EXPERIMENTAL AND NUMERICAL STUDY ON SHEAR DEFORMATION BEHAVIOR IN STEEL FIBER AND STIRRUPS RC BEAMS

Nagasaki University JSCE Member, Timothy NYOMBOI
Nagasaki University JSCE Member, Hiroshi NISHIDA
Nagasaki University, JSCE Member, Prof. Hiroshi MATSUDA

1. Introduction

In this study, strength and deformation behavior in steel fiber reinforced concrete (SFRC) and stirrup RC beams, under bending-shear, is investigated by numerical (FEM) and optical DCIM experimental methods. In the numerical simulation, SOFISTIK FEM code [1] was used where RC beam was modeled as a 2D plane structure and analyzed under plane stress conditions. SFRC material properties applied in the numerical analysis were experimentally obtained. Modeling and analysis procedure was programmed using Sofistik CADINP language. To account for post cracking strength and deformations, non linear analysis was undertaken. The numerical results were validated against the experimental results, whose deformation parameters were measured by conventional and optical DCIM method. The test specimens were reinforced with 1% steel fiber content determined using Eq.1 in order to equivalently match the stirrups content.

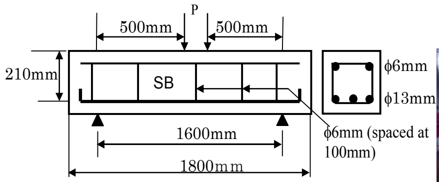
$$v_f = \frac{N_s a_s l_s}{l_b A_b} \qquad (1)$$

Where, v_f is the equivalent fiber fraction, N_s is the number of stirrups required and it corresponds to an equivalent fiber content, , l_b is the beam length, b is the beam width, A_b is cross sectional area of the beam, a_s and l_s are the stirrup cross-sectional area and lab length, respectively.

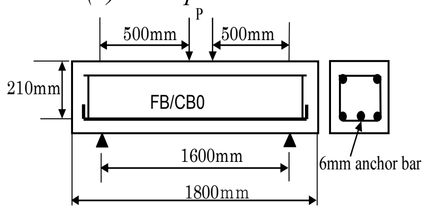
Strength, deformation and the failure characteristics in the beams were examined. Results showed that the numerical method predicted well the experimental results. FEM load deflection curves and deformation pattern were in accord with the experiment results. SFRC beams were found to have significant strength and deformation characteristics. The failure mechanism and effectiveness of the FEM and optical method in RC structure were verified

2. Experimental programme

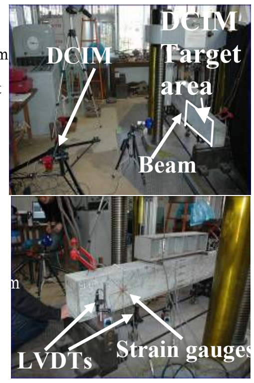
In the experimental programme, bending shear tests were conducted on 1800×230×150mm control, fiber and stirrup beams (Fig.1a and b). Tests on the specimens were done using a 300kN capacity universal testing machine. Deformations were measured by conventional (use of strain gauges and LVDTs) and optical Digital correlation image method (DCIM). In the manufacture of specimens, concrete with an average strength of 38MPa was used in which aggregate meeting JSCE guidelines [2] was used. SFRC was made by incorporating 1.0% high strength steel fibers (1000MPa, d_f/l_f of 48.4) in the concrete when in fresh state. The beams were reinforced in flexure with 13mm diameter deformed re-bars with yield strength of 340MPa as shown in Fig.1. The flexural reinforcement's capacity was determined by design and increased appropriately to ensure a diagonal shear failure mode based on the relative flexural capacity analysis by Russo and Puleri [3]. All the specimens were cured for a period of 28 days before testing.



(a) Stirrup beam



(b) Fiber beam



(d) Set up

Fig.1 Test beam details

3. FE Analysis

In the numerical study, modeling and analysis was programmed using SOFISTIK CADINP language [1]. Incremental loading and modified Newton Raphson method was applied in the analysis. Speed and convergence is increased through Crisfield accelerating algorithm. This method notices the residual forces developing during the iterations and calculates the Crisfield coefficients applied in which convergence is determined. In the iteration steps, new displacements and stresses are determined. It is checked whether cracks or any other non-linear effects have occurred at any element. Cracked elements are considered with a reduced stiffness.

Structural and material models

The structural model was designed to replicate the test specimens. Four node quadrilateral isoparametric plane stress elements were used to model the SFRC/plain concrete elements. In plane elements of SOFISTIK, a general quadrilateral element with four nodes (QUAD) is sufficient, so that the introduction of the six-to nine-noded isoparametric elements is not necessary [1].

The material model applied consisted of a non linear stress-strain relation in tension and compression whose details are reported elsewhere [4]. Material behavior for the reinforcing bars was defined with a standard elastic-perfect plastic stress strain relation. The flexural reinforcement (re-bars) properties were same as those used in the tests.

4. Results and Discussions

(1) Shear load deflection behavior

Fig.1 and Fig.2 depicts the performance response in terms of load deflection curves from the experimental and the numerical analysis, respectively. It is apparent from these results that the beams reinforced in shear with the use of steel fibers and stirrups ultimately failed at higher loads when

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Contact: 852-8521, 1-14, Bunkyo_ Machi, Nagasaki, E-mail:d707282e@cc.nagasaki-u.ac.jp, Tel 095-819-2590

compared with the control beams., Ultimate shear loads were found to be 67, 64, 55kN and 69, 66, 54 for FB1%,SB1% and CB0% in the experiment and numerical analysis, respectively. Flexural ductility is noted to be almost the same until failure. In the early phases, the numerical and experimental results are linearly in agreement and although there are minor differences in the non linear phase, generally they are in close accord.

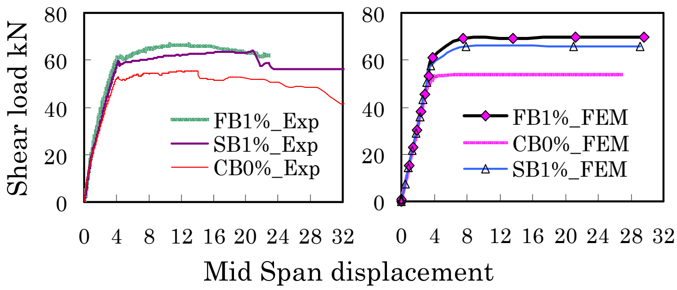

Fig.1 Comparative Load deflection response

(2) Shear stress strain response

Fig.2 shows the relationship between average shear stress and shear strains and in Fig.3 FEM the non linear shear stress distribution behavior in the FB1% is shown. As depicted in Fig.2, two sets of stress strain curves were made to also compare the strain measurements by the optical full filed method and those obtained by strain gauge rosette. Since the shear stresses are derived from the load response as previously discussed, a similar performance is noted in the fiber and stirrup beams over the controls beam in terms of strength. Ultimately the fiber concrete performed better both in terms of shear strength and strain ductility. The influence of the steel fibers in the shear region is clearly illustrated by the high strength-strain capacity in FB1%. Comparison of the strain measurements by DCIM and strain rosette shows a close agreement, however as for the stirrup beam (SB1%), it appears the measurement point coincided with a point of excessive shear deformations at failure which affected the results particularly after ultimate load. In the FEM shear stress distribution, the region under severe shear loading is found to be in accord with the region in which shear cracks were observed as depicted in Fig.4

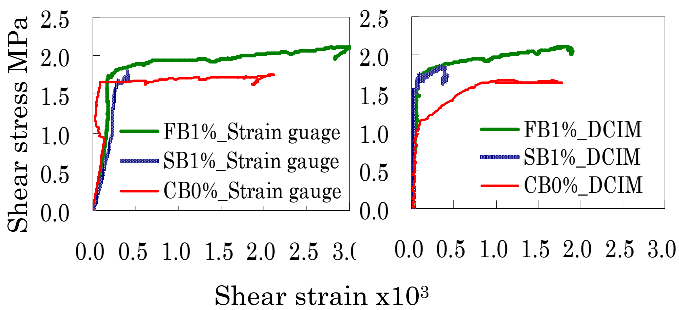

Fig.2 Comparative shear stress strain behavior

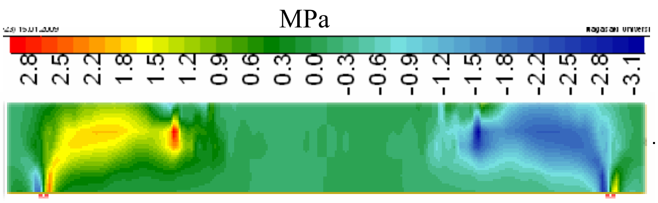

Fig.3 FB1% FEM shear stress pattern

(3) Failure mode

General physical failure modes and the cracking behavior in the shear region as captured by DCIM method were as shown in Fig.4 (a), (b) and (c). As depicted in these figures, a trend is noted whereby the fiber and stirrup-reinforced beams ultimately failed at different load levels. It appears that a combination of diagonal tension failure, flexural cracking near the mid span and concrete crushing in the compression region were responsible for the ultimate failure of the beams. This was more pronounced in the control beam which had no any form of shear reinforcements. The failure load for the fiber reinforced beams (FB1) was higher than that of the stirrup beam (SB1). Indeed both fiber and stirrup reinforced beams failed at higher loads than the control beam (CB0). By means of optical digital correlation image method, the shear cracks which could not be clearly seen by the naked eye could be monitored and captured as illustrated in Fig.4.

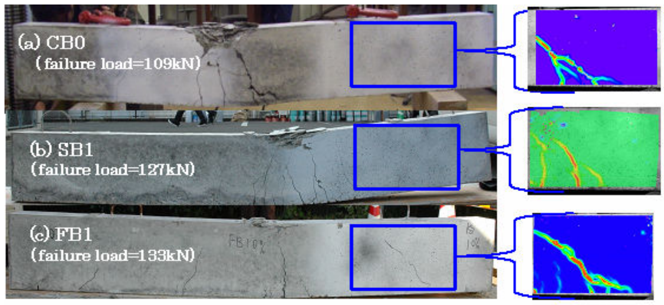

Fig.4 Failure pattern/shear cracking visualization by DCIM

5. CONCLUSIONS

The fundamental conclusions that can be drawn from the experimental and numerical investigation undertaken can be summarized as follows:

- ✧ Strength and deformation capacity in beams reinforced with steel fibers is higher than that of an equivalently reinforced stirrup beam
- ✧ Numerical simulation and the experiments were found to be in accord.
- ✧ Use of DCIM in the measurement of shear strains and cracking visualization was effective in an RC structure.

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