STUDY ON IMPACT ABSORBENCY OF SOIL MIXED WITH CRUSHED EPS WASTE
- RELATION TO THE DEFORMATION CHARACTERISTICS OF SOIL -

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ABSTRACT

As a contribution to solving environmental problems, some attempts at recycling waste into geomaterials have been carried out. The authors have also been investigating some possibilities to effectively use crushed EPS (Expanded Polystyrene) waste as a constituent of a light-weight mixed soil. The soil mixed with this crushed EPS waste needs; lightweight geomaterial strength properties, water retentivity and permeability for vegetation, an insulation effect and so on. Consequently, crushed EPS waste is expected to be used as a material for rooftop gardening foundations. In this study, focused on the cushioning function as a major characteristic of EPS, the impact absorption effect of soil mixed with crushed EPS waste was investigated. This is because by using this mixed soil as a rooftop gardening foundation, it is expected that the burden upon the legs and lower backs of the people who are resting there is reduced and that the propagation of discomforting vibrations caused by outdoor air conditioning units, to lower floors, is inhibited. Accordingly, a rammer was dropped on the mixed soil. The effect of decreasing the falling object's impact acceleration and reducing the bearing foundation's impact load, caused by using the mixture of crushed EPS waste, was examined. Then, the influence of the deformation characteristics of the mixed soil upon the impact absorbency was considered. As a result, it was found that the impact acceleration and bearing load were decreased in accordance with the crushed EPS waste mixture ratio. The ratio of decrease was almost in proportion to the decreasing ratio of mixed soil deformation modulus. Moreover, it was mostly found that the decreasing impact acceleration ratio was correlated with the elastic deformation component originating in the crushed EPS waste. These results are thought to give important information to clarify the mechanism of the impact absorption effect of soil mixed with various waste materials more easily deformed than soil particles. This is considered to contribute to the advancement of the effective use of recycled materials.

Keywords: Crushed EPS waste, recycle, mixed soil, deformation characteristics, impact absorption effect

INTRODUCTION

There are many problems caused by the self weight of soil, such as the settlement of embankments built on soft ground and excess load pressure of earth behind a retaining wall. In these situations, lightweight materials such as expanded poly-styrol (EPS) beads are mixed with soil to reduce the self weight of the soil (e.g. Yamada et al., 1989). Research has been conducted on the mechanical properties of lightweight mixed soils, and the literature related to these researches is listed and published by the Research Committee on Estimating the Properties of Lightweight Geomaterials, (1998) at the Japanese Geotechnical Society. On the other hand, as a contribution to solving environmental problems, it is very convenient to utilize adequately treated waste as lightweight geomaterials. From this point of view, the authors have been investigating the possibility of utilizing crushed EPS waste, which was already circulated for recycling. As a result, it was found that the strength parameters, such as internal friction angle, remained almost unchanged, while its compressibility increased (Kimata et al., 2001). Furthermore, it was also found that the soil mixed with this crushed EPS waste has; plant growth water retentivity, a drainage improvement effect and a stable insulation effect in spite of soil moisture content fluctuation. These results show a possibility that the crushed EPS waste mixed soil can effectively be used as a rooftop gardening foundation, for example (Kimata et al., 2007).

In considering the effective recycling of waste materials, it is desirable not only to think about the disposal method, but also to use such materials utilizing these merits. Therefore, in this study, focused on the cushioning function as a major feature of EPS, the impact absorption effect of soil mixed with crushed EPS waste was examined. This is because by using this mixed soil as a rooftop gardening foundation, it is expected that the burden upon the legs and lower backs of the people who are resting there is reduced and that the propagation of discomforting vibrations caused by outdoor air conditioning units, to lower floors, is inhibited.

As an example of the impact absorption effect, we imagine the scene in which a weight falls on to the ground mixed with such materials. It was decided to consider the impact absorption effect in two parts. Firstly the effect of reducing the impact acceleration received by the weight itself (impact giving side) and secondly the impact load transmitted through the ground (impact receiving side). In the experiment, a 4.5 kg rammer was dropped from a height of 450 mm on to the mixed soil prepared by compaction, in a 150 mm mold. We measured the impact acceleration received by the rammer and the impact load transmitted to the bottom of the mold. After that, the impact absorption effect caused by mixing crushed EPS was investigated by comparing the change in impact acceleration and load, according to the different EPS mixing ratios. Furthermore, it was considered that the impact absorption effect of crushed EPS mixed soil highly depends on the deformation characteristics of the soil. Therefore, the deformation modulus of the soil and the penetration amount at the time of impact loading were measured and influence of these deformation characteristics upon the impact absorption effect of the mixed soil was investigated.

TESTING METHODS

Materials and Specimens

The crushed EPS wastes used in this study was made from expanded plastic trays and containers used in the food industry and the like. They were heavier (unit weight is about 0.69 g/cm^3) than ordinary EPS, and their rigidity was also much higher, since the crushed EPS wastes was partially melted and hardened in the process of crushing for efficient recovery. For the experiment, the crushed EPS was shattered with water by using a cooking cutter and sieved to 2 ~ 19 mm. Figure 1 shows the picture of the crushed EPS. On the other hand, the soil used was commercially available decomposed granite soil, which contained 25.8% gravel, 60.4% sand, 13.8% silt and clay, and whose unit weight was 2.69 g/cm^3. For the experiment, this soil was used after the grain size was converged on fixed value by repeated aerial dropping.

The samples were prepared by mixing these materials in a real volume ratio. The mixing ratio was defined as the volumetric proportion of the crushed EPS in the mixed soil. Four samples were prepared; 0, 0.25, 0.5, and 0.75. The specimens were prepared by compaction, so that the effects of only the differences between the crushed EPS mixing ratios could be compared, taking into account that the state of the soil (such as moisture content and dry density) was considered to be the same in spite of the different mixing ratios. Specifically, the amount of decomposed granite soil compacted at optimum moisture content was set as the basis. The required amount of decomposed granite soil was calculated considering the volumetric ratio of soil in the specimen and the required amount of crushed EPS was calculated from the mixing ratio. The required amount of water was also calculated from the optimum moisture content and water absorption ratio of the crushed EPS. Then, these materials were packed into a mold and specimens were made by compacting so that the volume was adjusted to the theoretically calculated value. Table 1 shows the theoretical value of each mixing ratio in the case using a 150 mm mold. In addition, the error between the theoretical and actual value of specimens was largely about 2%. Experiments were thought to be conducted by using specimens made as nearly as possible, to theoretical conditions.

Testing Apparatus and Method

Since neither the testing methods nor the criteria for examining impact absorbing characteristics of ground material had been established, the testing

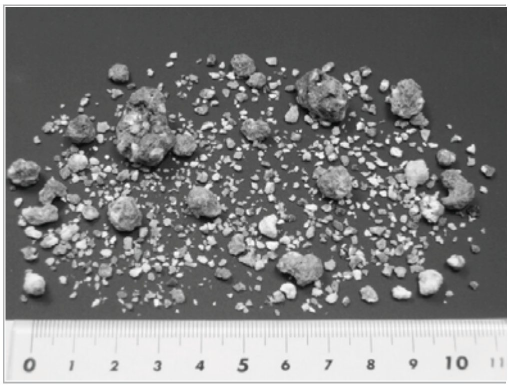

Fig. 1 Crushed EPS (after crushing)

Table 1 Theoretical conditions of specimens

Mixing ratio	Whole weight (g)	Dry density (g/cm^3)	Moisture content (%)
0	5,000.8	2.10	7.8
0.25	4,271.3	1.80	7.6
0.5	3,455.8	1.46	7.4
0.75	2,554.6	1.08	6.9

apparatus and method were conceived with reference to the method of measurement of ground bearing capacity by shock acceleration (e.g. Kinki Regional Development Bureau, 2005). That is, a rammer was dropped on to the mixed soil prepared by compaction in a mold. The impact acceleration received by the rammer and the impact load propagated to the bottom of mold were measured at that moment. As the outline of apparatus is shown in Figure 2, a mold of 150 mm inner diameter and a rammer of 4.5 kg weight (drop height was 450 mm) which are ordinarily used in compaction tests, were applied. The rammer was dropped freely from a height of 45 cm. Acceleration at the time of impact loading was measured by a small accelerometer installed in the rammer (to be precise, at the top of the rod). A load cell set under the mold also measured the load on the supporting base at the time of impact. In addition, the sampling frequency at the time of impact measurement was set at 5 kHz for both.

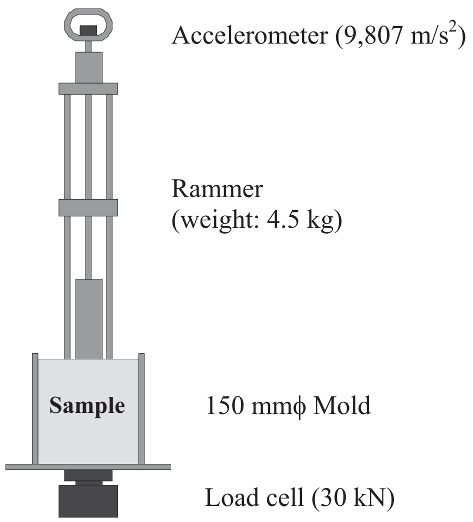

Fig. 2 Outline of testing apparatus

On the other hand, the mechanical properties of the mixed soil deformation modulus were obtained from a triaxial compression test. Specimens were prepared by compaction under the same conditions as the impact loading test described above. The dimensions were; diameter 50 mm and height 100 mm. Moreover, as for the amount of deformation during impact loading, maximum intruding deformation was calculated from the values measured by the accelerometer installed in the rammer, and the residual deformation was measured by caliper as the pit remaining on the upper surface of the specimen.

TEST RESULTS AND DISCUSSIONS

Acceleration and Load at Impact Loading

Figure 3 shows an example of the measured values on the accelerometer installed in the rammer. The number in the legend represents the mixing ratio. From this figure, it can be confirmed that the larger the crushed EPS mixing ratio, the smaller the maximum value of acceleration, in the case of impact. Numerically, it is observed that the acceleration has decreased to 1,555 m/s^2 in the mixing ratio of 0.75 whereas it was 2,082 m/s^2 in the mixing ratio of 0 (pure soil). This is about a 25% reduction in maximum acceleration when subjected to impact loading. In addition, the time reached at maximum acceleration is longer with the increase in mixing ratio. It was found that there is a difference of 1.5 times the value which is about 3.2 ms in the mixing ratio of 0.75 and 2.2 ms in the mixing ratio of 0 (pure soil). The reason is considered to be that when the stiffness of the mixed soil becomes less for larger mixing ratios of crushed EPS, the amount of deformation for the same impact is increased and more impact energy is absorbed by the soil.

Figure 4 shows an example of the measured values of the load cell set under the mold (the legend is the same as Fig. 3). From this figure, it is found that the maximum value of the impact load decreases gradually with the time to peak load being longer as the mixed ratio becomes larger. These are the same tendencies as in the case of acceleration, though the difference caused by mixing ratio is smaller. As it can be thought that these facts means the mixing of the crushed EPS contributes to reduce the shock in not only the impact loading side (rammer itself) but also in the bearing side (foundation and the bottom of the mold). It is considered that impact energy propagated through the soil was also absorbed more as the mixing ratio

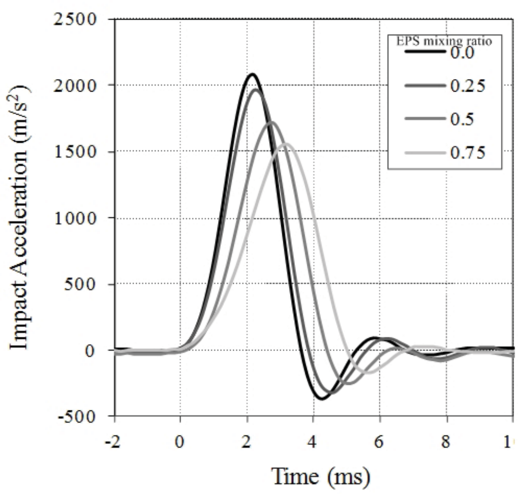

Fig. 3 Results of impact acceleration

of crushed EPS became larger.

In any case, it was found that the soil mixed with the crushed EPS exhibited an impact absorption effect for not only the impact received by the rammer (impact giving side) but also the impact transmitted through the soil (impact receiving side).

Impact Absorption Effect from the Viewpoint of Deformation Modulus

The impact absorption effect of soil is considered to be closely related to its deformation properties, because an impact is absorbed by the material's deformation. Therefore, the deformation modulus of the soil was determined and considered as it influenced the impact absorption effect. As a result of this, in this study, dynamic leading was selected as a condition of the impact loading test and the deformation caused by this loading was limited to only the area hit by the rammer. Accordingly, it is essential that the deformation modulus is determined under the same loading and deforming conditions as this and that the influence on the impact absorption effect is considered. But in this study, the initial deformation modulus was decided to be determined by static triaxial compression test and considered, from the viewpoint of using basic (generally use) soil properties.

Table 2 shows the initial deformation modulus of the mixed soil obtained by triaxial compression test. From this table, it was confirmed that the deformation modulus becomes smaller and the mixed soil becomes easier to deform as the mixing ratio is larger. However, the deformation modulus in the 0.25 mixing ratio was not reduced much. This is considered to be the reason that there are not so many crushed EPS in the mixed soil and the rigidity of the soil skeleton is mainly dominated by the rigid soil particles.

In any case, based on these values, the relationship between the maximum acceleration value measured at the time of impact loading and the deformation modulus is shown in Figure 5. From this figure, it is found that the deformation modulus of mixed soil is reduced owing to the mix of crushed EPS, and the maximum acceleration value also becomes smaller, accordingly. This is considered to provide the fact that the decreasing of maximum acceleration (that is the impact absorption effect) is directly affected by the deformation modulus which is one of the essential properties of the mixed soil. However, the stiffness of soil is much less than that of materials such as concrete or metal. Even a pure soil without mixing crushed EPS has some impact absorption effect. Therefore, the specific impact absorption effect caused by mixing crushed EPS needs to be clarified. For this reason, the properties of pure soil (mixing ratio of 0) are set as the basis and the rate of acceleration and load decline are

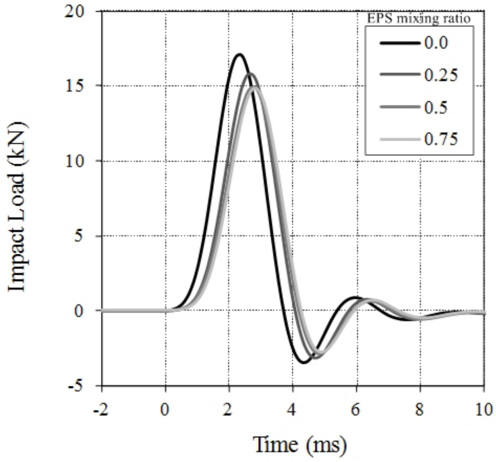

Fig. 4 Results of impact load

calculated for the study.

Figure 6 shows the relationship between the decreasing rate of deformation modulus and the decreasing rate of maximum impact acceleration calculated relative to the mixing ratio of 0 and it also shows the impact load together. From this figure, the decreasing ratio of maximum impact acceleration is found to be proportional to that of the deformation modulus. It is shown that the deformability of mixed soil directly affects the impact absorption effect, for the impact giving side. As for the decreasing ratio of

Table 2 Initial deformation modulus

Mixing ratio	0.0	0.25	0.5	0.75
Deform. modulus (kN/m^2)	38.6	31.0	14.8	7.4

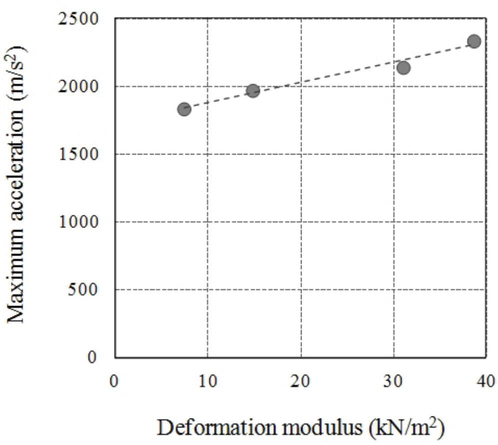

Fig. 5 Relationship between deformation modulus and maximum acceleration

maximum impact load, a positive relationship is also shown towards the decreasing rate of the deformation modulus, though it may not be regarded as a proportional relationship. Consequently, the deformability of mixed soil also affects the absorption (or reduction) effect for the impact transmitted through a soil. From the above consideration, it was found that the impact absorption effect of mixed soil became larger as the mixed ratio increased, for both the impact giving side and the impact receiving side, and the effect can be estimate by the deformation modulus of soil.

Impact Absorption Effect from the Viewpoint of Deformation Components

Though it was found that the impact absorption effect of the crushed EPS was greatly affected by the deformability of mixed soil, it was only a conclusion from a macroscopic point of view. Actually, a mixed soil is deformed by impact; the impact absorption effect is exhibited as a result. Therefore, it is decided to focus on the detailed amount of deformation caused by impact loading, and considered what kind of deformation component affects the impact absorption effect of soil, from the microscopic point of view.

Calculation of various deformation components

When such an impact loading test was carried out in this study, the soil caved in briefly to absorb the impact when the rammer was dropped, then the cave recovered to some extent. Therefore, the deformation occurring at the impact absorption can be divided into the recoverable elastic component and the plastic component remaining as a residual deformation. The residual deformation can be estimated by measuring the depth of the indentation after removing the rammer. On the other hand, the maximum deformation (maximum depth of the cave) can be calculated by using the value from the accelerometer installed in the rammer. In this case, initial velocity at impact loading was calculated from the rammer dropping height, and then the moving distance was calculated to integrate the measured acceleration value. Figure 7 shows the relationship between the impact load and the moving distance of the rammer, calculated from using the above mentioned method.

The elastic component of deformation occurring at the time of impact loading can be obtained by subtracting the amount of residual deformation from the maximum deformation. This elastic component is considered to consist of two components; the transformation of the soil skeleton and the deformation (compression) of the crushed EPS particles themselves. Therefore, the amount of elastic deformation was classified into two

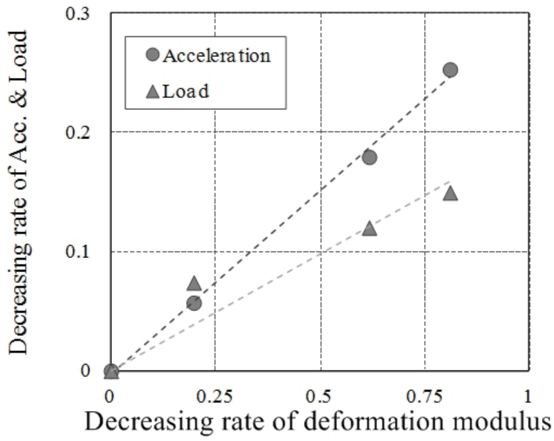

Fig. 6 Relationships of decreasing rates

components taking into account that the amount of elastic transformation of the soil skeleton occurred according to the occupied volume percentage of the soil, because the specimens used in this study have been made considering the state of soil part was the same regardless of the mixing ratio. More specifically, in the case of pure soil (mixing ratio of 0), the amount of residual deformation subtracted from the maximum deformation is entirely the elastic component caused by the transformation of the soil skeleton. As for the mixed soil, in the case of where the mixing ratio is 0.25, the elastic component caused by the soil skeleton is considered to be 75% of the whole elastic deformation (the amount of residual subtracted from the maximum), and the rest is the component caused by elastic deformation of the crushed EPS. The deformation components classified and calculated in such a way are shown in Table 3.

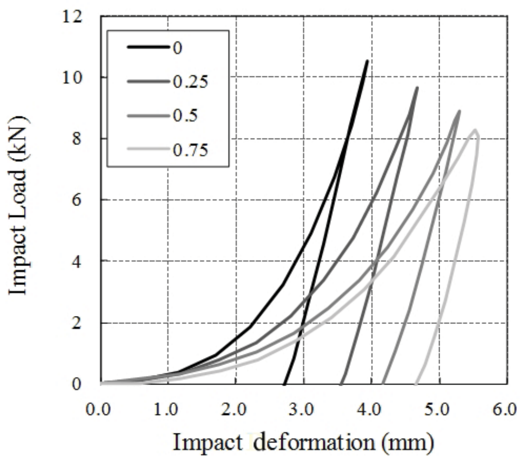

Fig. 7 Relationships between the calculated impact load and deformation

Theoretically, the amount of elastic deformation (volumetric compression) caused by the crushed EPS is expected to occur in proportion to the mixing ratio. From this table, the calculated elastic deformation component caused by the crushed EPS is found to increase in proportion to the mixing ratio, it is substantiated that the proposed method of classification is appropriate.

Relation to the maximum deformation

Figure 8 shows the relationship between the maximum deformation and the maximum impact acceleration of the mixed soil, based on the results of the preceding paragraph. From this figure, it is found that the maximum acceleration the rammer received at impact becomes smaller and more impact absorption effect is exhibited, as the amount of mixed soil deformation increases owing to the mixing of crushed EPS. This is considered to indicate the fact that the impact produced by the rammer is absorbed by deformation of the mixed soil, and supports the conclusion derived from the relationship with the deformation modulus shown in Fig. 6. In addition, Fig. 9 shows the calculated relationship between the increasing rate of maximum deformation and the decreasing rate of maximum impact acceleration based on pure soil (mixing ratio of 0). From this figure, it can be seen that the decreasing rate of maximum impact acceleration exceeds the increasing rate of maximum deformation. It is considered that the impact absorption effect of mixed soil is more greatly affected by the amount of deformation than by the deformation modulus of the soil.

Relation to the deformation component caused by crushed EPS

Lastly, it was considered which component of deformation affects most directly the impact absorption effect of a mixed soil. As mentioned above, the deformation of mixed soil is considered to be divided into elastic and residual (plastic) components, and the elastic component is divided into the component caused by soil skeleton transformation and compression of the crushed EPS itself. Therefore, we examine the relationship between these components and the decreasing rate of maximum impact acceleration, which is equivalent to the impact absorption effect of mixed soil. As a result, it was found that there is a strong proportional relationship between the elastic deformation component caused by the crushed EPS and the decreasing rate of maximum impact acceleration, as shown in Fig. 10. It is considered that the impact absorption effect created by mixing the crushed EPS is greatly affected by the elastic deformation component caused by the deformation of the crushed

Table 3 Initial deformation modulus

Mix. ratio	Max. Deform.	Min. Deform.	Elastic Deform. Soil	Elastic Deform. EPS
0.0	3.94	1.40	2.54	0.0
0.25	4.70	1.50	1.91	1.30
0.50	5.25	1.22	1.27	2.76
0.75	5.44	0.98	0.64	3.83

(Unit: mm)

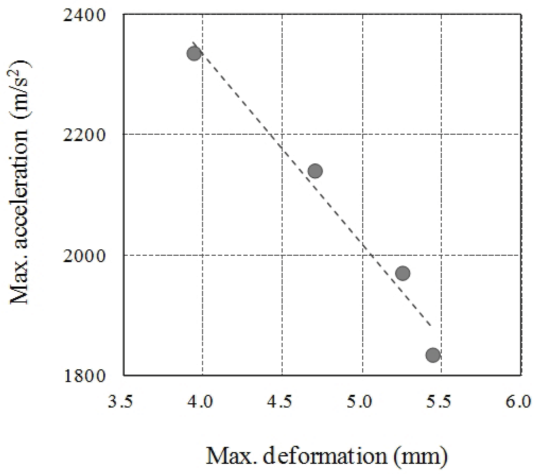

Fig. 8 Relationship between the maximum deformation and the maximum acceleration

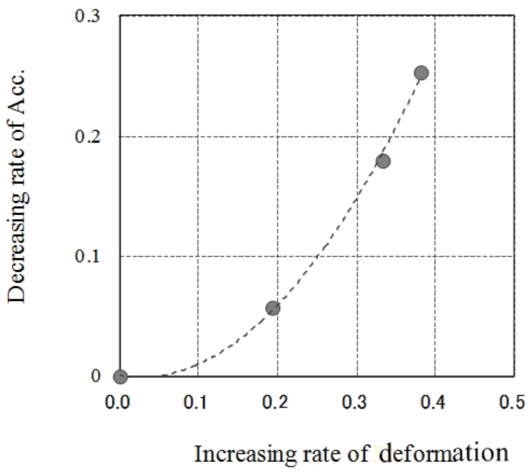

Fig. 9 Relationship of the rate of change based on pure soil

EPS itself. It is an important result of examining the mechanism of impact absorption caused by crushed EPS, though even more consideration is needed.

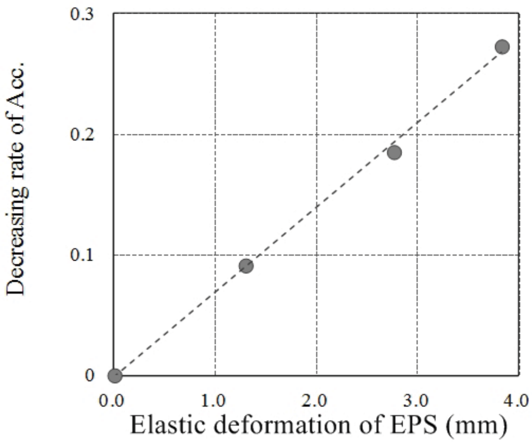

Fig. 10 Relationship of elastic deformation of crushed EPS and decreasing rate of maximum impact acceleration

CONCLUSIONS

In this study, the impact absorption effect of soil mixed with crushed EPS was investigated. The stiffness of soil is low compared to materials such as concrete or metal, and soil has a cushioning effect alone to some extent. In order to add more cushioning effect, the stiffness of soil was made to deteriorate; it also resulted in a deterioration of soil strength. However, it has been found that the crushed EPS intended for this study does not reduce the strength of mixed soil (Kimata et al., 2001), it is expected that the impact absorption effect can be increased while keeping the necessary strength for a geomaterial. Accordingly, considering such points and the utilization of crushed EPS as a recycled material, this study proceeded.

Specifically, impact loading test of crushed EPS mixed soil referred to general compaction test was conducted. The impact absorption effect of the soil was measured and the effect of deformability on the impact absorption was considered. As a result, it was confirmed that the impact absorption effect of soil was enhanced by mixing the crushed EPS, because the maximum acceleration of the impact giving side and the maximum load of the impact receiving side were decreased. It was also found that these effects will depend on; the deformation modulus of mixed soil, the decreasing rate of impact acceleration and load will be able to predict from the decreasing rate of the deformation modulus. In addition, from the viewpoint of the amount of deformation of mixed soil at impact loading, it was found that a decrease in impact acceleration was caused by an increase in the maximum deformation of mixed soil, and moreover, the decreasing rate of impact acceleration was almost proportional to the amount of elastic deformation of the crushed EPS itself. These results were thought to give some useful insights regarding understanding the effect on the impact absorption mechanism in soil, caused by mixing crushed EPS. Further investigation will be needed in the future.

REFERENCES

Kimata, T., Ohno, T. and Kuwabara, T. (2001). Mechanical properties of soils mixed with crushed expanded plastic wastes –Shear strength properties of compacted materials-, Trans. of the Japanese Society of Irrigation, Drainage and Reclamation Engineering, Japan, 213:93-100.

Kimata, T. and Shimada, K. (2007). Investigation on applicability of the soil mixed with expanded plastic wastes for the roof planting foundation material, Proc. of the 9th JGS Symposium on Environmental Geotechnics, 49-52.

Kinki Regional Development Bureau, Ministry of Land, Infrastructure and Transport. (2005). The Theory and Structure of Simplified Bearing Capacity Measuring Instrument, Guidance for using the Simplified Bearing Capacity Measuring Instrument (CASPOL), Japan, 1-2.

The Research Committee on Estimating the Property of Lightweight Geomaterials. (1998). List of Literature Concerning to Lightweight Geomaterials, the Committee Report of The Present Condition about the Property and Applicability of Lightweight Geomaterials, The Japanese Geotechnical Society, Japan, 66-88.

Yamada, S., Nagasaka, Y., Nishida, N. and Shirai, T. (1989). Light soil mixture with small pieces of expanded polystyrol and sand, Tsuchi-to-Kiso, the Japanese Geotechnical Society, Japan, 37 (2):25-30.