Behavior of Double -Vertical-Wall-Type EPS Fills During Major Earthquakes

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Abstract

Construction of double-vertical-wall-type EPS fills is becoming widespread in mountainous valley areas and behind bridge abutments in Japan. Recent EPS fills are becoming large and are required in design to have seismic stability against inland earthquakes, as exemplified by the 1995 Hyogo-ken Nanbu Earthquake. It is therefore urgently required to establish a method to verify double-vertical-wall-type EPS fills. The authors carried out a large shake-table test using full-size double-vertical-wall-type EPS fills to investigate their behavior under earthquakes. The authors also carried out numerical simulations to study the method of verifying aseismic design against major earthquakes and to identify aseismic design precautions. The aseismic performance of the fills was found to be very high even against earthquake motions equivalent to the 1995 Hyogo-ken Nanbu Earthquake, which was unprecedentedly disastrous even in an earthquake-ridden country like Japan.

Keywords: expanded poly-styrol (EPS), shake-table test of EPS fill, simulation analysis, aseismic performance of double-vertical-wall-type EPS fill

1. Introduction

The expanded poly-styrol (EPS) method is being frequently used recently for constructing road fills in landslide areas and behind bridge abutments for reducing both filling loads and earth pressure and suppressing lateral flow. Because EPS fills tend to become high when roads run across steep mountainous areas, not only static but also dynamic stability during earthquakes is a matter of concern. It is indispensable to check the stability of structures under earthquakes, which frequently occur in Japan. Sufficient study is required especially because structures using EPS tend to be "top heavy." Under these circumstances, a shake-table test using full-size models of double-vertical-wall-type EPS road fills was carried out and many findings were obtained. Also, a two-dimensional FEM analysis was carried out to simulate the behavior of the fills during earthquakes. This paper reports the basic data obtained, which may be helpful in establishing methods to evaluate aseismic capacity and to prepare aseismic design against major earthquakes.

2. Shake-table test using EPS fills

2.1 Test models and conditions

Double-vertical-wall-type EPS fills, which are considered to be less stable during earthquakes, were tested because construction of a greater number of high fills is expected in the future. Fill models with small width/height ratios (B/H), shown in Figure 1, were tested. While the width was fixed at 5 m, different heights of 3.3, 6.4, and 8.5 m were adopted (B/H ratios of 1.52, 0.78, and 0.59, respectively). Full-size D-20 type EPS blocks (200 cm in length, 100 cm in width, and 50 cm in thickness) were used for the models. Consideration was given to the following points in the test: (1) fixation of EPS blocks to the shake-table, (2) behavior of EPS blocks in contact with other blocks, and (3) behavior of EPS blocks in contact with the top load and the intermediate slabs.

(1) Fixation of EPS blocks to the shake-table

The large shake-table used for the test is 5 m in width and 5 m in depth. Because the width of each EPS fill was set to 5 m, the fill had no space to slide in the shaking direction. Because the lowermost EPS blocks were secured to the shake-table, the tipping of the entire fill and the pulling out behavior of the fill were investigated without considering the sliding behavior of the fill.

(2) Behavior of EPS blocks in contact with other blocks

EPS blocks were bound together by using metal connectors as is the case with practical works. When one connector per square meter was installed as usual in test case 1, sliding between blocks occurred when major (level 2) earthquake motions were applied. Two connectors per square meter were therefore installed in the other test cases.

(3) Behavior of EPS blocks in contact with the top load and the intermediate slabs
Separately formed concrete slabs were put on and in the EPS fill as the top load and the intermediate slabs. The test model therefore had coefficients of friction similar to those of actual EPS fills containing cast-in-place concrete.

2.2 Shaking conditions

The full-size shake-table test was carried out under the following shaking conditions (see Table 1).

(1) Sine waves with accelerations of about 50 gal were applied for determining the resonance frequency.

(2) Sine waves with accelerations of 100-200 gal were applied in consideration of the earthquake motion level of the seismic coefficient method (20 waves at the resonance frequency) were applied.

(3) Great earthquake motions, often taken into account in aseismic design in the wake of the 1995 Hyogo-ken Nanbu Earthquake, were applied (modified waves recorded at the Kobe Marine Observatory shown in "Specifications for Highway Bridges - Part V - Seismic Design"; see Figure 2).

2.3 Test results

As an example of the test results, Figure 3 shows a transfer function for the lower part and the top of the fill in case 2 (fill height: 6.4 m). The first-order resonance point of the EPS fill is clearly shown in the figure, which indicates that first-order mode is predominant in the structure. The sine-wave shaking in step 2 was performed within this resonance frequency band. Figures 4 through 6 show the distributions of maximum acceleration responding to major (level 2) earthquake motions for the three test cases. The greatest value of maximum response acceleration was found at the lowermost intermediate slab in either case. The maximum response acceleration in cases 2 and 3 decreased in the second-level intermediate slab and further decreased in the third-level intermediate slab.

Figure 7 shows how gaps occurred between EPS blocks after shaking in case 3 (fill height: 8.5 m). Gaps of about 2 cm were generated between the blocks in this case after repeating six times of level 2 earthquake motions. Most gaps between the blocks occurred in the vicinity of the lowermost intermediate slab.

It is considered that the EPS blocks around the lowermost intermediate slab could not be held together by the metal connectors because of vertical movement during the level 2 earthquake motions; residual displacement was generated so that the apparent response of the entire EPS blocks was lessened.

Compressive displacement occurred in the EPS blocks at both ends of the lowermost level after repetitive shaking. This is probably due to the concentration of stress in these blocks associated with the rocking of the EPS fill. Use of high-strength EPS blocks at both ends of the lowermost level is therefore required when level 2 earthquake motions are taken into consideration.

The test results indicate that double-vertical-wall-type EPS fills have aseismic capacity sufficient for road use even in consideration of the 1995 Hyogo-ken Nanbu Earthquake, which was unprecedentedly disastrous even in an earthquake-ridden country like Japan.

3. Simulation analysis of the shake-table test using EPS fills

3.1 Analytical method and conditions

The FLUSH program, based on the complex number method of frequency response analysis, was used for the simulation analysis. The physical properties of the members used in the analysis are listed in Table 2. Although the nonlinearity of the EPS members during strong quakes was found in laboratory element tests, they were treated as linear members in the analysis because the decrease of stiffness due to shear strain in the fill was not significant in comparison with the soil. The modulus of rigidity of the EPS members was deduced from the natural frequencies of the test models by using a simplified equation obtained from the existing results of shake-table tests [1]. The simulation analysis was carried out by assuming that the apparent damping coefficient lies on the line extrapolated from existing test results [1] as shown in Figure 9. A mesh division diagram is shown in Figure 10 for test case 3.

3.2 Analytical results

Figure 11 shows the distributions of maximum response acceleration and maximum response displacement for case 3. The simulation results, which well agree with the test results, provide the following findings.

(1) Aseismic performance of the EPS fills (resistance to tipping and pulling out) can be assured even against level 2 earthquake motions. Roads on EPS fills should remain functional right after major earthquakes.

(2) Major rocking mode occurred in the full-size shake-table test.

(3) The behavior of high fills during earthquakes is characterized by intermediate nodes in response. While simple first-order mode is predominant in fills of about 3.0 m in height, second- or third-order mode may become predominant in fills of 6.0 m or more in height. Aseismic reinforcement is therefore required in the middle and upper parts of high fills.

(4) Compressive stress was generated in the EPS blocks at both ends of the lowermost level due to repetitive rocking loads. This behavior should be taken into account when designing EPS fills. In a repetitive loading test of 4-million times [2], no significant decrease in the stiffness of EPS blocks occurred in the elastic region. In the case of repetitive loading under dynamic stress in the plastic region and in the case where the deformation mode of the entire fill is greatly affected by placing EPS members of low stiffness in these positions, appropriate EPS members must be selected after investigating their internal stability.

4. Aseismic design in consideration of major earthquake motions

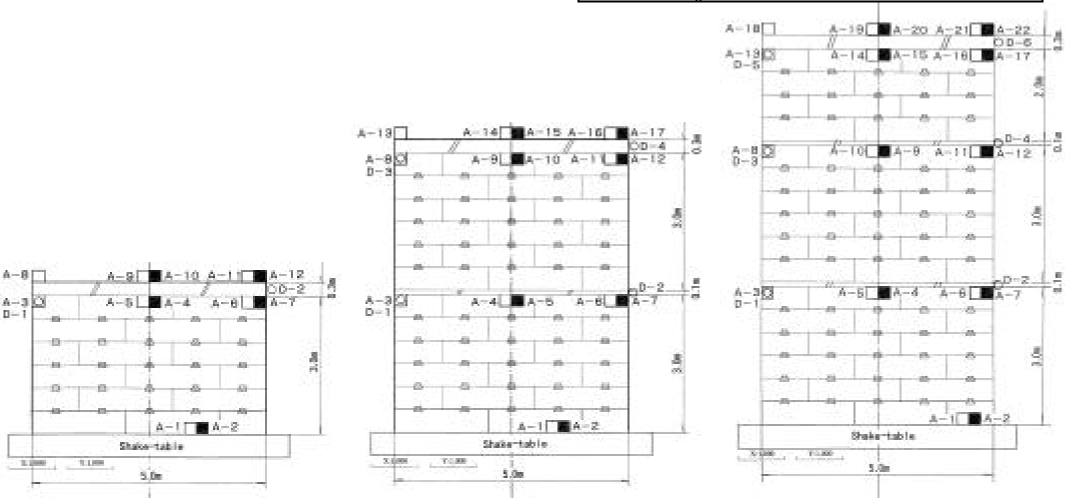
(1) When EPS road fills are subjected to major earthquake motions, gaps may be generated between EPS blocks. Metal connectors should therefore be installed twice as much as usual (two connectors per square meter). As for the stability of the entire fill, the occurrence of tipping, sliding in the middle/upper part, or pulling out of blocks is found to be unlikely.

(2) In aseismic design against major (level 2) earthquake motions, in particular inland earthquakes (type II earthquake motions), it should be noted that rocking mode becomes predominant as the height of the fill is raised. A possible countermeasure is to place EPS blocks of high stiffness in the lowermost level in due consideration of their relationship with the bearing capacity of the soil.

(3) When EPS road fills are subjected to level 2 earthquakes, great horizontal and vertical motions are expected at the fill top (road surface) although tipping and pulling out of blocks are not expected. Countermeasures against the impact loads of vehicles and the falling of blocks need to be taken into account in the design of the fills.

(4) Although the structural stability of EPS road fills during level 2 earthquakes was confirmed, road functionality may be affected when the road profile gradient (linear distortion due to the slide of the entire fill along the slope) or the boundary of cutting and filling is a matter of concern. Emergency rehabilitation measures to cope with such problems need to be identified in advance.

Legend	Instrument name
?	Accelerometer (Horizontal)
ヲ	Accelerometer (Vertical)
?	Displacement meter



(1) case 1 (2) case 2 (3) case 3

Fig.1 Test conditions

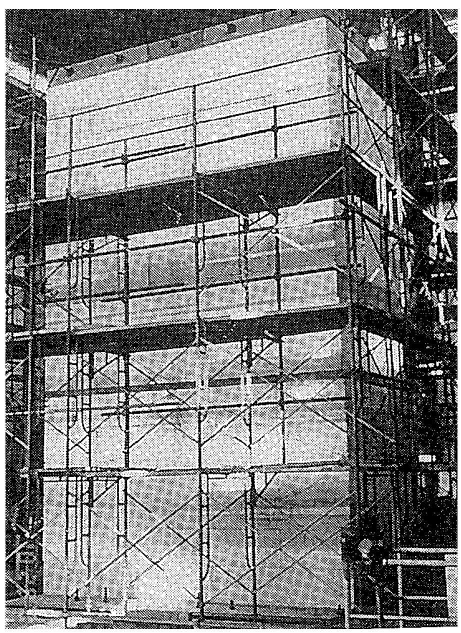


Photo 1 Test fill (fill height: 8.5 m)

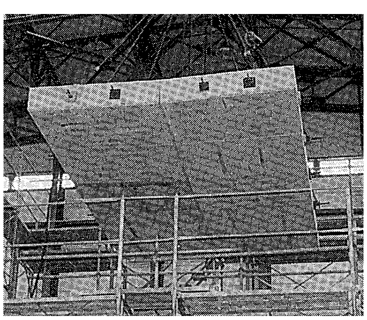


Photo 2 Placing a top load

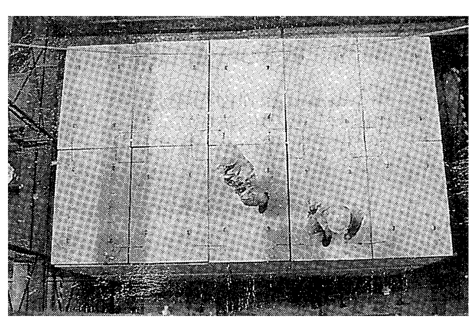
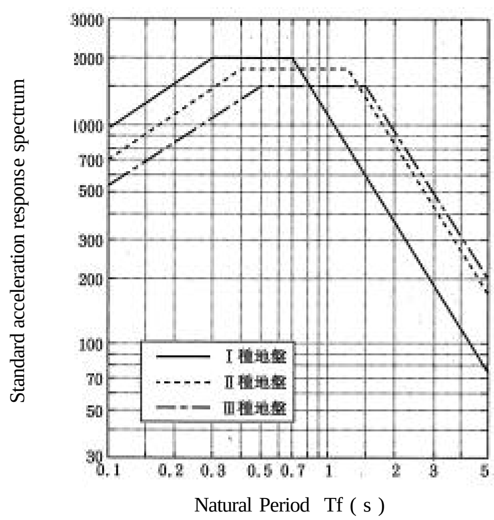


Photo 3 Placing an intermediate slab

Table 1 Full-size shake-table test conditions

Step	Input Waves			Purpose	Note
1	Sine Waves	0.5 – 15 HZ		Natural Frequency	About 50 gal
2	Sine Waves	Level 1 Earthquake Motion		Ordinary Design Earthquake Motion	About 100-200gal
3	Random Waves	Level 2 Earthquake Motion	Type? (inland) Earthquake	For Type 1 Soil	The 1995 KOBE-Earthquake*

Note: * KOBE-Earthquake: The 1995 Hyogo-ken Nanbu Earthquake (Modified Waves Recorded at the KOBE Observatory)



Type ?

Fig.2 Standard acceleration response spectrum (Level 2 earthquake)

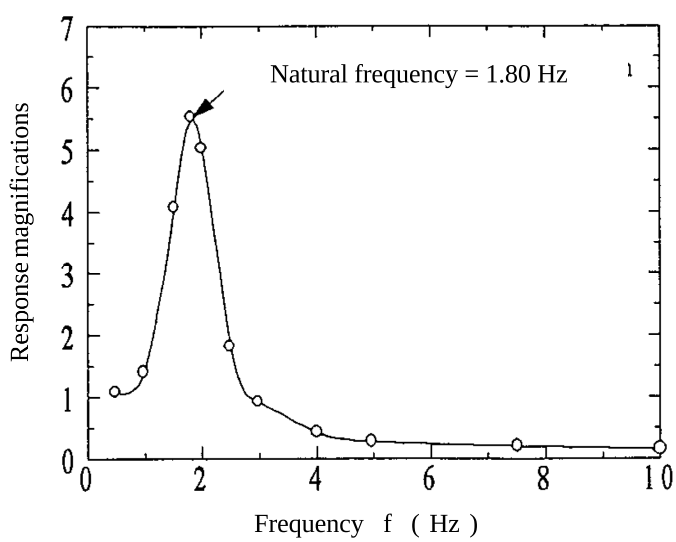
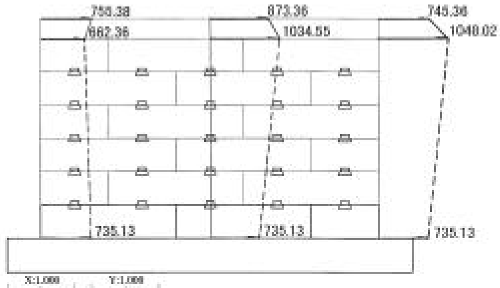
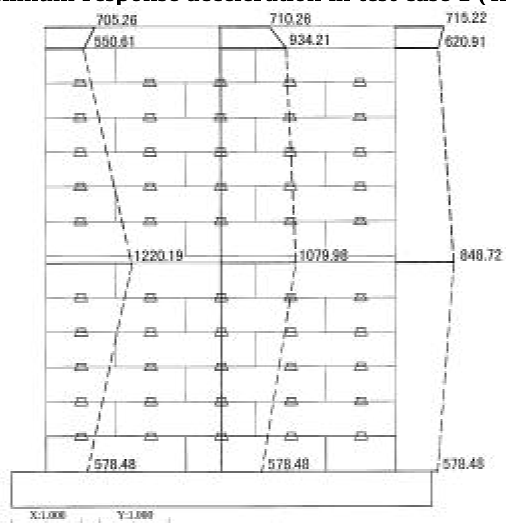


Fig.3 Transfer function (fill height: 6.4 m)



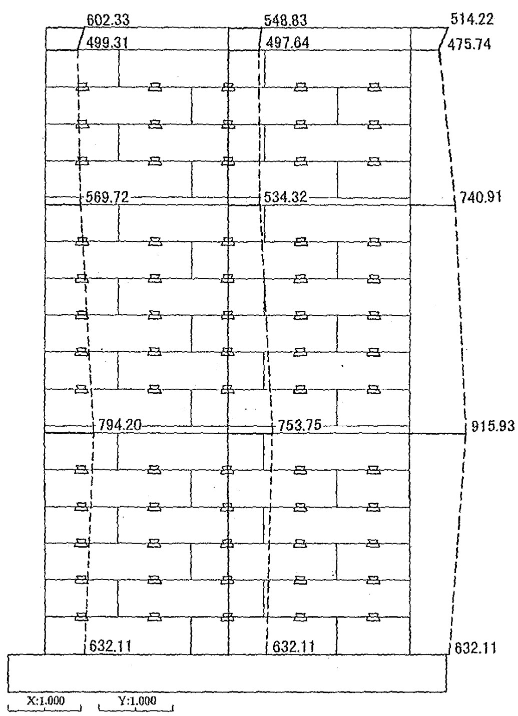
Unit : Gal

Fig.4 Distribution of maximum response acceleration in test case 1 (fill height: 3.3 m)



Unit : Gal

Fig.5 Distribution of maximum response acceleration in test case 2 (fill height: 6.4 m)



Unit : Gal

Fig.6 Distribution of maximum response acceleration in test case 3 (fill height: 8.5 m)

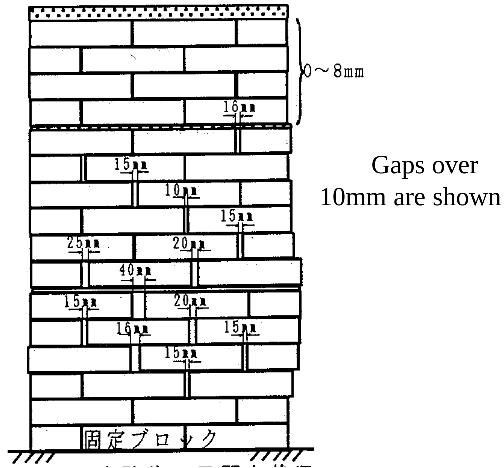


Fig.7 Distribution of residual deformation after shaking in test case 3 (fill height: 8.5 m)

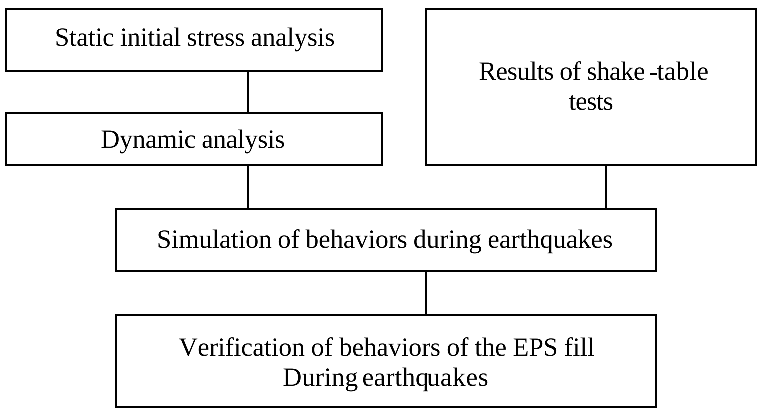


Fig.8 Flow of Analysis

Table 2 Input Property Values in the Simulation Analysis

Material	Weight per Unit Volume ? (kN/m^3)	Modulus of Rigidity G_0(kN/m^2)	Poisson's ratio ?	Damping Coefficient h	Remarks
EPS	0.20	2500.0	0.075	Varying	
Top Load	25.0	1.087E+07	0.167	0.05	
Top Slab	25.0	1.087E+07	0.167	0.03	
Intermediate Slab	25.0	1.087E+09	0.167	0.05	

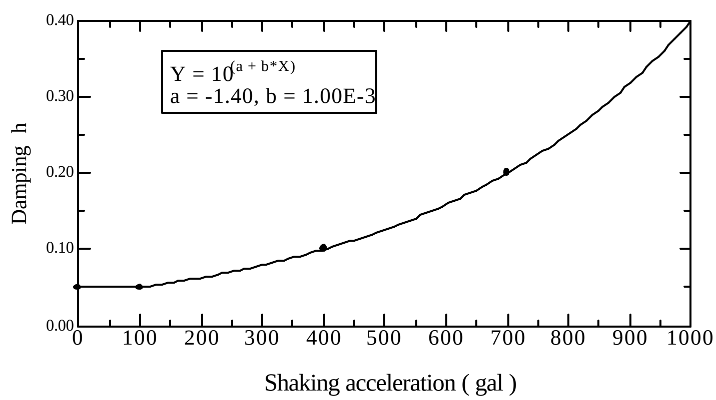
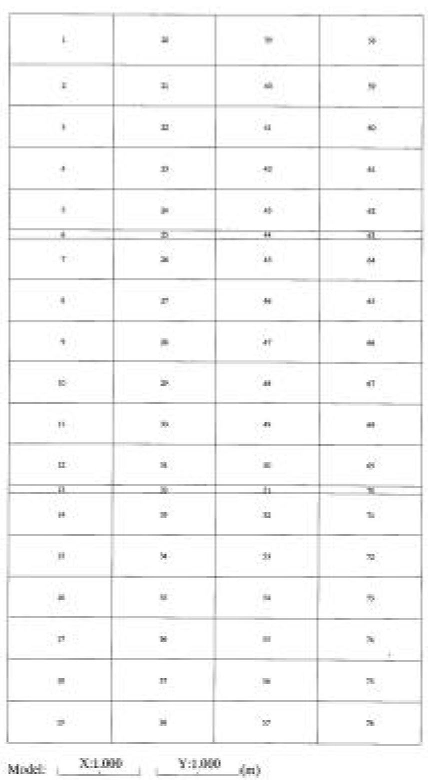
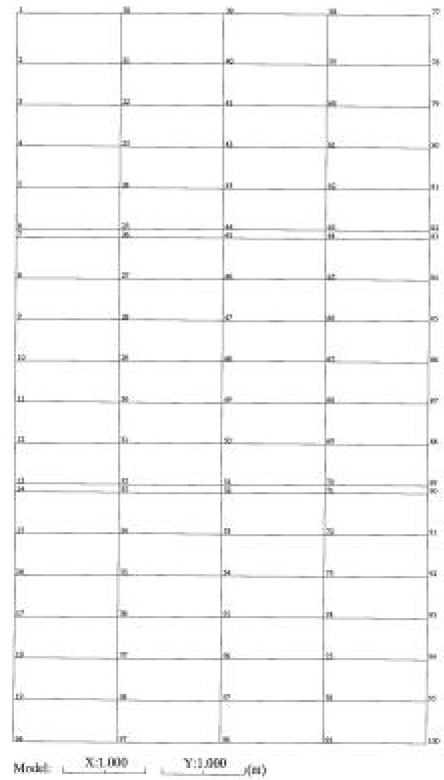


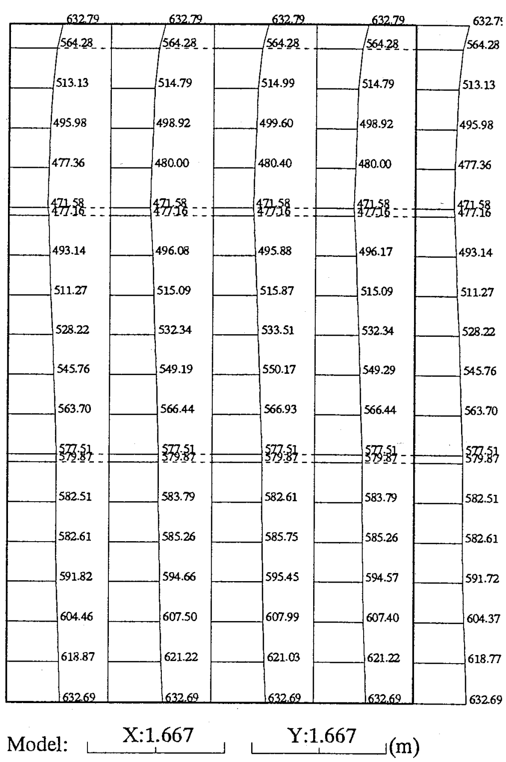
Fig.9 Relationship between max. shaking acc. and the damping coefficient of the entire EPS blocks

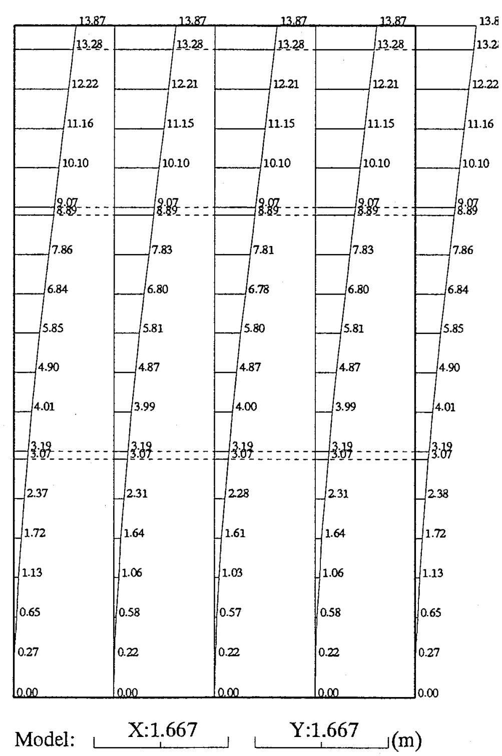




Element Joint

Fig.10 Mesh division for test case 3 (fill height: 8.5 m)





Max. response acc. Unit:Gal Max. response disp. Unit:cm

Fig.11 Results of simulation analysis for test case 3 (fill height: 8.5 m)