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Shear Fatigue Load Carrying Mechanism of Reinforced Concrete Beams with Corrosion Cracks along Longitudinal Rebars

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Abstract

Focused on reinforced concrete (RC) structures which have rebar corrosion cracks due to aging deterioration, it is predicted that these structures have fatigue damage which is accumulated in the service state. There is a possibility that the RC members will fail in shear by the combined deterioration. However, shear fatigue behavior of the RC members has not been made clear. For establishing suitable maintenance methods, the fatigue behavior of aged RC members has to be made clear to reduce the maintenance cost.

In this study, loading experiments and finite element analyses were conducted to make clear the shear fatigue load carrying mechanism of RC beams with rebar corrosion cracks.

From the analytical results of the beams with cracks along longitudinal rebars within the shear span without stirrups, when the crack tips existed on the lines which tied between loading points and supporting points, the static strength of the beam showed increasing tendency because of tied-arch effect. When the cyclic load was acting on the beam, in the case of the beams which had cracks along the compressive rebars within the shear span showed the same fatigue resistance as sound beams. However, the fatigue resistance of the beams which had cracks along the tensile rebars within the shear span showed remarkable decline. This study made clear that this decline tendency is caused by difference of stress transfer area at failure.

A possibility that load paths which are formed as passing at the crack tips in cracked beams characterize the fatigue resistance was represented.

1. Introduction

In Japan, a number of infrastructures made of reinforced concrete (RC) which has rebar corrosion cracks due to aging has increased. Fatigue damage is accumulated in the infrastructures due to a cyclic load under long term service state. There is a possibility that the combined deterioration of fatigue and corrosion changes failure pattern of RC structural members from the design assumption.

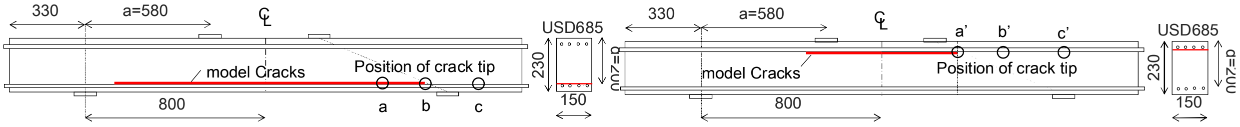
Focused on previous studies on the combined deterioration of RC beams, there are a few studies about flexural fatigue. According to the previous study, the flexural fatigue can be evaluated by mass loss of rebars. However, knowledge about the shear fatigue cannot be found. Therefore, it is needed to store the knowledge about the shear fatigue behavior of RC beams which have rebar corrosion cracks.

It is predicted that the shear fatigue mechanism of RC beams which have rebar corrosion cracks is governed by geometric conditions such as position and length of the corrosion cracks in concrete. Position and length of the corrosion cracks were decided as analytical variables in this study. Three dimensional finite element (FE) analysis and loading experiment were conducted to make clear the shear fatigue mechanism of RC beams which have rebar corrosion cracks under these analytical variables.

2. Details of target beams

Size and shape of target beams are shown in Figure 1. RC beams with rebar corrosion cracks along longitudinal rebars were decided as the targets of this study. The target beams were designed to fail in shear and to have no stirrup. Shear span ratios (a/d) of the beams was defined as 2.9 to confirm a cracking behavior of slender beams whose failure mode is easy to become diagonal cracking failure on the sound beams. A model crack was inserted in the target beam to secure a uniform crack surface property [1]. The model crack simulates an ultimate state which represents low meshing effect of the crack surfaces. The target beams are named T beams and C beams. The initial letter of the name of the target beams (Table 1) represents crack position and the following small letter represents the position of crack tips. Position b of T beam (T-b) and a’ of C beam (C-a’) represent that the crack tips exist on the lines which tie between loading points and supporting points. The positions of crack tips are illustrated in Figure 1. The crack positions of T-b and C-a’ are illustrated as examples.

The COM3 (three dimensional FE analysis) was used in this study. Basic constitutive model of COM3 is the orthogonal two-way fixed crack model [2]. The orthogonal two-way fixed crack model considers the active cracks which generate stronger nonlinearity on the elements. Crack propagation model on fatigue phenomenon are considered as an elastic stiffness reduction of the concrete elements. A number of FEs of analytical model in the direction perpendicular to the beam axis is only one due to symmetry. The FE model is fixed in the perpendicular to the beam axis direction. The model cracks are simulated by arrangement of two dimensional bond elements which permit slide of nodal points under Mohr-Coulomb's linear friction law.



(a) T beam (b) C beam

Figure 1: Details of specimen (Unit: mm)

Table 1: Analytical parameters of target beams

Specimens name	Crack tip positions	Specimens name	Crack tip positions	Upper limit load ratio
T-a	a	C-a’	a’	100, 80, 60, 40
T-b	b	C-b’	b’	
T-c	c	C-c’	c’	

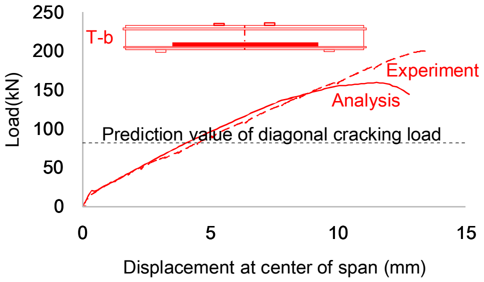


Figure 2: Load-deflection curve

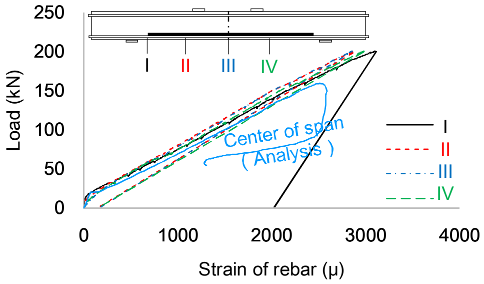
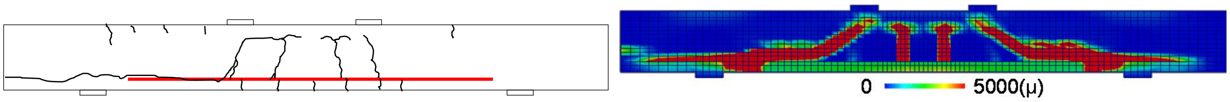


Figure 3: Strain of rebar



(a) Crack distribution map (b) Maximum principal strain map

Figure 4: Comparison of cracking property of T-b

3. Validity of analytical model

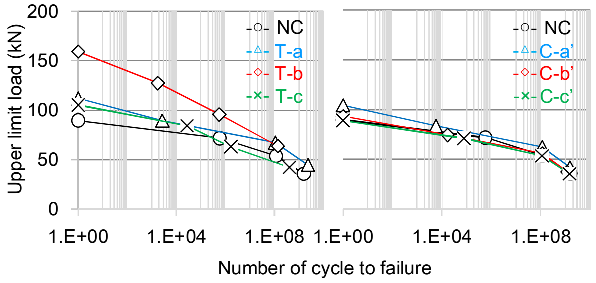
Static loading experiment was conducted to confirm validity of the analytical model. The target beam was T-b as shown in Figure 1(a). Loading experiment was conducted under four point bending condition and displacement control of 0.1mm/min. The load-deflection curve of T-b and predicted value of diagonal cracking load of the sound beam [3] were illustrated in Figure 2. The static strength of cracked beam was 2.4 times higher than predicted value of the sound beam. Strain of rebar versus load is shown in Figure 3. It can be confirmed that value of strain at each position were close to the value of other position with increase in load. It is considered that a load carrying mechanism of the beam represented tied arch mechanism because of increase in the strength for prediction value of a sound beam and asymptotic behavior of strain of rebar.

Focused on the analytical result, the peak load is a little lower than that of the experiment (Figure 2). Crack distribution map and maximum principal strain map which were obtained by experiment and analysis respectively are shown in Figure 4. It can be confirmed that the principal strain map coincides with crack distribution. Therefore, it can be said that validity of analytical models are confirmed.

4. Fatigue resistance of cracked beam

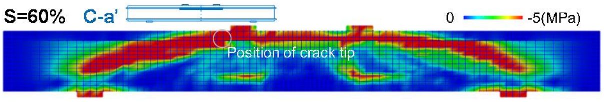
Fatigue analyses were conducted to obtain fatigue strengths and stress distributions of cracked beams. Upper limit load ratios were decided as four cases (100, 80, 60 and 40%) for each beam and sound beam (NC). Lower limit load was fixed at 9.8kN. The loading frequency was 1Hz in all cases. Failure displacement for fatigue analyses was defined as displacement of peak load in the static analyses.

S-N curves are shown in Figure 5. Static strengths of T beams are higher than that

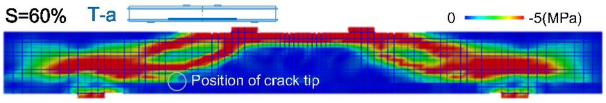


(a) T beam (b) C beam

Figure 5: S-N curve of analytical results

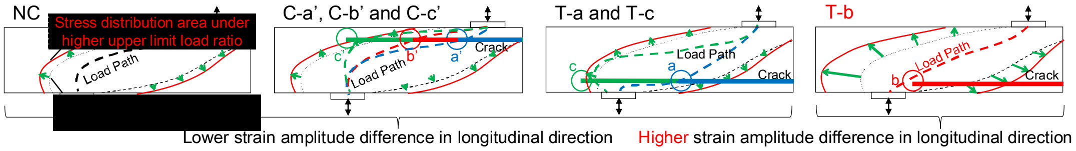


(a) C-a' (at failure)

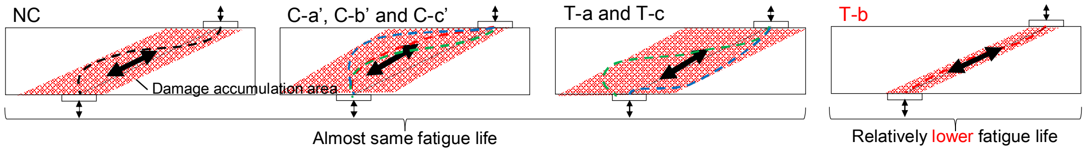


(b) T-a (at failure)

Figure 6: Minimum principal stress distribution map



(a) Restriction of load path by stress concentration at crack tips



(b) Localization of damage accumulation area by restriction of load path

Figure 7: Conceptual diagram regarding shear fatigue mechanism of a sound beam and cracked beams

of NC beam due to tied arch effect. In the case of T-b, the static strength shows the highest value in all cases. It means that tied arch effect appears most effectively when the crack tip is introduced in the position b. Focused on the fatigue behavior, it can be confirmed that the decreasing gradient of fatigue strength versus number of cycle to failure is the steepest in the all cases. In contrast, in the case of C beams, the gradients of S-N curves are almost constant. It means that a crack along compressive rebars gives no significant effect to fatigue strength.

The minimum principal stress distribution maps at failure of C-a' and T-a under 60% upper limit load ratio are shown in Figure 6. From the distributions, formations of compression struts were confirmed. It was also confirmed that the stress was distributed as passing at crack tip in all cases. This study focused on a load path in a beam to explicate the fatigue load carrying mechanism. The load path is defined as a ridgeline of minimum principal stress distributions [4]. Conceptual diagrams regarding load paths are shown in Figure 7. From this definition, it is considered that the load paths are attracted to crack tips due to stress concentration. The paths of the all beams except T-b are crooked by stress concentration at crack tips. When the paths show a crooked shape, the paths retain the stress transfer area constantly for each upper limit load ratio (Figure 7(a)). In contrast, the path of the case of T-b is restricted as forming linear shape because crack tips exist on the lines which tie between loading points and supporting points. Forming of the load path as a linear shape causes localization of a damage accumulation area (Figure 7(b)). Crack propagation speed with increase in acting number of cycles is intensified by this localization. Consequently, it can be deduced that decreasing gradient of fatigue strength in the case of T-b (Figure 5(a)) is caused by restriction of the load paths.

5. Conclusions

The main results of this study are shown as follows.

1) When the beams have cracks along longitudinal rebars, reduction of the fatigue strength becomes large in the case of the beam with cracks along tensile rebars.
2) In the case of the beam with cracks along tensile rebars, when a tied arch mechanism which contributes to increase in static strength of the beams appears, the fatigue resistance of cracked beams becomes small.
3) When the beam has a straight load path, a rapid decrease in the fatigue strength occurs. In contrast, when the beam has a crooked load path, the decrease in the fatigue strength is not remarkable.

6. References

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