Dynamic Response of EPS Blocks /soil Sandwiched Wall/embankment

J. C. Chai¹ and S. Hayashi²
¹Department of Civil Engineering, Saga University, Saga
²The Institute of Lowland Technology, Saga University, Saga

Synopsis

The dynamic behavior of an assumed lightweight EPS blocks/soil sandwiched wall/embankment was investigated by finite element analysis. First the mechanical properties of EPS blocks are discussed. The numerical procedure was verified by simulating a shaking table model test of a reinforced model wall/embankment system. Then the dynamic response of an EPS/soil sandwiched wall/embankment was investigated numerically and compared with an assumed conventional reverse “T” concrete wall/embankment system. In terms of dynamic load induced permanent lateral deformation and the factor of safety of wall/embankment system, the EPS/soil sandwiched wall/embankment has a higher seismic resistance than conventional reverse “T” case. In terms of dynamic load amplification factor, the values for EPS/soil system are almost the same with or slightly larger than reverse “T” case. The numerical results also indicate that for the assumed case, EPS/soil interfaces are weak zones. Further investigation on EPS/soil interface behavior and the techniques of strengthening the EPS/soil interface are needed.

Keywords

Earthquake resistance, lightweight embankment, numerical analysis

1 Introduction

To increase the stability and reduce the post construction settlement of embankments or retaining walls over soft subsoil, there are two possible approaches: (1) improving the strength and stiffness of soft deposit and (2) using lightweight fill materials. In several situations, such as deep soft deposit, using lightweight fill material or combination of partially improving the subsoil and lightweight fill material is more economic than fully improving the soft deposit. One of the widely used lightweight materials is
expanded poly-styrol (EPS), which has a unit weight of 0.12~0.3 kN/m³. There are several ways to use EPS material, such as EPS blocks, mixing EPS pieces in soil, etc. Earth-Stone Co. Ltd. [1] proposed a method of sandwiching the holed-EPS blocks with soil layers. This method has several advantages. (a) The unit weight of the system can be easily adjusted by changing the relative ratio of EPS and soil. (b) It is cheaper and the structure is stronger than the case of just using EPS blocks. (c) A variety of soils can be used in this sandwiched system.

To apply the EPS/soil sandwiched system in seismic area, the dynamic characteristics of the structure need to be investigated. Generally, the inertia force is proportional to the mass of a structure, and using lightweight material can reduce the earthquake-induced inertia force. However, since the stress-strain behavior of sandwiched system is different from conventional earth structure, further researches are needed to quantify the seismic response of the system. In this study, finite element method was used to investigate the dynamic response of the EPS/soil sandwiched wall/embankment. For calibrating the numerical procedure, a 1:2 larger scale shaking-table model test of reinforced road system with rigid facing (RRR wall) [2] were simulated first. Then the dynamic response of an assumed sandwiched wall/embankment was investigated numerically. In following sections, the properties of EPS blocks are described first followed the verification of numerical procedure. Then the dynamic responses of an assumed EPS/soil sandwiched wall/embankment system are presented. The discussion is made in terms of dynamic load induced permanent lateral displacement, dynamic load amplification factor, and the factor of safety of backfill material during dynamic loading.

2 Mechanical properties of EPS block

The properties of EPS block and EPS/soil interface are important for analyzing the behavior of EPS/soil sandwiched system. The test results from literatures are highlighted as follows.

(1) Compression strength. Several unconfined-compression tests (Fig. 1) [3] and triaxial tests [4] had been conducted using EPS samples. The general tendencies are as follows. (a) The linear elastic compression strain range is about 0~1%, and the yielding strain is approximately 2%. (b) The compression strength (defined by limiting strain) almost linearly increases with the increase of unit weight of EPS samples. (c) The confining effect slightly reduces the strength (a reverse tendency when compared with soil). (d) Manufacturing method has an effect on the mechanical properties of EPS.

![Figure 1 Stress-strain relation of EPS blocks](image-url)
Under the same unit weight condition, EPS expanded by push-out method (XPS) has a higher strength than that of expanded in a mould (EPS).

(2) Modulus. The modulus of EPS is also increase with the increase of unit weight. From Fig. 1, the modulus for 0~1% strain is in a range of 2500~11000 kPa for EPS and 15500 kPa for XPS. The Poisson’s ratio of EPS block increases with the increase of unit weight and decreases with the increase of compression strain. It is generally in a range of 0.05~0.2.

(3) Interface shear strength. The coefficient of friction (\(f = \tan \delta\), \(\delta\) is interface friction angle) of EPS/EPS interface is about 0.65 and about 1.0 for XPS/XPS interface. The coefficient of friction of EPS/sand interface is about 0.6, which corresponding to an interface friction angle of 31 degrees.

(4) Dynamic shear modulus (D) and damping ratio (h). A typical dynamic test result is shown in Fig. 2 [5] for EPS samples with a unit weight of 0.2 kN/m\(^3\). The figure indicates that within the strain range tested, the shear modulus not reduced significantly with the increase of strain. However, confinement reduced the shear modulus. The measured dynamic Poisson’s ratio was 0.14.

3 Verification of the numerical procedure

A dynamic analysis computer program named SADAP [6] was used in this study. To calibrate the numerical procedure, a larger scale (1:2) shaking-table test of a reinforced wall/embankment (RRR wall) (Fig. 3) was simulated and the results were compared with measured ones [2]. For the case simulated, the dynamic load was a sine wave inputted from the base. The maximum acceleration was 500 gal and the frequency was 3.4 Hz. The duration of the shaking...
was 20 seconds. The measured items were (a) dynamic load amplification factor (acceleration normalized by the inputted value at base of the structure), (b) permanent lateral deformation of the wall, and (c) the maximum increment of tensile force in reinforcement during shaking. In analysis, the dynamic behavior of the fill and foundation materials was modeled by Hardin-Drnevich model [7]. Reinforcement was repressed by elastic bar elements. Table 1 lists the adopted parameters. In determining the model parameters of back fill and foundation soils (sands), the test results of standard Toyoura sand were referred [8]. Simulated results are compared with measured data in Figs. 4 to 6. Fig. 4 compares the dynamic load amplification factor of the structure. Although the simulation (solid line) under estimated the amplification factor at the upper part of the structure, the general tendency is in agreement with measurement. Fig. 5 shows that the simulated permanent lateral deformation is larger than measured data. The difference may be due to the inexact of assumed model parameters. However,
the absolute values were small with a maximum value less than 1 mm. Also it is uncertain regarding to the continuity of 3 longer reinforcement layers (Fig. 3). It was stated [2] that the longer reinforcements were cut at the middle point (which was simulated). However, for the standard RRR wall/embankment, the longer reinforcements are continued [9]. Fig. 6 gives the maximum tensile force increment in reinforcement caused by shaking. The simulation over-predicted the tensile force increment at the upper part and under-predicted it at the lower part of the structure. This coincides with the simulated permanent lateral deformation pattern (Fig. 5). Both measured and simulated results indicate that the tensile force increments caused by shaking were small. From above comparison, it can be stated that the numerical results are acceptable and the numerical procedure can be used for investigating the dynamic response of earth structures.

For the model shown in Fig. 3, one more analysis was conducted to investigate the effect of reducing the unit weight of fill material on the dynamic response of the structure. Everything was the same as for simulating the model test, except the unit weight of backfill and facing panel was reduced to half. The analysis results are included in Figs. 4 to 6 also (dashed line). It can be seen that using lightweight fill material has an obvious beneficial effect on the dynamic response of the structure. The numerical results also indicate that RRR wall had a larger failure zone (factor of safety=1.0) beneath the wall than that of lightweight case. Within the backfill, lightweight case has a higher factor of safety (2.0 to 2.5) than RRR case (about 1.5).

### 4 Dynamic response of EPS/soil sandwiched wall/embankment system

Above analyses did not take into account of the mechanical properties of EPS blocks. A standard full-scale EPS/soil sandwiched wall/embankment system is shown in Fig. 7 (a), which was used for numerical investigation. A conventional reverse “T” wall/embankment (Fig. 7 (b)) with a wall thickness of 0.5 m was used for comparison. Thin solid elements with a thickness of 50 mm were used to simulate the EPS/sand interface behavior. To reduce the reflection at boundaries, a 2 m wide damping zone with the properties like rubber was adopted at lift and right boundaries. The finite element mesh used is shown in Fig. 8. Assuming using D-25 holed EPS blocks (unit weight of 0.25 kN/m³), the material properties for EPS and EPS/soil interface are listed in Table 2. The properties of backfill, foundation materials and concrete wall were the same as those in Table 1. The dynamic load was a sine wave with a maximum acceleration of 200 gal, and frequency of 3.4 Hz. The duration of loading was 10 seconds (30
Table 2 EPS and EPS/soil joint zone parameters

<table>
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<tr>
<th>Material</th>
<th>G_i kPa</th>
<th>γ_t kN/m³</th>
<th>c_d kPa</th>
<th>φ_d (°)</th>
<th>K0 kPa</th>
<th>v_s</th>
<th>v_d</th>
<th>α_1 kPa</th>
<th>n_1</th>
<th>α_2 kPa</th>
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<td>70*</td>
<td>0.0</td>
<td>0.11</td>
<td>0.1</td>
<td>0.1</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>Joint Zone</td>
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<td>20</td>
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<td>0.5</td>
<td>2733</td>
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</tr>
</tbody>
</table>

*Corresponding to 5% compression strain.

loading circles). Since the analysis is focused on the relative values of EPS/soil sandwiched wall/embankment system and conventional reverse “T” case, the numerical results of the two models shown in Fig. 7 are presented in a parallel form and compared. Fig. 9 compares the dynamic load induced permanent lateral deformation of the walls. The light-weighted EPS/soil sandwiched wall/embankment has a smaller permanent lateral deformation at the top of the wall with a maximum value of 6.5 mm. In the case of the reversed “T” wall/embankment, the maximum value is 8.4 mm. However, due to the lower stiffness of EPS block than concrete wall, EPS/soil sandwiched case has a larger lateral deformation at the toe of the wall/embankment system. Fig. 10 compares the dynamic load amplification factor of the systems. The maximum value (about 1.5) at the top of the wall is the same for two cases.

Figure 7 Model wall/embankment systems

Figure 8 Finite element mesh used

However, EPS/soil sandwiched case has a slightly larger value at the lower part of the wall. In the case of reverse “T” wall/embankment, the base of the concrete wall is embedded into the ground. Due to the higher stiffness of the wall, the part of the inertia force of upper structure is transferred onto the ground.

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below the base of the wall. As a result, the higher shear stress zone is shafted to below the base of the wall, and the deformation at the toe is reduced. EPS/soil system is flexible, the inertia force of the upper structure is transferred onto the ground from ground surface, which results in a higher dynamic load application factor and therefore the larger lateral deformation at a zone around the toe. These different mechanisms can be clearly seen from the contours of the factor of safety of the systems as shown in Figs. 11 (a) and (b). It can be seen that EPS/soil sandwiched case has 2 small failure zones near the toe compared with larger failure zones under the base of concrete wall of reverse “T” case. Another point needs to be noticed is that for EPS/soil sandwiched case, under the conditions assumed, at several EPS/soil interfaces, the factor of safety is around 1.1 to 1.2. This indicates that the EPS/soil interface may need to be strengthened.
Above comparisons show that the EPS/soil wall/embankment system has a better or equal performance under dynamic loading when compared with reverse “T” case. The higher seismic resistance of EPS/soil system is mainly due the reduction of self-weight of the system. The results also indicate that the EPS/soil interfaces are potential weak zones.

5 Conclusions

The seismic response of an assumed EPS/soil sandwiched wall/embankment was investigated by finite element analyses. Comparing with conventional reverse “T” case, under dynamic loading, the lightweight EPS/soil sandwiched wall/embankment has a smaller permanent lateral deformation, and a higher factor of safety. In term of dynamic load amplification factor, the EPS/soil sandwiched case has a slightly larger value at the lower part the system. Generally, EPS/soil sandwiched case has a higher or equal seismic resistance compared with reverse “T” case and can be applied in seismic area. The analysis also shows that the EPS/soil interfaces are a potential weak zones with a lower factor of safety for the parameters assumed. Further research on EPS/soil interface behavior as well as the method for strengthening the interface are needed.

References