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Shaking table test for lightweight spillway with geogrid

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ABSTRACT: During 1995 Hyogoken-Nanbu earthquake, heavy concrete spillways on the embankment of small reservoir were significantly damaged. Especially, it was pointed out that some spillways were detached from the embankment because of the inertia force, and the incidents could be the cause of secondary disaster in downstream area in floods. However, the research on spillways on such embankment is lacking.

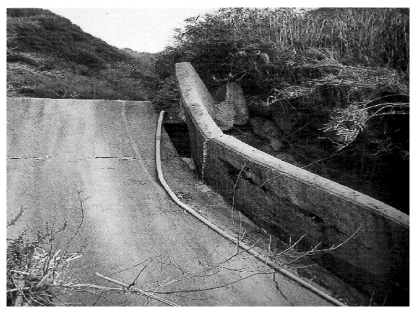
In this paper, firstly, a series of shaking tests at National Institute for Rural Engineering in Japan on heavy rigid spillway model was discussed. As the result, the detachment of the heavy spillway model from the embankment was confirmed. Moreover, newly-proposed countermeasures to fix the lightweight spillway by geogrid were discussed, and the superiority of the proposed method were confirmed.

1 INTRODUCTION

Japan has over 20 thousand small earth dams for irrigation. There is a spillway to discharge overflowed water safely to downstream during in high water level. In general, spillways on the embankment are made by reinforced concrete. On the other hand, the embankments themselves are soil structure. Therefore, in earthquakes, it was pointed out that the spillways detachment from the embankments or failure in the joint of the bottom plate and the sidewall might be occurred due to inertia force. Picture 1 shows the damage by the detachment of the concrete type spillway from the embankment during Hyogoken-Nanbu earthquake in 1995. In order to prevent the detachment, the researches on the safety of the structure are required.

As the countermeasure against earthquake, examinations on the behavior of geogrid-reinforced construction are discussed. For example, Watanabe et al. (2002) proposed a new seismic type bridge abutment with geogrid-reinforced cement treated backfill, Koseki et al. (2002) performed comparison of model shaking test results on reinforced-soil and gravity type retaining wall and Bathurst et al. (2002) conducted to assess the seismic performance of reinforced soil walls. However, most of the research on the geogrid-reinforced techniques has discussed the single wall or plate with the reinforced soil, there is lacking in discussion that could be applied to spillways in terms of the rectangular cross-section.

In this paper, a series of shaking table tests on the heavy spillway model, the lightweight PVC spillway models, and the newly proposed lightweight spillway models with geogrid were discussed.

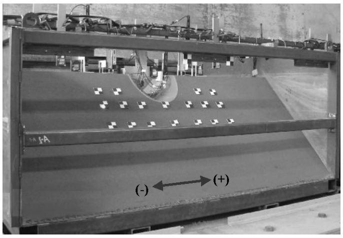


Picture 1. The damage of small earth dam spillway at Hyogoken-nanbu earthquake (Hyogo pref.).

2 SHAKING TABLE TEST

2.1 *Equipments setup*

The shaking table for the tests had plane dimensions of 6.0 × 4.0 m, with the maximum loading capacity of 50 tf and the maximum displacement capacity of 150 mm. The test pit (2400 × 1900 × 1000 mm) was placed on the shaking table and the experimental models were placed. The embankment size was 2400 × 1900 × 800 mm with 45 degree slope and 300 mm width of the crest as shown in Picture 2. The spillway models were positioned in the center



Picture 2. Embankment model (Case C).

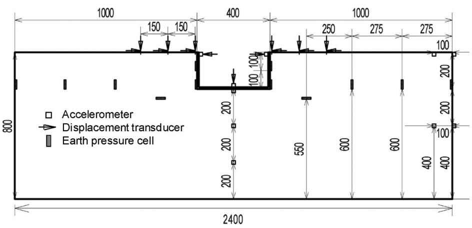


Figure 1. Elevation view of the test pit and positions of test equipments (Case A).

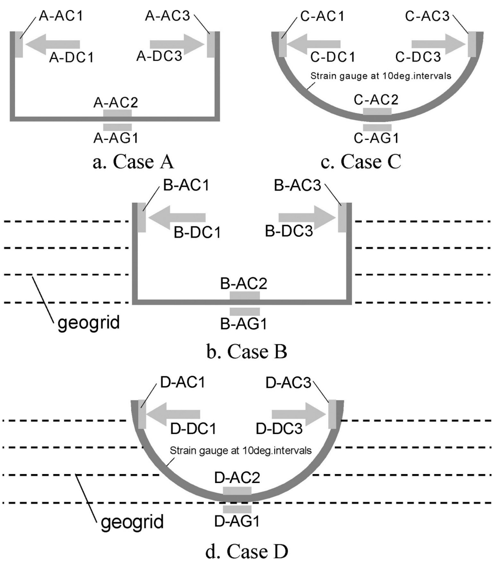


Figure 2. Discussed measure points in this paper (Initial letter is correspondent to the Cases).

of the crests. Figure 1 shows schematic elevation view of the test models. The models of embankments and spillways were instrumented extensively with instruments: accelerometers measured horizontal acceleration response of spillway models and grounds, displacement transducers measured displacement of the spillway models and ground level, and earth pressure cells measured earth pressure around soil of the models. As for the acceleration and displacement sign,

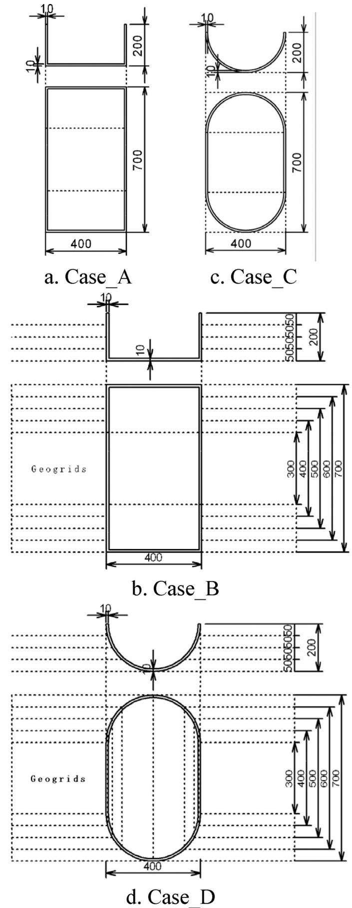


Figure 3. The spillway models.

right on the observer was positive in Figure 1. Note that the positions of the equipments were the same in every case. In addition, strain gauges were attached on inner surface of the spillway models and both surfaces along centerline of geogrid at appropriate intervals.

In this paper, the accelerometers of spillway models and the ground (AC1, AC2, AC3, and AG1 in Figure 2), displacement transducer of the spillway models (DC1, DC3) and strain gauges in the Case_C and D were mainly discussed.

2.2 *Materials and experimental program*

The soil material for the embankment was Kasumigaura-sand with the mean particle diameter (D_{50}) of 0.40 mm and the uniformity coefficient (U_C) of 3.16. The relative density (D_r) was about 65.5%. The geogrid used in the tests was HDPE and the tensile strength was 3.5 kN/m.

Figure 3 shows the spillway models. The model in Case A was made of rigid steel plate; other models

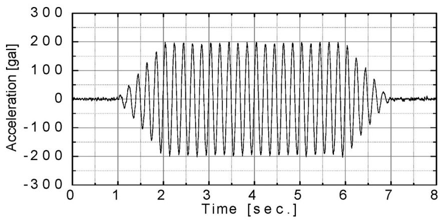


Figure 4. Input wave (200 gal).

were made of polyvinylchloride. The models in Case B and D were reinforced by geogrids.

In the experiments, 5 Hz horizontal sine wave was applied along the embankment axis. Figure 4 shows input wave. The shaking was applied at 200 gal, 400 gal, 600 gal, and 800 gal.

3 TEST RESULTS

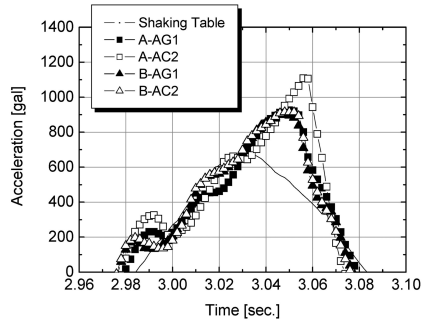
3.1 *Response acceleration*

Figure 5 shows the response accelerations of spillway model and the ground beneath the model in 600 gal shaking.

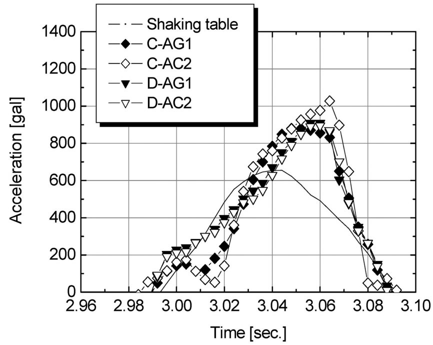
In Figure 5a, it was observed that A-AC2, which was positioned the bottom of the spillway model showed larger response acceleration amplitude than A-AG1. From this fact, it was confirmed that there was difference in inertia force between the heavy spillway model and the embankment. Moreover, it was visually observed that the spillway model in Case A showed slight detachment from the ground after 600 gal shaking. From these facts, it was confirmed that heavy spillway was detached when the shaking was applied in the horizontal direction to the embankment axis. The response acceleration of heavy spill way model also showed the rapid decline after the peak response acceleration. The response might be given the stiffness of the spillway model. On the other hand, the response acceleration of B-AC2 and B-AG1 showed almost same amplitude. That implied the spillway model with geogrid and surrounding soil was moved simultaneously, and it was just conceivable that the model with geogrid was fixed to the embankment well.

In Figure 5b, it was observed that the geogrid-fixed spillway model in Case D showed the same acceleration level to the ground accelerations. From this result, it was safe to say that the cylindrical spillway model with geogrid was also fixed to the embankment during the shaking.

From the discussion of the response acceleration, it was also implied the geogrid-fixed spillway models were moved with the embankment under the models simultaneously although the reinforcement was equipped on the sidewalls. This facts suggested that



a. Case_A and B



b. Case_C and D

Figure 5. Response accelerations of the spillway models in 600 gal shaking.

surrounding was moved by side positioned geogrid as soil mass.

3.2 *Response displacements*

Figure 6 shows response displacement in 800 gal shaking. In Case_A in Figure 6a, the response displacement of the spillway model was increased largely from 3.5 sec. and the maximum displacement amplitude approached to 15 mm. The spillway itself displaced about 10 mm as the residual displacement to the left from the initial position. On the other hand, in Case_B in Figure 6b, the response displacement spillway was increased from 5.0 sec., the maximum displacement amplitude was less than 5 mm. and the residual displacement was almost zero. From these response and residual displacements of Case A and Case B, the behaviors of the Case_B model showed the toughness as observed in reinforced soil compared with Case_A (Uchimura et al. 2002). Moreover, during the experiments, it was clearly and visually confirmed that the heavy spillway was detached from embankment in the 800 gal shaking. In addition, in reinforced rectangular spillway model in Case_B, it was observed that the both sidewalls were stretched to the backfills about

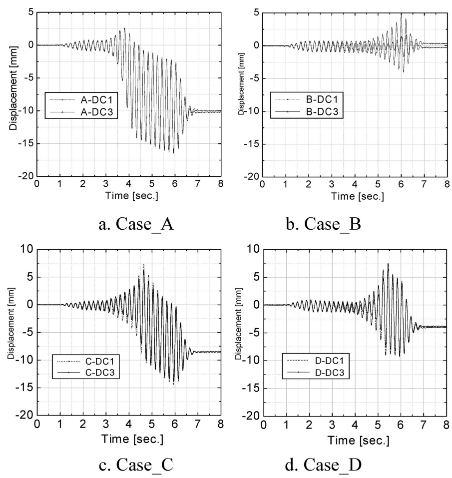


Figure 6. Response displacement in 800 gal shaking.

1.0 mm. The mechanism was not clarified, however, it was considered that the results was resulted by the mutual effect of geogrid and the embankment behind the both sidewalls. On this point, further discussion is needed to clarify the mechanism.

Figure 6c shows the response displacement of the model in Case_C increased rapidly from 3.0 sec. and residual displacement of the spillway model in Case_C was about 8.5 mm to left. On the other hand, Figure 6d shows the response displacement in Case_D increased from 4.0 sec. and the residual displacement of the spillway model in Case_D was about 4.0 mm to left. The reason was considered that Case_D model also showed the toughness as observed in reinforced soil, or Case B.

3.3 *Strain distribution*

Figure 7 shows transition of the deformation of the spillway models in Case_C and D while the shaking table was moving from the left end to the right end through the stroke.

Figure 7a–c shows the deformation transition in Case_C. In Figure 6a, the spillway model was concaved in 45deg. neighborhood. The spillway model was deformed by the active earth pressure at the left end of the shaking table. In addition, the spillway model was convexed in 135deg. neighborhood. In Case_C without geogrid reinforcement, the spillway model was deformed to the left when the shaking table was positioned at the left end and was deformed to the right when the shaking table was positioned at the right end.

Figure 7d–f shows the deformation transition of the spillway model equipped with geogrids. In Figure 7d, the spillway was convexed in the 45deg. neighborhood although the spillway model of Case C was concaved

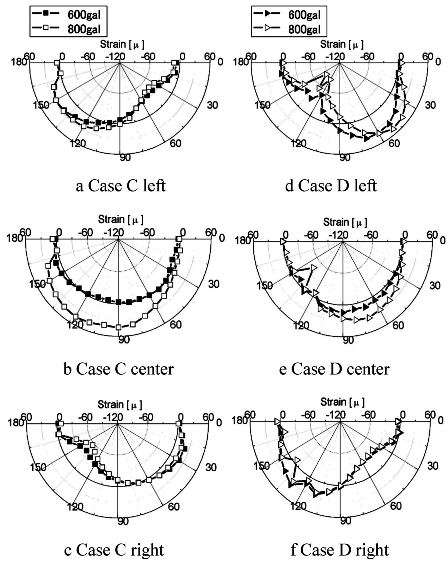


Figure 7. Strain distributions of Case C and D, during a stroke of shaking table.

in that area. In the transition, the shape of Case C was reversed to Case_D with geogrids although the time to measure the deformation was same. This tendency might be resulted from the mutual effect of geogrid, the spillway rigidity of the models, or earth pressure. However, more experiments, discussions and analysis are needed to clarify the mechanism.

4 CONCLUSION

In this paper, it was reported the results of shaking table test for the heavy spillway model assumed existing concrete-made spillway and the newly proposed lightweight countermeasures.

In the experiments, the heavy spillway model showed the detachment or large displacement by the shaking applied in the horizontal direction to the embankment axis, which was pointed out incidents in Hyogo-Nanbu earthquake.

As for the results of the proposed method, it was confirmed that the reinforced spillway models in Case_B and D were fixed to the embankment and showed the toughness during the shaking in terms of response displacement and showed less residual displacement than that of models without geogrids. Moreover, in Case_B, the sidewalls of the spillway model showed stretched to the backfill, or in Case_D, the deformation transition was opposite to the transition in Case_C. It was considered that these mechanisms were strongly tied to the rigidity of spillway model shapes and geogrid-reinforced earth, however, more experiment or discussion on these points are necessary to clarify the mechanism of newly proposed method.

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