AN ELASTO-PLASTIC IMPACT RESPONSE ANALYSIS METHOD FOR PROTOTYPE RC GIRDER WITH EQUVALENT FRACTURE ENERGY CONCEPT

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1. INTRODUCTION

The continuous expansion of urban zones in mountain regions needs to establish the systems for protecting infrastructures from natural hazards such as snow avalanches, falling rocks, and landslides. In numerical analysis for estimating dynamic response behavior and/or sectional forces of the RC structures by means of FE method, mesh size may act very important role if cracking or tearing or penetration occurs. However, considering the relationship between mesh size and material properties, rational response analysis method for precisely analyzing prototype RC structures under impact loading has not been established yet.

This work constitutes an effort directed towards the development of an objectivity algorithm for tensile failure of concrete elements based on the smeared cracking formulation. The algorithm has been implemented into LS-DYNA for hexahedron solid elements and correctly accounts for crack directionality effects. Thus enabling the control of energy dissipation will be associated with each failure mode regardless of mesh refinement.

2. OVERVIEW OF LARGE SCALE IMPACT TEST

2.1 Outline of testing model

RC girder, which is modeled considering roof of real RC rock-sheds, is taken for falling-weight impact test of prototype RC structures. The girder is of rectangular cross section and the dimensions are of 1.0 x 0.85 m and clear span is 8 m long. Figure 1 shows dimensions of the RC girder, arrangement of rebars, and measuring points for each response wave. 7#D29 rebars are arranged which is for 0.64% of main rebar ratio corresponding to designing of real RC rocksheds. Static flexural and shear load-carrying capacities P_{usc} and V_{usc} were calculated based on Japanese Concrete Standards. From these values, it is confirmed that the RC girder designed here will fail with flexural failure mode under static loading.

2.2 Experimental method

In the experiment, 2,000 kg heavy weight was lifted up to the prescribed height of 10 m by using the track crane, and then dropped freely to the mid-span of girder due to a desorption device. A heavy weight is made from steel in which outer shell is of 1 m in the diameter, 97 cm in height, and spherical bottom with 80 cm in radius and its mass is adjusted filling concrete and steel balls.

In this experiment, impact force wave (P), reaction force wave (R), and displacement waves (D) were measured. The accelerometer is of strain gauge type and its capacity and frequency range for measuring are 1,000 times gravity and DC through 7 kHz, respectively.

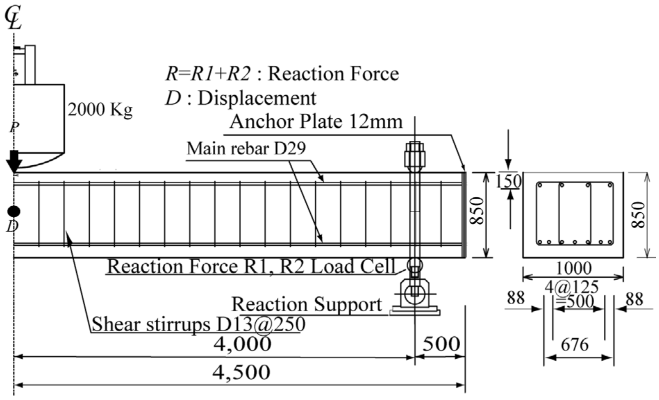

Fig. 1 Dimensions of RC girder and measuring items

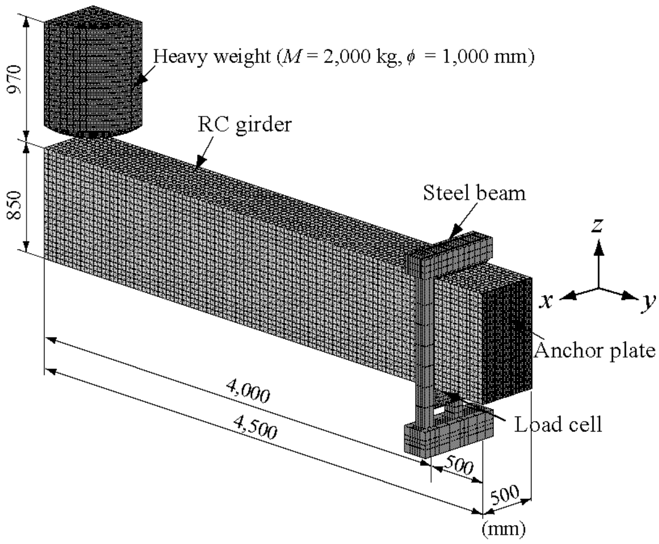

Fig. 2 Finite element mesh scheme for RC girder

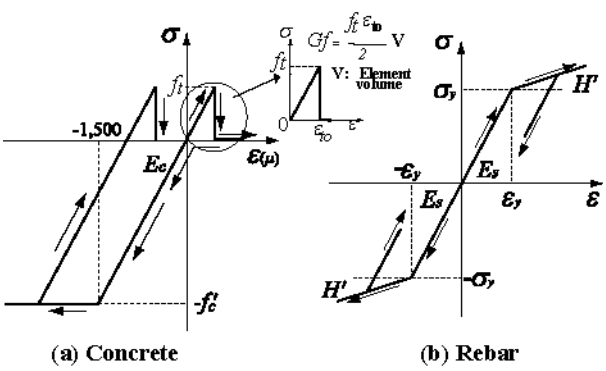

Fig. 3 Stress-strain relation of constitutive models

3. ANALYTICAL OVERVIEW

3.1 Finite Element model

The purpose of this research is to propose the method for

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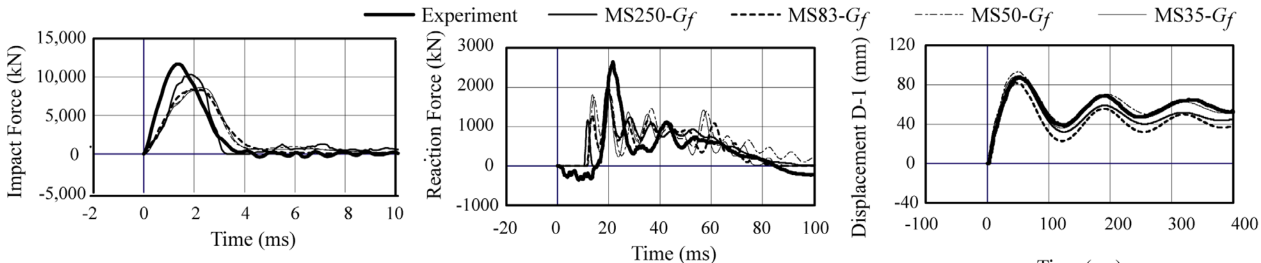

(a) Impact force time history (b) Reaction force time history (c) Displacemnet time history

Fig. 4 Comparison between analytical and experimental results

converting tensile strength of concrete element with arbitrary element size in span direction applying an equivalent fracture energy concept for full scale RC girder and the applicability is confirmed by comparing with the experimental results. Therefore, the standard element division for precise numerical analysis result is needed. The standard analytical model such as MS35-G_f was decided for prototype RC girder. Similarly the standard mesh size of the span and the cross section width and height of the RC girder were set as 35 mm, 41 mm and 31 mm, respectively. On the other hand, four cases were considered by assuming 1, 3, 5, and 7 division whose element sizes are 250 mm, 83 mm, 50 mm, and 35 mm, respectively and those cases are named as MS250-G_f, MS83-G_f, MS50-G_f and MS35-G_f respectively. For all cases, each mesh size along the girder near supporting area of 500 mm wide was set to be 35 mm long because of precisely analyzing an interaction between supporting gigues and girders[1].

One quarter of RC girder was three-dimensionally modeled for numerical analysis with respect to the two symmetrical axes. Figure 2 shows a mesh geometry of the girder, which is finally used for numerical analysis with optimum design accuracy investigated here. Geometrical configurations of the heavy weight and supporting gigue were also precisely modeled corresponding to the real ones. In this model, axial rebar and stirrup were modeled using beam element having equivalent axial stiffness, cross sectional area and mass with those of real ones. The others were modeled using eight-node and/or six-node solid elements. Total number of nodal points and elements for one-fourth model for MS35-G_f are shown in Fig. 2 are 38,875 and 34,832, respectively. Number of integration points for solid and beam elements are one and four, respectively. In order to take into account of contact interface between concrete and head of heavy weight elements and between adjoining concrete and supporting gigue elements, contact surface elements for those were defined, in which contact force can be estimated by applying penalty methods for those elements but friction between two contact elements were neglected. Impact velocity was applied to all nodal points of the weight.

3.2 Modeling of materials

Figure 3 shows the stress and strain relations for each material: concrete; and rebar. Stress strain relationships of concrete was assumed by using a bilinear model in compression side and a cut-off model in tension side as shown in Fig. 3(a). For main rebar and stirrup, an elasto-plastic model following isotropic hardening rule was applied as shown in Fig. 3(b). For concrete elements, fictitious tensile strength f_{ti} obtained from Eq. 1 for i element with y_i as the size in y-direction, the crack occurred in the i-element can be rationally estimated similar to f_{to} of the standard element with fracture energy G_f. The fictitious tensile strength for each element size in y-direction used in this study is given below.

$$f_{ti} = f_{t0}\sqrt{\frac{y_0}{y_i}} \qquad (1)$$

4. COMPARISON BETWEEN ANALYTICAL AND EXPERIMENTAL RESUTLS

The applicability of the proposed method is examined for the set of each element length for different cases considering G_f and comparing with experimental results. An analytical result concerning all cases with different element length considering G_f is compared with the experimental results as shown in Figure 4.

The maximum value of impact force wave is smaller than the experiment result regardless of the mesh size of the element length as previously observed. The maximum impact force indicates that the value in case of MS250-G_f is the nearest to the experimental results. It is understood that the response characteristics is similar regardless of the size of the element length as well as the case of impact force and for the reaction force waveform. From Fig. 4(b), it is confirmed that the reaction force wave at the one supporting point tends to be high amplitude in case of one-division was almost similar to experimental one.

It is understood the amplitude of mid span displacement D, the both cycle and the residual displacement are in the state of a free vibration after the maximum displacement regardless of the size of the element length by comparing the experimental results and the analytical one.

By applying the same characteristics properties as the case of MS35-G_f is shown, and it can be confirmed to an analytical result of MS250-G_f when the element length is the largest then the analytical accuracy is secured enough even if the element division is rough.

5. CONCLUSIONS

In order to establish a modification method for material properties of concrete so as to rationally analyze using coarse mesh, an equivalent fracture energy concept for concrete element is proposed and the applicability was conducted comparing numerical analysis results and experimental results. From this study, it is confirmed that even though coarse mesh was used for RC girder, similar results with those obtained using fine mesh can be assured and are in good with the experimental ones.

REFERENCES

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