Evaluation for Movements of Stirrups Due to ASR Expansion

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1. Introduction

For recent years, due to the Alkali-Silica Reaction, (ASR for short), many concrete structures suffered degradations. It is reported that the bending part of stirrups is frequently fractured due to the expansion of ASR. Further, based on previous studies the opening deformations are considered to influence the stirrups 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. The possibility for judging the behavior of inner stirrup from apparent damage is evaluated.

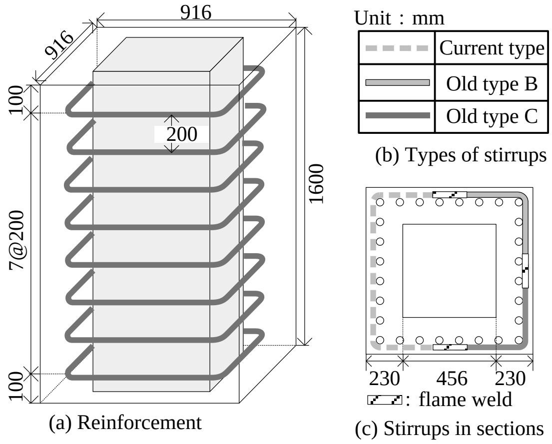


Fig.1 Specimen shape

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. The bending radius is 1.0d. In addition, stirrups are D16 rebars with current type (based on current specification) and old type B and old type C (based on old specification).

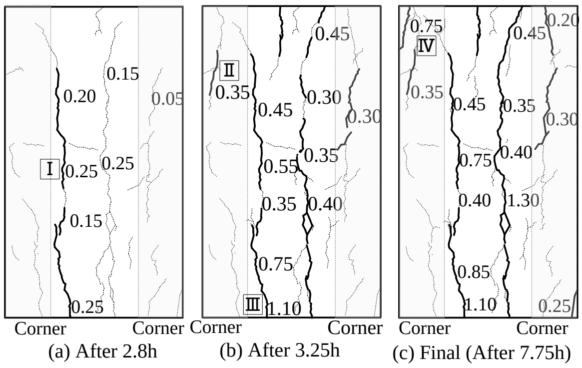


Fig.2 Evolutions for crack in profiles

3. Damages of exteriors

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 0.7mm ((c)-Ⅳ).

Then, the evolutions of deformations for cross section (section 3 is chosen for instance) are shown in Fig. 3. It is confirmed that after 2.8h, the greater deformations occur in the middles of four sides with max as 3mm, shown in Fig. 3-(a). After 3.25h, the deformations both in corners and middles develop greater with

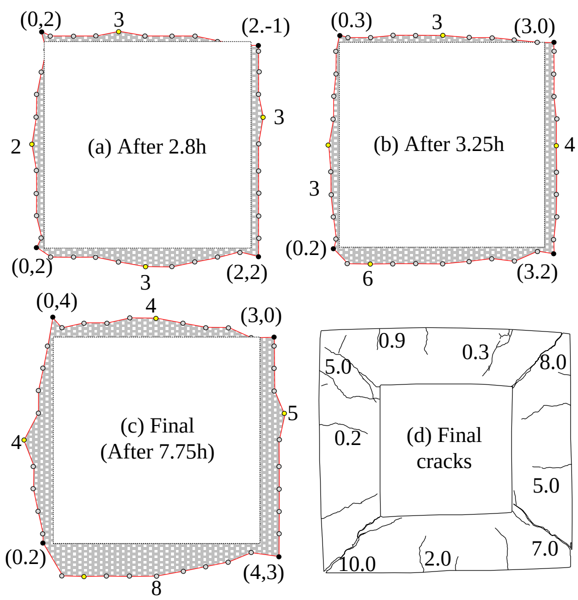


Fig.3 Evolutions for deformations

max as 6mm and 3mm for the middles and corners. Fig.3-(c) shows the final state of deformations. It is found that the deformation in the middle has greatest displacements as 8mm compared with the greatest deformation 4mm in the corners. General specimen is considered to have circular deformations. At the same time, the cracks condition in the upper side is shown in Fig.3-(d). Combined with the cracks and deformations, it is considered that due to the circular deformation, the cracks in the middles is developed from the exterior to the interior; meanwhile, the cracks in corners are developed due to the opening deformations, which are caused by circular deformation.

4. Deformations of stirrups

Fig. 4 shows one instance for the measuring method to study the angular variation of concrete. As illustrated in Fig. 4-(a), the part A in Fig. 4-(a) is enlarged for presenting the initial state. Points a,b,c are chosen for evaluating the angular variation. After expansion, the final state is illustrated in Fig. 4-(b). Spacing values of ab, ac and bc are 242.01, 243.02 and 346.48, from which, the angle degree of corner concrete θ_c is 91.18°. 1.18° is increased, which verifies the opening deformation of the corner.

Then, Fig. 5 illustrates one instance for the measuring method of angular variation of stirrups. Before casting the specimen, 3 points (a, b, c) were determined and marked in the actual stirrup, shown in Fig. 5-(a). The spacing values of ab, ac and cb were measured so that the degree of θ_s can be calculated as 105.93°. Furthermore, after expansion, the spacing values of same three points were measured again, from which, the degree of angle θ_s' can be calculated as 107.55°, shown in Fig. 5-(b). Therefore, the increasing degree is known as 1.62°, which is the difference between θ_s' and θ_s. From the increasing of angle in bending part, it is considered that the stirrup has opening deformation.

Thus, angular variations of corner concrete in corresponding positions to stirrups for old type B and C were measured by the same method. Fig. 6 illustrates the comparison of angular variations for stirrups and corner concrete. Apart from the two negative points a and b, the angular variation between stirrup and corner concrete is considered to have correlation with the ratio near 2.13. Therefore, it is considered that the movements of inner stirrups can be estimated roughly from the deformation of concrete in appearance.

5. Conclusions

(1).This experiment can confirm the stirrups deformations directly. It is revealed that the bending parts of stirrups with 1.0d have angular increment of +1.85°; while the angles of concrete increase by about 0.72°.

(2). It is considered that the angular increments of inner stirrups are correlative with those of surficial concrete. The angular increments indicate the tendency of opening deformation which is considered to be influential on the stirrups fracture.

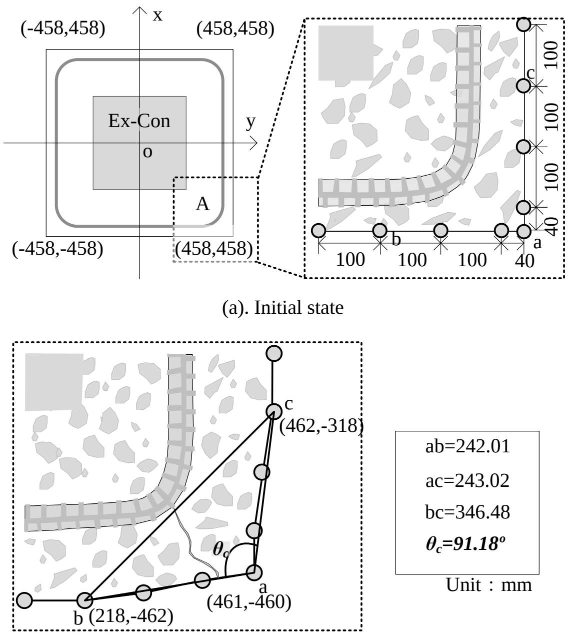
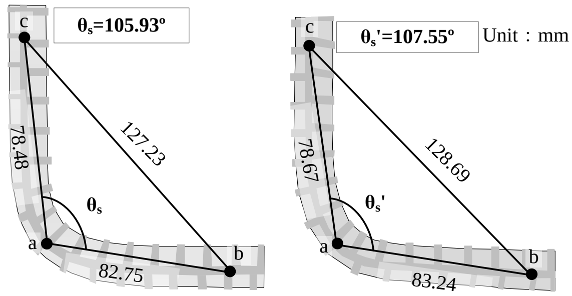


Fig.4 Method for measuring angle degrees of concrete



(a). Initial state (b). Final state

Fig.5 Method for measuring angle degrees of stirrup

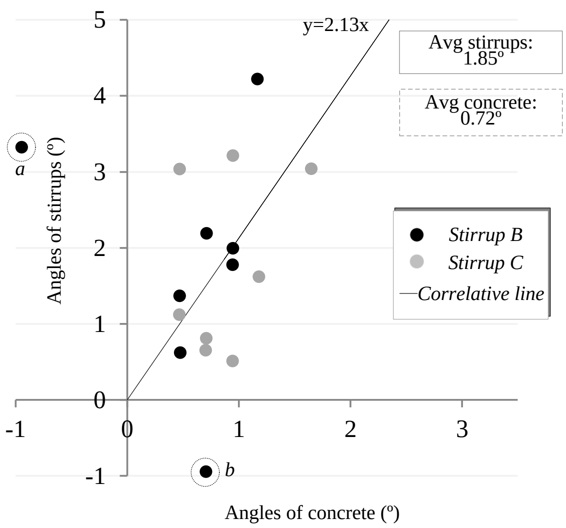


Fig.6 Relations for angles in concrete and stirrups