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Evaluation of EPS embankment behavior during large-scale earthquakes by full-scale shaking table tests

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ABSTRACT

Regarding the Expanded Polystyrol Construction Method (EPS method) using polystyrol foam, rocking phenomenon of the top-heavy structure at the time of earthquake is concerned, which is caused by its light weight. The authors conducted a full-scale shaking table tests against a large-scale earthquake with the aim of evaluating the seismic resistance of EPS embankments using a new type of joint metal binder that joins EPS blocks, which was developed as a countermeasure. The seismic resistance of the EPS embankment was verified by the tests, and a simulation analysis using a finite element method was also conducted for the purpose of making the test results more versatile. As a result of the analysis, the behavior observed in the test could be simulated appropriately, and the applicability of the analytical method was confirmed.

Keywords: EPS Embankment; Full scale shaking table test; Dynamic analysis; Resistance against earthquake; Joint metal

1 INTRODUCTION

Expanded Polystyrol Construction Method using expanded polystyrol foam (EPS method) is applied, because of its light weight and high workability, in a wide range such as widening embankment on steep slopes or on the soft ground. On the other hand, due to the top-heavy structure based on its light weight, it is predicted that, at the time of earthquake, behaviors such as rocking phenomenon that may cause problems of earthquake resistance will occur. Therefore, many studies on seismic resistance have been conducted and it is shown that this is a construction method with high earthquake resistance. (e.g., Koga et al. 1991; Hotta et al.1992; Nishi et al. 1998). On the other hand, In Japan in recent years, great earthquakes we have never thought of, such as 2011 Earthquake off the Pacific coast of Tohoku that big quakes lasted long and 2016 Kumamoto Earthquake that huge seismic motions acted continuously, have occurred. Under such circumstances, further improvement of seismic resistance of EPS construction method is required.

Under such background, the authors have developed a new type of joint metal binders that join EPS blocks (Nishi et al. 2018) to improve the stability, and conducted full scale shaking table test using them was conducted (Nishi et al 2019). As a result, it was confirmed that sufficient seismic resistance is shown even under the conditions where large scale earthquakes continue.

In this report, in order to make the test results more versatile, simulation of tests by dynamic analysis using the finite element method have been conducted. As the result, it was confirmed that behavior of the test is appropriately expressed from the analysis results, the effectiveness of using the analytical method shown in this paper for the evaluation of seismic resistance of actual structures has been shown.

2. SHAKING TABLE TEST

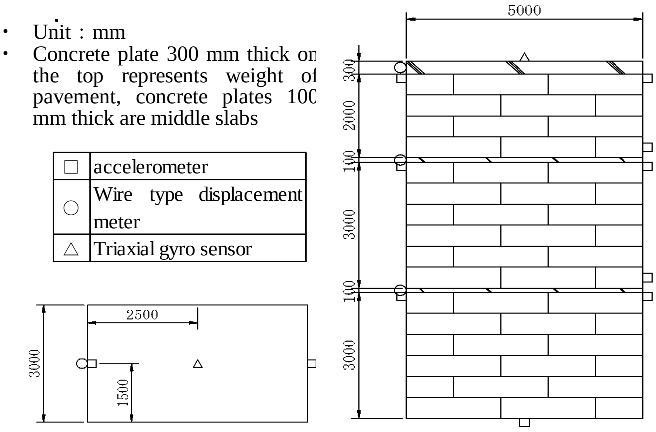
2.1 Test Conditions

In the test, subject was the EPS embankment on the back of the pier, and its shape was structural one as shown in Fig. 1. with a vertical wall shape on both left and right sides. In many cases, EPS embankment is constructed on the back of the pier for the purpose of preventing lateral flow by the soft ground, and the shape in the direction perpendicular to the bridge axis is double-sided type. As the influence of rocking is considered to become a big problem about structure with such cross-sectional shape, this shape was selected as the subject of test.

The width of embankment is 5 m, the depth is 3 m, and the height of EPS block is set to be 3 m (6 stacks), 6 m (12 stacks), 8 m (16 stacks). Similarly to the construction works, reinforced concrete deck with thickness of 100 mm was installed at every 3 m height of EPS. And, considering the pavement, a concrete deck with thickness of 300 mm was installed on the top of the model.

Fig. 1. shows the approximate cross-sectional shape of a case with an EPS height of 8 m as an example. In the figure, arranged measuring equipment is also shown. Measurement was made about acceleration and displacement around deck position, and a rotational acceleration of the center of crown. The rotational acceleration at the center of the crown was measured with a gyro meter.

The EPS blocks are connected with the joint metal binders shown in Fig. 2. There are two types of joint metal binders, new and old. Fig. 2 shows new type of binders. New type of joint metal binders has increased the number of spikes to strengthen the connecting power to improve seismic resistance



Floor plan (Top view) Side view (Case of EPS 8 m High)

Fig. 1. Outline of EPS embankment used for the test.

Joint metal binder A (spikes on both sides) Joint metal binder B (spikes on one side)

Fig. 2. Joint Metal Binders

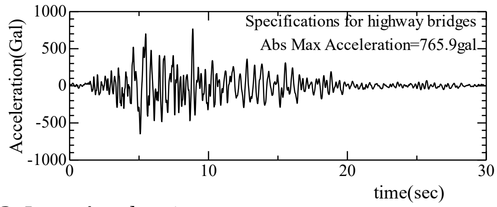


Fig. 3. Input Acceleration

compared with old type binders developed in 1995.

The joint metal binders were installed as a standard of 2 pieces per 1 m^2, but in the case of height 3 m of EPS embankment, 1piece per 1 m^2 was installed for the comparison.

The seismic motion used in the test were a white noise wave, sin wave whose frequency is changed stepwise from 10 Hz to 1 Hz, and the design seismic motion (II-I-1) of Specifications for highway bridges Part 5 shown in Fig. 3.

2.2 Test Results

In the tests, we compared the performance of the new joint metal binders and old ones in the cases of 3 m and 6 m height of EPS embankment. There were no cracks in the EPS blocks, but there were openings between the EPS blocks. Fig. 4. shows comparison of the amount of opening between the EPS blocks after tests. In this figure, the maximum and average values of the measured values are shown. This figure shows that joint opening in the case of new joint metal binders is smaller than that in the case of old joint metal binders, and from this fact, it can be said that the new joint metal binders have better seismic performance.

In the case of 8 m height, hybrid layout was applied as the rocking measures. Connection between the top and bottom of EPS blocks was made by the joint metal binders with both-sided spikes as shown in Fig. 1, and horizontal connection was made by the joint metal binders with one-sided spikes. The effect of the said layout was confirmed.

In the conventional layout, the joint metal binders with both-sided spikes were installed between the EPS blocks as shown in Fig. 5(a), and the joint metal binders with one-sided spikes were applied only under the deck.

Hybrid layout is defined as follows; joint metal binders with one-sided spikes are set between the blocks in the horizontal direction as shown in Fig. 5(b) and that with both-sided spikes are set in the middle of blocks. In the case of 8 m height, effectiveness of anti-rocking measures by this hybrid layout was confirmed.

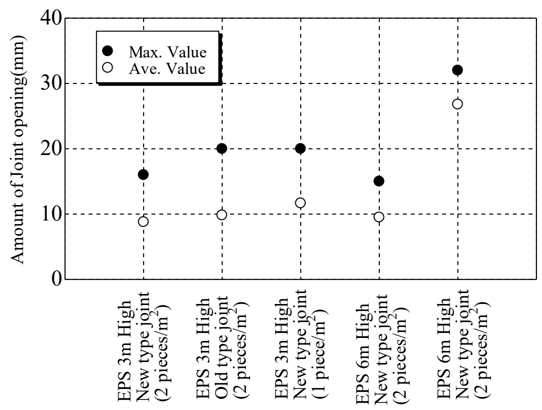


Fig. 4. Amount of opening between blocks after shaking test (performance comparison of metal)

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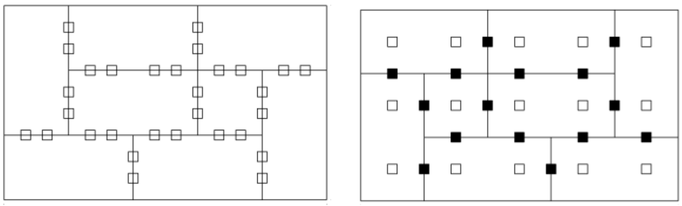

(a)Traditional placement (b) Hybrid placement

（□:Joint metal with both claw ■ :Joint metal with one claw）

Fig. 5. Placement conditions of joint metal bindings

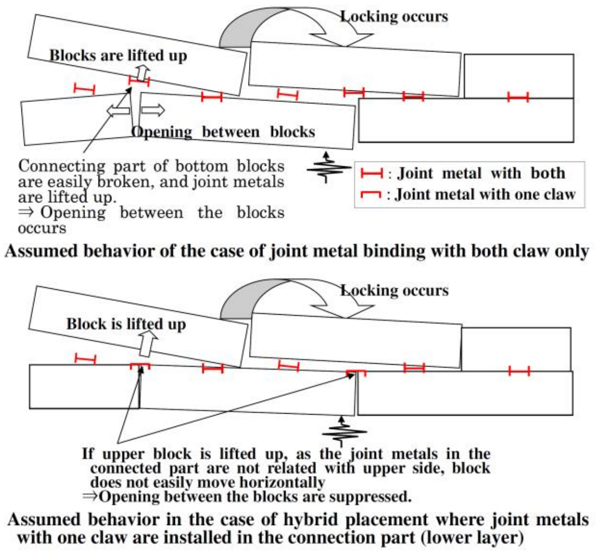

Fig. 6. Pattern diagram of deformation behavior due to locking

When a large seismic force acts on the EPS embankment, due to the vertical movement caused by rocking, EPS block is lifted up. As Fig. 6 upper shows, under the conditions of conventional layout, this caused lifting up of the joint metal binders installed between the blocks, and connection between the lower horizontal blocks comes off. Therefore, as shown in Fig. 6 below, by using the joint metal binders with one-sided spikes for connecting the horizontal blocks, slipping out due to rocking can be prevented, and connection between the horizontal blocks can be maintained.

Fig. 7. shows the situation after the vibration is completed. The front side is a hybrid layout and the back side is a conventional layout. Since the slip deformation of the EPS block on the decks installed every 3 m was confirmed at the time of vibration, a slip-prevention steel plate was installed on the side of decks under the condition of hybrid layout.

In Fig. 7, in the conventional layout on the back side, the deviation between blocks is confirmed, but on the front side, almost no deformation is seen. Fig. 7 shows the situation of large deformation (block breakout) after the test under the condition of the conventional layout. There is not a great damage to the joint metal binders themselves, and EPS block leaves some claw marks but no major damage has occurred. This shows that

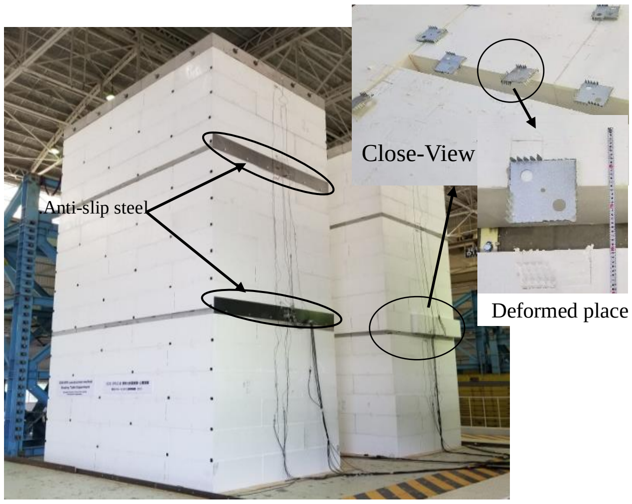

Fig. 7. Situation after shaking (hybrid placement in the foreground)

breakout of the joint metal bindings has occurred, and the block itself moved without restraint. That is to say, the motion shown in above Fig. 6 has occurred.

The seismic motion used in the test is a large-scale earthquake of 1995 Hyogo-ken Nanbu earthquake whose frequency in the observation record is corrected. Fig. 7 shows that there is some deviation in the EPS embankment with the conventional layout, but no major deformation has occurred. Thus, earthquake resistance of the EPS embankment was confirmed.

2.3 Simulation Analysis

Simulation analysis for the above test was carried out. The analysis was based on the two-dimensional finite element method. The image of the analysis model is shown in Fig. 8.

In the analysis, EPS material and the concrete block on the top were considered as plane strain, and the concrete deck 100 mm thick in the middle was used as the beam element. As shown in the lower left of Fig. 8, joint elements were installed between the EPS blocks and between the EPS blocks and the deck. In addition, 2 spring elements per block were installed between the EPS blocks which modeled the joint metal binders. The spring value is shown in the figure, which is the value set from the result of the trial by analysis. The boundary condition of the analysis was fixed to the bottom as in the test, and seismic motion was incident from this fixed bottom.

For analysis, the large deformation analysis program FLIP / TULIP was used. As a result of the analysis, Fig. 9 shows a comparison of the horizontal response displacement at the top position (left end) of the model with the test results. In the analysis, there is a residual behavior of the displacement after receiving a large displacement, but the peak of displacement and the maximum displacement amount are almost same. Fig. 10. Shows the horizontal acceleration. The test and analysis are almost in agreement. Similarly, the one showing vertical acceleration is Fig. 11. Except short-period peaks around t = 7.8 sec according to the test, they are almost same.

Thus, it was found from the analysis that not only the horizontal direction but also the vertical vibration due to rocking can be expressed. This confirms the applicability of the analysis to seismic resistance evaluation of large-scale EPS embankments and embankments of high importance.

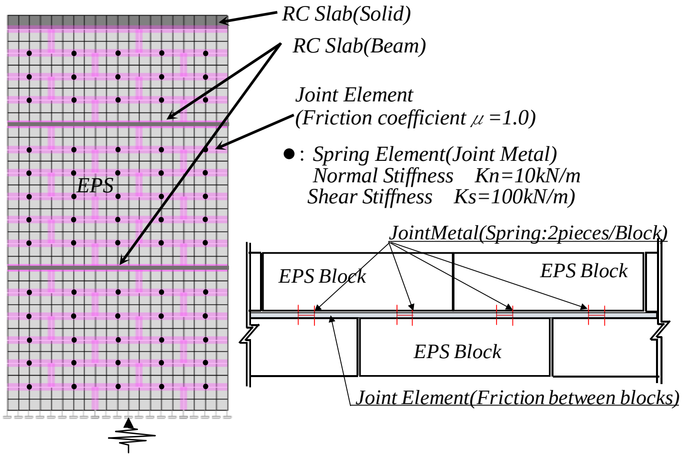

Fig. 8. Numerical Analysis Model

Table. 1. Physical Characteristics

Material	Poisson's Ratio ν	Unit Volume Weight γ (kN/m^3)	Young's Modulus E (kN/m^2)
EPS(D20)	0.075	0.20	10,800
RC Slab	0.167	23.50	23,500,000

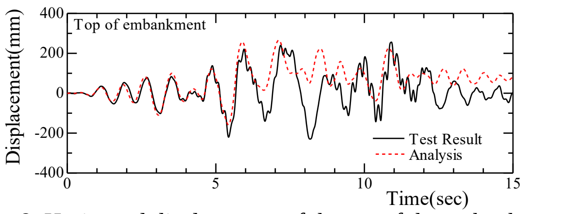

Fig.9. Horizontal displacement of the top of the embankment

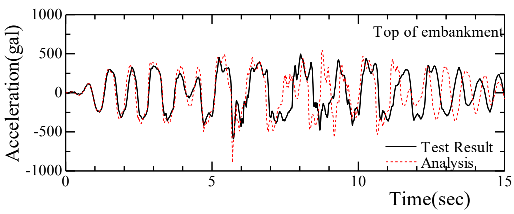

Fig. 10. Horizontal acceleration of the top of the embankment

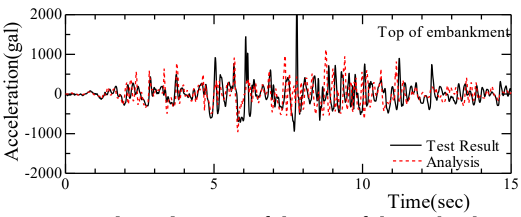

Fig. 11. Vertical acceleration of the top of the embankment

3 CONCLUSIONS

In this paper, full scale tests on resistance of EPS embankment against large earthquake motions and its analytical evaluation were described. The results are summarized as follows;

(1) The new joint metal bindings between the EPS blocks developed for improving earthquake resistance improve the seismic performance of EPS embankment compared to the conventional ones.

(2) Rocking deformation can be suppressed by the hybrid layout of joint metal binders where conventional joint metal binders with both-sided spikes are used for vertical connection of EPS blocks and joint metal binders with one-sided spikes are used for horizontal connection of EPS blocks.

(3) Numerical analysis using a large deformation analysis program FLIP/TULIP could be successfully performed to simulate the shaking table test behavior of EPS embankment including the rocking behavior.

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