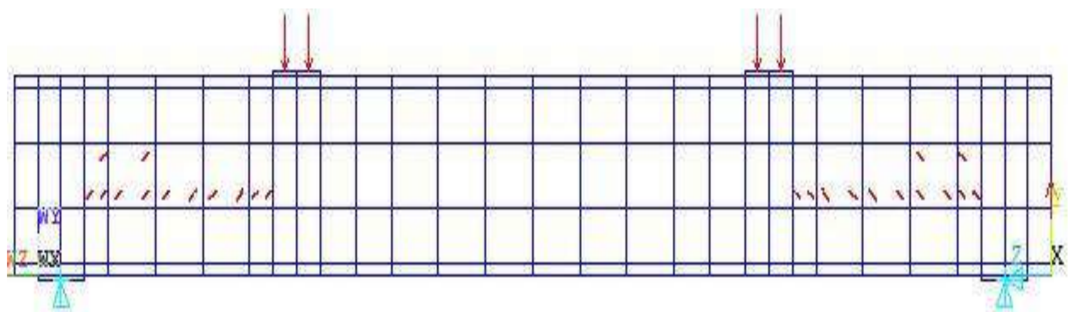
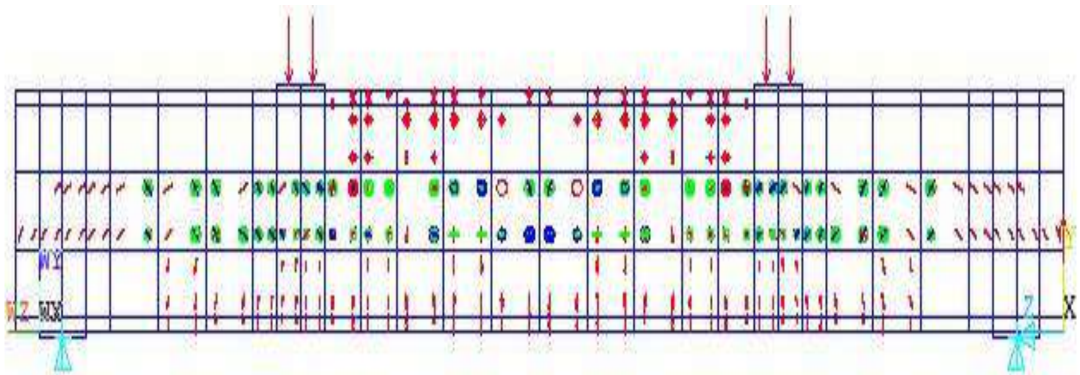


Figure 17.
RCB with number of TSB changed.

The beams begin to crack and get damaged when the number of TSB changes, as shown in Figure 18.



a) Beam start to crack (P_{crack}=22kN), 3ϕ22



b) Beam start to be damaged (P_{max}=76kN), 3ϕ22

Figure 18.
RCB start to crack and be damaged when the number of TSB changed.

Comment: The beam began to crack and was damaged at a later point when the tensile bars increased to 3ϕ22, compared to when there were only 2ϕ22 tensile bars. The beams in Figure 15a started to crack at a load of 21kN. On the other hand, the beams in Figure 18a began to crack at a load of 22kN, with an increase of 1kN afterward. When the beam started to be damaged, it occurred at 72kN for 2ϕ22 beams and at 76kN for 3ϕ22 beams. However, despite an increase in the number of TSB in the beam, the crack did not show significant changes (as observed in Figures 18a and 18b). It is worth noting that the beam only started to crack in the NC layer.

The relationships between L-CS, L-TS, and L-VD, shown in Figure 19.

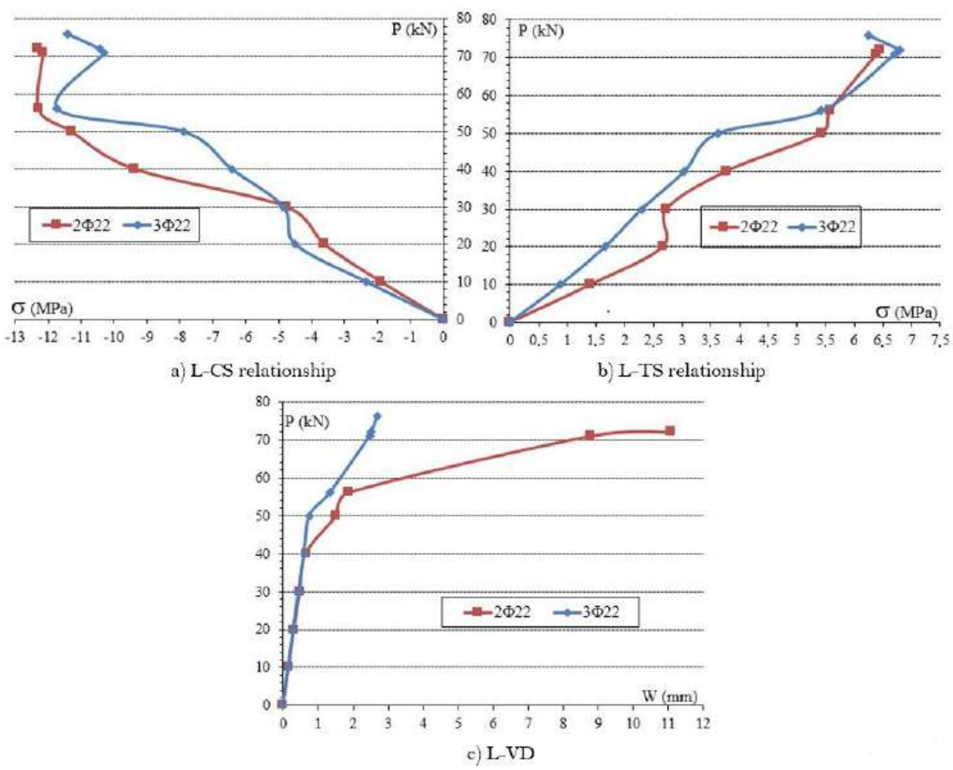


Figure 19.
Relationships of load - stress, L-VD.

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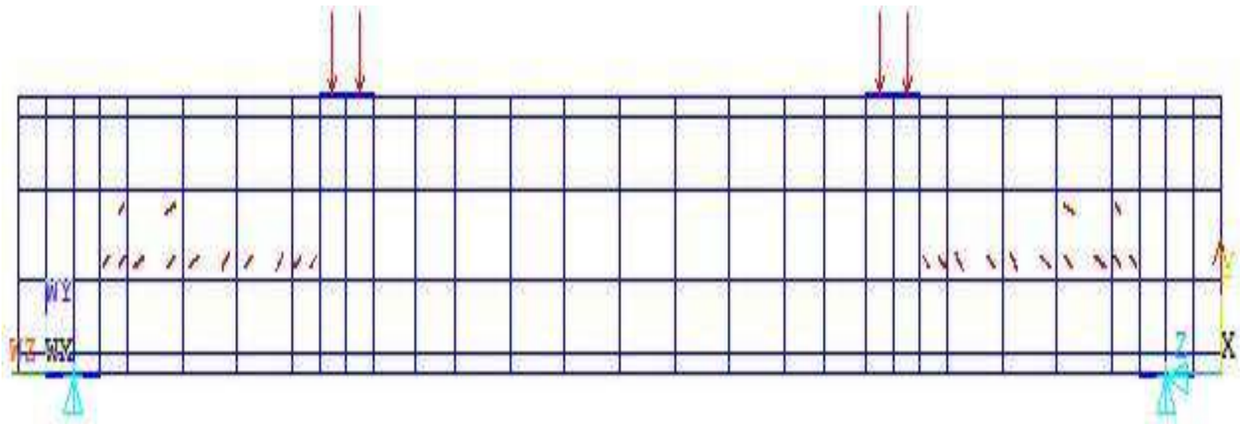
Comment: In Figure 19a, as the load increases from 0 to 30kN in CS, the CS between 2ϕ22 and 3ϕ22 remains relatively stable. However, once the load exceeds 30kN, there is a significant increase in CS, reaching 3MPa. TS undergoes a slight change of only 1MPa in the middle of RCB span, as shown in Figure 19b. When the RCB reaches a VD of 40kN, they begin to show changes as the value of 2ϕ22 increases. Additionally, it is worth noting that 3ϕ22 differs significantly from 2ϕ22. This demonstrates the effectiveness of increasing the quantity of TSB in the tensile zone.

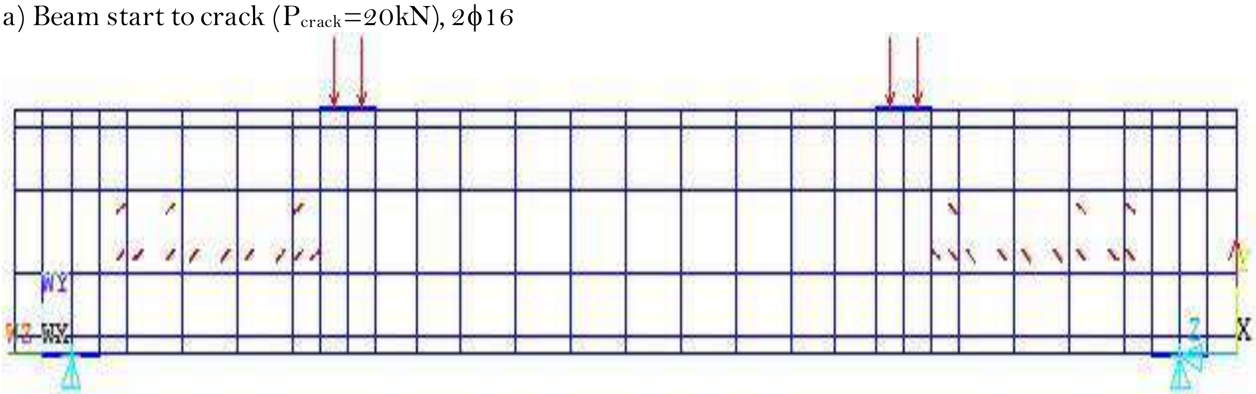
4.4 Investigate the Effects of the Diameter of the TSB

The RCB has a SF content of 2%. The stirrups are ϕ6a100. The TSB consists of 2ϕ22, 2ϕ16, and 2ϕ30 bars. The SF concrete layers are H1=H2= 0cm, and the NC layer is H3=10cm indicating the nonlinear behavior of the materials.

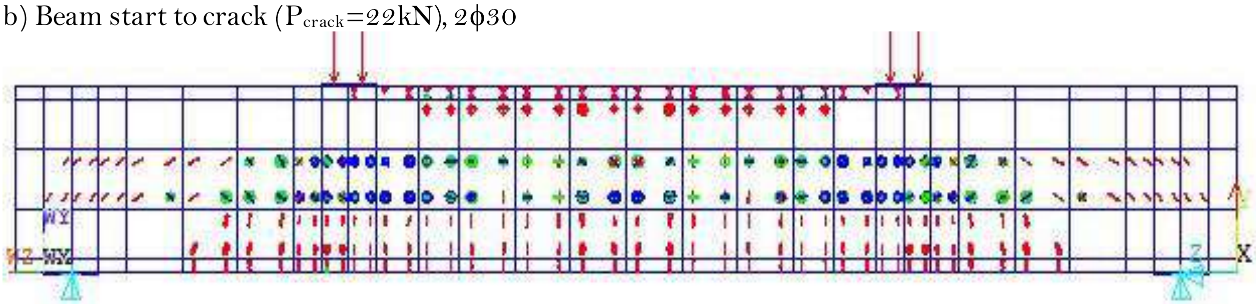
The RCB cracks and suffers damage when the diameter of the TSB is altered, as shown in Figure 20.



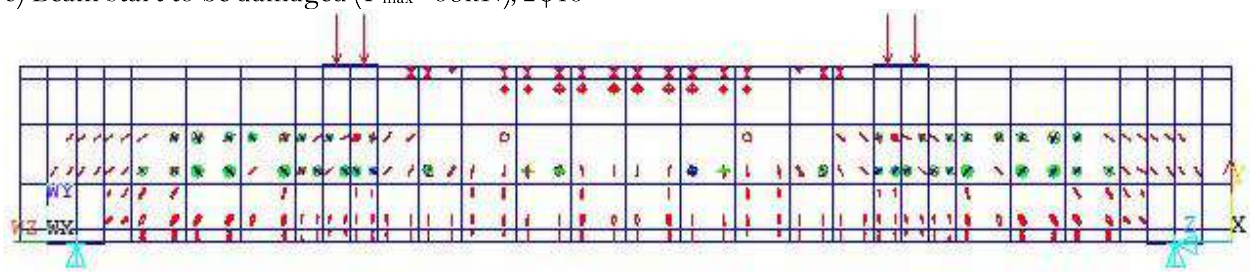
a) Beam start to crack (P_{crack}=20kN), 2ϕ16



b) Beam start to crack (P_{crack}=22kN), 2ϕ30



c) Beam start to be damaged (P_{max}=59kN), 2ϕ16



d) The beam starts to be damaged (P_{max}=82kN), 2ϕ30

Figure 20.
Beams start to crack and be damaged when diameter changed.

Comment: The cracks in Figures20aand 20b initially appear in the NC layer. Cracking occurs when the load is applied, and the diameter of the TSB remains relatively unchanged. The limit of the damaged beams varies significantly. Specifically, 2ϕ16 beams have a limit of 59kN, 2ϕ22 beams have a limit of 72kN, and 2ϕ30 beams have a limit of 82kN. The bearing capacity increases to 23kN between 2ϕ16 and 2ϕ30. However, there is not a significant change in the number of cracks.
The relationships between L-CS, L-TS, and L-VD are shown in Figure 21.

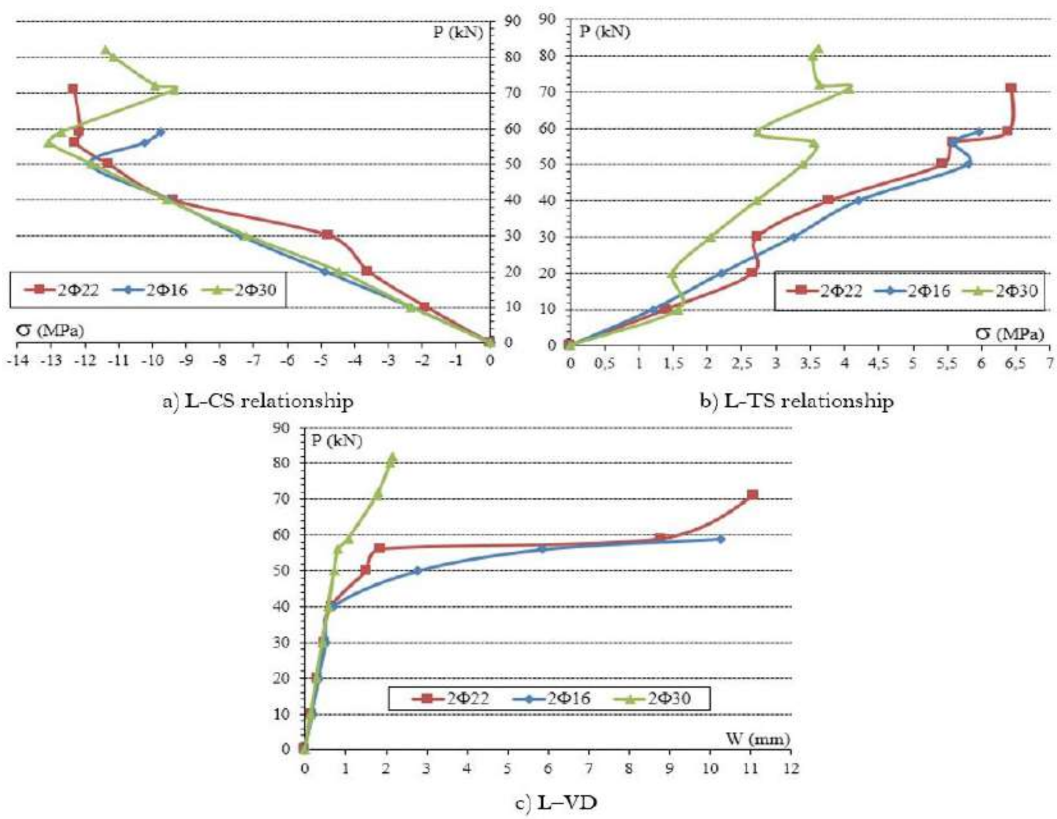


Figure 21.
Relationships of load - stress, L – VD.

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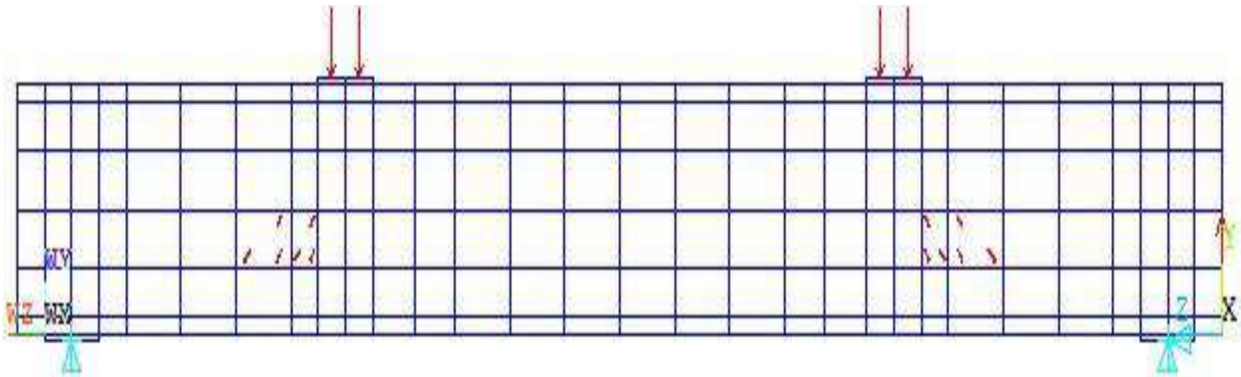
Comment: When the diameter of the TSB is changed, the stresses in the compression zone show minimal changes (refer to Figure 21a) for TS of 2ϕ16 and 2ϕ22. However, for the TS of 2ϕ30, there is variation, with a difference of 3MPa in the TS (as shown in Figure 21b). In the same way, the VD in the beams also varies when the load exceeds 40kN. During this period, beams of 2ϕ16 and 2ϕ22 show a higher displacement value than those of 2ϕ30.

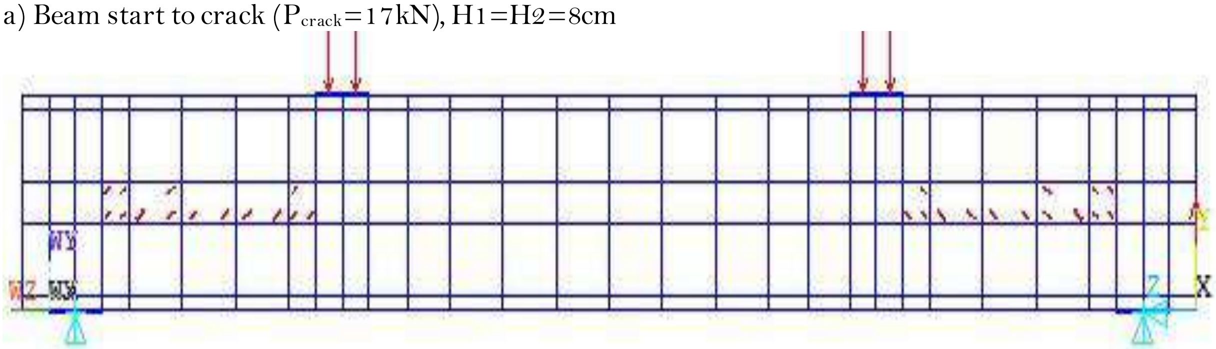
4.5. Investigate the Effect of a SF Concrete Layer that has the Same Thickness

The RCB has a SF content of 2%, stirrups isϕ6a100. The beam also contains 2ϕ22 TSB and 2ϕ10 compression steel bars. The thickness of the concrete layers of SFs is currently H1=H2=H=10cm, but will be changed to H1=H2=H=8cm and H1=H2=H=12cm in non-linear analysis.

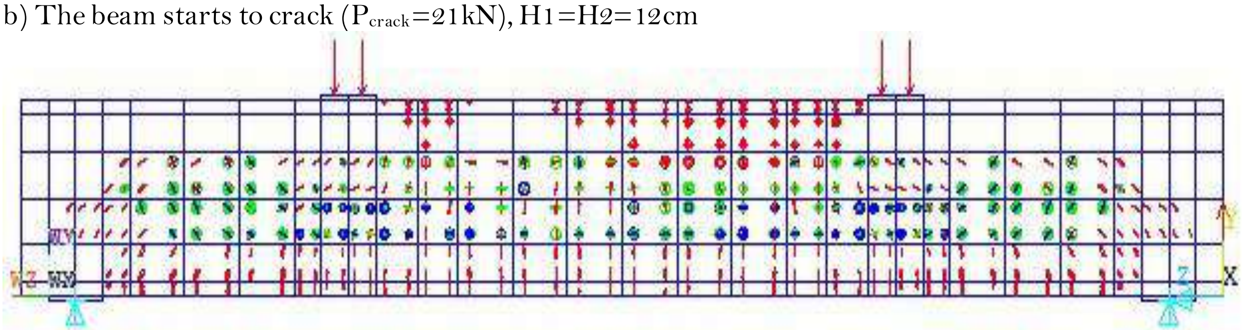
The RCB crack and damage when SF concrete layer changed, as shown in Figure 22.



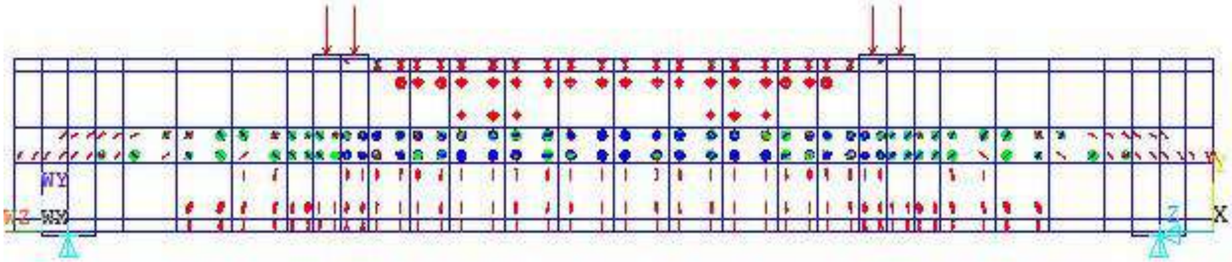
a) Beam start to crack (P_{crack}=17kN), H1=H2=8cm



b) The beam starts to crack (P_{crack}=21kN), H1=H2=12cm



c) The beam starts to damage (Pmax = 62kN), H1 = H2 = 8 cm



d) The beam starts to be damaged (P_{max}=78kN), H1=H2=12cm

Figure 22.
RCB when the SFCL changed.

Comment: Increasing the thickness of SF concrete layers from 8 to 12cm results in an improvement in the beam's bearing capacity from 17 to 21kN. Furthermore, cracks begin to appear in the RCB. In the same way, the beams increased from 62kN to 78kN when damaged. Additionally, there was a significant decrease in the number of cracks observed in the RCB. It is worth noting that in both cases, the NC layer of the beam showed cracking, as shown in Figure 22.

The relationships between L-CS, L-TS, and L-VD are shown in Figure 23.

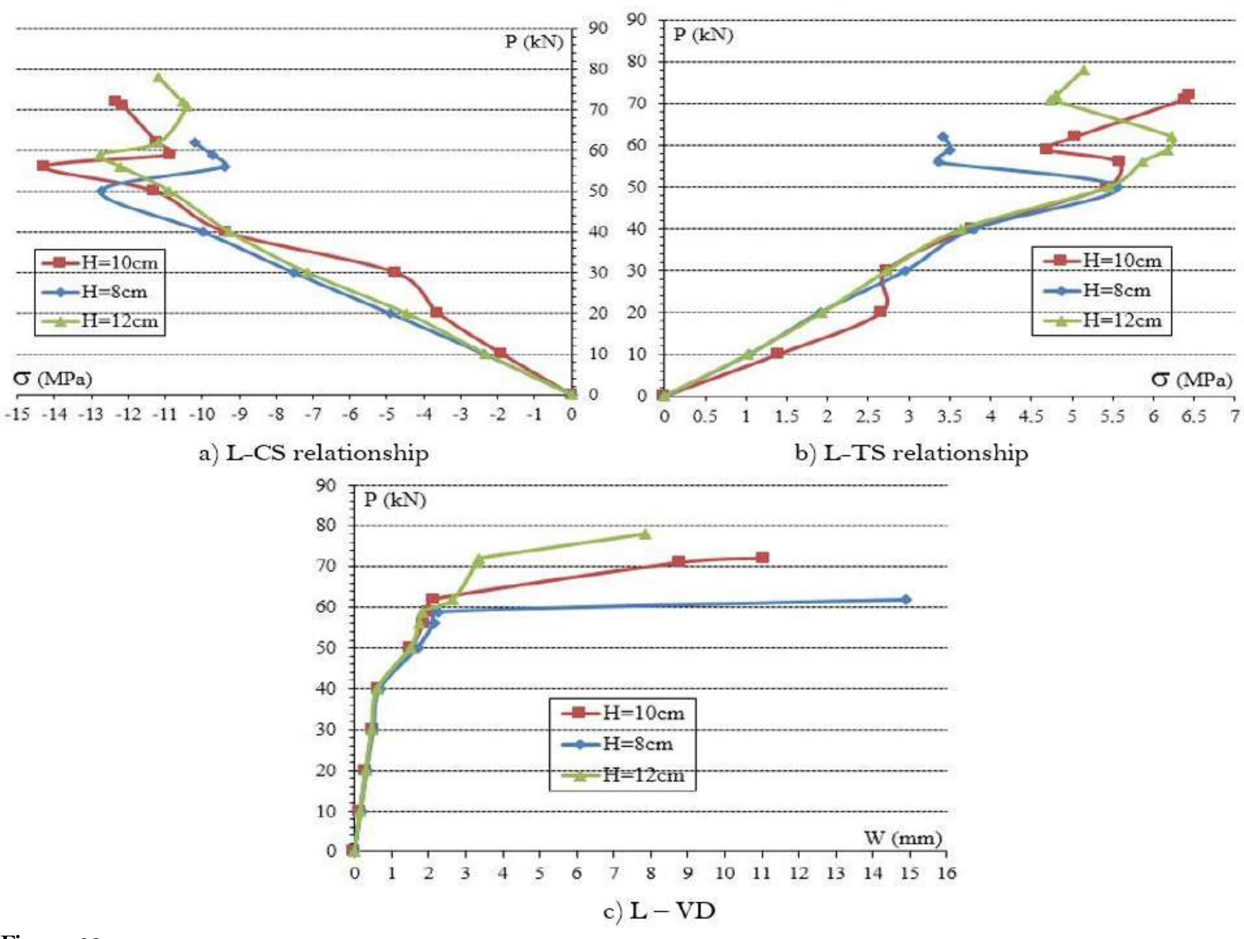


Figure 23.
Relationships of load - stress, L – VD.

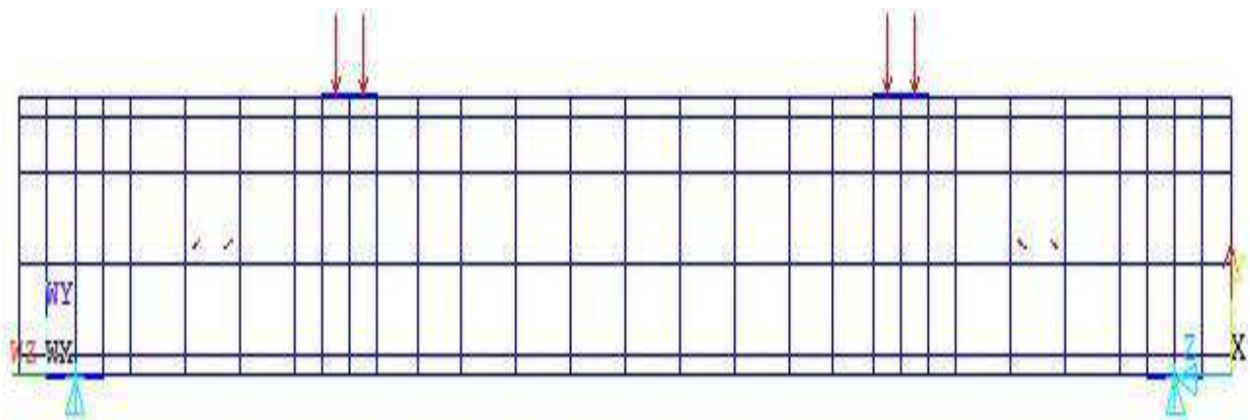
Comment: In Figure 23, the SF concrete layer is changed without modifying the size of the RCB, the stresses and VD in the RCB remain unchanged while the load is varied from 0kN to 50kN. The beams undergo a change when the load exceeds this value. The stresses and VDs of beams with a small thickness of SF concrete layer (H1=H2=H=8cm) undergo changes.

4.6 Investigate how the Thickness of a SF Concrete Layer Affects its Performance

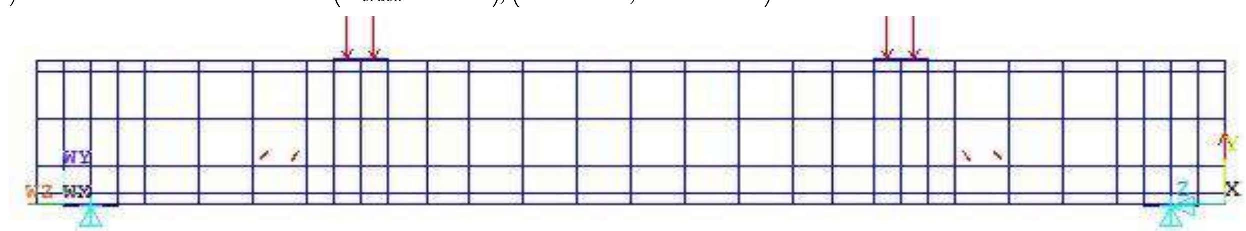
The beam contains SF in the concrete, with a content of 2%. The stirrups are ϕ6a100. The SF concrete layers are H1=H2=H=10cm, but they can be changed to H1=8cm and H2=12cm or H1=12cm and H2=8cm by non-linear analysis.

The SF concrete layer at the bottom H1, the thickness of the SF concrete layer at the top of H2.

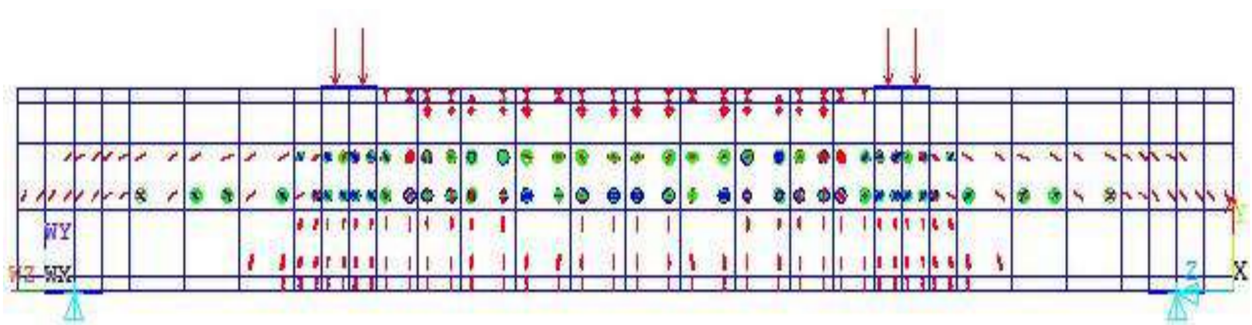
The RCB crack and damage increased when the SF concrete layer changed, as shown in Figure 24.



a) The beam starts to crack (P_{crack}=23kN), (H1=8cm, H2=12cm)



b) The beam starts to crack (P_{crack}=18kN), (H1=12cm, H2=8cm)



c) Beam start to be damaged (P_{max}=64kN), (H1=8cm, H2=12cm)

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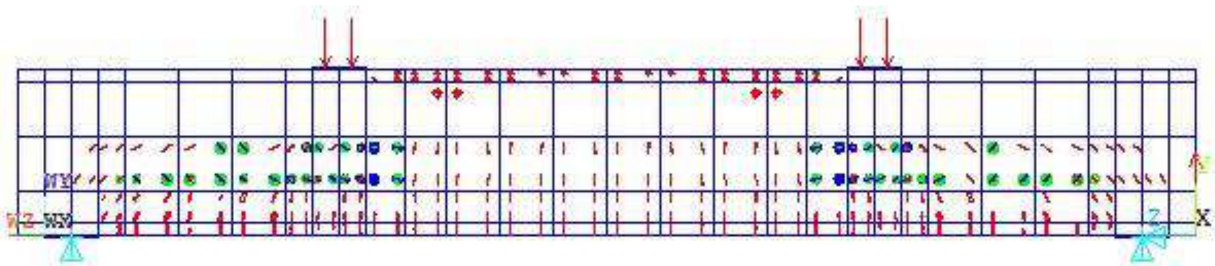

d) The beam begins to be damaged (P_{max}=67kN), (H1=12cm, H2=8cm)

Figure 24.
RCB when SFCL changed.

Comment: In Figure 24, the SF concrete layer on top is thicker than the SF concrete layer below. Specifically, the thickness of the top layer (H1) is 8cm, while the thickness of the bottom layer (H2) is 12 cm. As a result of this configuration, the bearing capacity of the beam increases from 18kN to 23kN when the thicknesses are reversed (H1=12cm, H2=8cm). However, it is important to note that this change in configuration also leads to the formation of cracks in the beam. When the beam is gradually damaged, a corresponding change is observed. The thickness of the SF concrete layer at the bottom becomes greater than the thickness of the SF concrete layer at the top. This increase in thickness leads to an improvement in bearing capacity, which increases from 64kN to 67kN. These findings suggest that increasing the thickness of the SFCL improves its performance.

The relationships between L-CS, L-TS, and L-VD are shown in Figure 25.

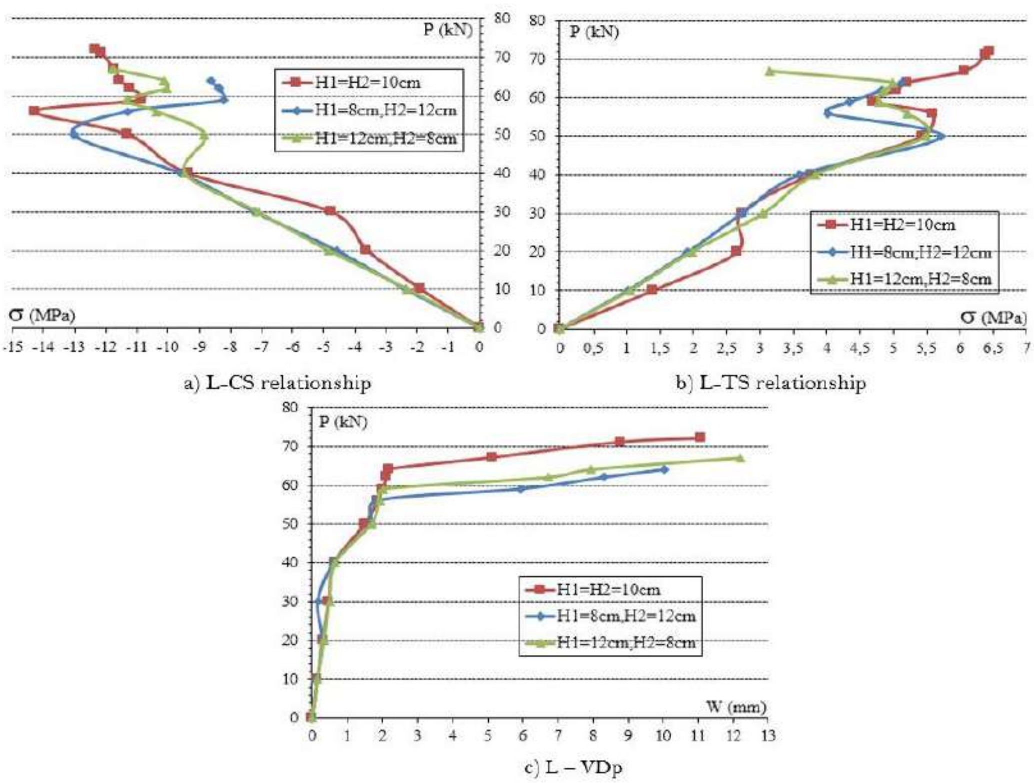

Figure 25.
Relationships of load - stress, L – VD.

Comment: In Figure 25, it can be observed that the change in thickness of various layers of SF concrete does not result in significant changes in the values of CS, TS, and VD. However, it is observed that when the heights of H1 and H2 are both 10cm, the beam shows a higher bearing capacity compared to other types. This is followed by beams with heights of H1=12cm and H2=8cm, and finally girders with heights of H1=8cm and H2=12cm.

According to this study, another experimental investigation of two-layer RCB [13, 14] demonstrates that the cracks observed in the tested RCB share similar characteristics in terms of shape, formation, and development of the crack. This is shown in Figures 26 and 27. This study uses ANSYS numerical simulation [18] to investigate crack formation and development in 3-layer RCB, as shown in Figure 28.

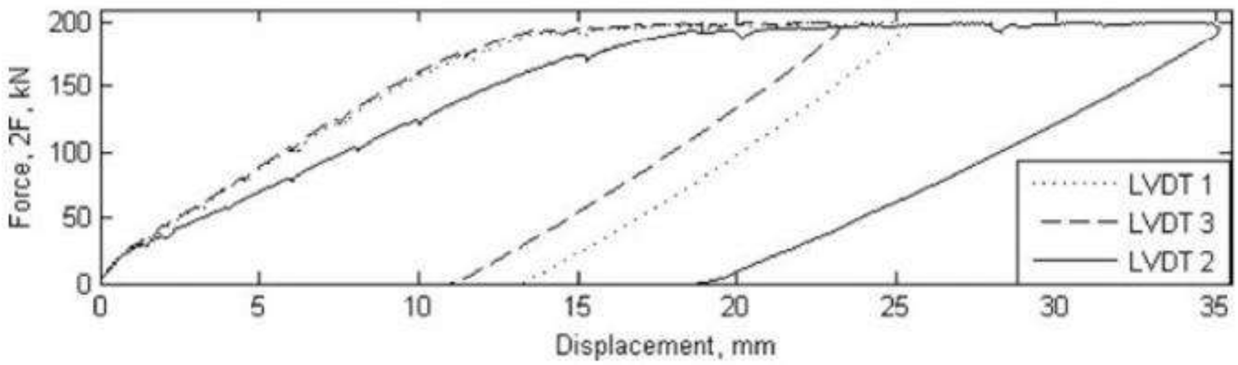

Figure 26.
Beam deflections.
Source: Iskhakov, et al. [13]

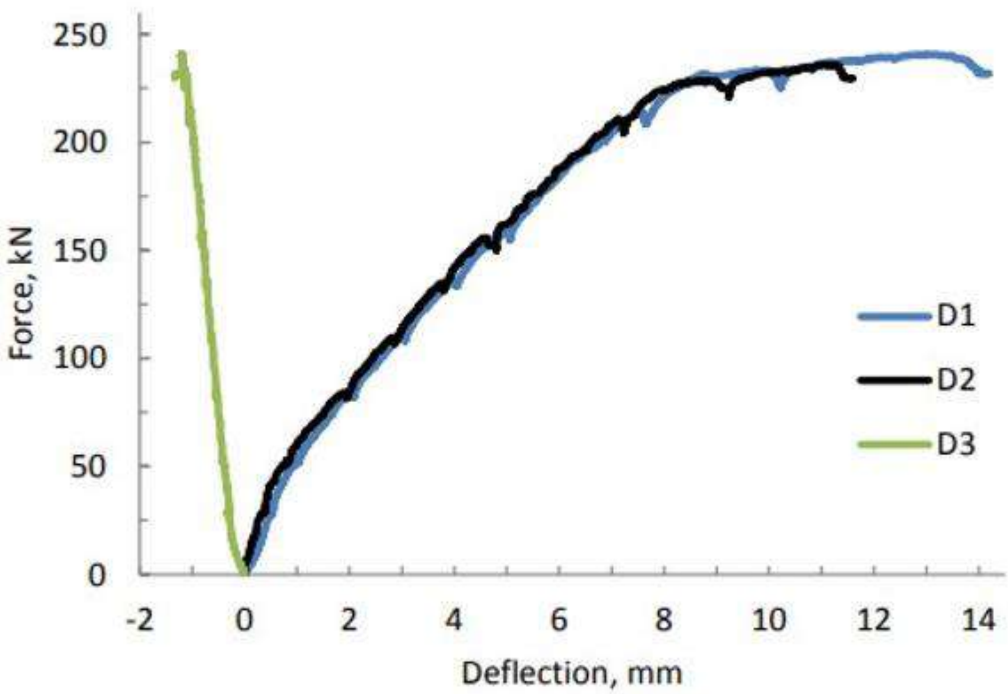

Figure 27.
Load deflection curves in the middle of the spans (D1 and D2) and the mid support uplift (D3).
Source: Iskhakov, et al. [14].

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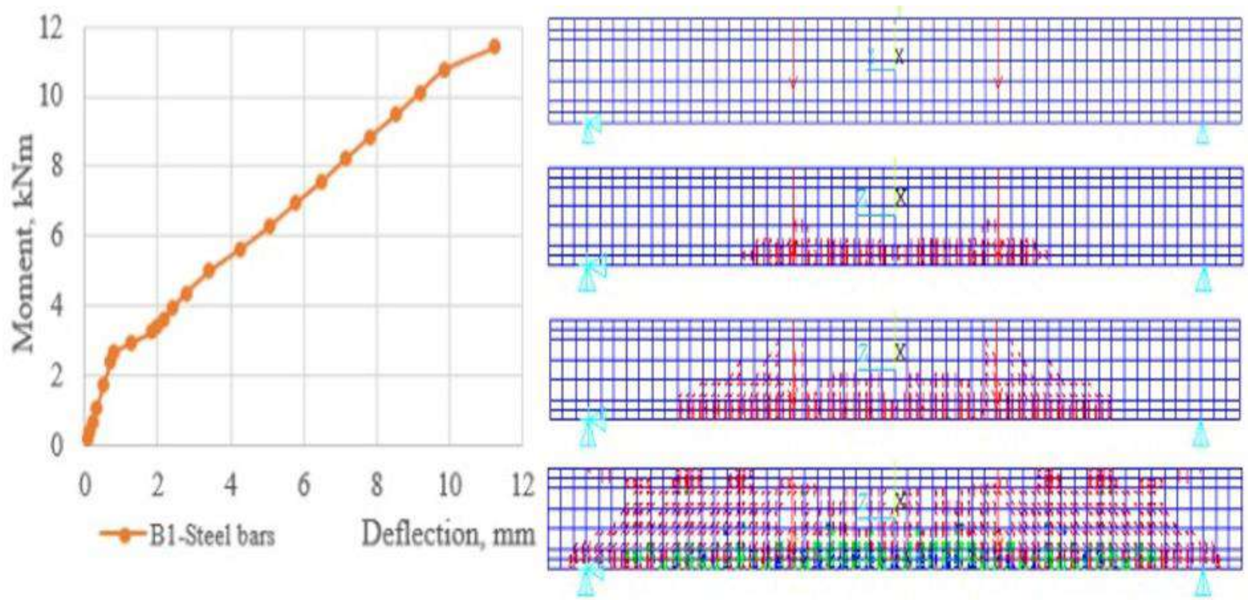

Figure 28.
Moment deflection curve and crack pattern.
Source: Dinh, et al. [18].

5. Conclusion

Based on the results of the study, the following conclusions can be drawn:

1. The addition of SFs to concrete resulted in a significant reduction in the number of cracks. When the SF content in the concrete is increased to 4%, the beam begins to experience damage at a load value that is at least twice as high as the load value for other SF contents.
2. The effectiveness of the beam performance was enhanced by extending the distance between bars to 100 mm. The reason for this is that the steel content in the concrete exceeds the permitted limits.
3. Increasing the number of TSBs and the diameter of these bars improves the load-bearing ability of the beams significantly, thereby reducing the occurrence of cracks. In this case, the increase in both the number and diameter of the steel bars in the tensile region has a significant impact on the tensile stress.
4. There is minimal change in the stress value and VD when altering the thickness of the SF concrete layers.
5. The survey conducted on the input parameters of three-layered SF RCB reveals that these parameters have a significant impact on the stress-strain state of the beam. This survey can help modify the parameters needed to restrict or improve specific values more appropriately for designing three-layered steel-RCBs.

Nomenclature:
RC = Reinforced concrete.
SF = Steel fiber.
SFRC = Steel fiberreinforced concrete.
FEM = finite element method
ANSYS = AnalysisSYStem.
RCB = Reinforced concrete beam.
VD = Vertical displacement.
CL = Concrete layer.

NSC = Normal-strength concrete.
HSC = High-strength concrete.
TLB= Two-layer beams.
CTLB= Concrete T-Beam with Lateral Bracing.
PTLB= Prestressed thin laminated beams.
TS = Tensile steel.
CS = Compression stress.
L = load.

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The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Competing Interests:
The author declares that there are no conflicts of interests regarding the publication of this paper.

References

[1] V. T. Ngo, T. Q. K. Lam, T. M. D. Do, and T. C. Nguyen, "Nano concrete aggregation with steel fibers: A problem to enhance the tensile strength of concrete," presented at the E3S Web of Conferences, 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. 93, no. 1, pp. 27-34, 2020.
[3] T. Q. K. Lam and T. M. D. Do, "Experiment and simulation analysis on full scale double-layer concrete shell," *Computers and Concrete*, vol. 31, no. 1, pp. 9-21, 2023.
[4] T. M. D. Do *et al.*, "Initial parameters affecting the multilayer doubly curved concrete shell roof," *Advances in Civil Engineering*, vol. 2021, pp. 1-18, 2021. https://doi.org/10.1155/2021/7999103
[5] A. Chepurnenko, "Calculation of three-layer shallow shells taking into account nonlinear creep," *Magazine of Civil Engineering*, vol. 76, no. 8, pp. 156-68, 2017. https://doi.org/10.1016/j.proeng.2016.11.810
[6] T. Q. K. Lam, D. D. T. My, T. C. Nguyen, and T. P. Huynh, "Numerical simulation and experiment on steel fiber concrete beams," In Journal of Physics: Conference Series (Vol. 1425, No. 1, p. 012007). IOP Publishing, 2019.
[7] A. Fatih, K. M. Metin, Y. Canan, A. Kamuran, and D. Adem, "Experimental investigation of RCBwith and without steel fiber under explosive loading," *Indian Journal of Engineering & Materials Sciences*, vol. 14, pp. 419-426 2007.
[8] A. Gokmen, "Buckling analysis of delaminated composite beams," *Indian Journal of Engineering & Materials Sciences*, vol. 20, pp. 276-282, 2013.
[9] S. Adam 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. https://doi.org/10.3311/ppci.10910
[10] 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. https://doi.org/10.1016/j.matdes.2006.03.017
[11] V. Travush, D. Konin, and A. Krylov, "Strength of reinforced concrete beams of high-performance concrete and fiber reinforced concrete," *Magazine of Civil Engineering*, vol. 77, no. 1, pp. 90-100, 2018.
[12] I. Iskhakov and Y. Ribakov, "Two-layer beams from normal and fibered high strength concrete," presented at the Conference: Modern Methods and Advances in Structural Engineering and Construction Switzerland, 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, 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 K. Stefan, "Experimental investigation of prestressed two layer reinforced concrete beams," *Structural Concrete*, vol. 18, no. 1, pp. 1-12, 2019.
[16] A. P. M. Mirza, K. S. Rizaldy, P. Poppy, I. K. Fuad, and B. N. R. P. Andika, "Finite element analysis of the bending moment-curvature of the double-layered graded concrete beam," presented at the In IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2019.
[17] D. T. Vu and A. K. Elena, "Influence of geometrical parameters of the cross section, strength and deformability of the materials used on stress-strain state of three-layered reinforced concrete," In IOP Conference Series: Materials Science and Engineering (Vol. 661, No. 1, p. 012121). IOP Publishing, 2019.
[18] T. V. Dinh, K. Elena, K. Yuliya, and H. N. Huy, "Finite element analysis of three-layer concrete beam with composite reinforcement," presented at the E3S Web of Conferences, 2019.
[19] L. T. Q. Khai, "Design parameters of steel fiber concrete beams," *Magazine of Civil Engineering*, vol. 2, no. 102, p. 10207, 2021.
[20] F. I. Olmedo, J. Valivonis, and A. Cobo, "Experimental study of multilayer beams of lightweight concrete and normal concrete," *Procedia Engineering*, vol. 172, pp. 808 – 815, 2017.
[21] F. Ranjbaran, O. Rezayfar, and R. Mirzababai, "Experimental investigation of steel fiber-reinforced concrete beams under cyclic loading," *International Journal of Advanced Structural Engineering*, vol. 10, pp. 49-60, 2018. https://doi.org/10.1007/s40091-018-0177-1