AN ELASTO-PLASTIC IMPACT RESPONSE ANALYSIS METHOD FOR FULL SCALE RC GIRDER WITH SAND CUSHION

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1. INTRODUCTION

In order to ensure the safety of rock-sheds, nuclear power plants, fuel tanks and/or other protective structures against impact loads, many numerical and experimental researches have been carried out. However, in order to rationally design this type of RC structures considering the performance up to the ultimate state, impact resistant behavior and dynamic load carrying capacity for these should be investigated precisely. For these, not only experimental study but also numerical one should be conducted.

From this point of view, here, in order to establish a rational numerical analysis method for real RC rock-sheds, nonlinear finite element (FE) analysis was conducted based on the falling-weight impact test results for prototype rectangular RC girder with partially mounted sand-cushion. An explicit and three dimensional finite element code LS-DYNA is used for this study.

2. OVERVIEW OF FALLING WEIGHT 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. The dimensions of the sand cushion set on the center of girder are of 1.5 x 1.5 x 0.9 m. Figure 1 shows dimensions of the RC girder with sand cushion, arrangement of rebars, and measuring points for each response wave. 4#D29 and 7#D29 rebars are arranged at the top and bottom of the RC girder with 0.64 % of main rebar ratio. 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, 5,000 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

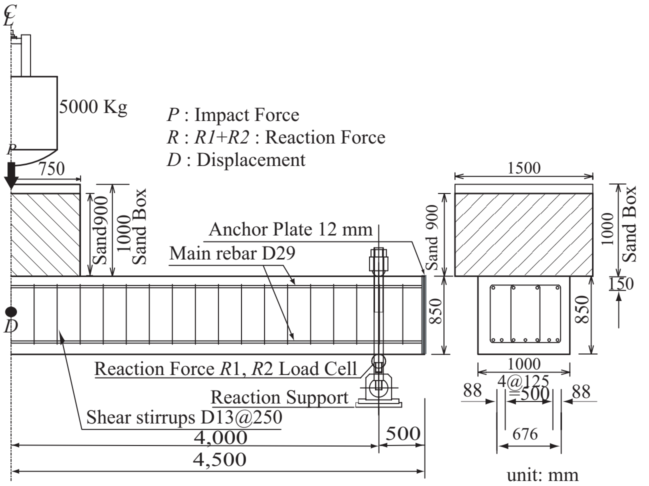

Fig. 1 Dimensions of RC girder with sand cushion

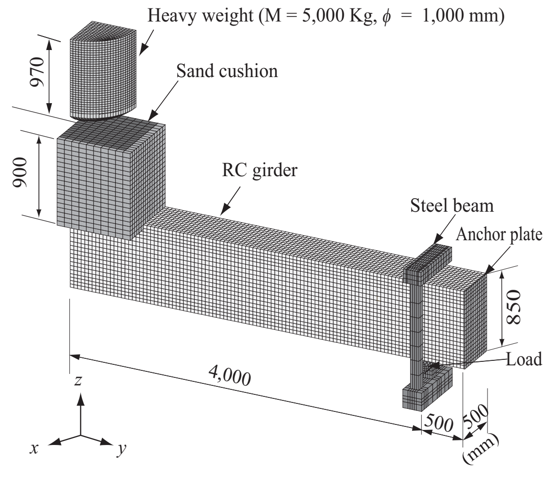

Fig. 2 Finite element mesh scheme for RC girder

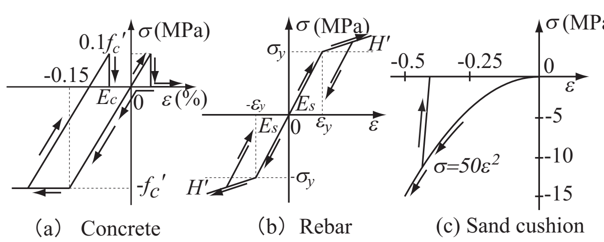

Fig. 3 Stress-strain relation of constitutive models

and its capacity and frequency range for measuring are 1,000 times gravity and DC through 7 kHz, respectively.

3. ANALYTICAL OVERVIEW

3.1 Finite Element model

One quarter of RC girder was three dimensionally modeled

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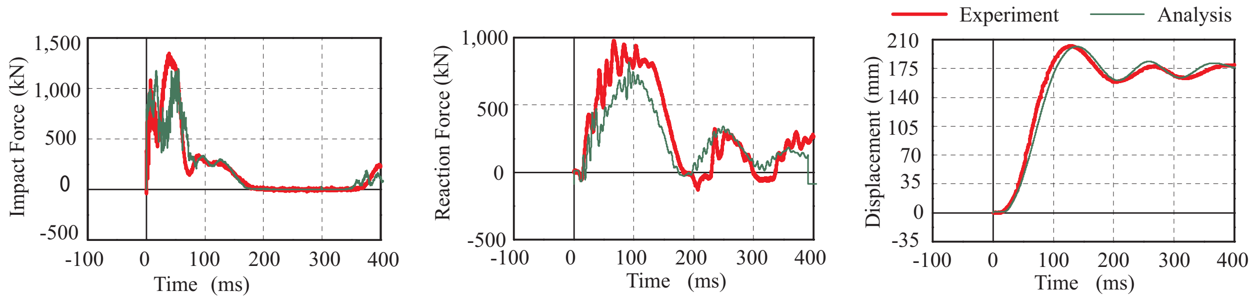

(a) Impact Force (P)　(b) Reaction Force (R)　(c) Mid span Displacement (D)

Fig. 4　Comparison between analytical and experimental results

for numerical analysis with respect to the two symmetrical axes. Four side-surfaces of sand cushion were confined laterally. Figure 2 shows a mesh geometry of the girder with sand as absorbing material. A geometrical configuration of the heavy weight, sand cushion, supporting gigues were precisely modeled following 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 and/or six-node solid elements. Number of integration points for solid and beam elements are one and four, respectively.

3.2 Modeling of materials

Figure 3 shows the stress and strain relations for each material: concrete; rebar; and sand. 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). Drucker-Prager yield criterion was applied to the yielding of concrete. For main rebar and stirrup, an elasto-plastic model following isotropic hardening rule was applied as shown in Fig. 3(b). Figure 3(c) shows the constitutive model for sand cushion. To rationally analyze in stress behavior of sand cushion when heavy weight collides, second order parabolic stress-strain relation was applied for sand cushion.

4. COMPARISON BETWEEN ANALYTICAL AND EXPERIMENTAL RESUTLS

4.1 Impact force, reaction force, and displacement

Figure 4 shows the comparisons of the impact response waves of the girder obtained using FE analysis method with the experimental results. Figure 4(a) shows the time histories of impact force waves during 400 ms. Comparing with analytical and experimental waves, it is confirmed that 1) duration time of a whole wave and wave configuration after about 75 ms from the beginning are in good correspondence with the experimental results; 2) period and phase of waves around the beginning of impact are a little different from experimental results; but 3) the maximum response value may be almost same to each other. From the comparison between analytical and experimental results for reaction force shown in Fig. 4(b), it is seen that the wave configurations from both results are almost same to each other, even though maximum amplitude from experimental results is a little bigger than that from analytical ones. From the Fig. 4(c) for mid span displacement wave, it is confirmed that numerical response wave during the impact load surcharging to the RC girder is similar to that of the experimental results.

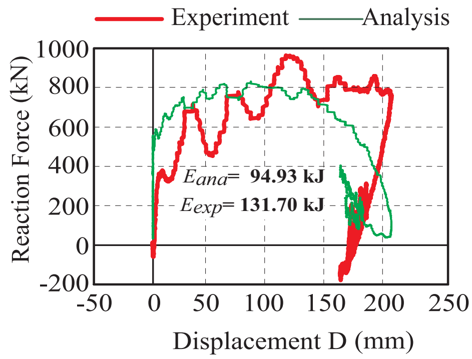

Fig. 5　Hysteric loops of reaction force displacement

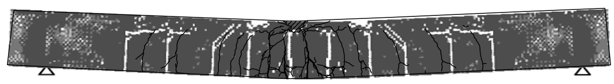

Fig. 6　Comparison between cracks patterns

4.2 Hysteretic loops of reaction force displacement

Figure 5 shows comparison of hysteretic loops of reaction force and displacement between analytical and experimental results. Moreover, the amount of the absorbing energy evaluated based on an area enclosed with the loop is indicated. Here, E_{ana} and E_{exp} are the amounts of energy calculated based on an analytical and experimental results.

4.3 Crack patterns on side-surface of RC girder

The crack patterns obtained from experiments were sketched in black solid lines and zero stress contour of maximum principal stress obtained from numerical analysis is colored with white as shown in Fig. 6. From the figure, it is seen that the distribution of white colored elements are almost similar with the crack patterns from experimental results.

5. CONCLUSIONS

The results obtained from this study are as follows: (1) the response characteristics obtained using proposed numerical analysis method have comparatively similar tendency for impact force, reaction force and displacement wave to those of experimental results; (2) distribution characteristics of the R-D loops are in good agreement between analytical and experimental results. (3) Crack patterns on side-surface can be roughly predicted by using the proposed FE analysis method.