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Design parameters of steel fiber concrete beams

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Keywords: steel fiber concrete, steel fiber content, nonlinear material, crack, stress-strain, numerical simulation

Abstract. In the study of steel fiber concrete beams, there are many design parameters that affecting stress-strain state, cracks formation and cracks development, etc. in beams. Changes of these design parameters will affect bearing capacity, displacement and cracks in beams. ANSYS can simulate the work of beams when design parameters be changed. Therefore, in this paper, the authors used ANSYS numerical simulation method to simulate design parameters of beams which be changed, to bearing capacity such as: steel fiber content in concrete, shear steel stirrups spacing at the ends of the beam, number of tensile steel bars, diameter of tensile steel bars, considering the nonlinear element of the materials, etc to consider the cracks formation and cracks development in beams from the beginning of loading to the damaged beams and then build the load and stress relationship, load and vertical displacement relationship in steel fiber concrete beams. Beam simulation results show that changes of these design parameters have affected the bearing capacity, stress-strain state, cracks formation and cracks development of beams, with the beams when increasing the content of steel fibers in concrete, increasing the number of tensile steel bars, increasing the diameter of tensile steel etc., making the beams reduce cracks, increase the bearing capacity, etc. for the beams. Simulation results were also compared with experimental methods. So, the study of these design parameters helps the design of steel fiber concrete beam structures to withstand impact loads and limit cracks in beams.

1. Introduction

Fiber concrete has been researched and widely applied in many types of constructions such as civil works, bridges, underground constructions, etc., with many different types of structures such as: basalt fiber concrete [1], crumb rubber in steel fiber beam [2], steel fiber concrete [3], steel fiber concrete of curved shells [4–6], nano concrete or high-performance concrete with steel fiber [7–10], self-compacting geopolymer concrete with and without GGBFS and steel fiber [11], etc. In particular, steel fiber concrete has been researched and widely applied, especially in steel fiber concrete beams. The studies go from analyzing static problems [12], abradability of steel fiber concrete [13], shear behavior, bending resistance, failure mechanisms, etc., [14–16] to use experimental method and numerical simulation on steel-reinforced concrete beams [17–19].

In the steel fiber concrete beams analyzed above, many authors have considered the factors affecting to shear strength of beams [20–21], to flexural behavior [22], to the strength of concrete [23–24], to fracture characteristics [25–26], to improve the quality of mass concrete [27], in study of numerical simulation and experiment on steel fiber concrete beams [28] investigated the effect of 0 %, 4 % and 8 % steel fiber content on stress, deformation and displacement in steel fiber concrete beams, or some another studies [29–34], etc.

In order to determine the stress-strain state and cracks in beams when design parameters be changed, it is necessary to study design parameters such as: steel fiber content in concrete, shear steel stirrups spacing at the ends of the beam, number of tensile steel bars, diameter of tensile steel bars, considering the nonlinear element analysis of the material, etc. To solve the mentioned main problems above, this paper presented ANSYS numerical simulation method to consider the cracks formation and cracks development in beams from the beginning of loading to the damaged beams and then build the load and stress relationship, load and vertical displacement relationship in steel fiber concrete beams with beam section 150×200×2200 mm and simulation results were compared with experimental methods.

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2. Materials and methods

2.1. Parameters in model

Beam of 150×200×2200 mm size, shear steel stirrups spacing at the ends of the beam, ⌀6, changed from 50 mm to 100 mm, shear steel stirrups spacing at the middle of the beam, ⌀6a200, constant. Tensile steel diameter changed from ⌀12 to ⌀20 and ⌀25, number of tensile steel bars changed from 2 bars to 3 bars and 4 bars. Fixed compression steel bars are ⌀10.

Concrete B20, all beams, fiber steel content were studied with 0 % to 4 % and 8 % by volume. Fiber steel content with 0 % that means normal reinforced concrete beams without steel fibers, in order to consider the impact of steel fiber content on normal reinforced concrete beams.

Load P is applied to the steel plate 140×140×6 mm, increased from 0 kN until the beam is damaged, each load level is increased by 5 kN, shown in Fig. 1.

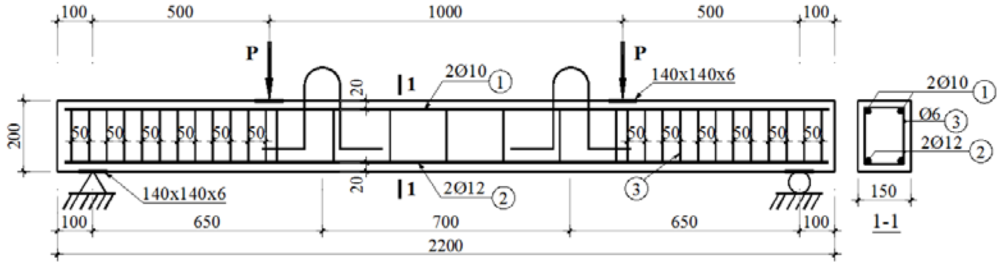


Figure 1. Reinforced concrete beam in the study.

2.2. Input parameters in ANSYS

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

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

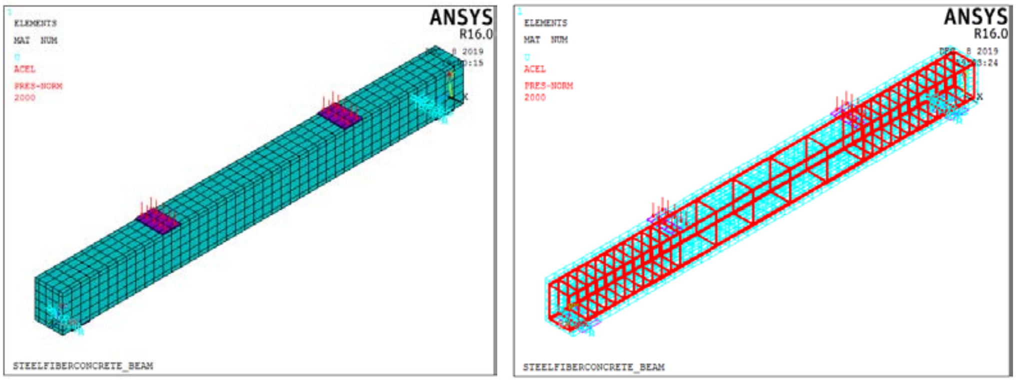
Constructing a finite element model for beams:

– Concrete simulation element: SOLID65 element, which is a specialized simulation of concrete materials, can simulate reinforcement in concrete with the phenomenon of cracking and compression, nonlinear material definition. This is a 3D element with 8 buttons. In SOLID65, it is allowed to declare steel fiber content through concrete reinforcement constant as a percentage.
– Steel bars element: used beam 188 element: is an element used to model the reinforcement in beams, used as a basis for Timosenko beams, the element consists of 2 nodes with 6 degrees of freedom at each node.

Material model: stress-strain model of concrete when tensile and compression: we have a model of Hognestad, a model of Todeschini, a model of Kent and Park, a model of Kachlakev, etc. Based on the survey of stress-strain models of compressive concrete presented above, we choose concrete model under compression according to Kachlakev model. Model of stress-strain of concrete under tensile stress, this model has been predefined in ANSYS.

Destructive standards: Willam and Warnke's destructive standard is used in this study and are defined in ANSYS.

Meshing for models, boundary conditions and loads: due to the simple beam structure, meshing (VSWEEP, ALL) with mesh shapes is divided by 3D blocks available in ANSYS and optimized element size, shown in Fig. 2.



a) Reinforced concrete beam model **b) Steel bar model and loads**

Figure 2. Model, meshing, boundary conditions and loads applied to the beam.

Input parameters for the model: In ANSYS to enter the input parameters for SOLID65 concrete element, we must enter the following 8 basic parameters:

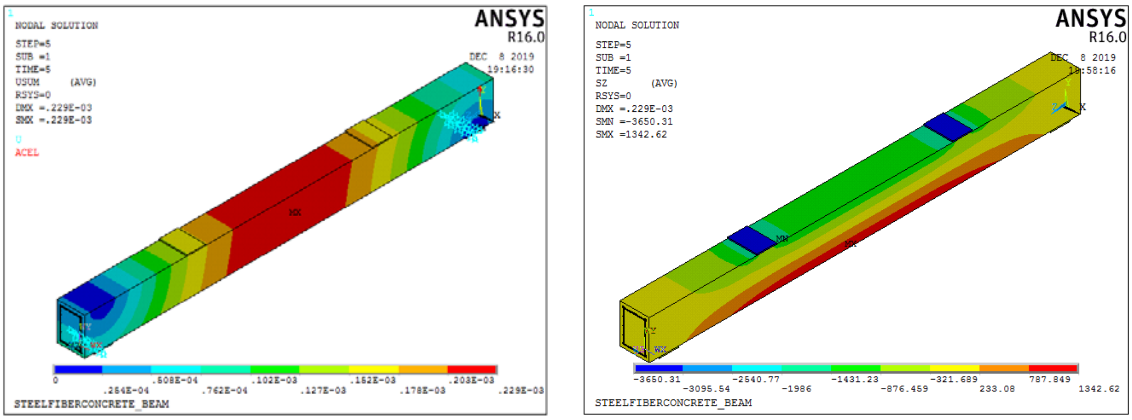
1. Shear force transmission coefficient when the crack is opened (β_0)
2. Shear force transmission coefficient when cracking is closed (β_C)
3. Cracking stress when tensile (f_r)
4. Compression stress $(f_C^{'})$
5. Weak reduction coefficient due to cracking when tensile
6. Modulus (E_C)
7. Poisson's coefficient: v
8. Stress-atrain relationship curve of concrete, considered the nonlinearity of the material.

3. Results and Discussion

3.1. Survey of steel fiber content in concrete

Tensile steel bars are 2⌀12, shear steel stirrups spacing at the ends of the beam is 50 mm, linear material. Steel fiber content in concrete are changed from μ = 0 % to 4 % and 8 %.

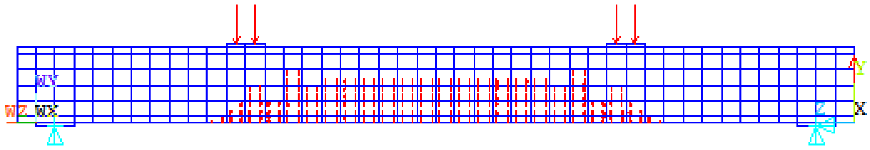
The color spectrum will help us to observe changed values, with the color spectrum of vertical displacement and the color spectrum of stresses in beams are shown in the Fig. 3.



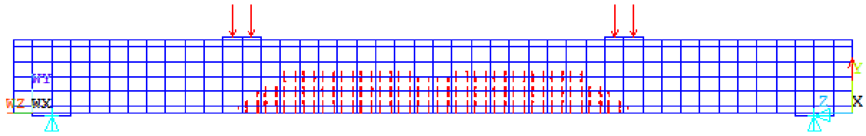
a) Color spectrum of vertical displacement **b) Color spectrum of stresses**

Figure 3. Color spectrum of vertical displacement and stresses values on beam.

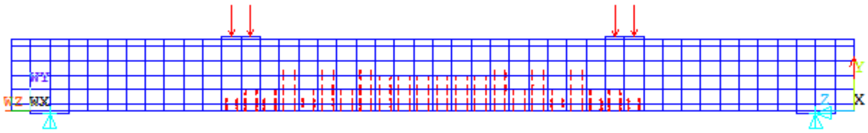
The beams begin to appear cracks when the steel fiber content are changed, are shown in Fig. 4.



a) Steel fiber content is 0 % (P_{carck} = 6 kN)



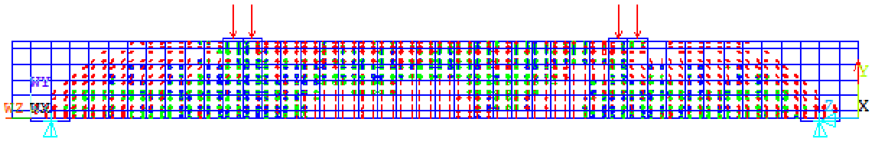
b) Steel fiber content is 4 % (P_{carck} = 6 kN)



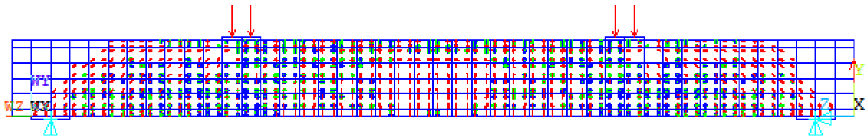
c) Steel fiber content is 8 % (P_{carck} = 5 kN)

Figure 4. Beams begin to appear cracks when the steel fiber content are changed.

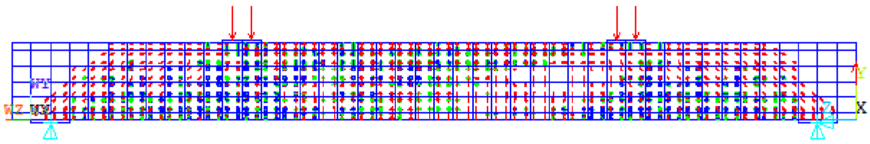
The beams begin to be damaged when the steel fiber content are changed, are shown in Fig. 5.



a) Steel fiber content is 0 % (P_{max} = 34 kN)



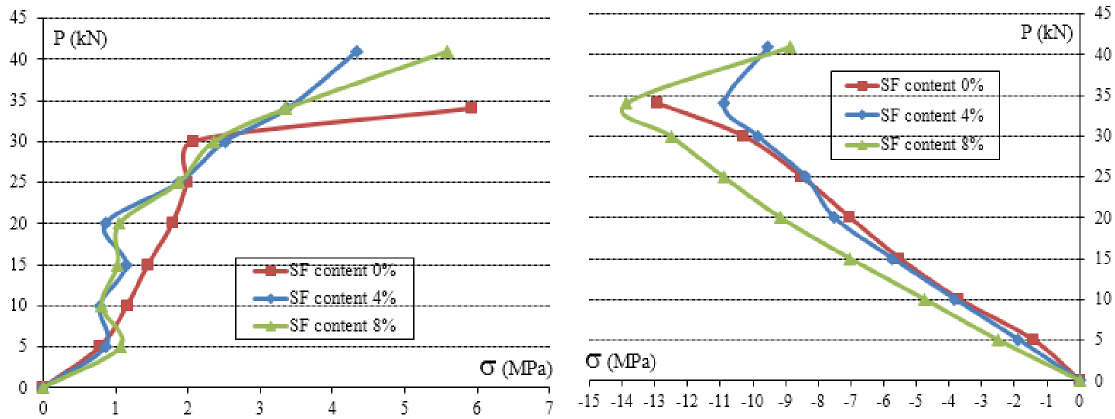
b) Steel fiber content is 4 % (P_{max} = 43 kN)



c) Steel fiber content is 8 % (P_{max} = 41 kN)

Figure 5. Beams begin to be damaged when the steel fiber content are changed.

Load and tensile stress relationship, load and compressive stress relationship when the steel fiber content are changed, shown in Fig. 6.

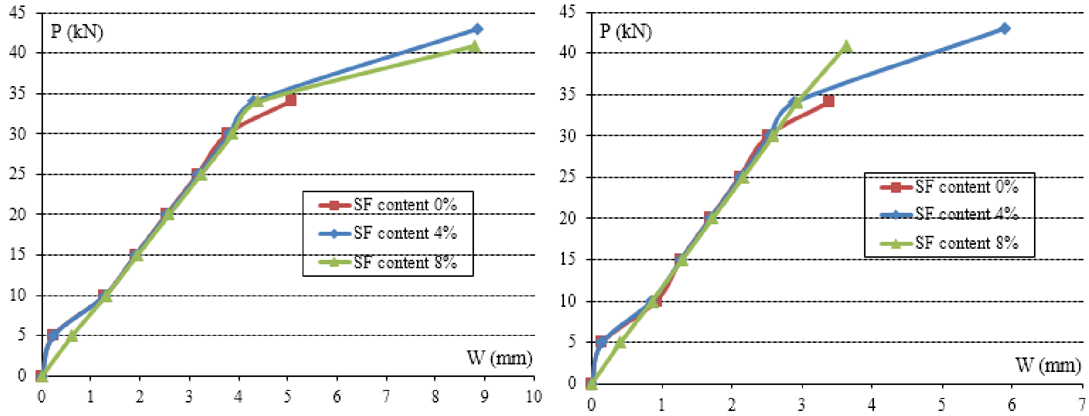


a) Load and tensile stress **b) Load and compressive stress**

Figure 6. Load and stresses relationship when the steel fiber content are changed.

With: SF content is steel fiber content.

Load and vertical displacement relationship at middle and at P forces of beams when the steel fiber content are changed, are shown in Fig. 7.



a) at middle of beams **b) at P forces of beams**

Figure 7. Load and vertical displacement relationship when the steel fiber content are changed.

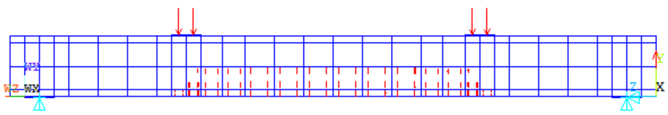
Comment: In Fig. 4, the beams with the steel fiber content in concrete are μ = 0 % and μ = 4 %, all start cracking at the load level P = 6 kN, μ = 8 % cracking earlier and starting to crack at load P = 5 kN. When the beams are damaged, μ = 0 % is damaged at the load of 34 kN, μ = 4 % is damaged at the load of 43 kN, and μ = 8 % is damaged earlier and the damaged at P = 41 kN (Fig. 5). It can be seen that when the steel fiber content is large, surpassing the permissible limit content of steel fibers in concrete, the bearing capacity decreases, in published studies, the steel fiber content ranges from 0.1 % to 4 % according to volume, meaning the beams are brittle. Therefore, do not increase the steel fiber content too high and exceed the permissible limits of steel fibers in concrete.

Load and stresses relationship in beams (Fig. 6), we see in the tensile zone, the steel fiber concrete beams have a tensile stress smaller than normal concrete beams. In contrast, in the compression region, with the participation of steel fibers, the steel fibers have played a role of increasing the bearing capacity for concrete. In relation to the load and vertical displacement in the beams, the steel fibers in the beams did not significantly change the displacement problem, all 3 beams had no significant change (Fig. 7).

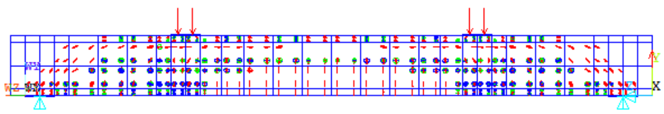
3.2. Survey with shear steel stirrups spacing at the ends of the beam

In this survey, fixed steel fiber content is μ = 4 %, tensile steel diameter 2⌀12 and linear material. Shear steel stirrups spacing at the ends of the beams changed from 50 mm to 100 mm.

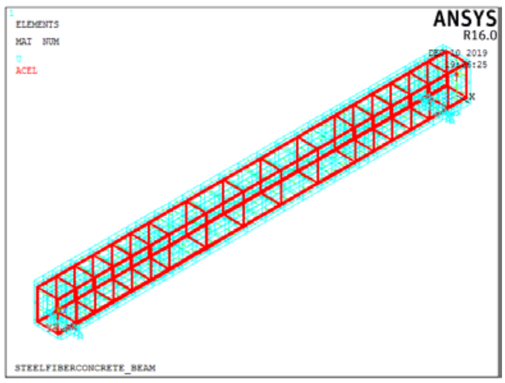
The beams begin to appear cracks and the beams begin to be damaged, are shown in Fig. 8.



a) The beams begin to appear cracks, P_{crack} = 6 kN



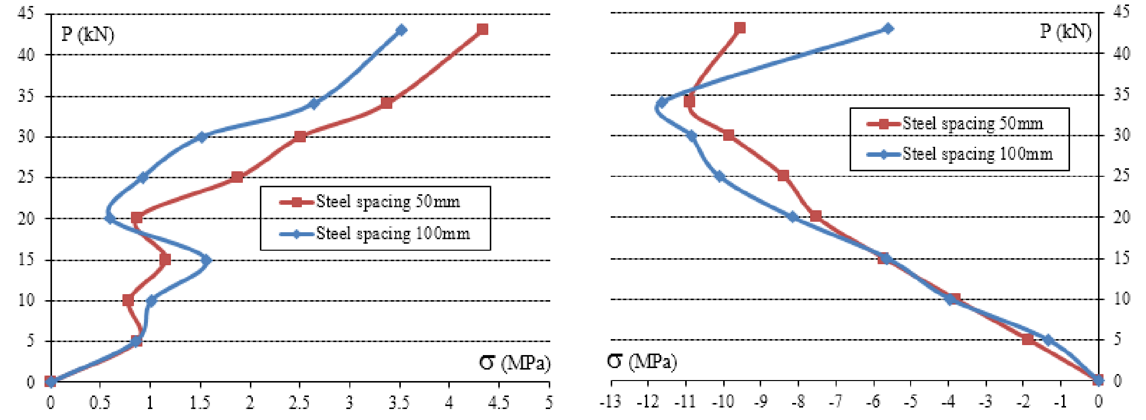
b) the beams begin to be damaged, P_{max} = 45 kN



c) shear steel stirrups spacing is 100 mm

Figure 8. Cracks in beams and shear steel stirrups spacing changed to 100 mm.

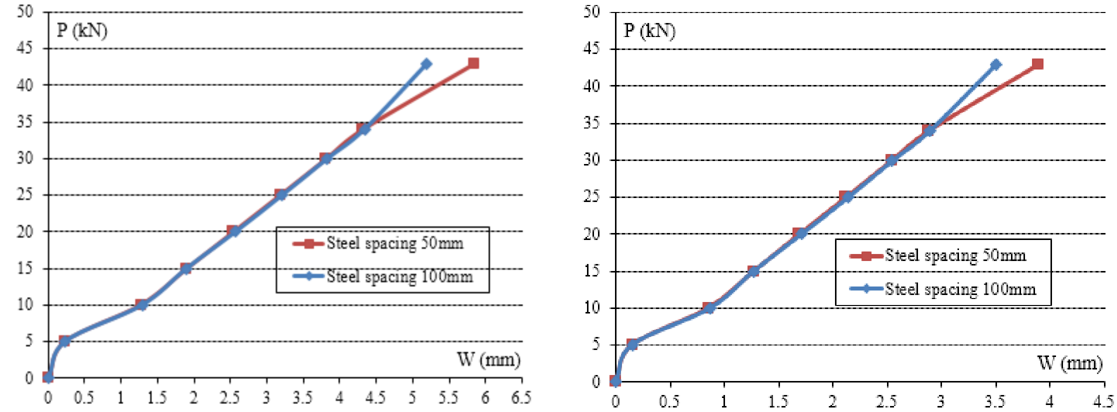
Load and tensile stress relationship, load and compressive stress relationship when shear steel stirrups spacing changed to 100 mm, are shown in Fig. 9.



a) Load and tensile stress relationship **b) Load and compressive stress relationship**

Figure 9. Load and stresses relationship when shear steel stirrups spacing changed.

Load and displacement relationship at middle and at P forces of beams when shear steel stirrups spacing changed to 100 mm, are shown in Fig. 10.



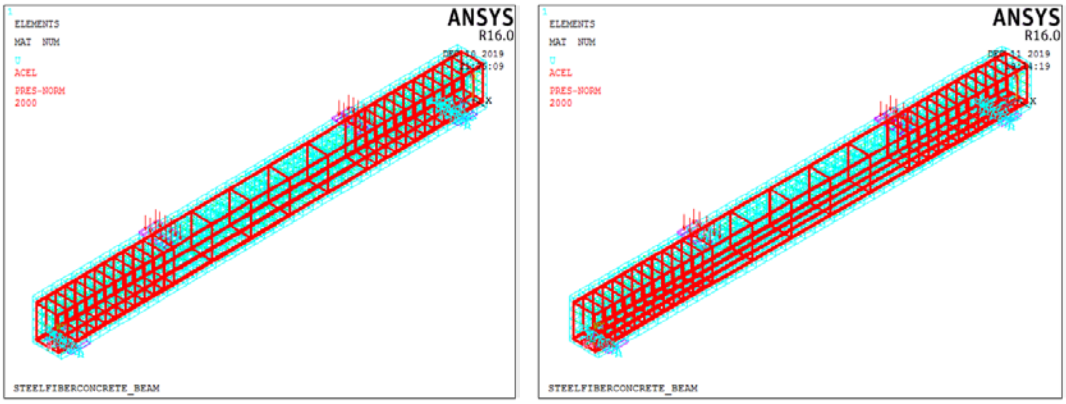
a) at middle of beams **b) at P forces of beams**

Figure 10. Load and displacement relationship of beams when shear steel stirrups spacing changed.

Comment: When shear steel stirrups spacing changed from 50 mm to 100 mm, beams start to crack at P = 6 kN, damaged at P = 45 kN, are shown in Fig. 8, compared to Fig. 4b and Fig. 5b with shear steel stirrups spacing is 50 mm, the cracks start to appear at the same time, but it is damaged later at P = 45 kN. However, the number of cracks decreases. When the content of steel fibers in concrete is still within the limit of steel fiber content in concrete, the stress in the beam will play a role of bearing as well as limiting cracks, stress value changes greatly when passing load level P = 20 kN (Fig. 9). Displacement in beams are not changed much and start to change when the beams pass the P = 35 kN load level (Fig. 10). This is similar to the case when increasing the fiber content exceeds the steel content limit in concrete. Thereby, we should not increase the distance of shear steel too thick.

3.3. Survey of the change in the number of tensile steel bars

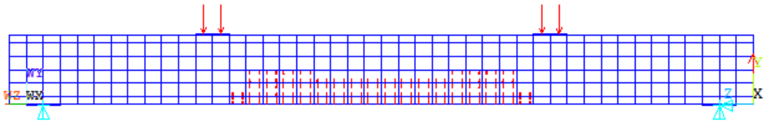
This case still does not change the steel fiber content in concrete beams, μ = 4 %, shear steel stirrups spacing at the ends of beams are 50 mm, linear material. However, this case changed the number of tensile steel bars that increased from 2⌀12 to 3⌀12 and 4⌀12, are shown in Fig. 11.



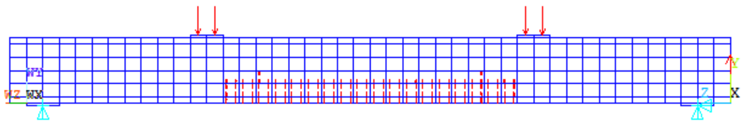
a) Beam model with 3⌀12 b) Beam model with 4⌀12

Figure 11. Beams model with change in the number of tensile steel bars.

Beams start to crack when increasing the number of tensile steel bars, are shown in Fig. 12.



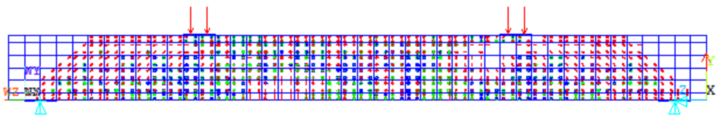
a) Beam model with 3⌀12, P_{crack} = 6 kN



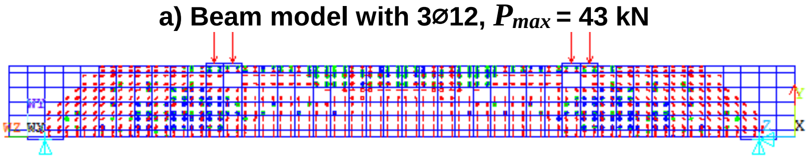
b) Beam model with 4⌀12, P_{crack} = 7 kN

Figure 12. Beams start to crack when increasing the number of tensile steel bars.

Beams are damaged by increasing the number of tensile steel bars, are shown in Fig. 13.



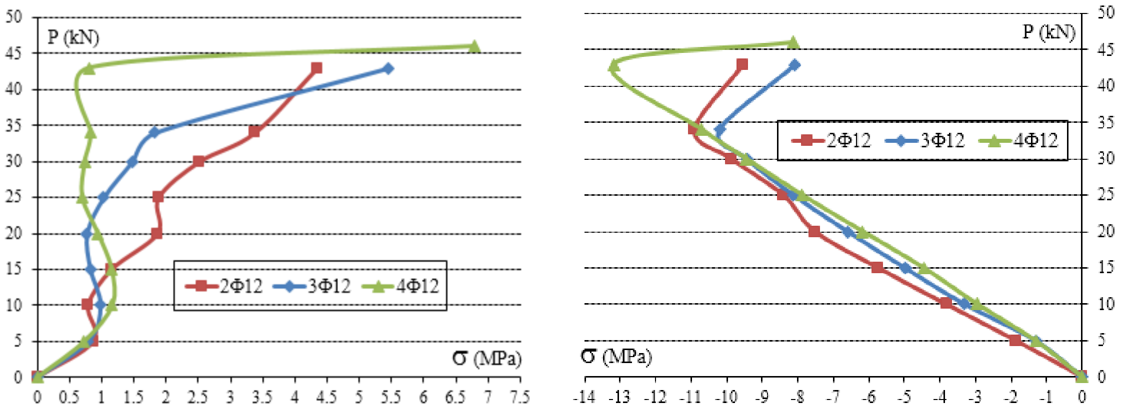
a) Beam model with 3⌀12, P_{max} = 43 kN



b) Beam model with 4⌀12, P_{max} = 46 kN

Figure 13. Beams are damaged by increasing the number of tensile steel bars.

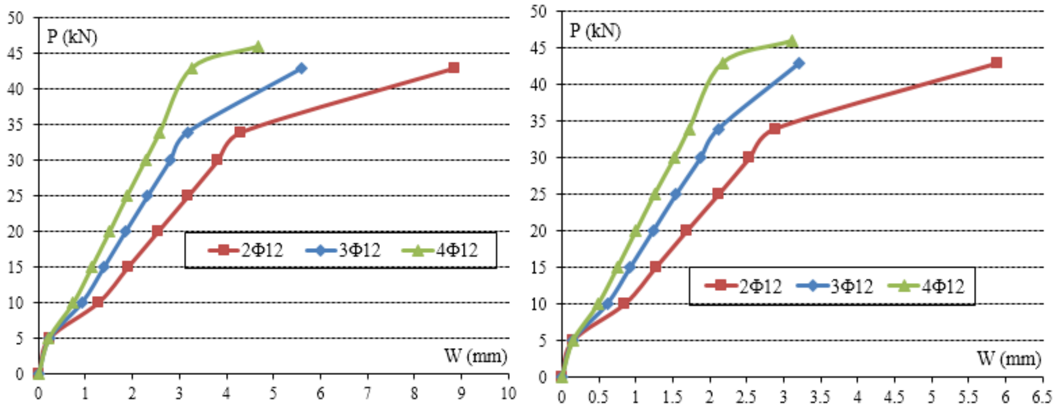
Load and tensile stress relationship, load and compressive stress relationship when increasing the number of tensile steel bars, are shown in Fig. 14.



a) Load and tensile stress b) Load and compressive stress

Figure 14. Load and stress relationship when increasing the number of tensile steel bars.

Load and displacement relationship at middle and at P forces of beams when increasing the number of tensile steel bars, are shown in Fig. 15.



a) at middle of beams **b) at P forces of beams**

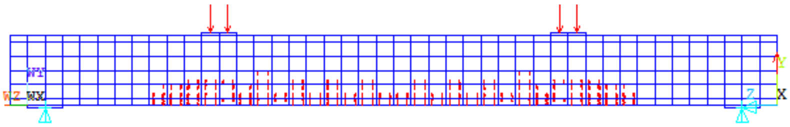
Figure 15. Load and displacement relationship when increasing the number of tensile steel bars.

Comment: when increasing the number of tensile steel bars, fixed μ = 4 %, with 2 beams have 2⌀12 and 3⌀12, crack at P = 6 kN, damaged at P = 43 kN. Beam with 4⌀12, Crack at P = 7 kN (Fig. 12) and damaged at P = 46 kN (Fig. 13). This means that with the increasing in the number of tensile steel bars, the working ability of the beams also increases, so increasing the number of tensile steel bars will increase the bearing capacity of the beam and are shown in (Fig. 14), (Fig. 15). In Fig. 14b, when changing the number of tensile steel bars, the relationship of load and tensile stress will change significantly when passing the P = 15 kN load level.

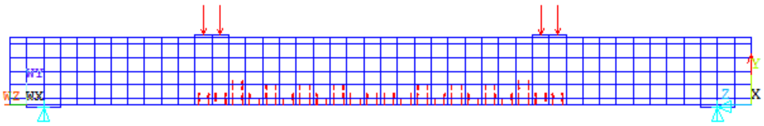
3.4. Survey the affect of diameter of tensile steel bars

This case still does not change the steel fiber content in concrete, μ = 4 %, steel stirrups spacing at the ends of beams are 50 mm, linear material. Diameter of tensile steel bars is changed from 2⌀12 to 2⌀20 and 2⌀25.

Beams begin to crack when increasing the diameter of the tensile steel bars, are shown in Fig. 16.



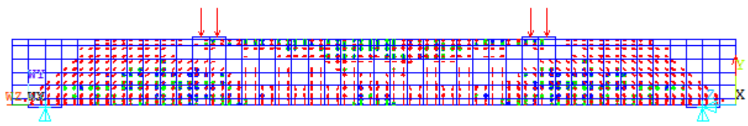
a) Beam model with 2⌀20, P_{crack} = 10 kN



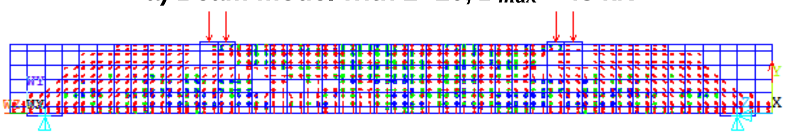
b) Beam model with 2⌀25, P_{crack} = 10 kN

Figure 16. Beams begin to crack when increasing the diameter of the tensile steel bars.

Beams begin to be damaged by increasing the diameter of the tensile steel bars, shown in Fig. 17.



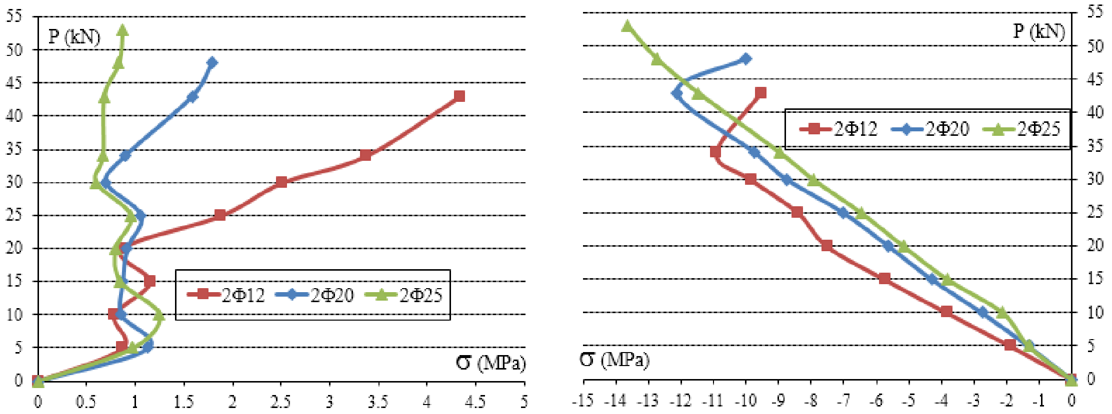
a) Beam model with 2⌀20, P_{max} = 48 kN



b) Beam model with 2⌀25, P_{max} = 53 kN

Figure 17. Beams begin to be damaged by increasing the diameter of the tensile steel bars.

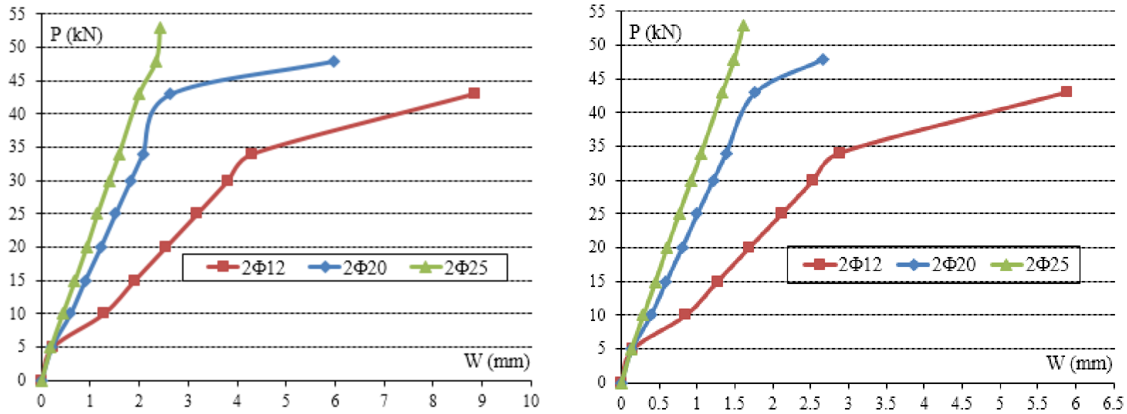
Load and tensile stress relationship, load and compressive stress relationship when increasing the diameter of the tensile steel bars, are shown in Fig. 18.



a) Load and tensile stress **b) Load and compressive stress**

Figure 18. Load and stresses relationship when increasing the diameter of the tensile steel bars.

Load and displacement relationship at middle and at P forces of beams when increasing the diameter of the tensile steel bars, are shown in Fig. 19.



a) at middle of beams **b) at P forces of beams**

Figure 19. Load and displacement relationship when increasing the diameter of the tensile steel bars.

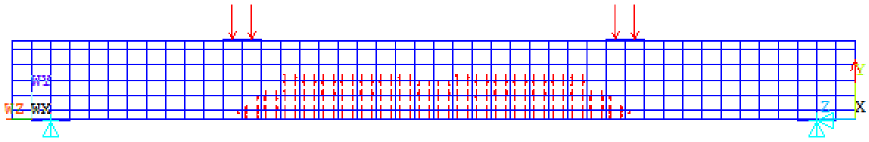
Comment: when increasing the diameter of the tensile steel bars from ⌀20 to ⌀25, all beams crack at P = 10 kN (Fig. 16), damaged at 48 kN of ⌀20 and 53 kN of ⌀25 (Fig. 17). In Fig. 16, beams appear cracks at the same load level but the number of cracks as the diameter of the tensile bar increases, the cracks decrease and is similar to the number of bars increased. Therefore, when increasing the number of tensile steel bars and increasing the diameter of tensile steel, it will make the beams quickly increase bearing capacity and quickly reduce cracks in the beams and load and tensile stress relationship be changed when the loads exceed the P = 20 kN load level (Fig. 18a).

3.5. Surveying the effect of nonlinear material analysis

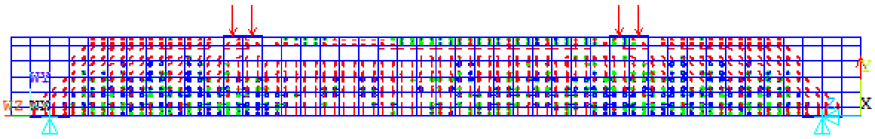
When increasing the content of steel fibers, increasing the diameter of tensile steel, increasing the number of tensile steel bars, etc., will help the beams reduce cracks, enhance the bearing capacity of the beams. However, nonlinear materials need to be analyzed, in order to use effectively.

This case still does not change the steel fiber content, μ = 4 %, steel stirrups spacing at the ends of beams are 50 mm, tensile steel bars 2⌀12. However, this case analyzes nonlinear material.

Beams start to crack and be damaged by nonlinear material analysis, are shown in Fig. 20.



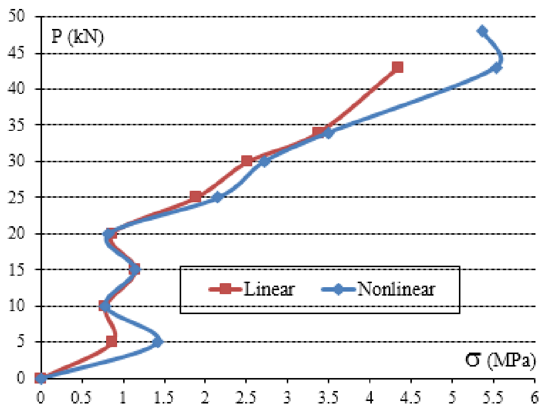
a) Beams start to crack, P_{crack} = 6 kN



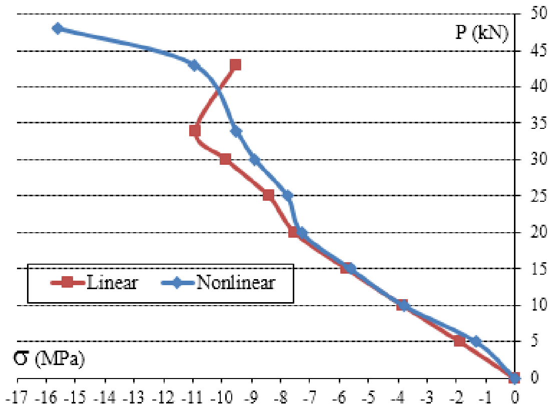
b) Beams start to be damaged, P_{max} = 48 kN

Figure 20. Beams start to crack and be damaged by nonlinear material analysis.

Load and tensile stress relationship, load and compressive stress relationship when nonlinear material analysis, are shown in Fig. 21.



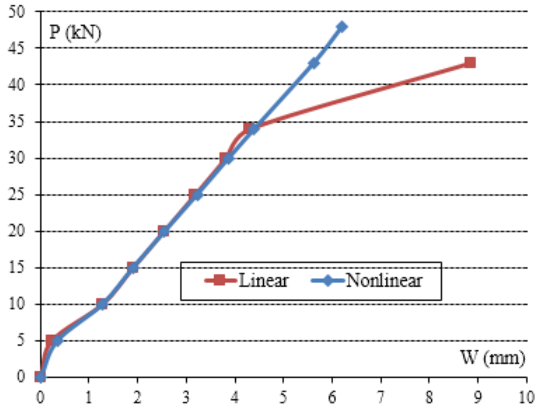
a) Load and tensile stress



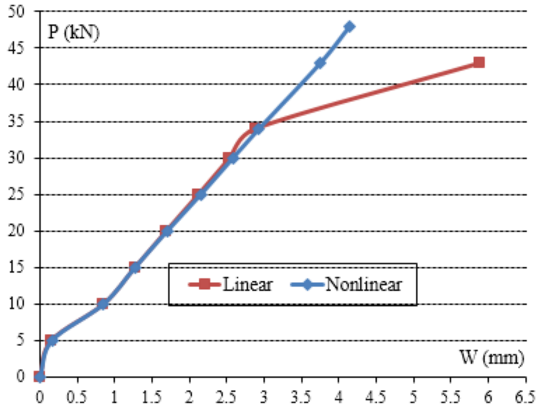
b) Load and compressive stress

Figure 21. Load and stresses relationship when nonlinear material analysis.

Load and displacement relationship at middle and at P forces of beams when nonlinear material analysis, shown in Fig. 22**.**



a) at middle of beams



b) at P forces of beams

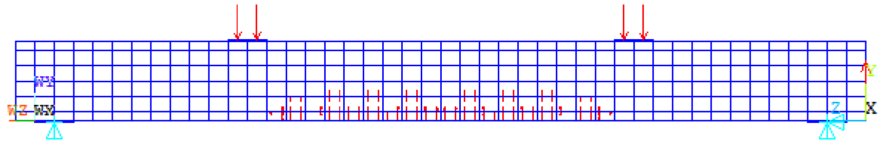
Figure 22. Load and vertical displacement relationship when nonlinear material analysis.

Comment: When considering linear and non-linear material analysis, beams begin to crack at load P = 6 kN, in nonlinear material analysis, beams are damaged later at 48 kN (Fig. 20). In Fig. 21 and Fig. 22 at the near destructive stage, the effect of nonlinear material analysis consideration, after the P = 35 kN load level, the difference in stresses and vertical displacements are growing. Therefore, in structural analysis, it is necessary to analyze nonlinear materials.

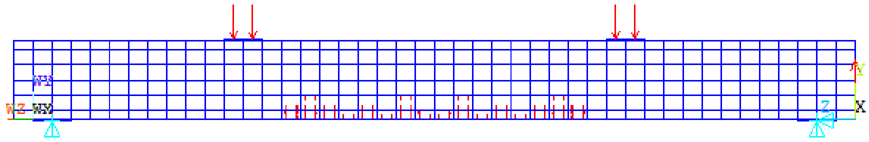
3.6. Case studies are influenced by many factors

Consider the following 3 cases: Case 1: μ = 0 %, shear steel stirrups spacing at the ends of beams are 50 mm, tensile steel bars 2⌀12 and linear material analysis. Case 2: μ = 4 %, shear steel stirrups spacing at the ends of beams are 50 mm, tensile steel bars 2ϕ20 and nonlinear material analysis. Case 3: μ = 8 %, shear steel stirrups spacing at the ends of beams are 50 mm, tensile steel bars 2⌀25 and nonlinear material analysis.

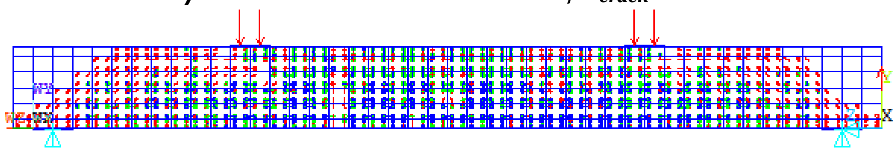
Beams start to crack and be damaged with many factors considered, are shown in Fig. 23.



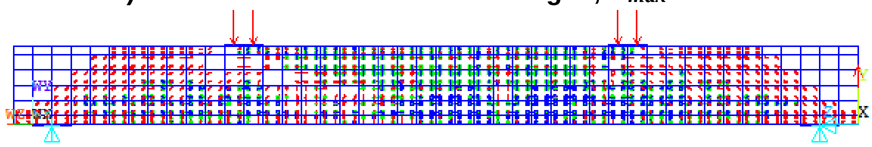
a) Case 2: Beams start to crack, P_{crack} = 7 kN



b) Case 3: Beams start to crack, P_{crack} = 8 kN



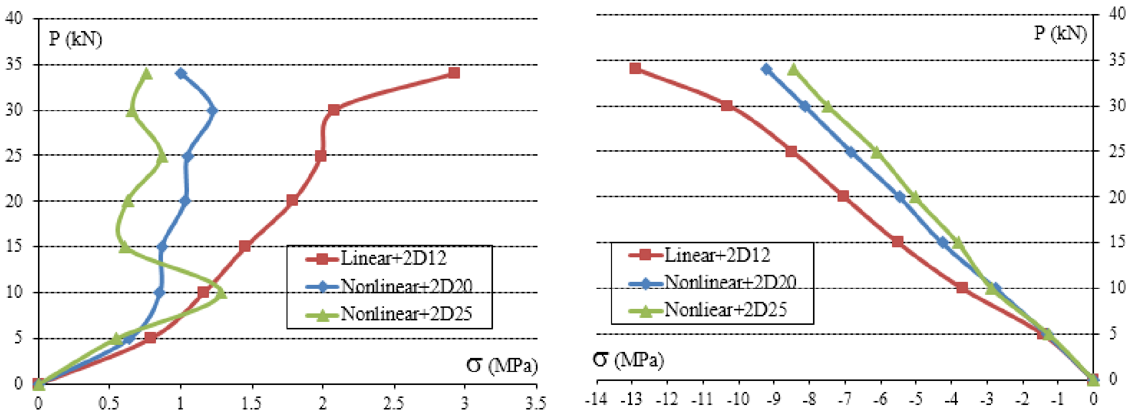
c) Case 2: Beams start to be damaged, P_{max} = 66 kN



d) Case 3: Beams start to be damaged, P_{max} = 67 kN

Figure 23. Beams start to crack and be damaged with many factors considered.

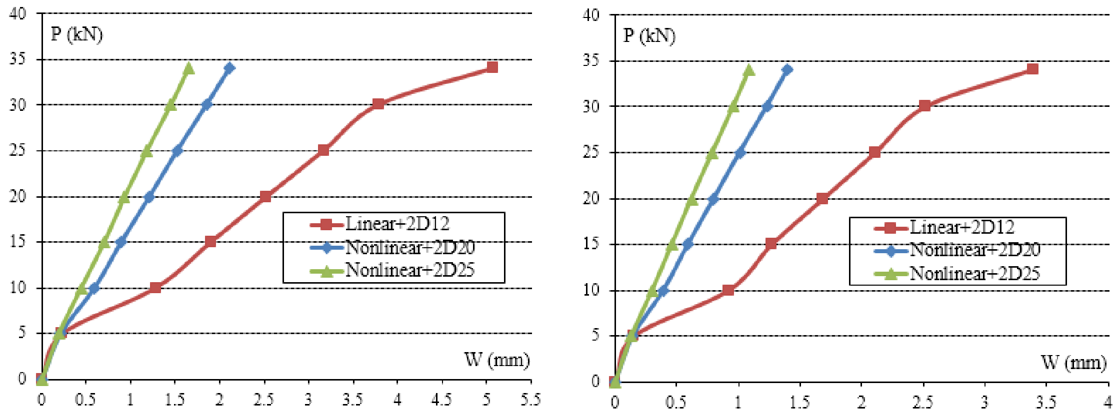
Load and tensile stress relationship, load and compressive stress relationship when many factors considered, are shown in Fig. 24.



a) Load and tensile stress **b) Load and compressive stress**

Figure 24. Load and stresses relationship when many factors considered.

Load and displacement relationship at middle and at P forces of beams when many factors considered, are shown in Fig. 25.



a) at middle of beams **b) at *P* forces of beams**

Figure 25. Load and displacement relationship when many factors considered.

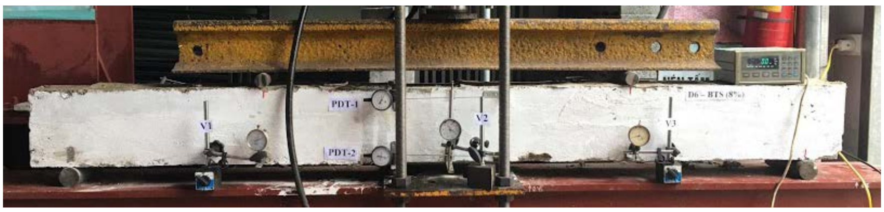
Comment: in case 2, the beams start to crack at 7 kN and damaged at 66 kN, while case 3 starts to crack at 8 kN and damaged at 67 kN (Fig. 23). In case 3 we see that when considering many factors, tensile stress and displacement are significantly reduced (Fig. 24), (Fig. 25).

3.7. Compare with experimental results

The numerical simulation results are compared with experimental results, in the experimental study, we poured concrete for 6 beams of a 150×200×2200 mm size, of which: 2 beams with steel fiber content of 0 %, 2 beams with steel fiber content of 4 % and 2 beams with steel fiber content of 8 % [27].

– The beams were tested with varying steel fiber content, are shown in Fig. 26.

a) Formwork and reinforcement of beams **b) Concreting beams**

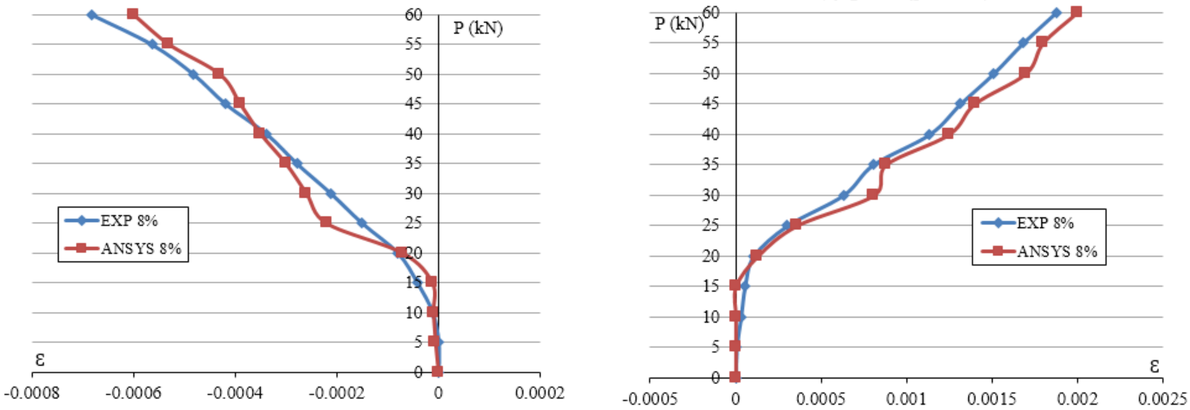


c) Beams with experimental equipments

Figure 26. The beams were tested with varying steel fiber content [27].

– Load and deformation between experiment (EXP) and ANSYS: The simulation results are compared with the test case of 8 % steel fiber content, because in the experiments the authors measured deformation values in beams, in ANSYS, so the authors took deformation values.

Load and deformation between EXP and ANSYS, are shown in Fig. 27.



a) Load and tensile deformation **b) Load and compressive deformation**

Figure 27. Load and deformations between EXP and ANSYS, μ = 8 % [27].

Comment: The research results of steel fiber content are suitable for the experiment when μ = 8 %, so the results of the survey of the effects of the above design parameters are reliable. In the study [27], the experiment investigated cracks formation and cracks development by microscopy, so the authors were able to read at the load level of P = 25 kN or higher when cracking appeared. In ANSYS, the program can accurately simulate the position and number of cracks in the beam, so it will show at a smaller level. And this ANSYS program can be used to survey other parameters such as beams cross section, distributed load, etc. With the two simulation and experiment methods above, the difference between the two results is not significant and acceptable.

4. Conclusions

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

1. When considering the effect of steel fiber content in concrete, increasing the steel fiber content, the beams reduce cracks, but the stress and displacement do not change much. When the steel fiber content exceeds the allowed steel content in concrete, the beams will be brittle damaged.

2. When shear steel stirrups spacing at the ends of beams too thick, it will affect the working of the beam, so, the content of steel should be sufficient.

3. Considering influencing factors such as the number of tensile steel bars and the diameter of tensile steel bars, the role of steel bars will change stress, vertical displacement and cracks significantly reduced when adding steel fiber content in concrete.

4. When considering the influence of nonlinear materials analysis and considering many factors, steel bars in bending beams have the effect of bearing and reducing obvious cracks.

5. Through studies on steel fiber concrete beams, it is effective to add steel fibers into the concrete, which will make the beams reduce cracks, resist collisions, increase the long life of the works, etc. This shows that the efficiency of steel fiber concrete is not high when using normal concrete. Research is needed on fibers when adding high strength concrete or silica nano concrete.

5. Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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