Deformation Behavior of Structures suffering ASR-induced Damage

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1. Introduction

For structures with ASR progressing notably, fracture has been confirmed to easily occur in bent part of stirrups. As one of the inferred fracture mechanisms, stirrup would have angular increment which promotes the progress of initial damage in stirrup till to fracture. To confirm the behavior of stirrup together with external deformations, experiments are attempted.

Specimens with expansive mortar cast into the frame of ordinary concrete are made. The general form of external deformations is studied; thus, characteristics of deformation is evaluated through classification; further, the movement of corner concrete concerning the stirrup fracture is investigated.

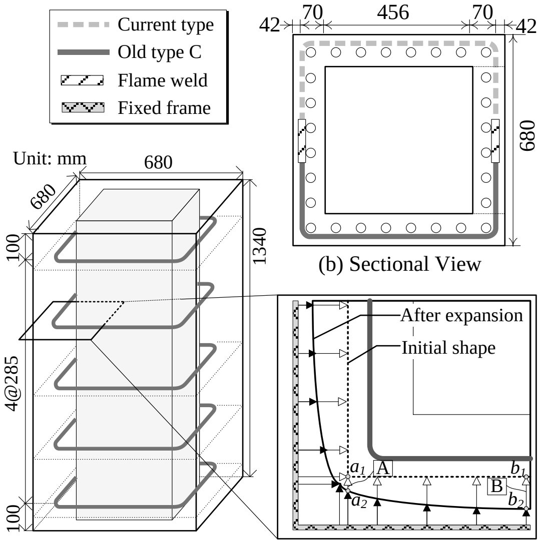
2. Experimental Conditions

Fig. 1 illustrates the specimen and measurement conditions. The external size is 1/4 of the actual bridge beam with stirrups fractured. The stirrup ratio as 0.22% is same to the actual bridge beam. Shown in Fig. 1-(b), D16 rebar are adopted with one type using the rib shape based on current specification (current type) and another using the bamboo joint rib from old specification (old type C). The frame concrete uses the strength 27N/mm^2 as the design strength of the bridge beam. Besides, the lime type expansive agent is applied as 200kg/m^3 to simulate the severe degradation condition.

As in Fig. 1-(c), for measuring deformations, fixed frame is set around cross sections with stirrups. To obtain the length from fixed frame to concrete surface, measuring scale is set in the fixed frame. From the difference value before and after expansion, the deformation is obtained. Besides, it is noted that deformation is composed of elongated and circular deformation. For instance, the deformation A (displacement from a_1 to a_2, Fig. 1-(c)) in corner point is defined as elongated deformation; while the difference between the maximum deformation B (displacement from b_1 to b_2, Fig. 1-(c)) and the deformation A is defined as circular deformation.

3. Deformation Behavior

The deformation form in the ultimate state after 24.0hr of expansion is illustrated in Fig. 2. The maximum deformations is 8.85mm and 4.21mm in center and corner of profile, respectively. The general specimen has produced the ASR-induced circular deformation. In detail, the elongated deformation is 3.33mm and the circular deformation is 5.00mm. Herein, Fig. 3 is plotted for studying the time variation of classified deformations. Circular deformation increases slowly before 8.0hr ((1) of Fig. 3) with 0.84mm. Thus, intense raise occurs via 10.0hr ((2)) as 2.84mm. After 11.0hr, increment of deformation begins to decreasing.



(a) Specimen Shape (c) Measurement Method

Fig. 1 Specimen and Measurement Conditions

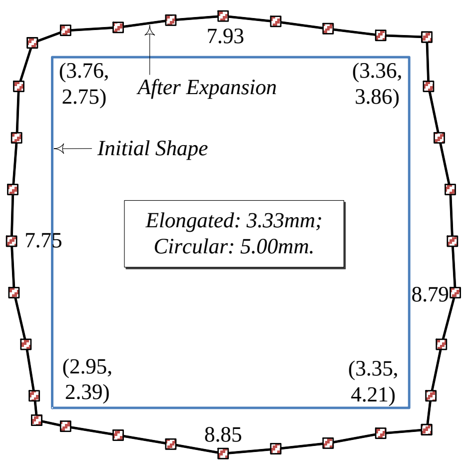


Fig. 2 Deformation Forms (Ultimate)

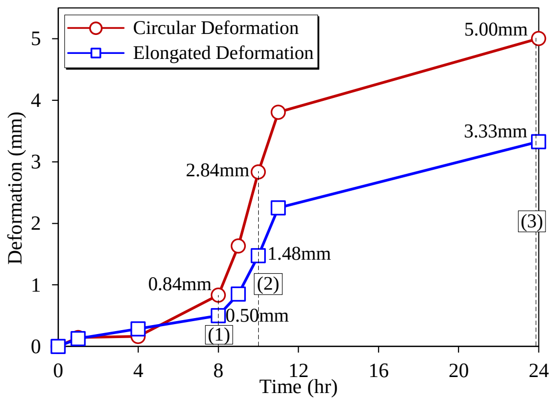


Fig. 3 Time Variation of Deformations

Expansion is supposed to converge with the maximum as 5.00mm ((3)). Similarly, elongated deformation also has smaller increase before 8.0hr as 0.50mm and then dramatic growth by 10.0hr as 1.48mm. After 11.0hr, slight raise occurs with the maximum 3.33mm. In summary, it is clarified that elongated and circular deformations are produced along with the inner expansion.

To confirm the fracture mechanism, the movement behavior of corner concrete is considered to be significant. Thus, illustrated in Fig. 4, there points *bac* with the spacing value as 240mm are selected at the corner. The angular variations of *bac* (θc) in four corners is averaged due to their small difference. Thus, smaller rise is confirmed before 8.0hr ((1) of Fig. 4) with the value 0.30°; then, drastic variation generates through 10.0hr ((2)) with the value 1.09°; after 11.0hr, the value raise slowly with the maximum 1.99° in 24.0hr ((3)). From the positive angular variations, the corner concrete is verified to have opening deformation.

Fig. 5 presents the estimation of possible influences from external deformations on the movement of stirrups. The elongated deformation might cause the stirrup to be stretched. Further, circular deformation is influential for the opening deformation of corner concrete, which further leads to the opening deformation of stirrup. In addition, initial crack is occurred in bending operation and thus the opening deformation of stirrup is considered to promote on progressing of the initial crack or even to fracture.

In addition, the mechanisms for generation of elongated and circular deformation are discussed. Distributed load is assumed to act on the frame concrete. The frame part *AB* (Fig. 6-(a)) is concentrated and assumed to receive fixed restrains in two ends. Thus, the distributed load in the vertical direction w_y produces moment (M) with the distribution image shown in Fig. 6-(b); the corresponding maximum displacement δ_m is generated in the central frame due to the bending rigidity. Further, the distributed load in horizontal direction w_x transmit to the part AB to produce the axial force (N) with the uniform distribution referred to Fig. 6-(b); similarly, the deformation δ_n is produced from the tensile rigidity. Therefore, it is considered that the circular and the elongated deformation is correlated with δ_m and δ_n. Besides, shown in Fig. 6-(c), due to the combination of tensile and bending effect, cracks penetrating the frame with the width as 0.2mm occur and cracks not penetrating with the width as 1.5mm also generate.

4. Conclusions

(1) For the ultimate state, maximum deformation around 9.0mm occurs in center of each profile. The general specimen is confirmed to have the ASR-induced circular deformation.

(2) By classifications, it is noted that maximum 5.00mm occurs for circular deformation by bending effect while 3.33mm generates for elongated deformation from tensile effect.

(3) Together with the circular deformation, corner concrete has maximum angular increment 1.99°. This is estimated to produce the opening deformation in the bent part of stirrup, which is very influential on progress of initial damage.

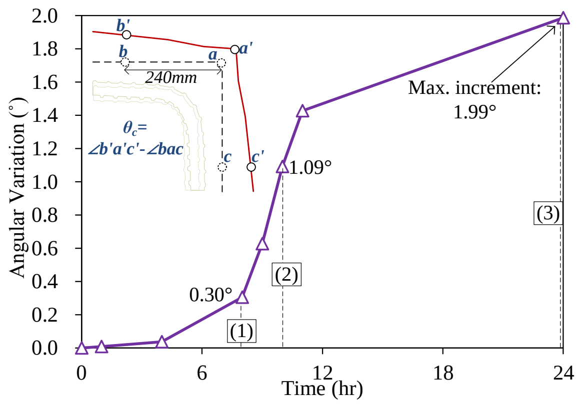


Fig. 4 Angular Variation of Corner Concrete

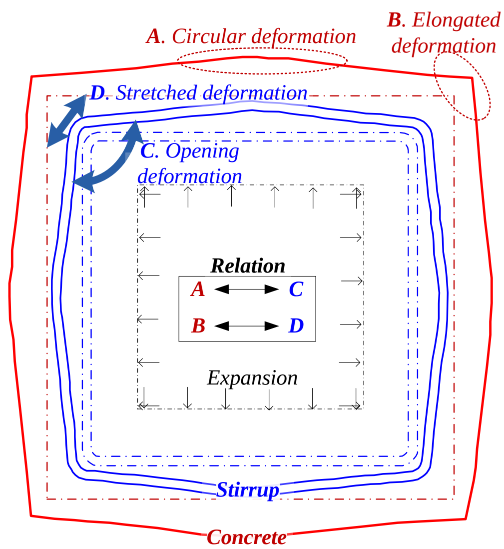
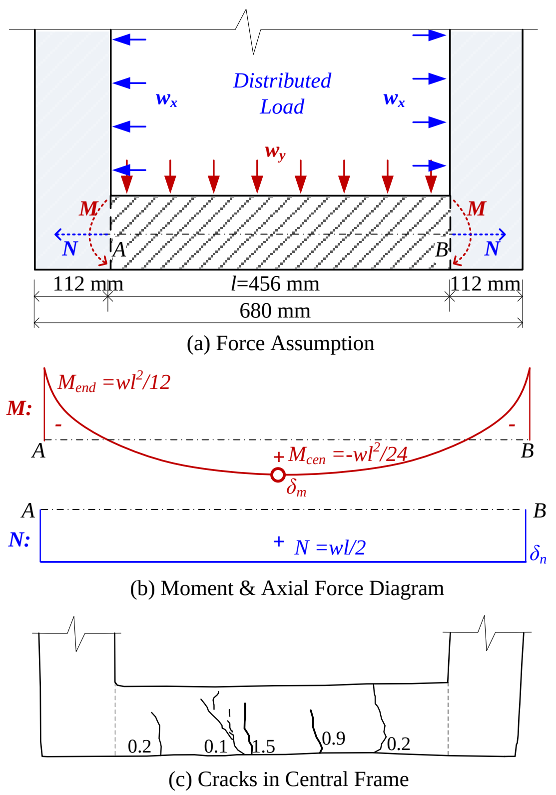


Fig. 5 Relation of Deformations



(a) Force Assumption

(b) Moment & Axial Force Diagram

(c) Cracks in Central Frame

Fig. 6 Mechanism for Generation of Deformations