EVALUATION FOR EXTERNAL AND INTERNAL DAMAGES INDUCED BY ASR

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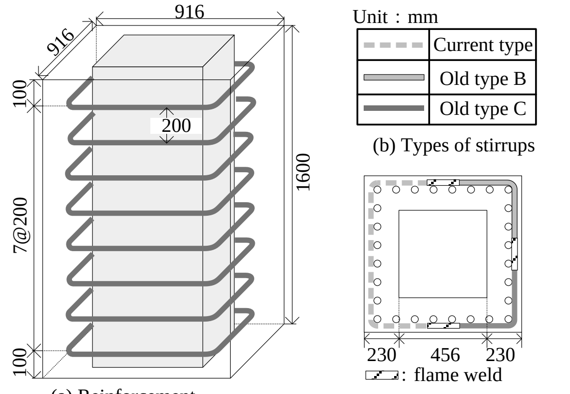
1. INTRODUCTION

For recent years, due to the Alkali-Silica Reaction, (ASR for short), the bending part of stirrups is frequently fractured. It is reported that due to the expansion, the actual structures are produced circular deformations. Opening deformation in corner can promote the initial cracks in stirrups progressing, which can lead stirrups to fracture. So far, opening deformations of stirrups, which have been estimated indirectly based on the deformations of external concrete, have not ever been verified directly. Therefore, to investigate the stirrup deformation directly, states of stirrup were recorded and measured before and after the expansion. Then, relation between the movement of internal stirrup and the external concrete will be discussed.

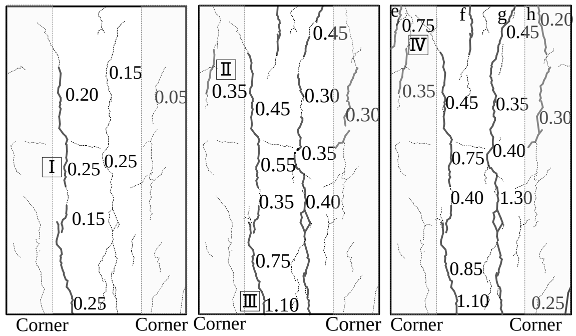


(a) Reinforcement (b) Types of stirrups (c) Stirrups in sections

Fig. 1 Shape of Specimen

2. EXPERIMENTAL CONDITIONS

For simulating the influence from ASR expansion on external degradation and stirrups, the specimen with expansive mortar casted into the frame surrounded by ordinary concrete were conducted, shown in Fig. 1-(a). The external size of the specimen is 916×916×1600mm. The inner dimension of section for expansive mortar is as 456×456mm. The specimen with spacing of stirrups 200mm and stirrup ratio 0.22% same with the actual bridge pier with stirrups fractured were used. Stirrups adopt current type and stirrups chipped from actual structures.



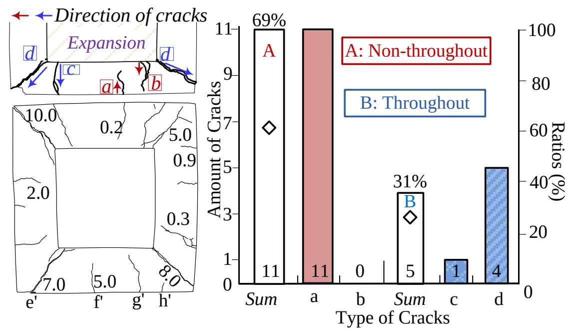
(a) After 2.8h (b) After 3.25h (c) Final (After 7.75h)

Fig. 2 Cracks in profiles

3. EXTERNAL DAMAGES

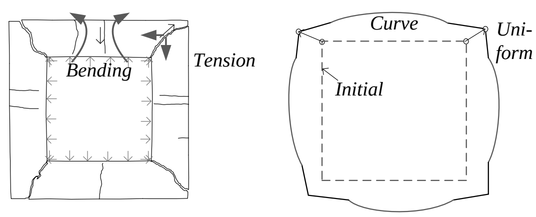
Fig.2 shows the evolutions for cracks in the profiles. Dotted lines and solid lines stand for the cracks widths smaller and greater than 0.2mm. It is revealed that after 2.8h (shown in Fig.2-(a)), the main cracks in the middle part have generated with max width as 0.25mm((a)-Ⅰ). After 3.25h (shown in Fig.2-(b)), the crack in the corners develops into as wide as 0.35mm ((b)-Ⅱ); meanwhile, the cracks in the middle part get wider, reached to 1.10mm ((b)-Ⅲ). In the final state, shown in Fig.2-(c), all cracks have gotten wider and more corner cracks are generated with the max width as 0.75mm ((c)-Ⅳ). Besides, due to smaller restraints in the lateral direction, great cracks are developed along in direction of main reinforcements.

Fig.3-(a) shows the cracks in the upper side. It can be found that the cracks e, f, g and h in the profiles (Fig.2) are in direct continuity with cracks e ', f ', g ' and h 'in upper side. Thus, it can be confirmed that the cracks in upper side are related with those in profiles. Meanwhile, from features of cracks, it is considered that cracks in upper section can be classified into 4 types, as shown in Fig. 3-(a). In general, crack of type a and b is not running through the frame. Their progressing direction is opposite as from exterior for a and interior for b. The crack of type c and d is running through the frame with the directions



(a) Final cracks (b) Final cracks

Fig.3 Cracks in upper side



(a) Crack condition (b) Image for deformation

Fig.4 Cracks related to deformations

Keywords: ASR Experiment, External Cracks, Deformations, Stirrups Damages
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both from interior. Thus, based on these definitions, classification of crack types is illustrated in Fig. 3-(b). For general, the crack type A (sum of a and b) has occupation of 69% for the amount of cracks while the type B (sum of c and d) takes 31%. The type A crack is considered to be caused by bending effect mainly. This will probably induce the curve deformation in the central area (refer to Fig. 4). Type B crack is caused by tension. This might also lead to uniform deformations in corners. From the results shown in Fig. 4, it is known that both bending and tensile effects exist by expansion.

4. DEFORMATIONS OF CONCRETE AND STIRRUPS

Fig. 5 illustrates the measuring method of deformations for the specimen. Fixed frame is set around each cross section .By calculating the difference value of lengths from the fixed frame before and after expansion, one example is shown in Fig. 5-(a)-(1). The length between the angle and the concrete surface is 47mm ((a)-(2)) and 44mm ((b)-(3)) for the initial and the ultimate state, respectively. Thus, the deformation is 3mm ((b)-(4)) as their difference.

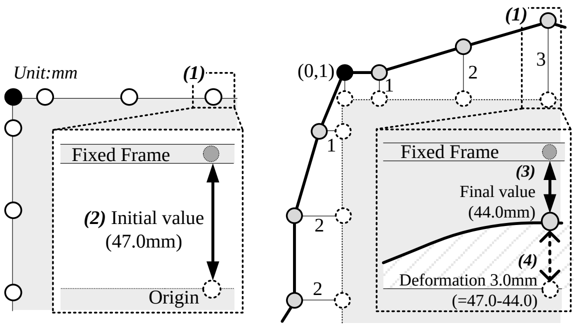
Based on this method, the ultimate deformation of one cross section is shown in Fig.6-(a). It can be found the displacements with the value of 5mm (average 4 maximum values) in middles are greater than those with the values of 2mm (average 8 values in two directions) in corners, which can be confirmed to be circular deformations. Then, the corner A will be enlarged, shown in Fig.6-(b). The increased angle degree of concrete corner θ_c is 0.95°, which is calculated by the spacing of a', b' and c' before and after expansion; besides the increased angle degree of corresponding inner stirrup θ_{incr} is 1.78°, which is the difference of angle (abc) before and after expansion. It is illustrated that the increased degree of stirrup is about 1.88 times of that of concrete. The reasons, shown in Fig.6-(c), are considered that the angular variation of corner concrete θ'_1 can be roughly calculated by the ratio δ/r_1, shown in Fig.6-(c)-(1). Besides, the stirrup is supposed to have same deformation δ. Thus, the angular variation of stirrup θ'_s is approximate to be δ/r_s, shown in Fig.6-(c)-(2). The ratio θ'_s/θ'_1 is then decided by r_1/r_s, shown in Fig.6-(c)-(3). Due to the influence from different measuring scopes, the spacing r_s in stirrup is smaller than the r_1 in concrete. So the ratio r_1/r_s is then calculated as 1.9 (r_1 is around 240-70=170mm and r_s is around 90mm), similar with the ratio 1.88 shown in Fig. 6-(b). Thus, it can be confirmed that the both inner stirrups and concrete have opening deformations.

However, shown in Fig.7, the increment of concrete degree is negative of -0.94° and the stirrup is with positive deformation with 3.32°. The reason is that there is great dislocation in the surface so that the evaluating point c_2 shift inward compared with point c_1. Hence, the evaluated angle θ_2 (angle $b_2a_2c_2$) is even smaller than the initial state.

5. CONCLUSIONS

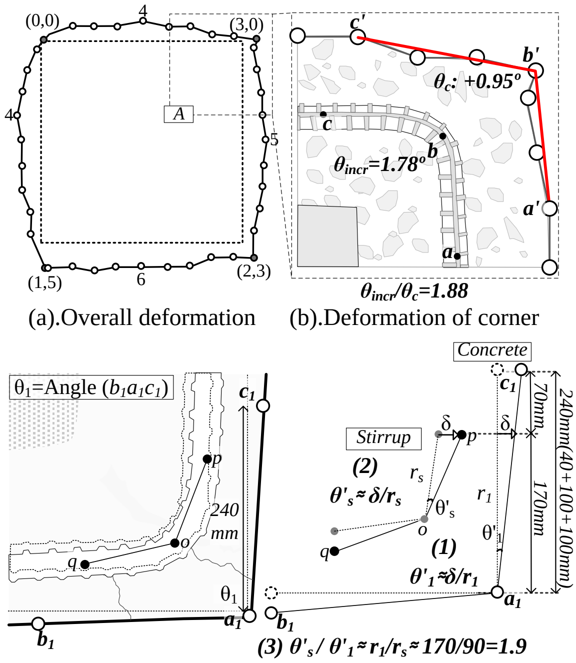
1. It is confirmed general specimen has produced the circular deformation.

2. It is observed that the bent part of stirrup and concrete have the angular increments of 1.78° and 0.95 ° respectively, which are considered that without great dislocation, the movement level of stirrups roughly has correlation with concrete.



(a) Initial state (b) Final state

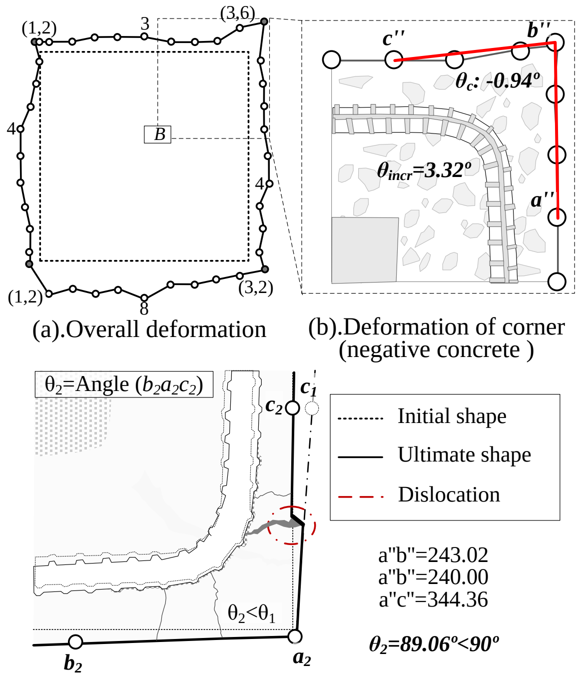
Fig.5 Method for deformations of sections



(a).Overall deformation (b).Deformation of corner

(c). Reason for deformations

Fig.6 Deformations for stirrups and concrete



(a).Overall deformation (b).Deformation of corner (negative concrete)

(c). Actual condition with dislocation

Fig.7 Influence from dislocation in corners