

Numerical Simulation of Flexural-tensile Properties of Reinforced Concrete Beam

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Abstract: Reinforced concrete is a kind of typical composite and reinforced concrete structure is widely used in the construction of a kind of structure, the flexural-tensile properties is very important for structure design optimization. In this study, the 2 dimensional numerical model of reinforced concrete beam is established by using ANSYS software and the effects of the thickness of the protective layer, the reinforcement ratio and the size of the specimen on the flexural performance of reinforced concrete beams are studied. The research shows that the failure of reinforced concrete beams is started in the middle and bottom of the beam and the influence of the specimen size on the failure load is the most significant, the mid-span stress increases with the decrease of thickness of protective layer and reinforcement ratio.

Keywords: Reinforced Concrete, Failure Load, Numerical Simulation, Flexural-Tensile and Properties

Introduction

Concrete is a kind of building material with strong compressive strength but weak tensile ability and its failure is a kind of brittle fracture. Compared to plain concrete, the bearing capacity of reinforced concrete beam which has the same section form, size and concrete strength is much larger and it will produce large deformation before failure. It is because of the advantages of reinforced concrete structure that it has been widely used in water conservancy and hydropower engineering and civil engineering. The mechanical performance of reinforced concrete structure is more complex than that of steel structure, so far there are still many problems remains unsolved, so it is necessary to study the flexural-tensile performance of reinforced concrete. Compared with experiments, numerical simulation software has many advantages. In the structural analysis, the numerical simulation can accurately reflect the mechanical and deformation properties of the whole process, which provides a scientific basis for the optimization of the structure design (Guan, 2010). Meanwhile, the numerical simulation can also be used to copy and reuse the model and can be appropriately modified according to the requirements of different situations, so as to save testing expenses and speed up the process of theoretical and experimental research. In a sense, compared to theory

and experiment, numerical emulation can numerical simulation can show the development of things continuously, dynamically and repeatedly and also can make the details of the whole and local development process understood.

There are many research results about numerical simulation research of reinforced concrete structure at home and abroad. Based on finite element method, Deng *et al.* (2010; Du *et al.*, 2005; Li *et al.*, 2016; Jin and Du, 2012; Du *et al.*, 2012; Mohamed and Hansen, 1999) have carried out numerical simulation about mechanical properties such as uniaxial tension, uniaxial compression and shear-resistance and good results are obtained; Tao *et al.* (2015) study on stress monitoring and strength analysis of step-by-step translation structure in electric drilling rig; Yu *et al.* (2015a) Carried out the numerical simulation of casing stress and the influence factors of are analyzed. Tang and Xiang (2015) Yu *et al.* (2015b) Mohamed and Hansen, (1999) studied the situation of crack penetrating aggregate; Liu (2003) Studied the influence of the thickness of protective layer on the fracture failure; Xu *et al.* (2014) Wang *et al.* (2012) Studied the influence of reinforcement ratio on rupture failure; Hu *et al.* (2014; Hu and Mi, 2015) studied the influence of steel position on rupture failure; Hu and Mi (2015). Tang (2009), Li *et al.* (2016) and Licheng *et al.* (2012) studied the size effect of reinforced

concrete; Zhang *et al.* (2007) studied on the difference of mechanical properties of reinforced concrete and plain concrete in loading damage. Wang *et al.* (2012) treat reinforced concrete beam as a three-phase heterogeneous composites material, analyzing the stress change of longitudinal carrying bar in failure mode and loading process of the beam. Li *et al.* (2016) treat reinforced concrete column as a three-phase heterogeneous composites material while consider the homogeneity, respectively studied the axial compressive shear failure under macro-scale and axial shear failure under micro-scale. Guan (2010) carried out simulated model tests of reinforced concrete multi longitudinal beam flume and the numerical model used the three-dimensional nonlinear finite element method, making steels diffused in every unit, calculating the mechanical performance under the load of self-weight, design water level and check water level and the aqueduct is optimized with the goal of the most light self-weight of the structure. Zhong and Liu (2015) in order to describe the heterogeneity of concrete materials better, assuming that mechanical parameters of two phases of concrete two-dimensional planar micromechanical model satisfied with the Weibull probability distribution and the failure of 3 reinforced concrete beams with different shear span ratio were calculated by ANSYS software. Xu *et al.* (2014) carried out the simulation of shear-compression failure of reinforced concrete beam and the longitudinal rib thickness in the two-dimensional model is equivalent to the volume fraction of reinforcement in the original test beam and the failure process of beams is analyzed through Uniaxial compressive stress-strain curve and the external force displacement curve.

In the study of the flexural performance of reinforced concrete, further research is needed in the aspects of influence factors and combining with numerical simulation. In this study, ANSYS numerical simulation software is used to calculate midspan stress and displacement under flexural-tensile load of reinforced concrete and analyze influence of three factors, including layer thickness, reinforcement rate and size, on flexural-tensile performance of reinforced concrete beam.

The Finite Element Model of Reinforced Concrete Beams

The finite element model of reinforced concrete beams in this study adopts distributed simulation and PLANE182 units are selected for the types of reinforcement and concrete units. The material properties and dimensions of reinforcement and concrete are valued according to the data of Guan Junfeng's 28 pieces of reinforced concrete simply supported beam test and the

selection of concrete material is C40, elastic modulus 32.5 GPa and Poisson's ratio is 0.2; the selection of reinforcement is HRB335, taking measured average value of the same samples as elasticity modulus and Poisson's ratio is 0.3. Three series of models are using planar quadrilateral 4 node elements. The distance between the support center of the original test specimen and the beam-end is 150 mm, that is to say the test beam is simply supported at both ends and the two symmetrical concentrated pressure loading is adopted. The series of test beam with different protection layer thickness and reinforcement ratio are kept pure bending section is 1200 mm, while the series of different section are loaded by 1/3 span.

In this study, the constraint of the model is equivalent to the corresponding node constraint and the load is equivalent to symmetric node concentrated load. For the DP-3 model with reinforcement ratio of 1.4%, its size is 3000×450 mm and the equivalent thickness of reinforcement is 20 mm, the protection layer thickness is 40 mm and the concrete tensile strength of this beam is 2.61 MPa. Due to the size of mesh is 20 mm, applying equivalent simply supported constraint of UX and UY on the 120-180 mm and 2820-2880 mm node in the bottom of the model and put Y symmetry equivalent concentrated force at corresponding nodes, respectively 500 N, direction as y axis negative and ensure pure bending section is 1200mm, as shown in Fig. 1.

Due to the original test also studied the similarity ratio of each performance under different proportion, including two-dimensional similar and tri-dimension similar, so this paper only selects part trials of the BC and DP series for simulation, that is only to study the destruction load of beam under different protection layer thickness and reinforcement ratio. Among them, in this study, the model for the study of the influence factors on the dimensions of the specimen is selected the 3 test beams of HB series, that is to select the size and material property of HB5011, HB5021 and HB5031, this three test beams of section height series in original test. In this study, the longitudinal thickness of the model is based on the equivalent value of the volume fraction of reinforcement in the original test beam, as shown in Table 1.

This paper mainly studies the influence of 3 variables on the flexural-tensile performance of reinforcement concrete, that is different protection layer thickness, reinforcement ratio and model dimension. Among them, the protection layer thickness series is BC20~BC70, respectively 20-70 mm, a total of 6 sets; the reinforcement ratio series is DP-1~DP-4, respectively 3.0, 2.3, 1.4 and 1.2%, a total of 4 sets; the model dimension series is HB501~HB503, respectively 1740×240, 6000×950 and 7500×1200 mm, a total of three sets.

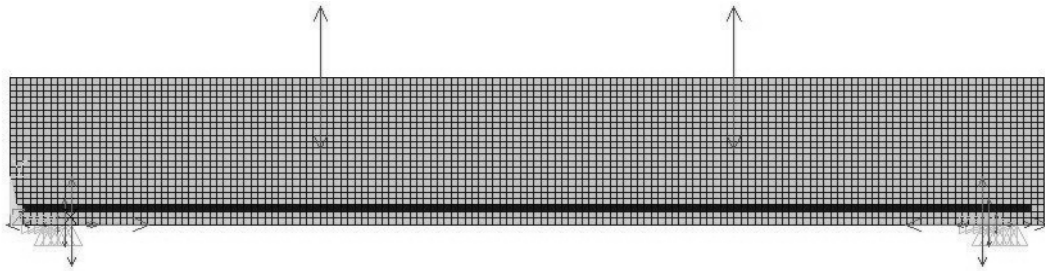
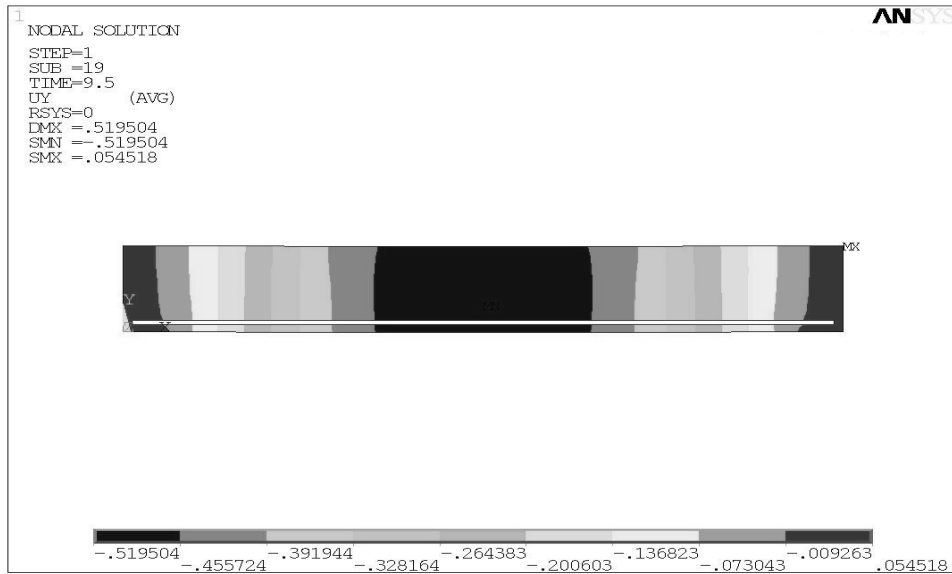
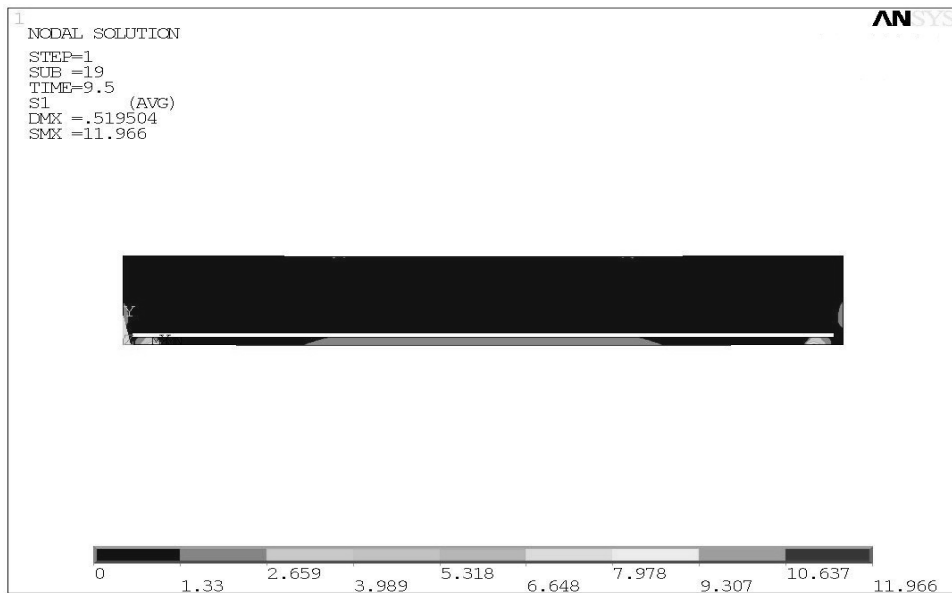


Fig. 1. Loading diagram of DP-3 model



(a)



(b)

Fig. 2. Stress nephogram of concrete at grid size 20 mm (a) Displacement of loading direction (mm) (b) The 1st principal stress (MPa)

Table 1. Section size of the model and thickness of steel bar and material properties

Number of models	Equivalent thickness of steel bars d/mm	Depth of section h/mm	Span l/mm	Effective span l_0 /mm	Protection layer thickness c/mm	Longitudinal carrying bar		Concrete fts/Mpa
						f_y /MPa	$E_s/10^5$ MPa	
BC20	20	445	3000	2700	20	409.36	1.92	2.64
BC30	20	455	3000	2700	30	409.36	1.92	2.64
BC40	25	465	3100	2800	40	381.14	1.90	2.61
BC50	28	475	3100	2800	50	399.43	1.88	2.61
BC60	31	485	3200	2900	60	368.33	2.01	3.04
BC70	35	500	3300	3000	70	366.68	1.94	2.64
DP-1	35	410	2650	2350	40	366.68	1.94	2.64
DP-2	28	390	2650	2350	40	399.43	1.88	3.04
DP-3	20	450	3000	2700	40	409.36	1.92	2.61
DP-4	17	450	3000	2700	40	375.78	1.86	3.04
HB501	17	240	1740	1435	50	375.78	1.86	3.04
HB502	40	950	6000	5700	50	399.43	1.88	3.47
HB503	50	1200	7500	7200	50	366.68	1.94	3.65

Numerical Simulation of Flexural-Tensile Properties of Reinforced Concrete Beams

Sensitivity Analysis of Dimensions

In this study, the study start with BC20 model as an example, sensitivity analysis was carried out on the grid size. The model size is 3000*3000 mm, the equivalent thickness of steel 20 mm. By ANSYS before the processor model and define the nature of the material and unit, choose the size of the different meshing model and applied in the same load and constraints. This series are balanced on both sides of the equivalent load of 1 kN, constraint for equivalent node constraint. After loading to solve, after entering the processor, get on the direction of its principal stress and the load displacement variation, such as in Table 2, determined by comparison of cell size of 20 mm, after solving the concrete stress nephogram as shown in Fig. 2.

Analysis and calculation results show that the third principal stress and the displacement change of the three dimensions are small, but the first principal stress decreases gradually increases with the size.

Many Factors Numerical Simulation

The three series of simulated adopts load step load. Besides HB502 and HB503 two models, the model of symmetrical load by 25 N increases, the total load by 50 N increases. Such as DP-3 model, the load step with 20 step loading, in order to solve the menu of the From LS Files after reading load Files to solve, for each step of concrete part across different principal stress and the displacement, such as Table 3 and the model of DP-3 tables can draw the load-displacement diagram, as shown in Fig. 3, we can see load-displacement curve is a straight line.

By the first principal stress and the tensile strength of the specimens in the table 2.61 MPa, known in step 19th damage, destroy the symmetry concentrated load

is 475 N, the total load of 950 N. Its damage of concrete stress and displacement nephogram as shown in Fig. 4. Figure illustrates the DP-3 reinforced concrete beam damage mainly occurs in the cross beam bottom, as to achieve the maximum of the displacement in the cross.

Reinforcement Ratio Effect on the Flexural-Tensile Properties of Reinforced Concrete Beam

Until the destruction of concrete under different reinforcement ratio of load-displacement relationship as shown in Fig. 5, load-stress relations as shown in Fig. 6. The figure shows that under the same load, the displacement along with the increase with the decrease of the reinforcement ratio. Model of DP-4 reinforcement ratio is 1.2%, the cross in the largest displacement and the model of DP-1 reinforcement ratio is 3.0%, the minimum displacement across; To cross the stress under the same load, the model of DP-3 reinforcement ratio is 1.4%, the biggest across the stress and the model of DP-1 reinforcement ratio is 3.0%, the smallest across the stress. As the load increased damage to the model, various models of displacement and stress under the same load gap slowly become larger and the gap is more and more obvious. By comparing figures, we can see the stresses of DP-1 and DP-4 have similar magnitude, but the displacement of DP-4 is larger. The reinforcement rate of 1.2% and 3.0% when the destruction of the reinforced concrete beam, but the reinforcement ratio was 1.2% of beam deformation is bigger.

For reinforced concrete beam of different reinforcement ratio, the breaking load, besides DP-3 models, namely, reinforcement ratio of 1.4% has dropped significantly, Up to 950 N. All the rest of the model of damage load in about 1200 N, floating up and down 50 N. Specimens under different reinforcement ratio when damage occurs across the concrete parts of

the displacement and stress in Table 4, the stress and displacement of reinforced part in Table 5. You can see from the table of reinforced concrete beams of

concrete section first achieve tensile strength and damage occurs, the stress is far from the yield strength of reinforced part.

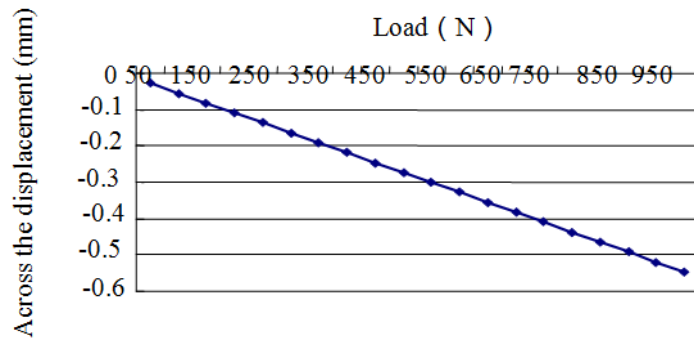
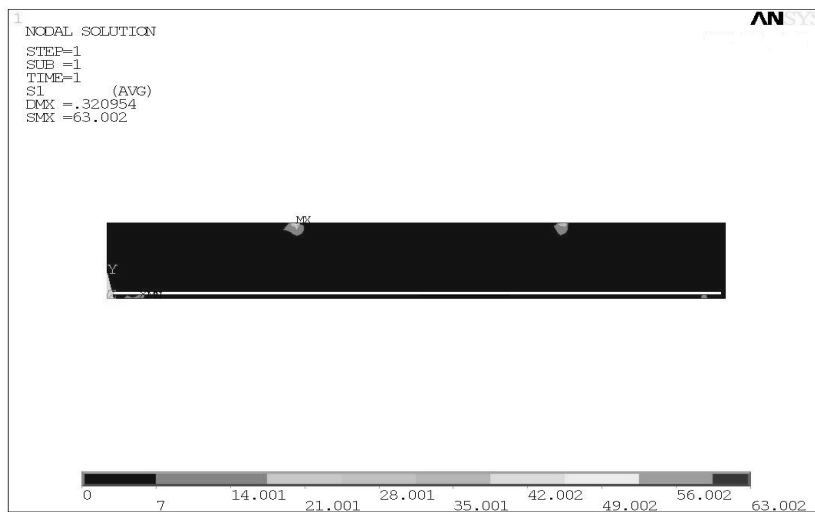
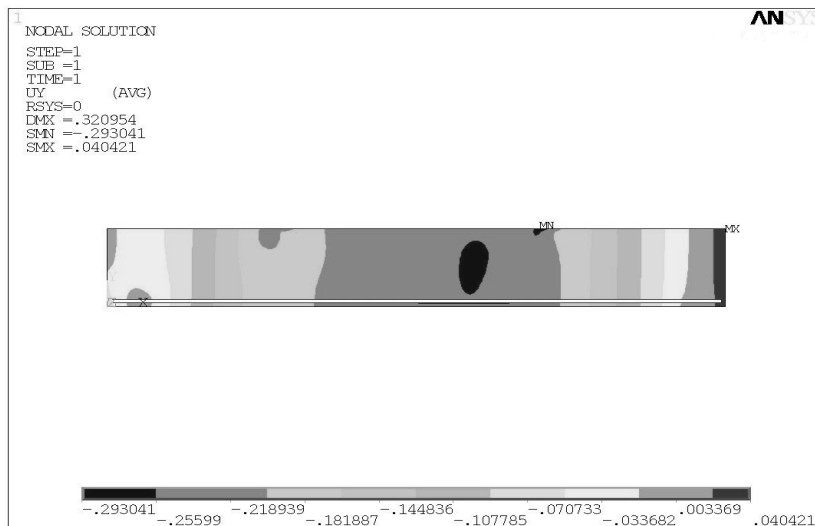


Fig. 3. Relationship between load and displacement of DP-3



(a)



(b)

Fig. 4. Stress and displacement nephogram of DP-3 models (a) The 1st principal stress (MPa) (b) Displacement of loading direction (mm)

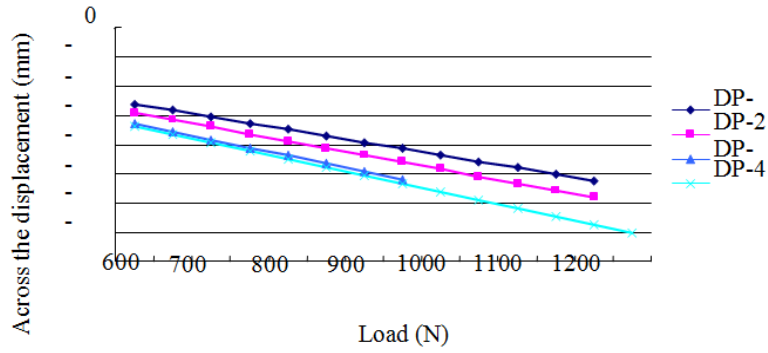


Fig. 5. Load-displacement relation of concrete under different reinforcement ratio

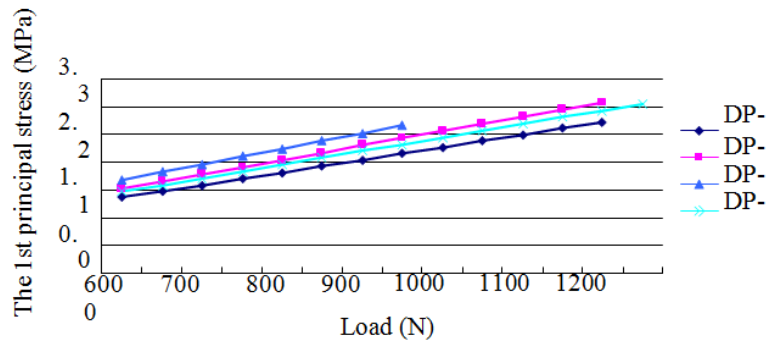


Fig. 6. Load-stress relation of concrete under different reinforcement ratio

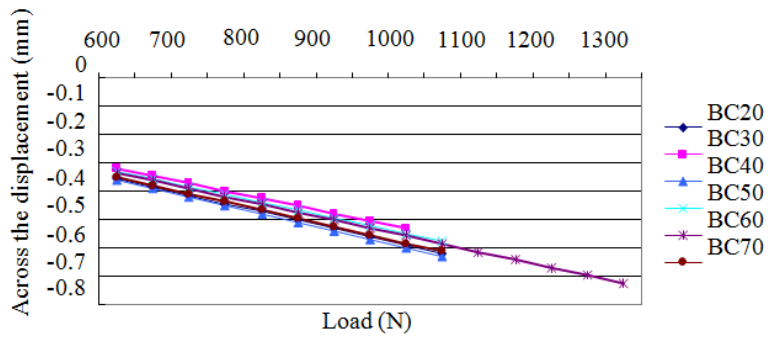


Fig. 7. Load-displacement relation of concrete under different protective layer thickness

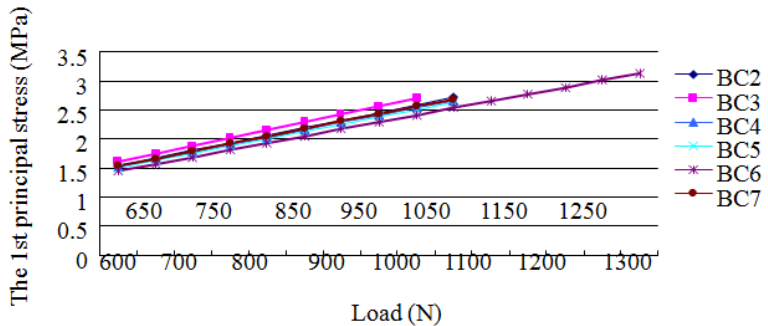


Fig. 8. Load-stress relation of concrete under different protective layer thickness

Table 2. Results of the model under different grid sizes

Number	Grid sizes (mm)	Number of elements	Number of nodes	The 1st principal stress (MPa)	The 3rd principal stress (MPa)	Displacement of loading direction (mm)
1	10	13580	13934	5.307	-6.383	-0.01105
2	20	3648	3470	4.5	-6.046	-0.02093
3	40	1006	1098	3.465	-6.3	-0.02782

Table 3. Solving results of the model at each load step

Steps	Load (N)	Across the displacement (mm)	The 1st principal stress (MPa)	The 3rd principal stress (MPa)
1	50	-0.02734	0.139958	-0.35275
2	100	-0.05469	0.279917	-0.70549
3	150	-0.08203	0.419875	-1.058
4	200	-0.10937	0.559837	-1.411
5	250	-0.13671	0.699792	-1.764
6	300	-0.16405	0.839751	-2.116
7	350	-0.1914	0.979709	-2.469
8	400	-0.21874	1.12	-2.822
9	450	-0.24608	1.26	-3.175
10	500	-0.27342	1.4	-3.527
11	550	-0.30077	1.54	-3.88
12	600	-0.32811	1.68	-4.233
13	650	-0.35545	1.819	-4.586
14	700	-0.38279	1.959	-4.938
15	750	-0.41014	2.099	-5.291
16	800	-0.43748	2.239	-5.644
17	850	-0.46482	2.379	-5.997
18	900	-0.49216	2.519	-6.349
19	950	-0.5195	2.659	-6.702
20	1000	-0.54685	2.799	-7.055

Table 4. The displacement and stress of concrete during failure

Number	The 1st principal stress (MPa)	The 3rd principal stress (MPa)	Across the displacement (mm)	Failure load (N)	Tensile strength (MPa)
DP-1	2.716	-7.889	-0.52194	1200	2.64
DP-2	3.061	-8.33	-0.58103	1200	2.64
DP-3	2.659	-6.702	-0.5195	950	3.04
DP-4	3.047	-8.705	-0.70368	1250	2.61

Table 5. The stress and the displacement of the loading direction

Number	The 1st principal stress (Mpa)	The 3rd principal stress (Mpa)	Displacement (mm)
DP-1	9.091	-27.396	-0.52191
DP-2	9.817	-28.937	-0.58097
DP-3	10.057	-24.139	-0.51928
DP-4	13.669	-33.02	-0.70332

Protective Layer Thickness Effects on the Flexural-Tensile Properties of Reinforced Concrete Beam

For reinforced concrete beam of different protective layer thickness, the load-displacement relationship of until the destruction as shown in Fig. 7, the load-stress relationship as shown in Fig. 8. The figure shows that under the same load, the protective layer thickness of 40mm, the cross in the largest displacement and protective layer of 30 mm, the minimum displacement across; To cross the stress under the same load, the model of BC30 namely protective layer thickness of 30 mm, the largest across

the stress and the thickness of protection layer for 60 mm BC60 namely model, the stress in the least. But both across the displacement and stress in the cross, at the beginning of the load that the load is small, its various model not much of a difference. With the increase of load, various models of displacement and stress under the same load grow big difference, to model to destruction. Comparing figure can see, small amount of BC30 displacement stress is larger, but its produce BC60 small displacement and stress is small, so the protective layer thickness of 30mm than protective layer of reinforced concrete beam is 60 mm beam damage more easily.

For different protective layer thickness of reinforced concrete beam, the breaking load you have elevated in the protective layer thickness of 60mm, 1300 N, in addition to the rest of the model of damage load are about 1000 N, the floating up and down 50 N. Specimens under different thickness of protective layer

destruction occurs across the concrete parts of the displacement and stress in Table 6, the stress and displacement of reinforced part in Table 7. You can see from the table of reinforced concrete beams of concrete section first reach the tensile strength and produce damage, stress is far from yield strength steel parts.

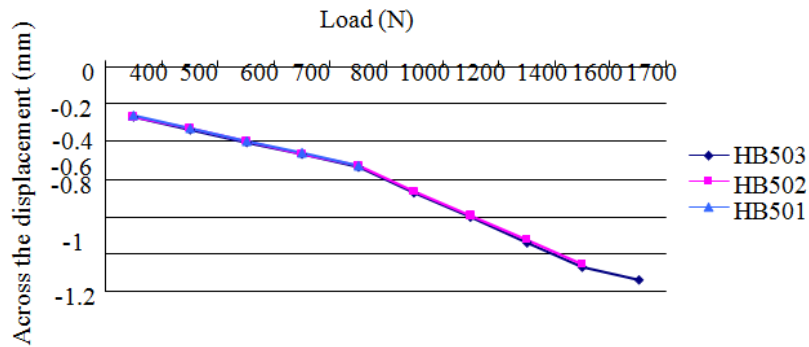


Fig. 9. Load-displacement relationship of concrete under different specimen sizes

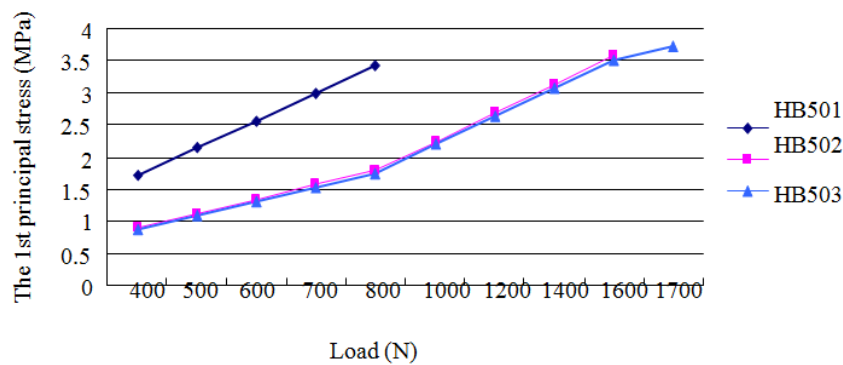


Fig. 10. Load-stress relationship of concrete under different specimen sizes

Table 6. Displacement and stress of concrete during failure

Number	The 1st principal stress (MPa)	The 3rd principal stress (MPa)	Across the displacement (mm)	Failure load (N)	Tensile strength (MPa)
BC20	2.716	-7.717	-0.6197	1050	2.64
BC30	2.698	-7.458	-0.53197	1000	2.64
BC40	2.667	-7.495	-0.62884	1050	2.61
BC50	2.628	-7.54	-0.57529	1050	2.61
BC60	3.139	-8.802	-0.72437	1300	3.04
BC70	2.692	-7.506	-0.61247	1050	2.64

Table 7. The stress and the displacement of the loading direction

Number	The 1st principal stress (Mpa)	The 3rd principal stress (Mpa)	Displacement (mm)
BC20	13.427	-42.517	-0.61934
BC30	11.195	-30.62	-0.53169
BC40	11.415	-28.211	-0.62862
BC50	9.565	-22.872	-0.57515
BC60	11.447	-26.033	-0.72426
BC70	8.533	-18.509	-0.61242

Table 8. The displacement and stress of concrete during failure

Number	The 1st principal stress (MPa)	The 3rd principal stress (MPa)	Across the displacement (mm)	Failure load (N)	Tensile strength (MPa)
HB501	3.206	-7.728	-0.494	750	3.04
HB502	3.579	-9.959	-1.058	1600	3.47
HB503	3.73	-10.031	-1.139	1700	3.65

Table 9. The stress and the displacement of the loading direction

Number	The 1st principal stress (MPa)	The 3rd principal stress (MPa)	Displacement (mm)
HB501	8.666	-22.598	-0.494
HB502	12.825	-33.041	-1.058
HB503	11.685	-34.291	-1.138

Specimen Size Effect on the Flexural-tensile Properties of Reinforced Concrete Beam

The load-displacement relationship of the concrete of different specimen size until the destruction as shown in Fig. 9, load-stress relationship as shown in Fig. 10. The figure shows that under the same load, the displacement of almost no change with the increase of specimen size and to cross the stress, under the same load, model HB501 model into smaller size 1740*240 mm, the largest across the stress and the model HB503 namely model 7500*1200mm for the larger size, the stress in the least. As load increases until model, under the same load stress in the various models across the gap between slowly become larger and because HB501 is differ from HB502 size is larger, the stress in its span is far apart.

For different specimen size, breaking load increases with size has obvious rise. Which model HB501 and HB502 specimen size is large, the breaking load is larger gap, HB502 breaking load of 1600 n, probably for HB501 twice; And model HB502 and HB503 specimen size difference is not big, so only a modest increase the breaking load of 1600 n and 1700 n respectively. Under different size specimen damage occurs across the concrete parts of the displacement and stress in Table 8, the stress and displacement of reinforced part in Table 9. You can see from the Table of reinforced concrete beams of concrete section first achieve tensile strength and damage occurs, the stress is far from the yield strength of reinforced part.

Conclusion

In this study, it establishes the mechanical model of two phase plane by using ANSYS numerical simulation software and analyzes the change of specimen size, stress and displacement in across of the different protective layer thickness, reinforcement ratio and failure load. The study found that the destruction of the reinforced concrete beam are started in reinforced concrete beam across the concrete parts

of the bottom and the influence of specimen size on fracture load the most significant. Main conclusions are as follows:

When the protective layer thickness of 40 mm, its across displacement reaches maximum and the protective layer thickness of 30 mm, the across displacement reaches minimum; For the stress in the cross, under the same load, the protective layer thickness of 30 mm, its stress in the cross reaches maximum and protective layer thickness of 60 mm, the stress in the cross is least. For the reinforced concrete beam of different thickness of protective layer, when the protective layer thickness is 60 mm, the failure load has a little rise, up to 1300 N, in addition to the rest of the model of damage in 1000 N load.

With the increase of reinforcement ratio, the across the displacement of reinforced concrete beam reduces. Under the same load, when the reinforcement ratio was 1.4%, across the stress is biggest and when the reinforcement ratio is 3.0%, across the stress is least. For the reinforced concrete beam of different reinforcement ratio, the failure load, besides the DP-3 model, namely, when the reinforcement ratio is 1.4%, has dropped significantly, up to 950 N, the failure load of the rest model are about 1200 N.

The reinforced concrete beams cross displacement almost don't change with the increase of size. When the model is HB501, namely, the specimen size is smaller 1740*240 mm, the across the stress is largest. However, when the model is HB503, scilicet the specimen size is larger 7500*1200 mm, across the stress is least. Because of the size difference between HB501 and HB502 is larger; the gap of stress value in its span is larger. For model HB503 and model HB502, they are similar in size, but their stresses in the cross have a gap which is not visible. For different specimen size, breaking load increase significantly with the rise of the size, 950 N, 1600 N, 1700 N respectively.

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Author's Contributions

Shi Di: Made considerable contributions to acquisition of data and analysis and interpretation of data, contributed in drafting the article. Give final approval of the version to be submitted and any revised version.

Wang Juan: Made considerable contributions to conception and design. Contribution in reviewing the article critically for significant intellectual content.

Liu Jianjun: Contributed in reviewing the article critically for significant intellectual content. Give final approval of the version to be submitted and any revised version.

Ethics

This article is original and contains unpublished material. The authors have read and approved the manuscript and no ethical issues involved.

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