Nonlinear Finite Element Analysis on Flexural Bearing Capacity of Reinforced Concrete Beams Strengthened by SGFRP

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Abstract. 6 finite element models of ANSYS were constructed. A material nonlinear finite element analysis by the finite element calculation software ANSYS on reinforced concrete beams strengthened by SGFRP under the gravity symmetric concentrated loads was performed. The load-displacement curves of the models obtained from ANSYS simulation were described. The ultimate loads of the 3 models strengthened by SGFRP increased significantly. The bond length and the thickness of the GFRP layer affect the bearing capacity and the deformation capacity of the beam. The results of the nonlinear finite element analysis of the models reveal the influence factors to reinforcement effect. Some effective and reasonable reinforcement suggestions are proposed.

Introduction

A large number of structures including civil constructions and transportation infrastructures in China were constructed after new China was founded. Many of them have reached the end of their service life. Because of many years' erosion by air and water, especially the experiencing loads which significantly bigger than the design load; deterioration in the form of steel corrosion and concrete cracking is prevalent. So, it is necessary to strengthen the structure by successful and economical repair, rehabilitation and strengthening techniques. The technology of Sprayed Glass Fiber Reinforced Polymer (SGFRP) means strengthening structure by the mixture of short grass fibers and high-performance binder high-speed spraying to the surface of structure by spraying machinery. The advantages of SGFRP technology are high construction speed, good integrity, and less impact of the member weight, so it is suitable for the reinforcement of reinforced concrete structure. At present, most research results about the strengthening of reinforced concrete structure by GFRP fabric or sheet wrapped paste have achieved. A few experimental researches about the concrete structure reinforcement by sprayed glass fiber reinforced polymer (SGFRP) have carried out in some western countries [1, 2]. But in China, the application and research about the technology used in concrete structure reinforcement are relatively rare. In order to verify the influence factors to the reinforcement effect about flexural bearing capacity of reinforced concrete beams strengthened by SGFRP, in this paper, some finite element analysis models of ANSYS were constructed, and the material nonlinear finite element analysis on flexural bearing capacity of reinforced concrete beams strengthened by SGFRP was performed.

Beam Design

Specimens and Strengthening Program. Six specimens were made in this research. One specimen among them is a contrasting specimen without strengthened by SGFRP, and the other five were strengthened by SGFRP. All the specimens were the same size, and the dimensions of the concrete beams are shown in Fig. 1.

The concrete strength grade of all the specimens is C20. The longitudinal steel bars in the specimens are 2B10 with the strength class of HRB335, and the thickness of concrete cover is 35mm. The auxiliary steel bars are 2A8 with the strength class of HPB300. The spacing of stirrups in the shear-compression zone is 50mm and the spacing of stirrups in the pure bending zone is 200mm. All the stirrups are A6 with the strength class of HPB300.

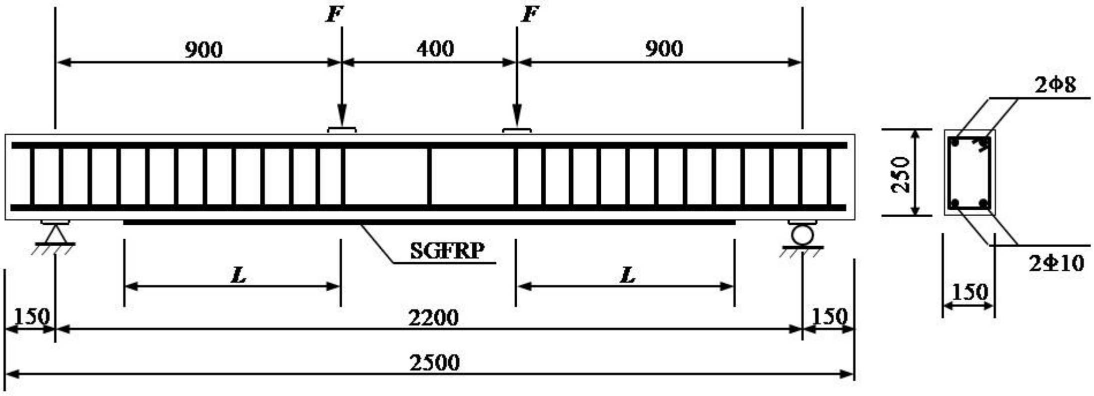


Fig. 1 Dimensions of specimens

The SGFPR layers in this research can be sprayed by a kind of equipment called Chopper Unit equipped with a spray gun [3]. All the specimens were strengthened by SGFRP at the beam bottom and the width of SGFRP layers are the same as the width of the beams. Specimen numbers and strengthening program are shown in Table 1.

Table 1 Specimen number and strengthening programs

Specimen No.	Thickness of GFRP layer (mm)	bond length (mm)
WL-1	No SGFRP strengthening	\
SWL-1	4	100
SWL-2	7	100
SWL-3	10	100
SWL-4	7	350
SWL-5	7	600

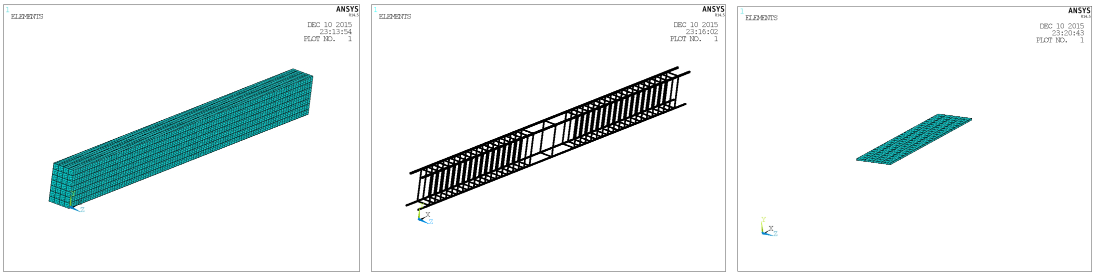
Loading procedure. The load mode to the specimens is a static loading. As shown in Fig. 1, two concentrated forces were applied on the upper surface of the beam symmetrically [4]. The load's inflictions were controlled by a per level 0.2kN multi-stage loading until the specimens damaged.

FEM Analysis

FEM Models: Because of the complexity of the models, in this paper, the models were constructed by separately models. The difference between United Model and Separately Model is the concrete elements, the steel elements and the GFRP layers elements are three different element types in separately model. The concrete element is SOLID65, the steel element is LINK8 and the GFRP layer element is SHELL 41. The concrete, steels and GFRP layers were meshed into finite elements by free meshing which the size and density were automatic controlled by intellectual finite element mesh division, and the tetrahedral meshes were created automatically in the solid models. The rigidity matrixes of SOLID65, LINK8 and SHELL41 were calculated respectively [5].

In order to simulate the actual constrained state, the supports of the beam were simplified as fixed supports.

The loads applied on the models are two concentrated forces. In the actual load application, each force is composed by 20 concentrated forces applied on 20 element nodes at the top surface of the beam along -Y axis direction, and one stage force value on each element node is 50N. The FEM models are shown in Fig. 2.



(a) Concrete model (b) Steel model (c) GFRP layer model

Fig. 2 FEM models

Bearing Capacity. The load and mid-span deflection results got from the FEM calculation are showed in table 2.

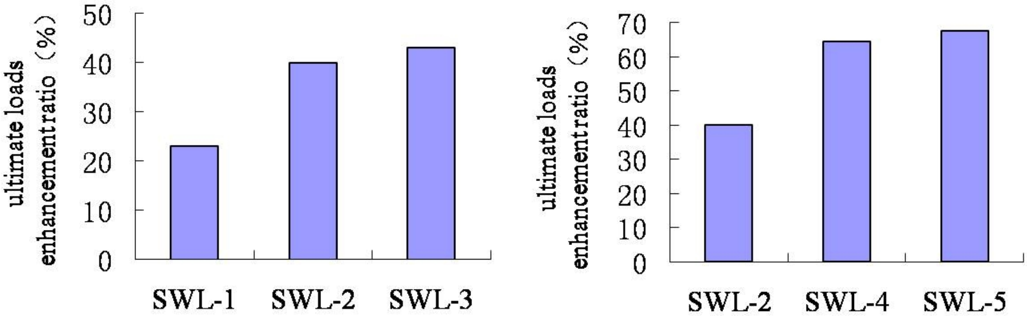
Table 2 Load and mid-span deflection results

Specimen No.	Fcr/kN	Δ c/mm	Fu/kN	△ u/mm
WL-1	12	0.306	26	1.268
SWL-1	14	0.378	32	1.657
SWL-2	14.8	0.412	36.4	1.878
SWL-3	15	0.423	37.2	1.863
SWL-4	18.6	0.438	42.8	2.210
SWL-5	16.8	0.439	43.6	2.231

Notes: Fcr is the cracking load, Δc is the cracking mid-span deflection, Fu is the ultimate load and △ u is the ultimate mid-span deflection.

It's shown in Table 2 that the cracking loads and ultimate loads of the 5 specimens strengthened by SGFRP increased significantly compared with the contrasting specimen without SGFRP strengthening. The finite element analysis result indicates the reinforcement by SGFRP has significant effect on improving the flexural strength and flexural stiffness of reinforced concrete structure.

Contrastive analysis. The contrastive analysis about the ultimate loads enhancement ratio got from FEM analysis are showed in Fig. 3.



(a) Different thickness (b) Different bond length

Fig. 3 Ultimate loads enhancement ratio

Compare with SWL-1, SWL-2 and SWL-3 (the same bond length and different thickness), the ultimate load enhancement ratios of them grow along with the increase of the thickness, but the grow rate has a decreasing tendency when the thickness exceed 7mm. At the same time, the ultimate mid-span deflection even decrease when the thickness exceed 7mm. Compare with SWL-2, SWL-4 and SWL-5 (the same thickness and different bond length), the ultimate load enhancement ratios and the ultimate mid-span deflection of them grow along with the increase of the bond length, but the grow rate of ultimate load enhancement ratios has a decreasing tendency when the bond length exceed 350mm.

Conclusions

In this paper, according to reinforced concrete beam specimens, the finite element models of ANSYS were constructed, and the material nonlinear finite element analysis of reinforced concrete beams strengthened by SGFRP under two concentrated forces were applied on the upper surface of the beam symmetrically was performed. Compared with the FEM analysi results of the reference specimen, verify the influence factors to the reinforcement effect about flexural bearing capacity of reinforced concrete beams strengthened by SGFRP, the effects to flexural bearing capacity of SGFRP strengthened reinforced concrete beams were discussed. The results of the nonlinear finite element analysis can be summarized as follows:

1) The finite element analysis by ANSYS indicates the ultimate loads and ultimate mid-span deflection of the 5 models strengthened by SGFRP increase significantly compareing with the contrasting model. The SGFRP strengthening is effective to improve the flexural bearing capacity and deformation capacity of reinforced concrete beam.

2) The ultimate load enhancement ratios of the strengthened models grow along with the increase of the thickness, but the grow rate has a decreasing tendency when the thickness exceed 7mm. At the same time, the ultimate mid-span deflection even decrease when the thickness exceed 7mm. The most suitable thickness for the SGFPR layer is 7mm.

3) The ultimate load enhancement ratios and the ultimate mid-span deflection of the strengthened models grow along with the increase of the bond length, but the grow rate of ultimate load enhancement ratios has a decreasing tendency when the bond length exceed 350mm. The minimum suggested values of the bond length for the SGFPR layer is 300mm.

Acknowledgements

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