Shake-Table Tests on the EPS Fill for Road Widening

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Abstract
Model tests using a large shake-table were carried out to investigate the behavior of EPS fill during earthquakes and to simplify the retaining walls placed on both sides of the fill. Random-wave loads were applied to a 1/5-scale model of EPS fill intended for road widening, while varying the type of retaining wall and the presence of anchors that share inertial force during earthquakes. The test results indicate that residual deformation occurs but the EPS fill remains self-sustainable and the road remains functional even without walls and anchors. Residual displacement can be suppressed by placing anchors appropriately.

Keywords: expanded poly-styrol (EPS), shake-table test, aseismic performance of EPS fill, anchor, retaining wall type.

1. Introduction
The EPS method is used for road widening in soft soil and mountainous areas because of its superb characteristics (lightweight material, self-sustainable structure, easiness of construction, etc.). Recently, large size fill structures are being used and retaining walls on both sides of the fill and anchors that receive inertial force during earthquakes are being diversified. However, the effects of retaining walls and anchors on the behavior of EPS fill during earthquakes have not been clarified. Against this background, model tests using a large shake-table were carried out with the aim of making retaining walls simple and reducing costs. This study was carried out as a joint research of the EPS Development Organization and the Civil Engineering Research Institute of Hokkaido.

2. Test model
The tests were carried out at the Civil Engineering Research Institute of Hokkaido by using a shake-table and a 1/5-scale model (Figure 1). 1/5-scale EPS blocks (20 x 40 x 10 cm in size) were used in the portion within 40 cm (30 cm, for the lowest layer) from the front face of the retaining wall, and monolithic blocks were used behind this portion. The D-20 type EPS was used. To simulate intermediate slabs, 2-cm thick steel plates were placed at 0.6-m vertical intervals in the fill. Sand paper was attached to the steel plates in consideration of the friction between actual EPS blocks and concrete slabs. Sand was pasted on the back EPS surfaces in consideration of the friction between actual EPS blocks and the soil embankment. Thumb tacks, which were found through preliminary tests to have properties very similar to those of actual metal connectors, were used to bind EPS blocks together. This data was supplied by Mr. Mae of Sekisui Plastics Co., Ltd. A load of 150 kN/m2 was applied to the top of the model in consideration of the dead weight of pavement and other objects. Six cases with varying conditions of retaining walls and anchors were tested as shown in Table 1.

3. Shaking conditions and measurement items
The shaking tests were carried out by using mainly seismic input data generally used for aseismic design in Japan (Table 2). A sine-curve shaking session of 0.5-15 Hz was applied in step 1 to obtain auxiliary data for later investigation. Then, level 1 and 2 seismic motions were applied in steps 2 and 3, respectively. The same model was used in steps 1 through 3, and each test was terminated when significant residual deformation occurred. Measured items are shown in Table 3 and the setting of measurement equipment is

shown in Figure 2.

4. Experimental results

<1> Deformation of the EPS fill by shaking

Residual deformation occurred in the lower part of the EPS fill in cases 1 and 6, where anchors were not installed, but the fill did not collapse. This indicates that the fill remains self-sustainable even during large-scale earthquakes. The fill remained sound without residual deformation when anchors were installed. The same results were obtained even when retaining walls were not installed, indicating that residual deformation during large-scale earthquakes can be suppressed by installing anchors (Photo 1).

<2> Relationship between the predominant frequency and input acceleration of the EPS fill

Figure 3 shows the relationship between the predominant frequency and input acceleration of the EPS fill. Predominant response frequencies are mostly in the range of 1.3-2.0 Hz regardless of the presence and structure of retaining wall. Predominant frequencies tend to increase when anchors are not present and converge to a value of 1.3 Hz when anchors are present. No significant difference was found between the different numbers of anchor layers. The results indicate that the presence of anchors in the upper part of the EPS fill have a great influence on the behavior of the fill during earthquakes. The magnification of response with anchors installed was in the range of 1.5-2.0 in the cases of level 2 earthquakes (Figure 4).

<3> Effect of the EPS fill structure on stress increase at the fill bottom during earthquakes

Figure 5 shows the relationship between the stress increase at the EPS fill bottom during earthquakes and the structural type of the fill. The stress increase increases with the magnitude of shaking. The greatest stress increase was found in the case of "no retaining walls and no anchors", followed by "retaining walls and no anchors", "no retaining walls and anchors only in the upper part", "retaining walls and anchors only in the upper part", "no retaining walls and anchors in the whole part", and "fixed retaining walls and anchors only in the upper part" in descending order. This indicates that overturning moment (stress increase) during earthquakes is suppressed by the presence of anchors in a way more prominent than conventional retaining walls. Overturning moment was reduced by increasing the number of anchor layers. The H-steel embedment anchored into the foundation ground was found to be an effective structural type of retaining wall. Generally, a stress increase of 2.5 tf/m2 can be expected in the D-20 type EPS during earthquakes (shown by the dotted line in Figure 5). The allowable stress was satisfied during level 2 earthquakes by using the D-20 except for the cases of no anchors and the case of "no retaining walls and anchors only in the upper part". In the latter case, the fill was self-sustainable even after the test. While solid ground was assumed in the test model, the EPS method is supposed to be applied to soft ground, leading to smaller values of stress increase due to ground displacement during earthquakes. The use of the D-20, therefore, is considered to be sufficient even in the case of "no retaining walls and anchors only in the upper part".

<4> Relationship between the load shared by anchors and shaking acceleration during earthquakes

Figure 6 shows the relationship between shaking acceleration and the anchor load sharing ratio of the top slab versus the upper intermediate slab versus the lower intermediate slab. A constant load sharing ratio of 1:0.2:0.05 from top to bottom was found regardless of the shaking acceleration. This is close to an inertia force ratio of 1:0.12:0.06 for the top slab versus the upper intermediate slab versus the lower intermediate slab.

Figure 7 shows the relationship between shaking acceleration and the load shared by the top slab anchors. The figure shows that the shared load increases with shaking acceleration and that the amount of increase does not depend on the presence of retaining walls and the number of anchor layers.

Figure 8 shows the ratio of the load shared by the upper anchors versus the inertia of the top slab. The ratio depends on the type of retaining wall and the number of anchor layers. A ratio of 0.93 was found for the case of "no retaining walls and anchors only in the upper part". This is consistent with a ratio of 0.93 obtained through discussion on the sliding data shown in Document 1. This supports the possibility of setting the load shared by anchors from the shape of the EPS fill.

5. Summary

The test results indicate that the EPS fill, even without retaining walls, remains self-sustainable and the road remains functional during large-scale earthquakes. Residual displacement can be suppressed by placing anchors appropriately. The top slab anchors have great influence on the residual deformation of the fill during earthquakes.

Further studies will be carried out in consideration of the deformation mode of the EPS fill in order to develop retaining walls that are easy to construct and cost efficient.

References

"The EPS Method - Super Lightweight Banking Using Expanded Poly-Styrol", Edited by the EPS Development Organization, Rikoh Tosho Co., Ltd.
"Study on the Aseismic Performance of EPS Fill", March 1991, The Soil Dynamics Division of the Construction Method and Equipment Department of the Public Works Research Institute of the Ministry of Land, Infrastructure and Transport, Technical Memorandum of PWRI, No. 2946.

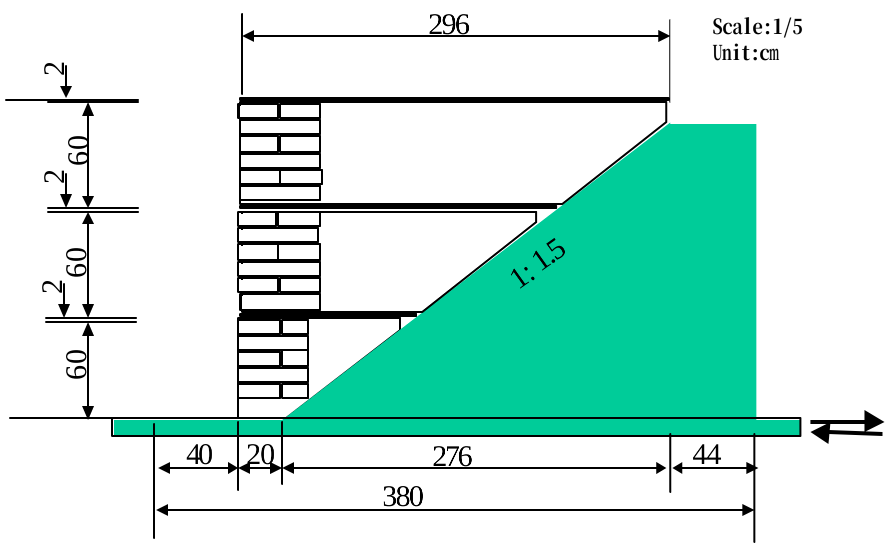


Fig 1 Image of filling up EPS

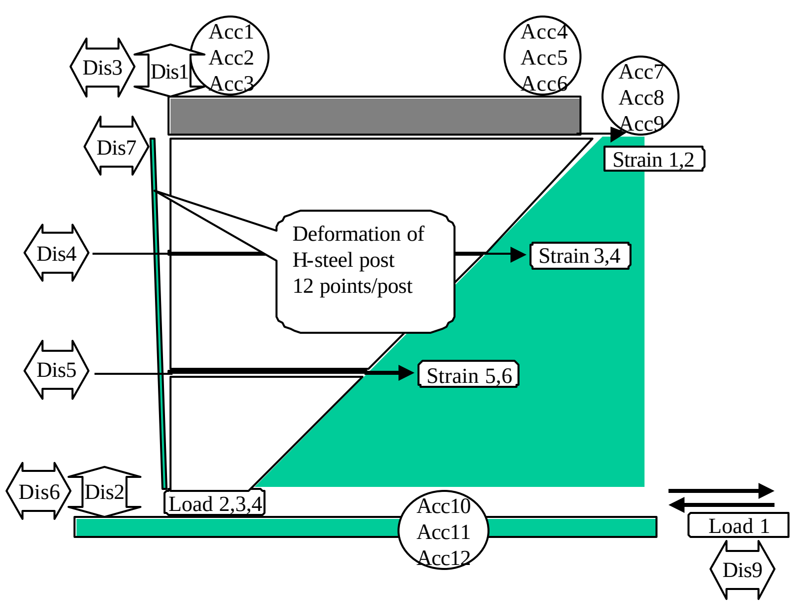


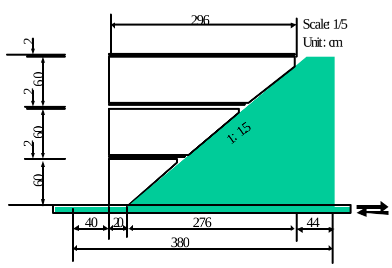
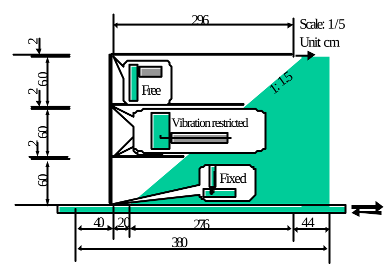
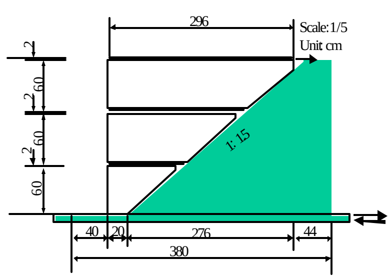
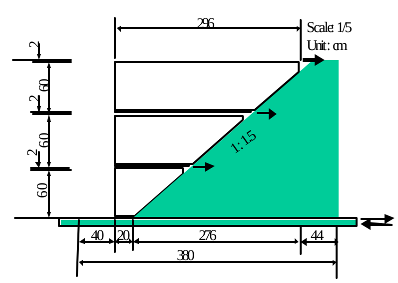
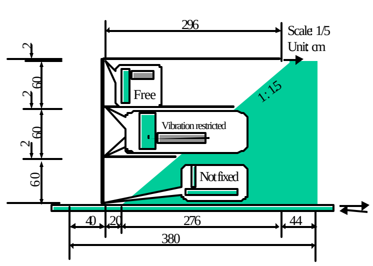
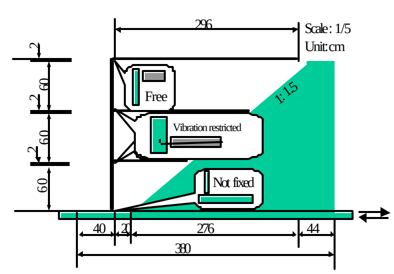
Fig 2 Positions of monitoring equipments

Table 2 Shaking condition in this experiment

Step	Input wave		Purpose	Remarks
1	Sine curve	0.5~ 15Hz	Basic data for specific frequency of the fill	About 50gal
2	Random wave	Level 1 seismic motion	Kind ? ground	1968 Hyuganada-oki Earthquake, modified
3		Type ? seismic motion	Kind ? ground	1994 Hokkaido-toho-oki Earthquake, modified
			Kind ? ground	1994 Kushiro-oki Earthquake, modified
		Type ? seismic motion	Kind ? ground	1995 Hyogoken-nanbu Eearthquake, recorded at Kobe Maritime Weather Bureau
			Kind ? ground	1995 Hyogoken-nanbu Eearthquake, recorded at JR Takatori Station, modified

Table 1 Test Model Table

Test Case	Wall	Anchor
Case1	Nil	Nil
Case2	Nil	Top slab only
Case3	Placed, lower part open	Top slab only
Case4	Placed, lower part fixed	Top slab only
Case5	nil	Top slab intermediate slabs (upper and lower) all placed
Case6	Placed, lower part open	nil

Test Case	Simplified illustration	Test Case	Simplified illustration
Case1		Case4	
Case2		Case5	
Case3		Case6	

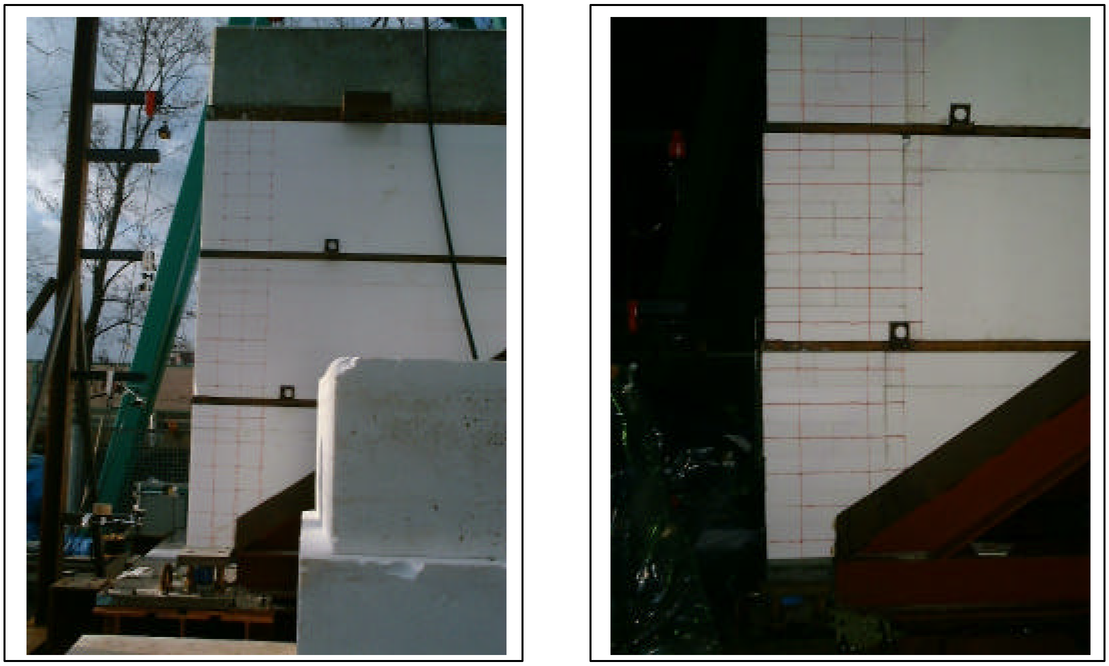


Photo 1 The condition in the experiment end

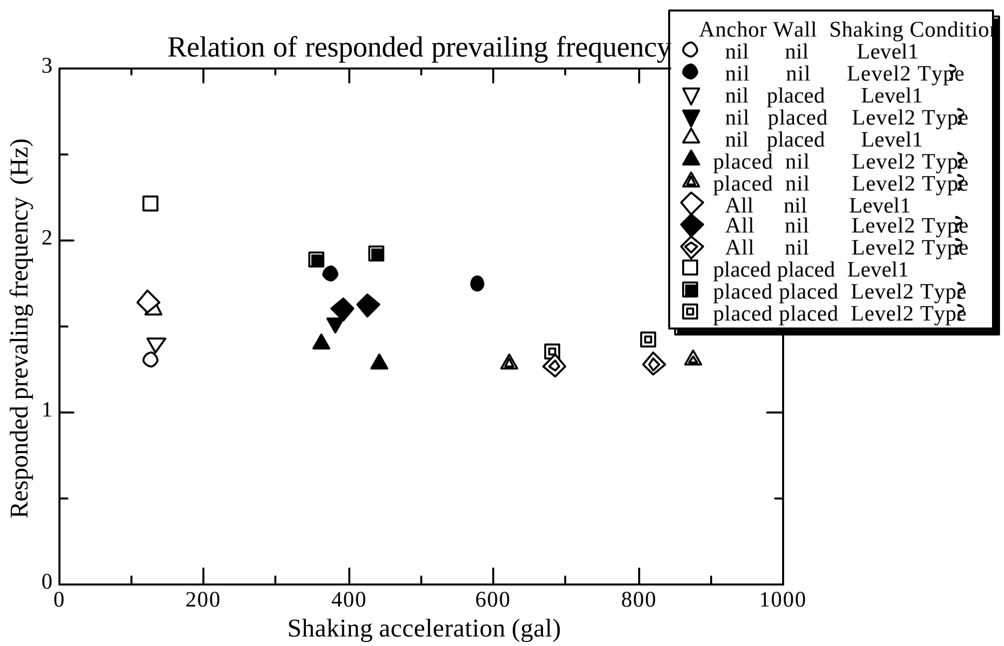


Fig 3 Relation of responded prevailing frequency

Table 3 Table of Measured Items

Equipment	Item	Location	Direction	Equip. Name	Range
Acc1	Acceleration	Upper Slab (front side)	Shaking Direction	Servo type Accelerometer	ｱ 2G
Acc2	Acceleration	Upper Slab (front side)	Lateral Direction of Shaking	Servo type Accelerometer	ｱ 1G
Acc3	Acceleration	Upper Slab (front side)	Vertical Direction	Servo type Accelerometer	ｱ 1G
Acc4	Acceleration	Upper Slab (groundside)	Shaking Di rection	Servo type Accelerometer	ｱ 2G
Acc5	Acceleration	Upper Slab (ground side)	Lateral Direction of Shaking	Servo type Accelerometer	ｱ 1G
Acc6	Acceleration	Upper Slab (ground side)	Vertical Direction	Servo type Accelerometer	ｱ 1G
Acc7	Acceleration	Backside Ground, Upper Part	Shaking Direction	Servo type Accelerometer	ｱ 2G
Acc8	Acceleration	Backside Ground, Upper Part	Lateral Direction of Shaking	Servo type Accelerometer	ｱ 1G
Acc9	Acceleration	Backside Ground, Upper Part	Vertical Direction	Servo type Accelerometer	ｱ 1G
Acc10	Acceleration	Shake-table	Shaking Direction	Servo type Accelerometer	ｱ 2G
Acc11	Acceleration	Shake-table	Lateral Direction of Shaking	Servo type Accelerometer	ｱ 1G
Acc12	Acceleration	Shake-table	Vertical Direction	Servo type Accelerometer	ｱ 1G
Dis1	Displacement	Upper Slab	Vertical Direction	Optical Strain Meter	ｱ 100mm
Dis2	Displacement	Shake-table	Vertical Direction	Optical Strain Meter	ｱ 100mm
Dis3	Displacement	Upper Slab	Shaking Direction	Optical Strain Meter	ｱ 100mm
Dis4	Displacement	Upper Part ofMiddle Slab	Shaking Direction	Optical Strain Meter	ｱ 100mm
Dis5	Displacement	Lower Part of Middle Slab	Shaking Direction	Optical Strain Meter	ｱ 100mm
Dis6	Displacement	Shake-table	Shaking Direction	Optical Strain Meter	ｱ 100mm
Dis7	Displacem ent	H-steel Tip	Shaking Direction	Optical Strain Meter	ｱ 100mm
Dis8	Displacement	Actuator	Shaking Direction	Strain Meter with Actuator	-
Load1	Load	Actuator	Shaking Direction	Load Cell with Actuator	-
Load2,3,4	Load	EPS Lower Part	Vertical Direction	Load Cell x 3 units	For 10t
St1,2	Strain	Upper Slab Anchor Tension	Shaking Direction	Strain Gauge	
St3,4	Strain	Upper & Middle Slab Anchor Tension	Shaking Direction	Strain Gauge	
St5,6	Strain	Lower & Middle Slab Anchor Tension	Shaking Direction	Strain Gauge	
St7~ 18	Strain	Strain Measurement of H-steel @20cm 1/2of Middle Section	Vertical Direction	Strain Gauge	
St19~ 30	Strain	Strain Measurement of H-steel @20cm 2/2 of Middle Section	Vertical Direction	Strain Gauge	

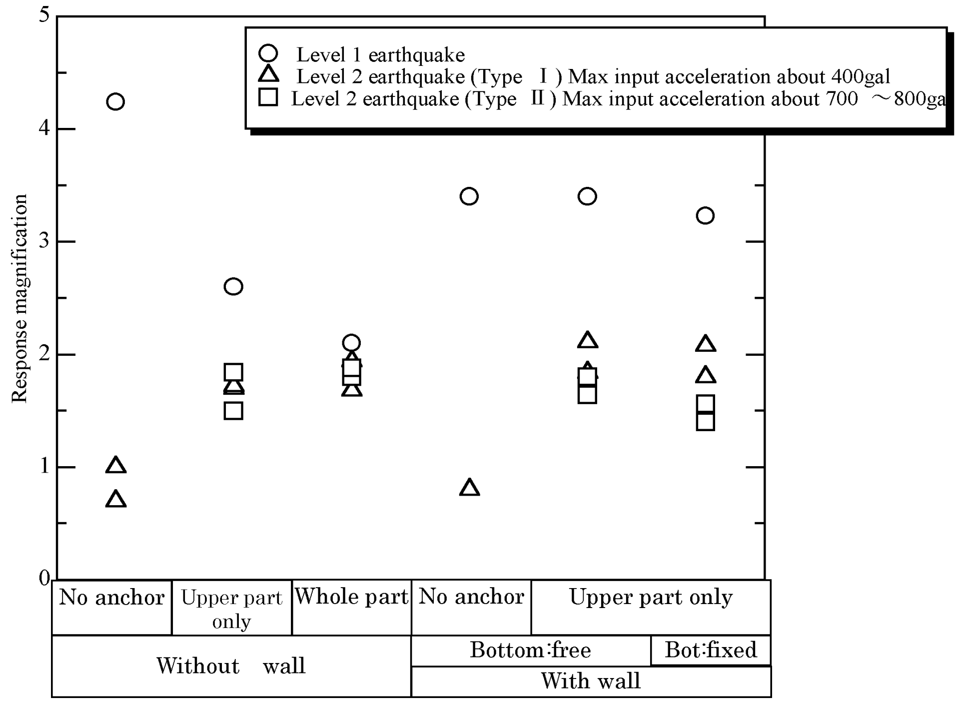


Fig 4 Relationship between Magnification of Acceleration Response of EPS Fills and Structure Type

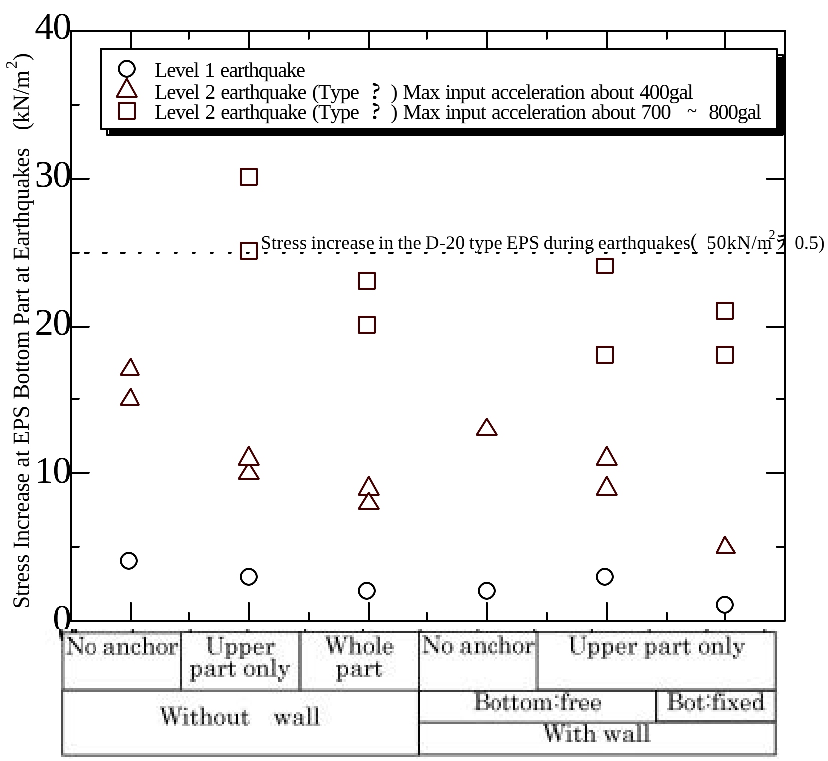


Fig 5 Relationship between Stress Increase at EPS Bottom Part at Earthquakes and Structure Type

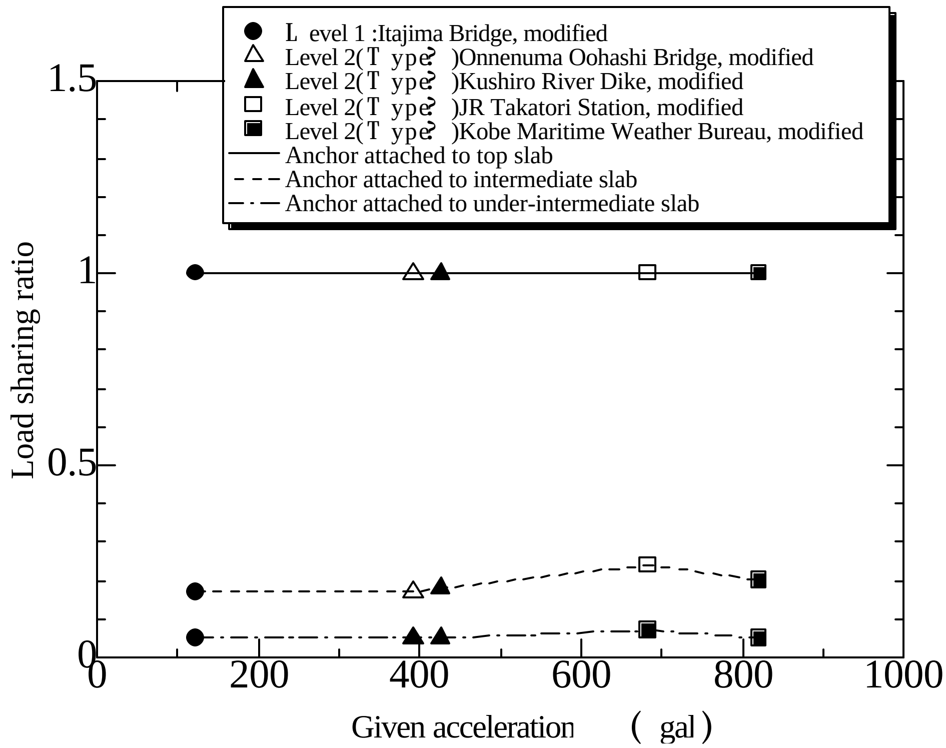


Fig 6 Relation between Load Sharing Ratio of each Anchor and Shaking Acceleration

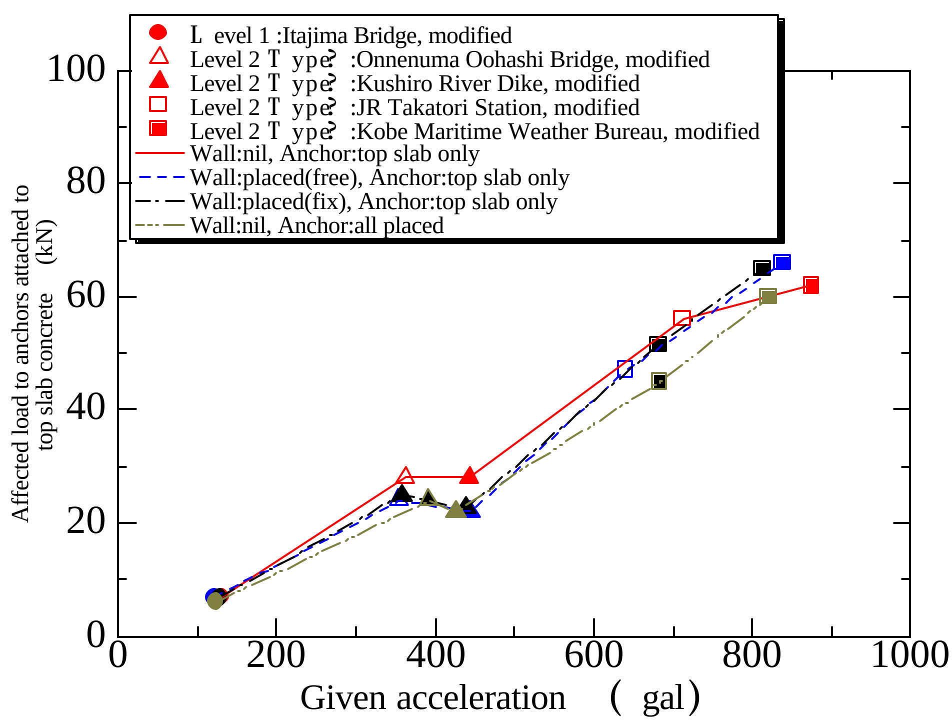


Fig 7 Relation between Affected Load of Anchors attached to top slab concrete and Shaking Acceleration

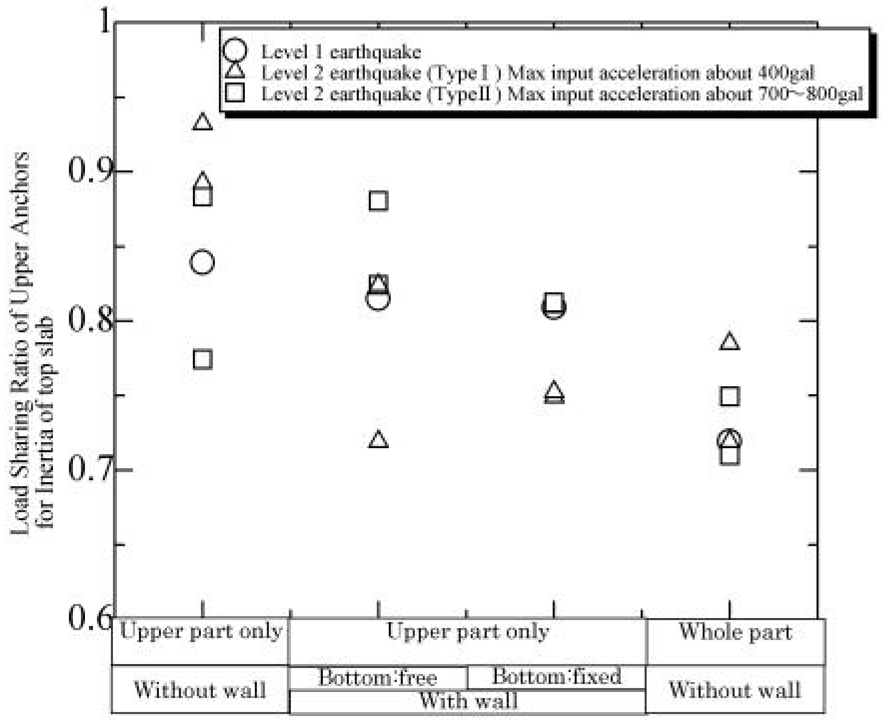
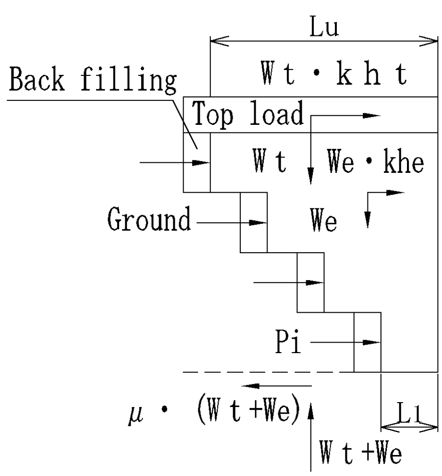


Fig 8 Relation between Load Sharing Ratio of Upper Anchors for Inertia of top slab and EPS structure type



The safety factor for the sliding of the EPS structure is given by

$$F_s=\frac{\frac{L1}{Lu}\mu\cdot(Wt+We)+T}{Wt\cdot kht+Wt+khe+\Sigma i\,Pi}$$

$$T=\mu\cdot(Wt+We)-\mu\cdot(Wt+We)=1-\left(\frac{L1}{Lu}\right)$$

Wt:Weight of the top load
We:Weight of the EPS including the concrete slabs
kht:Modified seismic coefficient of the top load
khe:Modified seismic coefficient of the EPS
Pi:Total horizontal earth pressure
μ:Coefficient of friction on the EPS bottom
L1:Ground contact width of the EPS bottom
Lu:Width of the top load

Document 1