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Reinforcement effect of RC beam with compressive force applied to the direction perpendicular to the axis of beam

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ABSTRACT

Deterioration due to aging of civil engineering structures has become serious problems. The reconstruction of the deteriorated structure costs a lot. So, there is a need for periodically inspection, repairing and maintenance of the structure to increase the life of the existing structure. This paper describes a shear reinforcement method for RC beam especially T shaped cross section which has comparatively smaller width. The method is that steel rod is inserted in the direction perpendicular to the axis of beam and tensile force is applied on these rods. This generates compressive force on the reinforcing member helping to increase resistance to the shear force. The experiment for this reinforcing technique of RC beam is carried out and the numerical analysis is performed to verify the reinforcing effect.

1. INTRODUCTION

In recent years, deterioration due to aging of civil engineering structures that have been built in the period of high economic growth of Japan has become serious problems. Construction of new infrastructure from the financial point of view is on the decline. In contrast, there is social need for maintenance and repair of existing structure to make them long lasting. To address this situation, recently there is increase in interest in reinforcement approaches to structure and new reinforcement methods are proposed. On the other hand, there are many RC bridges, currently in service, designed based on the old Specifications for highway bridges before 1993. These bridges have insufficient shear force. This paper describes a shear reinforcement

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method for RC beam especially T shaped cross section which has comparatively smaller width. The method is that steel rod is inserted in the direction perpendicular to the axis of beam and tensile force is applied on these rods. This generates compressive force on the reinforcing member helping to increase resistance to the shear force. The reinforcement effect will increase for the RC beam as both steel rods is inserted and compressive force is used.

The experiment for this reinforcing technique of RC beam is carried out to verify the reinforcing effect. Based on the experimental method, elastic-plastic analysis of RC beam is performed by using finite element analysis program ANSYS. The analysis is done by changing the reinforcement conditions to find the effective reinforcement pattern.

2. LOADING TEST OF RC BEAM

2.1 Specimen and reinforcement method

Fig. 1 and Fig. 2 show specimen, reinforcement method and overview of the loading test (Endoh 2013). The shear strength of the specimen is smaller than the bending strength (JSCE 2007). When the loading test is performed, RC beam is calculated so that shear fracture occurs first.

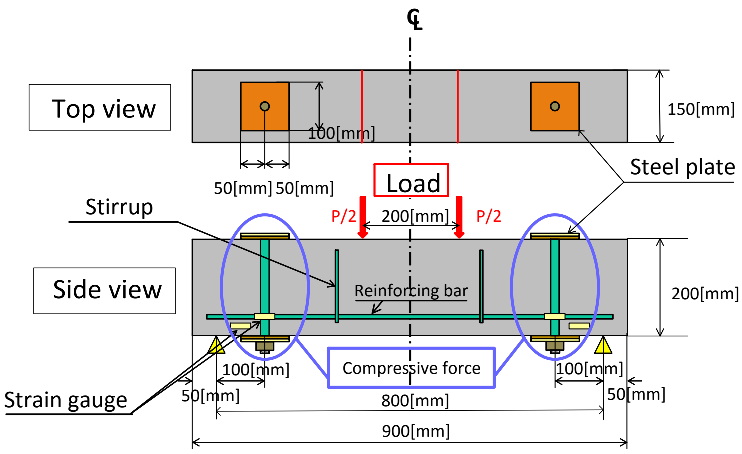


Fig. 1 Experiment outline (specimen)

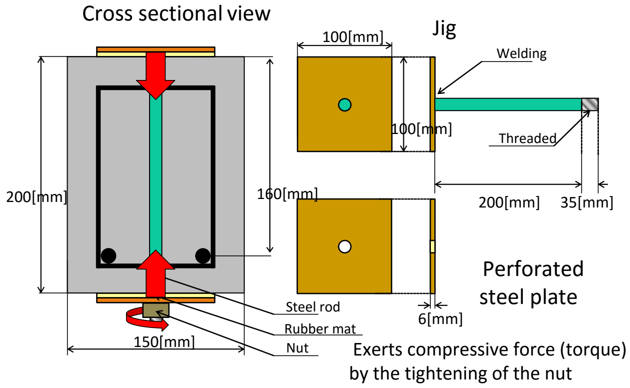


Fig. 2 Experiment outline (cross section and reinforcement method)

The construction process of the reinforcement is described below. First, at the distance of 100 (mm) from support point where the occurrence of shear cracks of RC beam is expected, hole of *φ*23 (mm) is created in the direction perpendicular to the axis. Jig used for reinforcing has the steel plate of geometry 100 (mm) × 100 (mm) × 6 (mm). Hole of *φ*23 [mm] is made at center part and steel rod of *φ*19 (mm), length of 240 (mm) is inserted (material SR235). Next, after inserting a steel rod to the hole, grout material is injected into the void (as a grout, mortar which water-cement ratio is 0.37 and fine aggregate cement ratio 2.0 is used). The bottom part of beam, steel plate of with hole of *φ*23 (mm) was placed and after inserting a steel rod into the hole given torque is applied to the nut. In order to make the contact between tool and the steel sheet uniform, rubber of same size as the steel sheet of 100 (mm) × 100 (mm) × 3 (mm) is placed between the upper and lower surfaces of RC and steel sheet. Flat washer is also placed between steel plate and the nut.

When the shear crack is generated in the RC beam, change in volume occurs in inner part of concrete. Further, when the shear fracture occurred, since fracture is a brittle in nature, strength will be significantly reduced. With respect to above, the reinforcement technique proposed here is insertion of steel rod in the perpendicular direction to the axis, fix them by steel plate and application of tensile force. Therefore, when carrying out the reinforcement, the following two effects are expected. At first, by insertion of the steel rod in the perpendicular direction to the axis, increase in amount of shear reinforcement rods occurs. Furthermore by setting a steel rod and steel plate and applying tensile force on concrete near the reinforcement, shear deformation is restricted and cross section restraining effect occurs. By the application of tensile force in the concrete of reinforcement portion in the vertical direction to the axis, transition of principal stress to horizontal direction occurs. Therefore the horizontal component of principal stress is burden by tensile reinforcement arranged in same direction. In general, shear cracks are generated from bottom of RC beam of tension side. The bending stress is small in the portion near support point. When the horizontal component of the principal stress is very high, it can bear a sufficient tensile stress and the control of shear cracks is expected.

2.2 Loading test

Loading test is performed in the following five RC beams with the properties shown in Fig. 1.

BEAM1: Before loading tests, the round steel of φ19 (mm) is inserted in RC beams
BEAM2: Before loading tests, 100(N･m) torque is applied in jig
BEAM3: Before loading tests, 50 (N･m) torque is applied in jig
BEAM4: No reinforcement
BEAM5: After conducting a load test on BEAM4, unload after shear failure and reinforcement is done by applying 100 (Nm) torque on jig.

Fig. 3 shows the relationship between the load and vertical displacement of central part of span. Load carrying capacity of BEAM1 reinforced by inserting a steel rod is a 91.0 (kN) whereas load carrying capacity of BEAM4 with no reinforcement is 79.6 (kN). When steel bar is inserted in same position as proposed reinforcement technique, the fracture pattern is shear and load after reaching the maximum load is significantly reduced. In contrast, load carrying capacity of BEAM2 and BEAM3 is about 160 (kN). The load carrying capacity is improved up to 75 (%) by applying a compressive force. Comparing BEAM2 and BEAM3, the former has been applied twice the compression force of the latter, the maximum value of the applied load is 3 (%) larger in the former. In addition, immediately after the maximum load loading of BEAM3, load is reduced. This is caused because the amount of the torque introduced to BEAM3 is half the torque introduced to BEAM2. In the unloading process of BEAM2, the significant decrease in vertical displacement can be confirmed. Further, the residual displacement of BEAM2 is significant decrease nearly 0. By the application of compressive force in the vertical direction to the axis, the cross section restraint effect is formed. This effect is same as increased of restoring force in prestressed concrete structure.

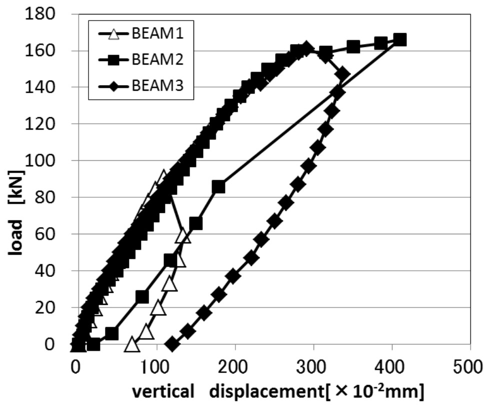


Fig. 3 Load-deflection curve (BEAM1, BEAM2 and BEAM3)

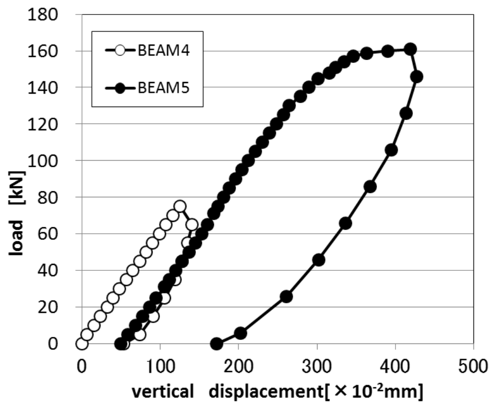


Fig. 4 Load-deflection curve (BEAM4 and BEAM5)

Fig. 4 shows the relationship between the applied load and vertical displacement of the central part of span of BEAM4 and BEAM5. BEAM4 is unloaded immediately after shear failure occurred and reduction of surcharge load. From the figure, load carrying capacity of BEAM4 is 79.6 (kN) whereas BEAM5 is 160.8 (kN). The 102 (%) improvement by the reinforcing is observed. Also, the maximum value of the vertical displacement of the former is 140 ($\times 10^{-2}$mm) whereas the latter is 378 ($\times 10^{-2}$mm). The increase in value by 170 (%) is observed. Reinforcement is done in BEAM5 in the portion where shear cracks occurred in BEAM4, but shear cracks in the preceding becomes brittle which cause progress and formation new cracks. Significant reduction of load carrying capacity followed by shear cracks was not observed. Thus by performing a proposed reinforcing technique, when the shear fracture occurred, significant improvement of load carrying capacity is confirmed.

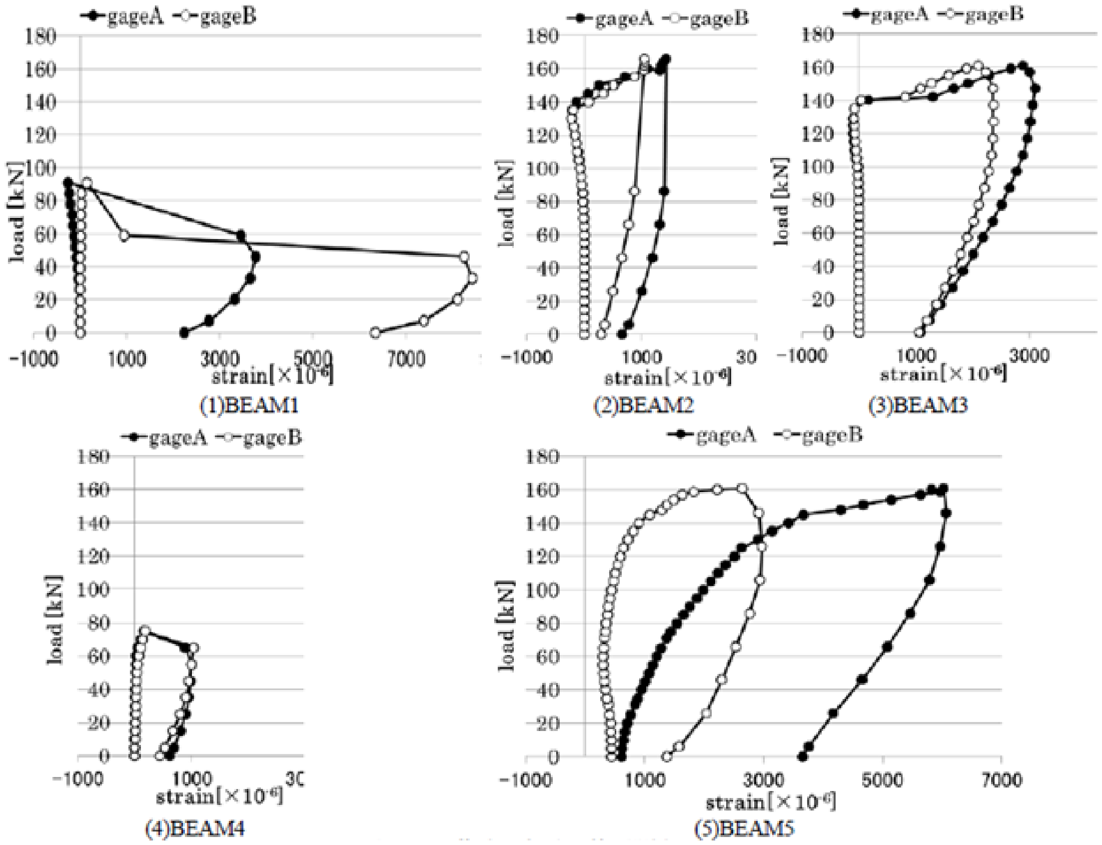


Fig. 5 Load-horizontal strain curve

Fig. 5 shows the relationship between load and the horizontal strain of each beam. Figure is drawn by plotting of stain of the end side where maximum strain is formed. As shown in Fig. 1, symbol ● in the figure is the value measured using gauge A installed near support point while symbol ○ is value measured with the gauge B installed in central part. In BEAM1, reinforced by round steel bar, after the formation shear crack, relatively large strain occurs as the result of delay of unloading. Maximum horizontal strain of BEAM3 is three times that of BEAM2. Since the compressive force is higher in BEM2, restoring force is formed which reduce the residual strain significantly. In the same way, during maximum loading, bending cracks and shear cracks are formed in BEM3. In the case of BEAM4, since no reinforcement is applied, shear cracks are formed and when the load carrying capacity is reduced, beam is unloaded. Therefore even when the load is maximum loading, the horizontal strain is very small. BEAM5 is the reinforcement done in the BEAM4 where shear cracks has formed. So, during loading new cracks are formed from the bottom portion of the former cracks, and from this it can be concluded that larger strain is formed by the expansion of brittle areas. Furthermore, the strain history differs with respect to the installation position of gauge. This is caused by the effect of the progress of cracks in the direction of support point and formation new cracks in bottom portion. However, despite the increase of the horizontal strain, load carrying capacity is improved by the effect of reinforcement.

3. FINITE ELEMENT ANALYSIS USING ANSIS SOFTWARE

Based on the experimental method, elastic-plastic analysis of RC beam is performed by using finite element analysis program ANSYS. Analysis model is shown in Fig. 6. Nut at reinforcement part and rubber mat in the experiment is omitted in the analysis and tightening of the nut is treated as surface load of the steel sheet. The stress-strain relationship of the tensile bar, the stirrup and the steel rod are defined using Bilinear type model and the stress-strain relationship of concrete is modeled based on Kent & Park model (Dere 2011) shown in Fig. 7. The yield strength and modulus of elasticity of steel and concrete are given in Table 1. The tensile strength of concrete is assumed to be 3.0 (MPa).

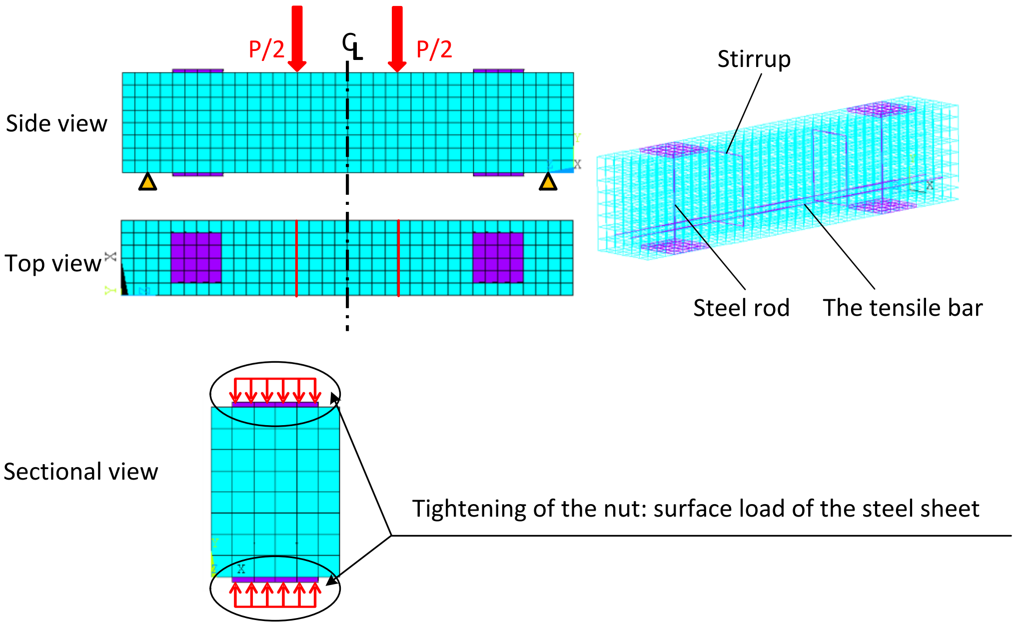
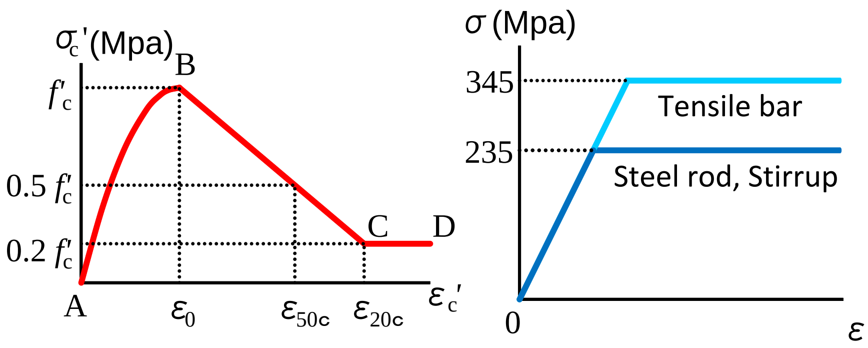


Fig. 6 Analysis model



(a) Concrete (b) Steel

Fig. 7 Stress-strain curves

Table 1 Material model

Material name	Stress-strain curve	Young's modulus (GPa)	Yield stress (MPa)	Crack stress (MPa)
Concrete	Kent & Park model	35.0	40.0	3.0
Tensile bar	Bilinear model	206.0	345.0	-
Steel rod	Bilinear model	206.0	235.0	-
Stirrup	Bilinear model	206.0	235.0	-

In Table 2, the load carrying capacities obtained from the experiment and FE analysis are shown for each RC beam. It is found that improvement of the load carrying capacity is possible by the application of reinforcement. However, the difference occurs in the analysis and experimental results. Analysis value is greater compared with the experimental value in BEAM1 and BEAM4. On the other hand, analysis value is smaller compared with the experimental value in BEAM2, BEAM3 and BEAM5. The reason for this is not being able to reproduce the difference of fracture morphology of bending and diagonal shear cracks. There is need to consider an index for evaluating the fracture morphology and the load carrying capacity for the stress and strain of the analysis results. The reinforcing effect of compressed steel plate is confirmed by the inhibitory effect observed on cracking progress on the region near the reinforcement in BEAM2 and BEAM3 (Fig. 8).

Table 2 Comparison of load carrying capacity

	Experiment (kN)	Analysis (kN)	
BEAM1	91.0	115.0	No compression force
BEAM2	160.0	125.0	With compressive force
BEAM3	160.0	125.0	With compressive force
BEAM4	75.0	100.0	No compression force
BEAM5	160.0	120.0	With compressive force

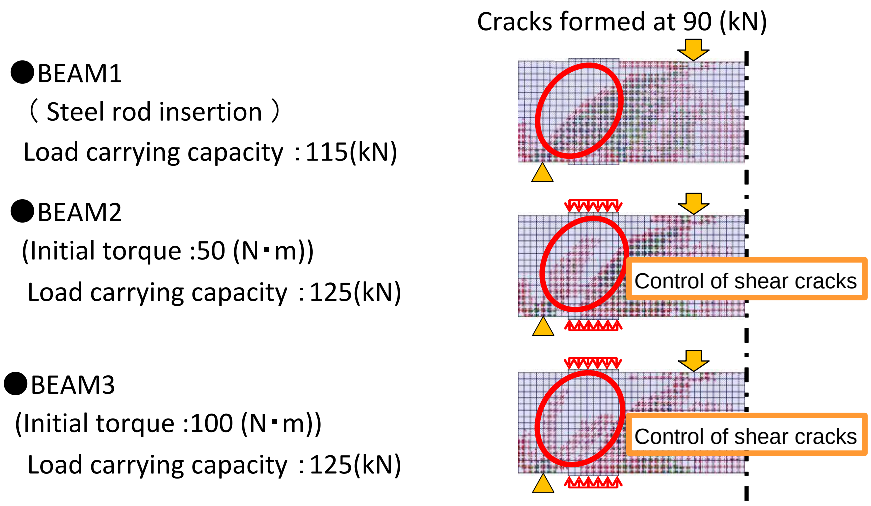


Fig. 8 Analysis result

In the same way, the simulation with varying reinforcement conditions is performed. Fig. 9 shows a comparison of the load carrying capacity and the cracking situation for the four cases. Following results are observed; 1) Load carrying capacity and suppression of crack propagation cannot be expected from the increase in cross-section area and the changing the number of the steel rod. 2) Reduce in the development of cracks is observed by applying reinforcement in the region of occurrence of diagonal cracks. However, it does not cause a difference in load carrying capacity. 3) In compare to the other models, significant suppression of cracks is observed by the increase of compressive force.

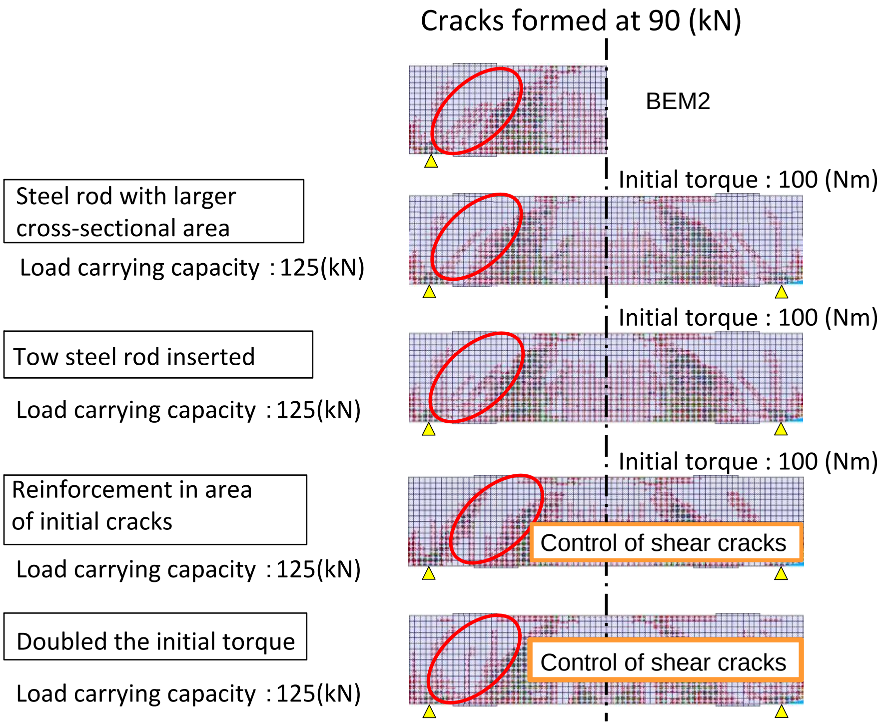


Fig. 9 Analysis results with different reinforcement conditions

4. CONCLUSIONS

In this study, a shear reinforcement method for RC beam is proposed. The experiment for this reinforcing technique is carried out to verify the reinforcing effect, and elastic-plastic analysis is performed by using finite element analysis ANSYS software based on the experimental method. Results are summarized as follows:

1. From the experiment, it is confirmed that the proposed reinforcement technique not only increased the load carrying capacity but also controlled the shear cracks.
2. In the analysis using ANSYS, the reinforcing effect of compressed steel plate is confirmed by the inhibitory effect observed on cracking progress on the region near the reinforcement.
3. With respect to load carrying capacity, the difference occurs between the analysis and experimental results. There is need to consider a criterion for evaluating the fracture morphology and the load carrying capacity for the stress and strain of the analysis results.
4. The simulation results with changing reinforcement conditions reveal that the crack growth is restrained by applying reinforcement to the region of occurrence of diagonal cracks. However, it does not cause a difference in load carrying capacity.
5. Load carrying capacity and suppression of crack propagation cannot be expected from the increase in cross-section area and the changing the number of the steel rod.

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