SIMULATIONS FOR DEFORMATION BEHAVIOR OF STRUCTURES DUE TO ASR

Graduate School of Kyushu Institute of Technology Student Member ○Yulong ZHENG
Kyushu Institute of Technology Member Kenji KOSA
Sumitomo Osaka Cement Member Nobuo UEHARA

1. INTRODUCTION

For structures with ASR progressing notably, fracture has been confirmed to occur in bent part of stirrups. As one of the inferred fracture mechanisms, stirrups 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, experiment and FEM analysis are attempted.

Specimens with expansive mortar cast into the frame of ordinary concrete are made. The general form of external deformations is studied based on comparisons between experiment and analysis; thus, characteristics of deformation are evaluated through classifications; the movement of corner concrete concerning the stirrup fracture is investigated; at last, the generating mechanism of deformation and the influence on the stirrup fracture is discussed.

2. EXPERIMENTAL AND ANALYTICAL 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. D16 rebar are adopted with one type based on current specification (current type) and another 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.

Further, 2-dimensional elastic-plastic finite element analysis is conducted. As expansion in axial direction is also confirmed, four-node quadrilateral isoparametric plane stress elements considering strain in three directions are applied. The time variation of recorded temperature in the specimen is used for the time variation of thermal expansion acting on the model of expansive mortar. The coefficient of expansion as 1.0×10^{-5} /°C is applied to produce the maximum free expansive strain 30000μ.

3. EVALUATION OF RESULTS

The general external deformations in the final state is presented in Fig. 2. It is noted that from the corner point, deformation increases toward to the center area. All cross-sections are confirmed to have the circular deformation. Further, in the two ends of specimen (cross-section 1 & 5), the average deformation values have greater values than those of the other cross-sections, which is due to the free of restraints from stirrups in two ends. Fig. 3 shows the comparison of deformation shapes. The analysis is confirmed to have maximum value as 7.35mm in the middle of profile. Similar deformation form is

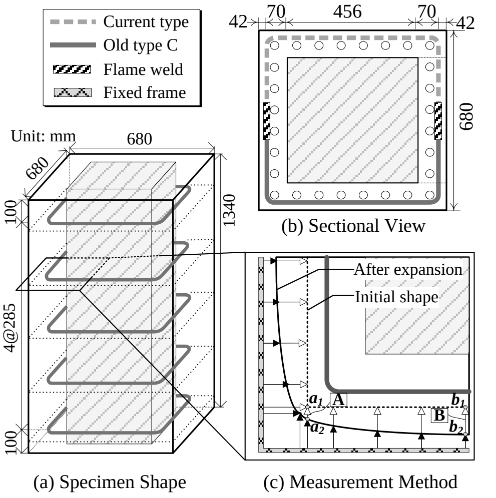


Fig. 1 Specimen and Measurement Conditions

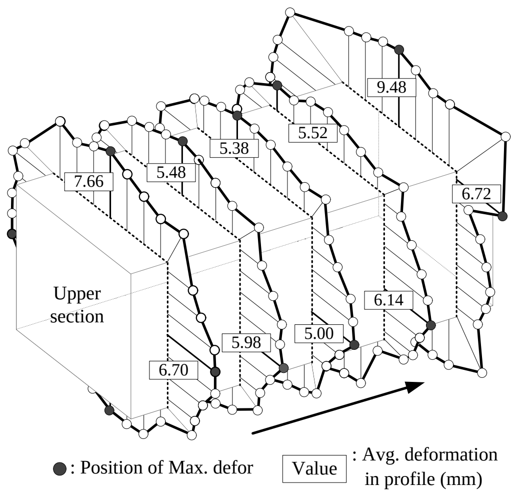


Fig. 2 Deformation Forms (Ultimate)

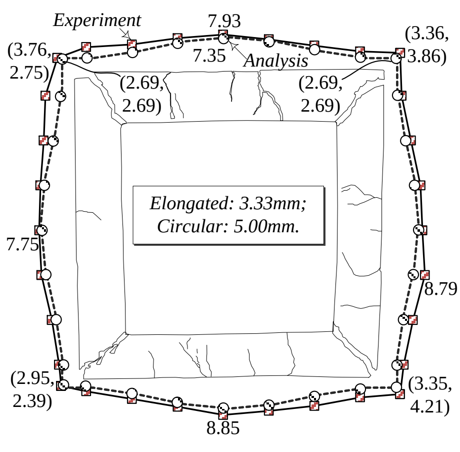


Fig. 3 Comparison of Deformation Shapes

Keywords: ASR, Experiment, FEM, Fracture of Stirrup, Deformation Behavior
Address: 〒804-8550 Kyushu Institute of Technology, 1-1 Sensui, Tobata, Kitakyushu, Japan, 093-884-3123

reproduced corresponding to the experiment.

Based on the definitions illustrated in Fig. 1, the comparison of circular deformation is presented in Fig. 4. Similar time variation trend is obtained compared to the experiment. The maximum circular deformation is obtained as 4.66mm in analysis closing to 5.00mm of the experiment. Besides, the time variation of elongated deformation is also confirmed to have similar trend with the maximum as 2.69mm and 3.33mm for analysis and experiment. Further, for confirming the fracture mechanism of stirrups, the behavior of corner concrete is considered to be significant. Thus, as presented in Fig. 5, three points *bac* with the spacing value *ab* and *ac* as 240mm are selected at the corner. The angular variation of *bac* (θ_c) is used for evaluation. Thus, from Fig. 5, angular change of corner concrete is confirmed for both analysis and experiment with the maximum increment as 1.80° and 1.99°.

In addition, to confirm the generation mechanism of deformations, the strain distribution of frame concrete is studied. After 24.0hr, the maximum principle strain in the central frame of the 1/4 cross-section is illustrated in Fig. 6. Great strains mainly generate in 5 sections (A to E) which infers occurrences of cracks. For evaluating numerically, the detailed strain distributions in *x* direction of the sections are plotted. For sections A to C, it is noted that strains are divided by two parts as those from tensile and bending effect. For sections D and E, similar form is confirmed while the strain from bending in the upper section is negative due to the minus moment in corner part.

Further, the strains from tensile effect in the 5 sections are summed to be 0.251 (0.0557 for *A*, 0.0278 for *B*, 0.0553 for *C*, 0.0487 for *D* and 0.0630 for *E*). From the product of the summed strain and equivalent length (10mm based on element size), it is obtained that deformation from tensile effect is 2.51mm which is close to the elongated deformation as 2.69mm. Therefore, caused by the inner expansion, tensile and bending effects both generate. Further, it is confirmed that tensile effect produce the elongated deformation while bending effect would give the occurrence of circular deformation. Meanwhile, combined with tensile and bending effects, cracks in the frame generate as illustrated in Fig. 3.

To explain the generation mechanism further, the strain and stress distributions of expansive mortar are illustrated in Fig. 7. From Fig. 7-(a), greater strain in inclined direction as 0.41 occurs in the corner part, which is corresponding to the opening deformations of corner concrete and stirrup; besides, from Fig. 7-(b), the stresses can be decomposed by those in *x* and *y* directions in the boundary to frame concrete (like side A). In addition, the stress in *y* direction w_y produces moment; while the stress in *x* direction w_x generates tension in frame concrete. Therefore, bending effect corresponding to the circular deformation and tensile effect corresponding to the elongated deformation occur in frame concrete (refer to Fig. 6).

4. CONCLUSIONS

(1) From both experiment and analysis, deformation can be classified as circular deformation and elongated deformation with maximum near to be 5.0mm and 3.0mm, respectively;

(2) In the boundary between expansive mortar and frame concrete, stress in *y* direction produces bending effect corresponding to the circular deformation and stress in *x* direction generates tensile effect corresponding to the elongated deformation in the frame concrete;

(3) Due to the circular deformation, corner concrete is confirmed to have angular increment with maximum around 2.0°. This is estimated to produce the opening deformation in the bent part of stirrup, where, the initial damage is progressed until to fracture.

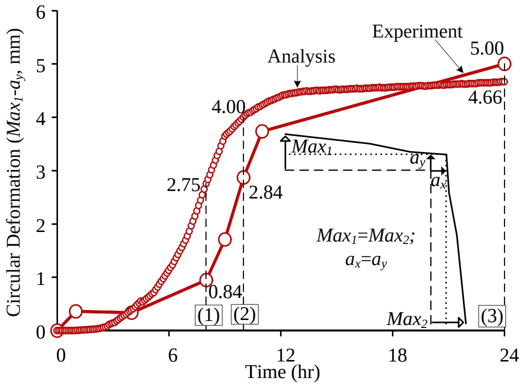


Fig. 4 Time Variation of Circular Deformation

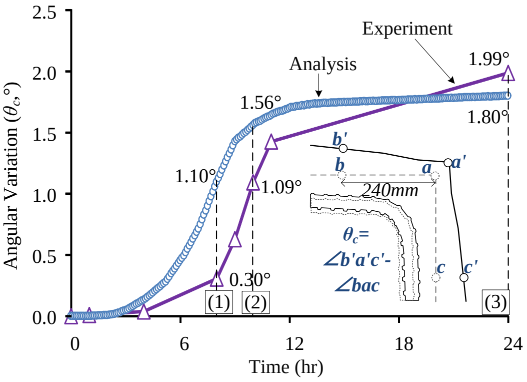


Fig. 5 Time Variation of Angular Change

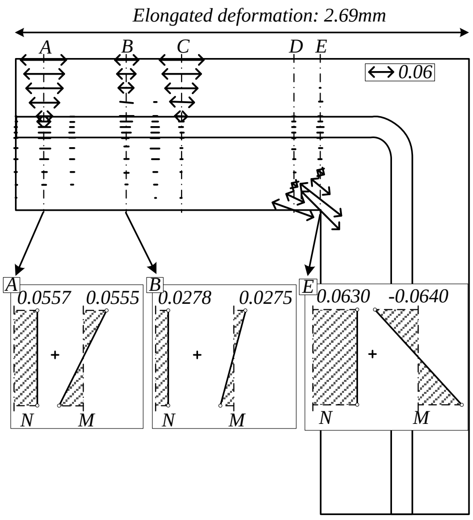
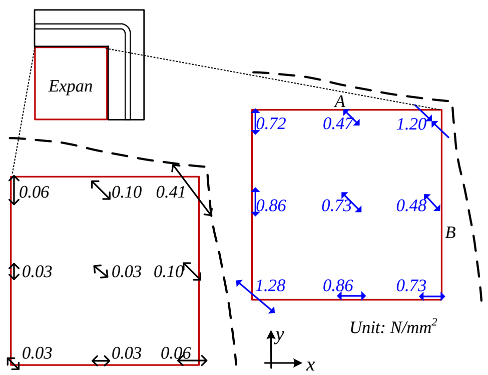


Fig. 6 Strain Distributions in Frame Concrete



(a) Strain Distributions (b) Stress Distributions

Fig. 7 Behavior of Expansive Mortar