EXPERIMENTAL STUDY ON STRESS TRANSFER OF JOINTS CONNECTED STEEL MEMBER WITH REINFORCED CONCRETE MEMBER USING ANCHOR BOLT

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ABSTRACT :

To clarify the behavior of the joint connected steel member with reinforced concrete member using anchor bolt based on stress transfer from steel member and reinforced concrete member, three specimens were tested under reversed cyclic loading. All specimens had same the dimensions and the cross sections of steel member and reinforced concrete member, respectively. The experimental variables were the length of the anchor bolt embedded in reinforced concrete member and having transverse reinforcements in the joint or not. It is designed so that yielding of steel member and anchor bolt does not occurred. The effect of these experimental variables on the stress transfer from steel member to reinforced concrete member and seismic behavior of the joint were discussed.
From the test results, it was shown that stress transfer from steel member to reinforced concrete member in the joint could be mobilized by transverse reinforcements arranged intensively around anchor bolt even if the length of the embedded anchor bolt was relatively short for the effective depths of reinforced concrete member and the failure mode of specimen was controlled greatly by the length of the embedded anchor bolt than transverse reinforcements in the joint.

KEYWORDS: steel-concrete composite structure, joint, anchor bolt, transverse reinforcements, embedded length, stress transferring mechanism

1. INTRODUCTION

The joint connected steel member with reinforced concrete member using anchor bolt could be considered to be one of joint in steel-concrete composite structure. As such a typical joint, there is exposed-type column base in steel frame system structure. To establish a rational design method of the joint in steel-concrete composite structure, it is necessary to clarify stress transfer from steel member to reinforced concrete member. However, analytical model capable of estimating generally for the stress transfer from steel member to reinforced concrete member in the joint is not established.
The purpose of this experimental study is to clarify the behavior of the joint connected steel member with reinforced concrete member using anchor bolt based on stress transfer from steel member and reinforced concrete member.

2. STRESS TRANSFERRING MECHANISM

The assumed mechanism of the stress transfer from steel member to reinforced concrete member in the joint is shown in Figure 1. In this model, joint is composed of concrete compression strut transmitting the compression force alone and it is not supposed that stress transfer from steel member to reinforced concrete member is influenced on the frictional forces caused by the bearing forces.
Stress transfer from steel member to reinforced concrete member could be classified into two cases: the length l_e of the anchor bolt embedded in reinforced concrete member is about the effective depths of the cross sections of reinforced concrete member (shown in Figure 1(a)) and is relatively short in comparison with it (shown in

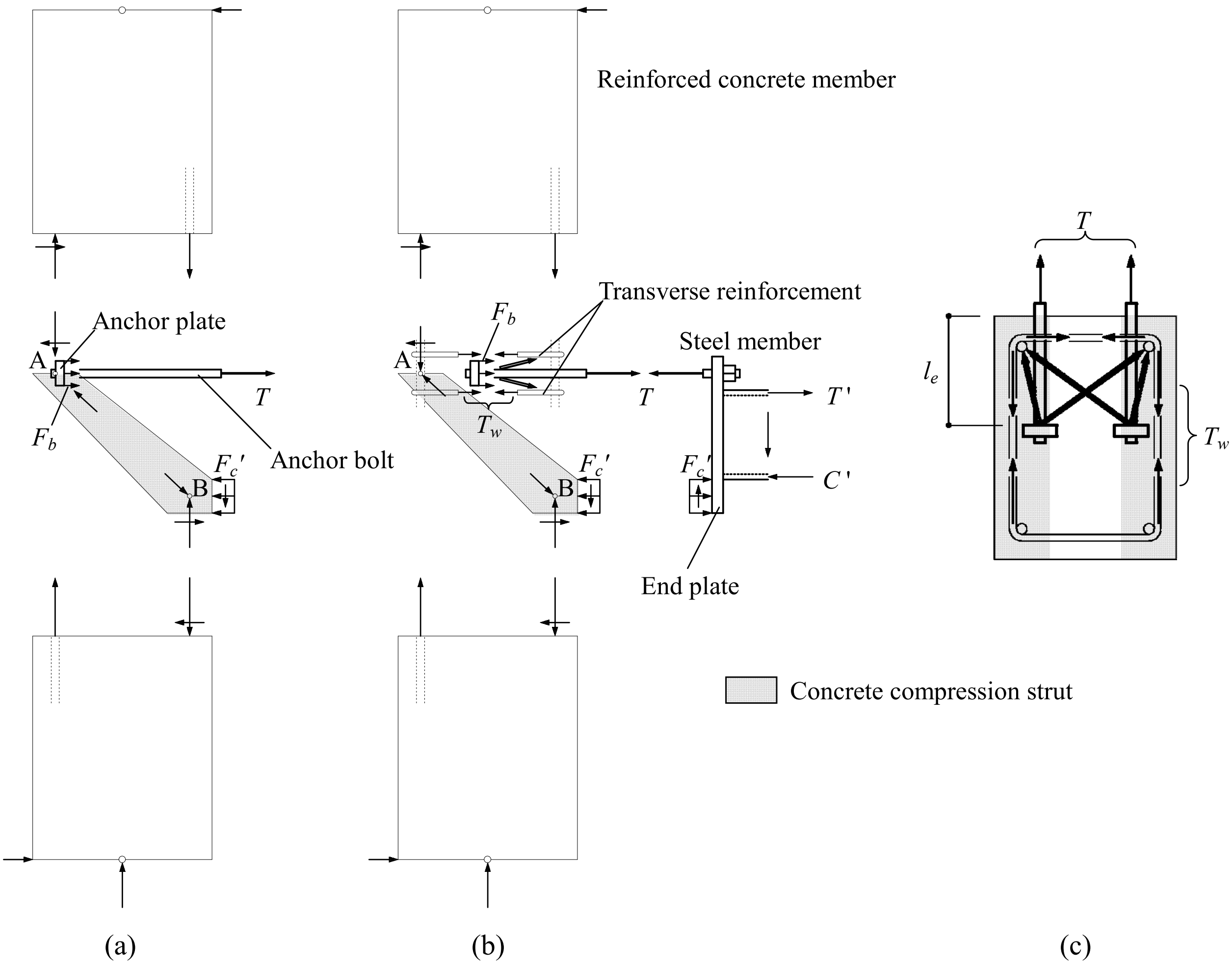

Figure 1 Stress transferring mechanism

Figure 1(b)).
The bearing stress F_c' and F_b acting on the compression side of end plate and anchor plate through the tension force T of anchor bolt is mobilized by the bending moment applied steel member.
In case that the length l_e of the embedded anchor bolt is long, the compression result force as these reaction forces transmitted to reinforced concrete member acts for maintaining equilibrium of compression force transmitted by concrete compression strut at point A and B as shown in Figure 1(a).
On the other hand, in case that the length l_e of the embedded anchor bolt is short, stress transfer mechanism explained above is not developed. However, if transverse reinforcements were arranged intensively around anchor bolt, the outward thrust at the end of concrete compression struts that form through direct bearing stress F_b acting on anchor plate is resisted by tension force T_w of transverse reinforcement as shown in Figure 1(b) and (c). As the result of this stress transfer, tension force T_w acts for maintaining equilibrium of compression force transmitted by concrete compression strut at point A, and the arch mechanism might be developed in the joint as shown in Figure 1(b).

3. EXPERIMENT

To clarify the behavior of the joint connected steel member with reinforced concrete member using anchor bolt based on stress transfer from steel member and reinforced concrete member in the joint mentioned above, three specimens were tested under reversed cyclic loading. Typical the dimensions, the cross sections and details of reinforcement are shown in Figure 2. The specimens have T-shaped beam-column sub-assemblages and about a

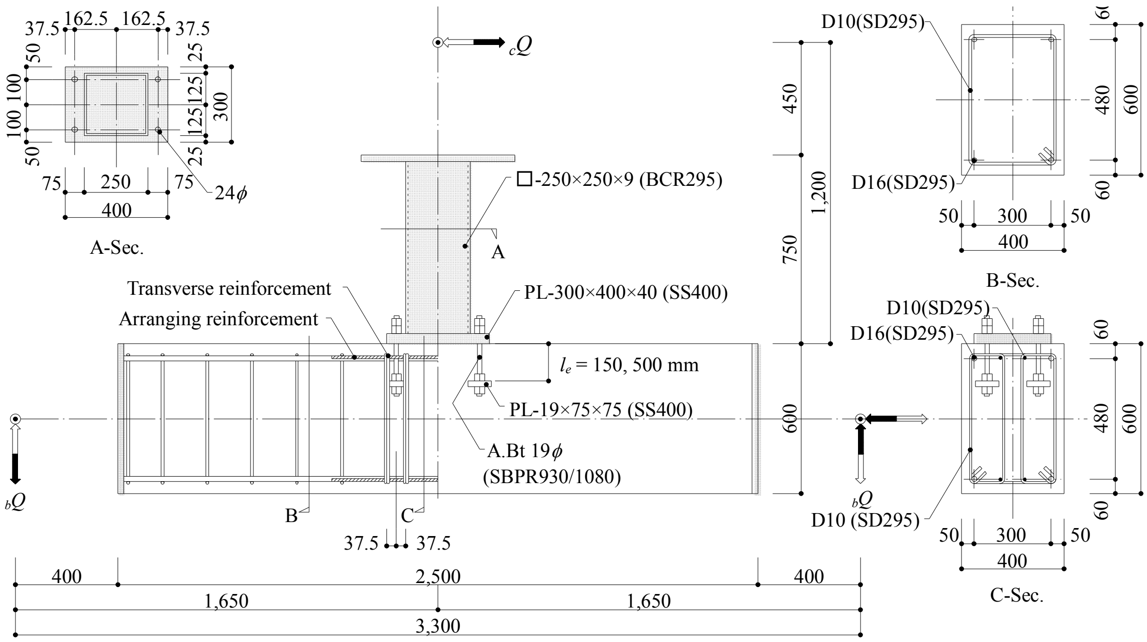

Figure 2 Details of test specimens

Table 1 Mechanical properties of materials

Materials \ Stress		σ_y (N/mm^2)	σ_u (N/mm^2)	E_s (N/mm^2)	note
Steel	PL9 (BCR295)	372	460	1.72×10^5	-
	PL19 (SS400)	294	436	2.08×10^5	
	PL40 (SS400)	253	411	2.09×10^5	
Reinforcement	D10 (SD295)	344	488	1.83×10^5	
	D16 (SD295)	345	516	1.82×10^5	
Anchor Bolt (PC)	19ϕ	889	1081	1.86×10^5	1
		984	1125	2.01×10^5	2
Materials \ Stress		**σ_B (N/mm^2)**	**σ_t (N/mm^2)**	**E_c (N/mm^2)**	**note**
Concrete		28.7	2.81	2.67×10^4	-

*) 1: Values used for Specimen A-150 Series
2: Values used for Specimen A-500
σ_y : Yield Stress
σ_u : Maximum Strength
σ_B : Compressive Strength
F_t : Splitting Strength
E_s, E_c : Yang's Modules Steel and Concrete, respectively

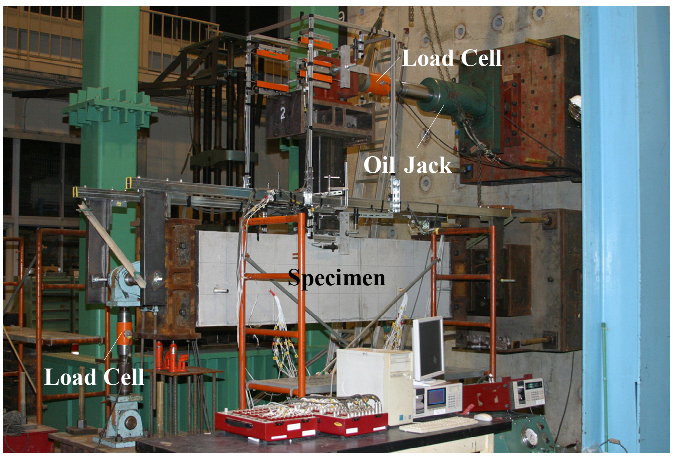

Figure 3 Test setup

half scale model. The reinforced concrete member has widths of 400 mm and depths of 600 mm, and the longitudinal reinforcements have a nominal diameter of 16 mm. The steel member has 250 mm square steel tubes with nominal b/t ratio 27.8 (b: widths of square steel tubes, t: thickness of square steel tubes). The

experimental variables are the length of the embedded anchor bolt and having the transverse reinforcement in the joint or not. The lengths l_e of the embedded anchor bolt were two types: a quarter of the depths of reinforced concrete member (150 mm, specimens A-150 and A-150ST) and the effective depths of it (500 mm, specimen A-500). In specimen A-150ST that the length of the embedded anchor bolt has a short, based on stress transferring mechanism of the joint as mentioned above, transverse reinforcements with nominal diameter of 10 mm which are necessary to develop the ultimate flexural strength of reinforced concrete member were arranged intensively around anchor bolt. All specimens were designed so that yielding of steel member and anchor bolt does not occurred. The mechanical properties of materials are listed in Table 1.
As shown in Figure 3, specimen is simply supported and the cyclic load is applied at the top of steel member with increasing displacement amplitudes. The program is based on drift angle R, which is defined as equal to δ / h (δ: story drift of the top of steel member measured by deflection transducer, h: distance between principal axis of the cross sections of reinforced concrete member and the inflection point of steel member).

4. TEST RESULT

The crack patterns of specimens are illustrated in Figure 4. For specimen A-150 series, regardless of having transverse reinforcements or not, the cone shaped splitting failure at the anchored portion was remarkable with pull-out of anchor bolt. However, whereas the crack of specimen A-150ST was developed in approximately 45 degrees direction for axial of reinforced concrete member, the crack angle of specimen A-150 was quite half degree for that of specimen A-150ST. Accordingly, in specimen A-150ST, the flexural cracks were remarkably developed. On the other hand, In specimen A-500, the flexural cracks were very remarkably observed. And slight diagonal tension cracks and bond splitting cracks along upper longitudinal reinforcements were observed at the joint panel. However, the cracks caused by pull-out of anchor bolt were not observed up to R = 0.05 radium of the maximum applied distortion.
The relationships between the applied lateral load and drift angle at the top of steel member are shown in Figure 5. The vertical axis represents the applied lateral load ${}_cQ$. Horizontal axis gives the drift angle R. The number shown in "○" represents typical cracking loads and maximum load. The dotted line in the graph represents the ultimate flexural strength ${}_cQ_{rc}$ of reinforced concrete member. For each specimen, slight pinching was observed during initial loading cycle. In subsequent loading, pinching behavior was remarkably observed. Specimen A-150 reached its maximum strength by the cone shaped splitting failure during initial loading cycle. However, no significant strength degradation was observed after specimen reached its maximum strength, and a constant strength was kept up to R = 0.03 radium. In specimen A-500, although large stiffness degradation was

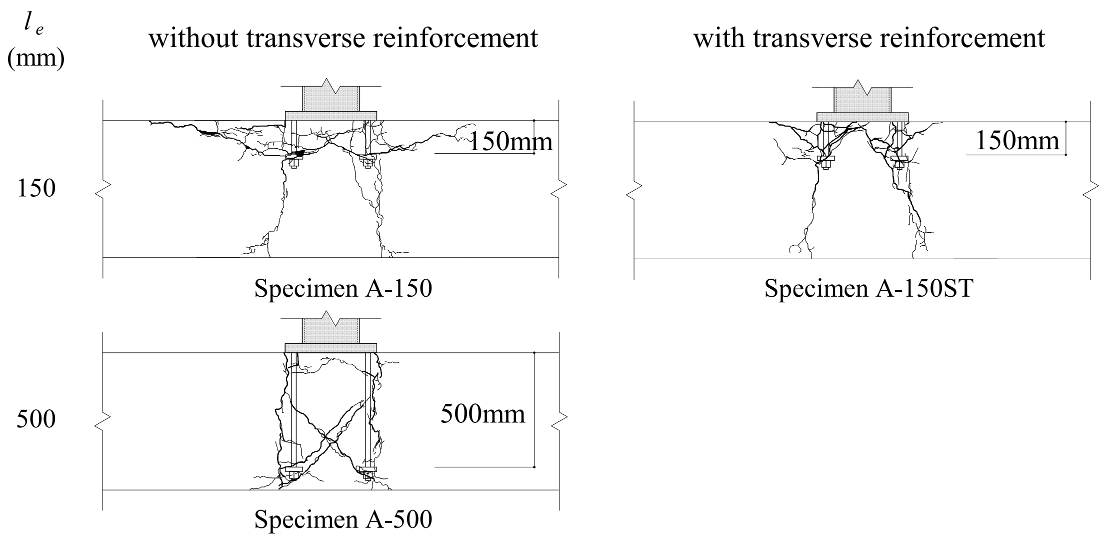

Figure 4 Crack Patterns

observed at the same time as the flexural cracks occurred. However, the strength increased after yielding occurred at the longitudinal reinforcements, and it was shown typical flexural behavior of reinforced concrete member that strength degradation was not seen up to the maximum applied distortion of R = 0.04 radium. On the other hand, in specimen A-150ST, although the cracks caused by the cone shaped slipping failure were observed at the initial cycle, the applied loads increased with displacement amplitudes. Because hysteresis characteristics of specimen were similar to that of specimen A-500 until specimen reached the maximum strength, it was supposed that the behavior was controlled by flexural behavior of reinforced concrete member. However, large degradation was observed after yielding occurred at the longitudinal reinforcing bars

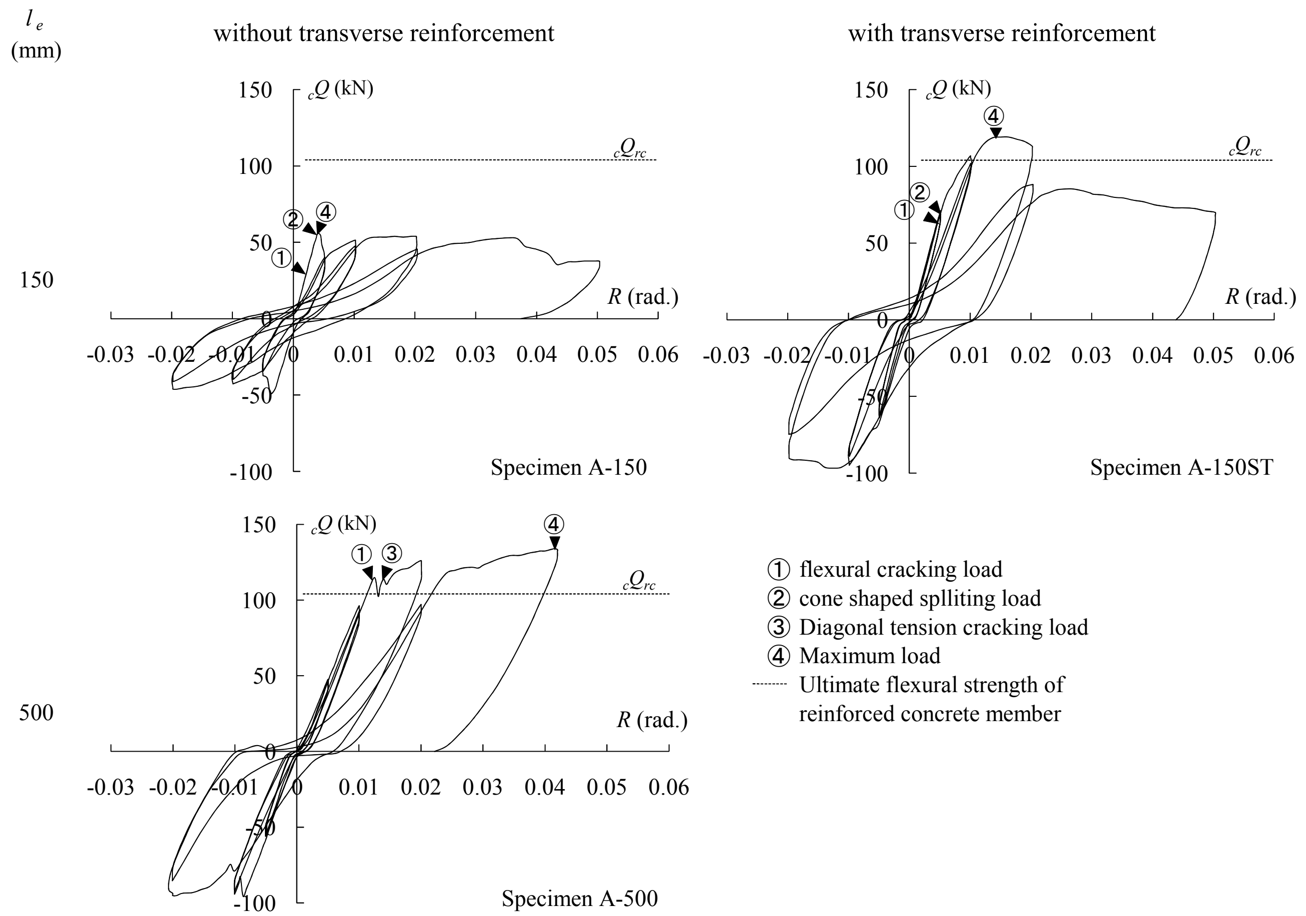

Figure 5 Hysteretic loops

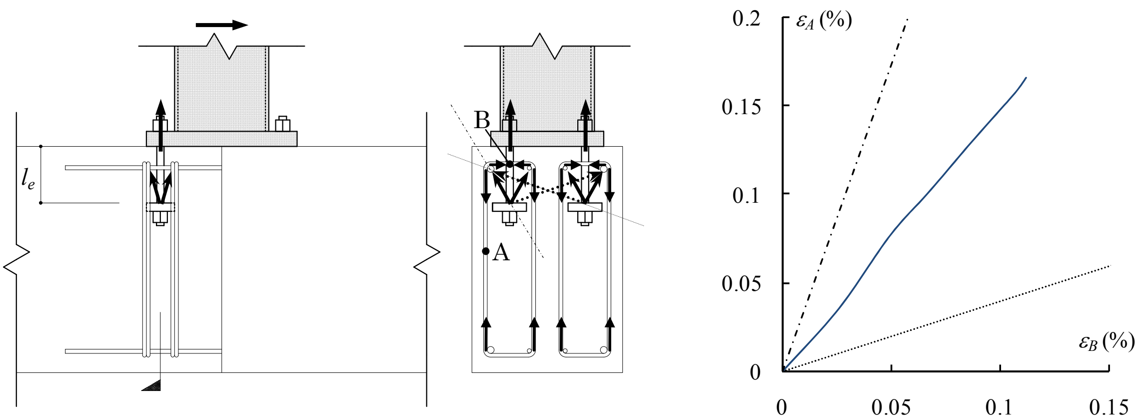

Figure 6 Strain distributions on transverse reinforcements around anchor bolt under tension

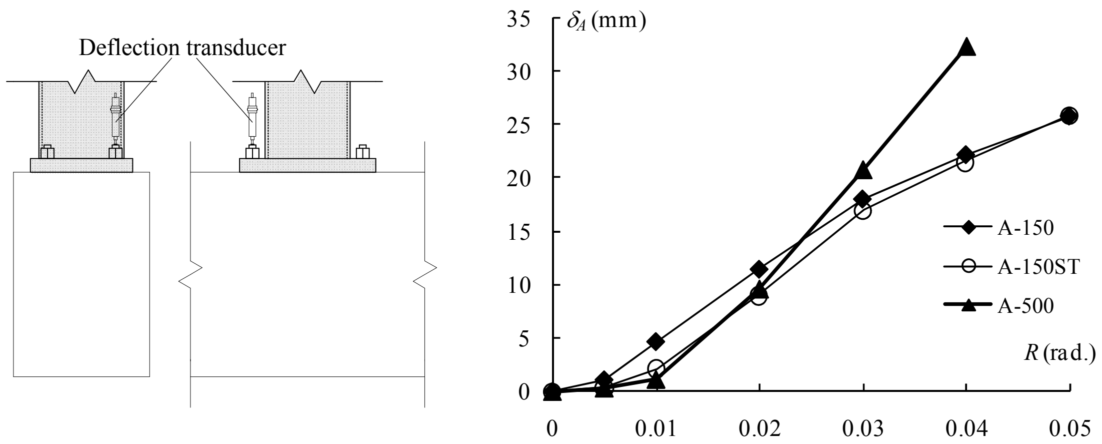

Figure 7 Relationships between pull-out displacement of anchor bolt under tension and drift angle

and specimen reached its maximum strength, and the hysteresis characteristics of specimen were shifted from that of specimen A-500 to specimen A-150. Therefore, it is supposed that the behavior of specimen was shifted from the flexural behavior of reinforced concrete member to the cone shaped slipping failure. This result depended on yielding of the longitudinal reinforcing bars, but, in future, it will be necessary to clarify the effect of the longitudinal reinforcements on stress transfer in the joint. And the failure mode was controlled greatly by the length of the embedded anchor bolt than transverse reinforcements in the joint.

Figure 6 shows the strain distribution on transverse reinforcements around anchor bolt under tension until specimen A-150ST reaches its maximum strength. The vertical axis represents the strain on the point A. The horizontal axis gives the strain on the point B. The dash line and the dotted line in the graph show the assumed angle of the concrete compression struts that form through direct bearing stress acting on anchor plate as shown in Figure 6, respectively. The strain distributed between assumed the dash line and the dotted line and along the dash line side. From these test result, it was shown that stress transfer from steel member to reinforced concrete member could be mobilized by transverse reinforcements arranged in the joint.

Figure 7 shows pull-out displacement of anchor bolt under tension versus drift angle. The vertical axis represents pull-out displacement δ_A of anchor bolt measured by deflection transducer at the bolt end. The horizontal axis gives drift angle R. The displacement - drift angle enveloped curve of specimen A-150ST was shifted from that of specimen A-500 to specimen A-150 after R = 0.02 radium. This result roughly corresponds to the hysteresis characteristic as mentioned above. And, from result of specimen A-500, pull-out displacement of anchor bolt tends to suddenly increase after the flexural cracks occurred.

5. CONCLUSION

The following remarks can be drawn from the discussion presented above.

1) Stress transfer from steel member to reinforced concrete member in the joint could be mobilized by transverse reinforcements arranged in the joint even if the length of the embedded anchor bolt was relatively short for the effective depths of reinforced concrete member.

2) The failure mode of specimen was controlled greatly by the length of the embedded anchor bolt than transverse reinforcements in the joint.

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