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DEVELOPMENT OF A GEOMATERIAL WITH VIBRATION DAMPING CAPABILITY AGAINST EARTHQUAKE MOTION USING INDUSTRIAL WASTES AND CONSTRUCTION BY-PRODUCTS
- Mechanical Properties under Cyclic Loading -

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ABSTRACT :

The authors proposed a composite foundation capable of mitigating the responses of structure against an earthquake motion built on soft grounds. We attempted to develop a new geomaterial that has a mitigating effects and suitable characteristics for use as a plant-base that is one of the constituents of the proposed composite foundation. Major advantages of this new geomaterial are as follows. (a) Vibration damping plant-base blocks can be settled at the surface of the ground around the building. These blocks contribute not only to seismic vibration damping but also to urban greening. Cost-effectiveness of this method is promising because it works daily without regard to earthquakes. (b) The ground improvement considers active reuse of industrial wastes and construction by-products as well as greening, which may reduce the carbon dioxide emission and urban heat island phenomenon. In this paper, the mechanical properties of the new geomaterial evaluated by cyclic triaxial test were mainly discussed. From the test results, wood-chip with recycled fine component was deemed an excellent mixture for the geomaterial with vibration damping capability. In addition, recycled fine component was hardly reused in its present state. Moreover, it was found that the control of curing days and compacted layer numbers (i.e. bulk density) was very important.

KEYWORDS: Industrial Wastes, Construction by-Products, High Damping Performance, A Soft Ground, Geomaterial,

1. INTRODUCTION

The effectiveness of a new design method entitled “seismic isolation” was proven after the 1995 Hyogoken-Nanbu Earthquake in 1995. Buildings with the seismic isolation capability are often built as a long-life building that may contribute to the global environment. However, most of the high and mid-rise buildings in Japanese urban areas have to be built on soft ground that is not always a desirable from the point of view of structural design. Structures with the conventional seismic isolation devices have had to bear the duplicated cost of piling and installation of seismic isolation layer resulting in an inactive dissemination of this method.
The authors discussed mitigating effects of a material that mixed with tire-chips, aggregates, and asphalt from the forced vibration tests supported by two-types of foundation blocks (Ishimaru et al., 2004). From these test results, we start to investigate a composite foundation capable of mitigating the seismic responses of buildings built on soft ground. This paper mainly deals with the mechanical properties of a geomaterial under cyclic loading, capable of applying high performance vibration damping as well as planting base block, which forms a part of the proposed composite foundation and discussed the factor of the effect on the mechanical properties of geomaterials under cyclic loading. Mechanical properties under cyclic loading were evaluated with cyclic triaxial test. An unconfined compressive test was already performed in the paper (Sako et al., 2007). The relevance to a planting base is still being examined and part of the results was presented at the 50th meeting of the Japan Science Council, Engineering Union (Miwa et al., 2006).

2. OUTLINE OF THE COMPOSITE FOUNDATION

As a performance based seismic design, the limit state design method was introduced into the Japanese Building Standard Law in 2001 and the dynamic structure-ground interaction could be reflected in the design. This method is based on the impedance function of foundation and effective input.
Because non-dimensional frequency $\omega L/V_s$ and the imaginary part of the impedance function K increase when the length of foundation mat L increases, the radiation damping h may increase and the seismic responses of the structure generally decrease. When the mass of superstructure is identical, the increase in non-dimensional frequency may be more notable with an increase in softness of the ground.

$$K(\Omega) = k_{\mathrm{Re.}}(\Omega) + ik_{\mathrm{Im.}}(\Omega) \approx k_0 + i\alpha\Omega \approx k_0(1+i2h) \qquad (2.1)$$

where $\Omega = \omega L/V_s$, ω=circular frequency, L= length of foundation mat, k_0=static value of the impedance function and V_s=shear wave velocity.

The authors noticed on this relation and proposed a composite foundation capable of mitigating the responses of structures built on soft grounds. The concept of this idea is illustrated in Figure 1.
The vibration damping plant-base block discussed in this paper can be settled at the surface of the ground around the building. These blocks contribute not only to seismic vibration damping but also to urban greening. Cost-effectiveness of this proposal is promising because it works daily without regards to an earthquake.

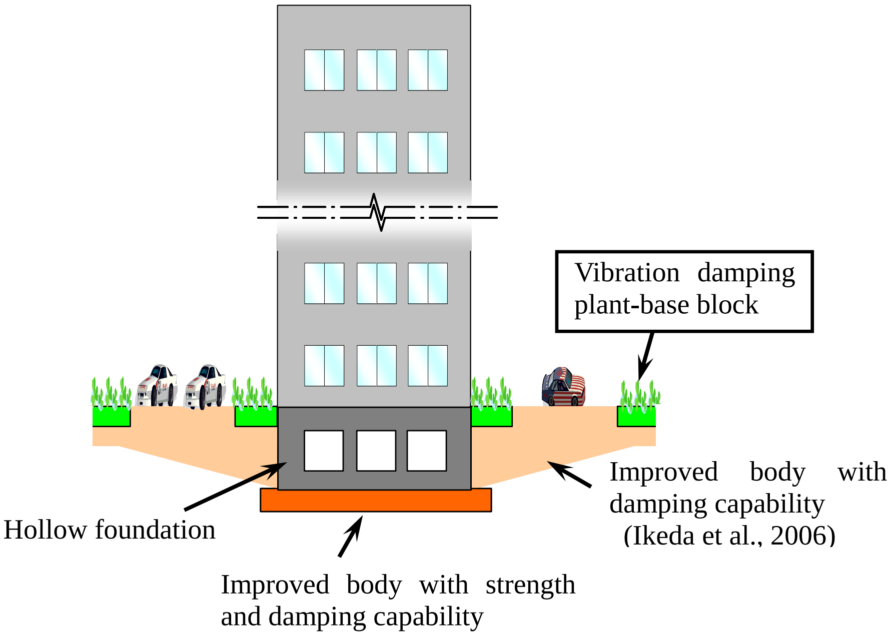

Figure 1 Concept of the proposed composite foundation

3. MATERIAL & TEST CONDITION

3.1. Materials

Expected performance of the new geomaterial includes mitigation of seismic vibration and plant-base capability for a better urban landscape. The geomaterial is therefore needed to have the following properties: a) high damping ratio at a small displacement to assure high performance vibration damping, and b) water retaining capability and designed porosity. In addition to these properties, reuse of industrial wastes and construction by-products was considered for the reduction of carbon dioxide emissions.

Materials used for the experiment are listed in Table 1 and some of them are shown in Photo 1. Abbreviation of materials shown in a parenthesis will be used in the subsequent figures.
The composition of the materials which consist of the vibration damping plant-base block were as follows. The wood-chips were made from scrap conifer timber left unused in construction. The tire-chips were manufactured from shredded scrap tires. The recycled fine component was produced during the manufacture of fine quality recycled aggregates. From the viewpoint of reuse rate, wood-chips are 68% and tire-chips are only 18% as materials and recycled fine component are hardly reused in their present state.
A wood-chip was used as a major constituent of the plant-base vibration damping block while silica sand, tire-chips, recycled fine aggregate and recycled fine component were used as fillers. Binding components were emulsified asphalt and water. The emulsified asphalt solidifies at a normal temperature by dehydration. The gradation curve of wood-chips, tire-chips and recycled fine component are shown in Figure 2. The particle densities also are shown in the same Figure.

Table 1 Materials used in this experiments

Materials	symbol	Specification	Usage
Wood-chip	WC	Crushed conifer of conifer with an aspect ration from 4 to 25 and max. length of 40 mm	Main constituent
Tire-chip	TC	Cut scrap tire with max. length of 10 mm	Filler
Recycled fine component	RF	Crushed concrete with a grain size less than 1 mm	Filler
Recycled fine aggregate	RA	Crushed concrete with a grain size from 5 to 10 mm	Filler
Silica sand	SS	Grain size from 0.07 to 0.6 mm	Filler
Kasaoka clay	KC	Powder with controlled size	Protection for specimen
Emulsified asphalt	EA	Nonion type emulsion, solidification at normal temperatures	Binder
Water	WT	Tap Water	Binder


Emulsified asphalt


Wood-chip


Tire-chip


Recycled fine aggregate


Recycled fine component


Specimen

Photo 1. Materials used for manufacturing the plant-base vibration-damping block.

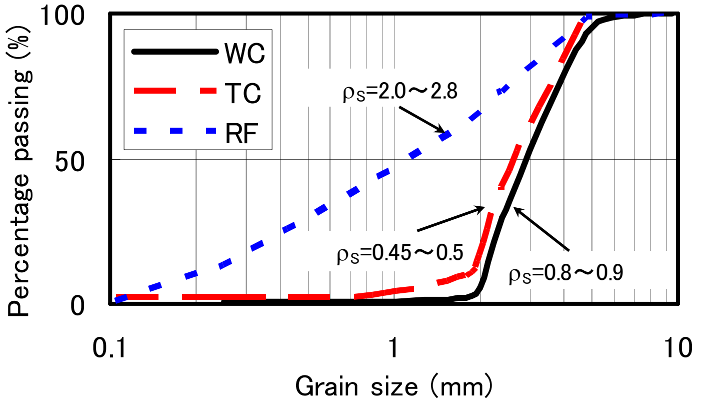

Figure 2 Particle size distribution of WC, TC and RF

3.2. Mixing and curing

Because the amount of specimen per batch of mixing was small, the mixing was performed by hands. Five conditions of specimens were prepared to demonstrate the factor of the effect on the mechanical properties of the geomaterial under cyclic loading. Specimen was formed in a steel mold with a diameter of 5 cm and a height of 10 cm, compacted into three layers and troweled carefully except case 5. In the case 5, the compacted layer numbers (i.e. layer numbers when the specimen was formed by compacting) were varied 2, 3, 5 and 10 because of investigating the effect of bulk density. The specimens were cured in the air under several conditions: 20°C for temperature and 60% in humidity. The conditions of making specimens are shown in Table 2.

Table 2 Conditions of making specimens

Case	Factor of effect	Mix proportion of filler to WC	Proportion of WT to EA	Cured days	Compacted layer numbers
1	Amount of emulsified asphalt	WC/RF=0.67/0.33	EA/WT=0.5/0.5 EA/WT=0.75/0.25	21	3
2	Mix proportion of filler	WC/RF=0.5/0.5 WC/RF=0.67/0.33	EA/WT=0.5/0.5	21	3
3	Variety of filler	WC/TC=0.5/0.5 WC/RF=0.5/0.5 WC/SS=0.5/0.5 WC/RA=0.5/0.5	EA/WT=0.75/0.25	21	3
4	Cured days	WC/RF=0.67/0.33	EA/WT=0.85/0.15	14 28	3
5	Compaction numbers	WC/RF=0.67/0.33	EA/WT=0.85/0.15	28	2, 3 5, 10

3.3. Cyclic triaxial test

The test equipments used hydraulics and air pressure to run. The two different types of test equipments were examined beforehand to allow for consistent performance. The cyclic triaxial test was performed based on the fundamentals derived from the Method and Comments on Soil Test (JGS 2000) of the Japan Geo-technical Society. The load cell was used with the capability of soil test, and displacement was measured with non-contact type for measuring small strain, and with trans-type for measuring large strain. A possible improved depth of a ground was assumed to be 5 meters and the initial confining pressure and the lateral pressure were set to be 150 kPa and 100 kPa of the K_0 consolidation. The cyclic load adopted was 1-2 Hz because the unsaturated ground can be expected when the improvement extends shallower than the ground water level.

4. TEST RESULTS & DISCUSSIONS

4.1. Effect of the amount of emulsified asphalt

Figure 3 (a) and 3 (b) illustrates an example of the stress-strain relationship in case 1. Two Figures were extracted wave 6 from 11 numbers. It was showed that both hyasteresis loop were large enough even at an axial strain $1x10^{-4}$. Figure 3 (b) with more emulsified asphalt content showed larger hysteresis damping ratio rather than Figure 3 (A). The Young's modulus of 3 (b) is similarly larger than 3 (a). It was found to show a large hysteresis damping ratio even in other cases with much asphalt emulsified content when the filler was different.

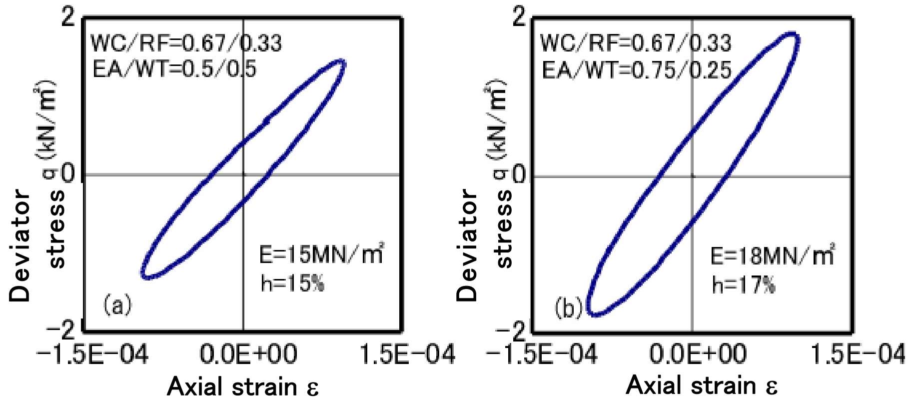

Figure 3 The stress-strain relationship in case 1

4.2. Effect of wood-chip / filler ratio

The influence of strain level on the decrease in Young's modulus, E and increase in hysteresis damping ratio, h are shown in Figure 4 (the relationship is named strain dependency of E & h later) in case 2. The Young's modulus of WC/RF=0.5/0.5 was larger than WC/RF=0.67/0.33, but the hysteresis damping ratio was approximately the same value. The value is 15-26 % at an axial strain $1x10^{-4}$ -$1x10^{-3}$. Incidentally, the decreases in Young's modulus with the strain level were not so different in the range of the mix proportion.

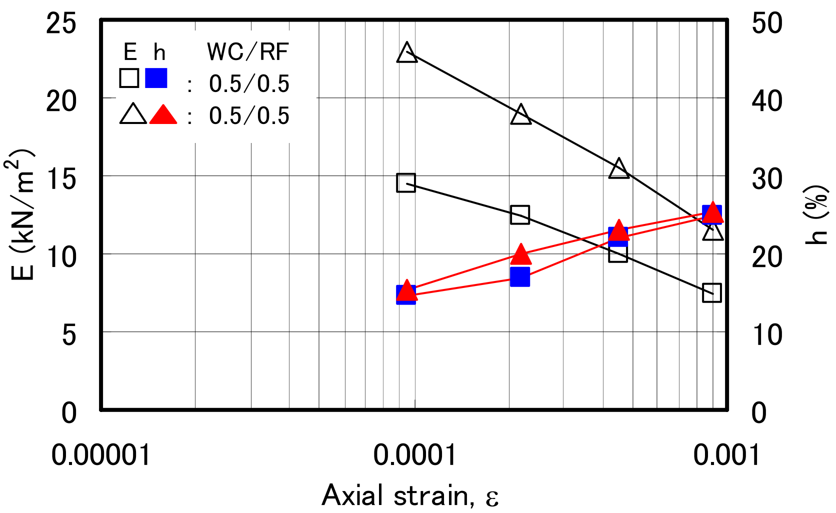

Figure 4 Strain dependency of E & h in case 2

4.3. Effect of filler variety

Figure 5 shows strain dependency of E & h in case 3. Filler material of RF case, the Young's modulus, and the hysteresis damping ratio, showed the greatest results. On the other hands, filler material of TC case showed contrastive results. The Young's modulus and the hysteresis damping ratio were smaller than the other cases, even though the material of tire-chip was considered to have high elasticity. The compatibility between emulsified asphalt and the filler may lead to a different result based on the mechanical properties.

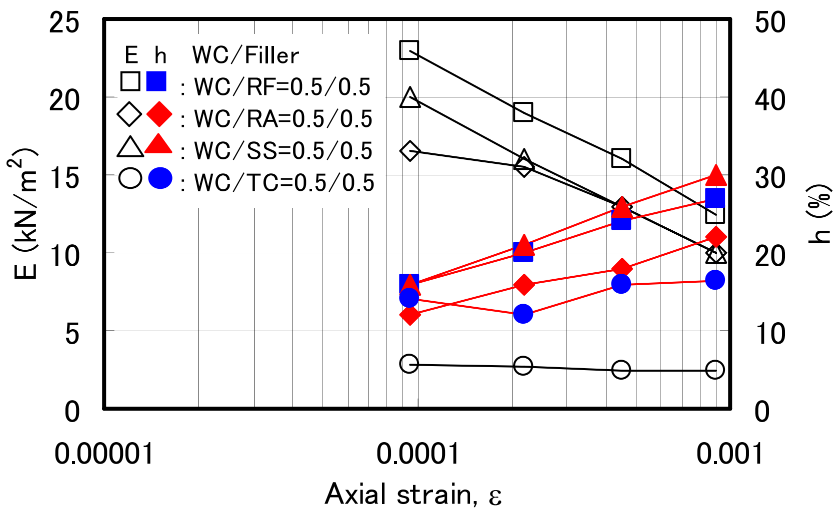

Figure 5 Strain dependency of E & h in case 3

4.4. Effect of curing days

Figure 6 is shows strain dependency of E & h in case 4. The Young's modulus of curing for 28-days indicates a little larger value than that of curing for 14-days, and the hysteresis damping ratio of curing for 28-days was the same value as that of curing for 14-day. However, the Young's modulus and the hysteresis damping ratio of curing for 7-days does not indicate such a large value as curing for 14-day or 28-day (Sako et al., 2007). The reason can probably be attributed to a dosage of emulsified asphalt and the duration of curing for 7-days, which was not long enough to allow for the release of sufficient water.

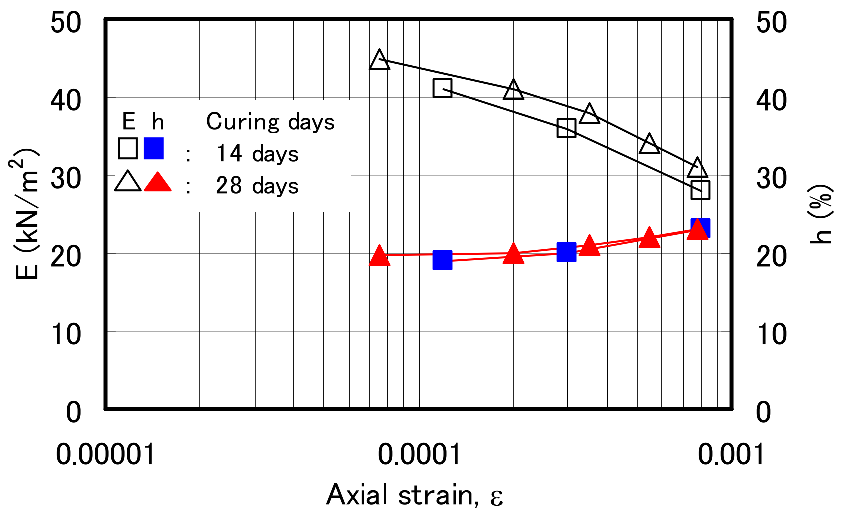

Figure 6 Strain dependency of E & h in case 4

4.5. Effect compacted layer numbers

Figure 7 is shows strain dependency of E & h in case 5. The bulk density of specimens was not noted in the Figure, because the bulk density was not measured correctively. The Young's modulus of 2-layer case was remarkably smaller than that of other cases. The Young's modulus showed a larger value when the number of compacted layers were greater. The hysteresis damping ratio of all cases was approximately the same value, except in the 5-layer case. The reason for this is still being investigated but it maybe because of the number of people present when the specimen was formed by compacting.

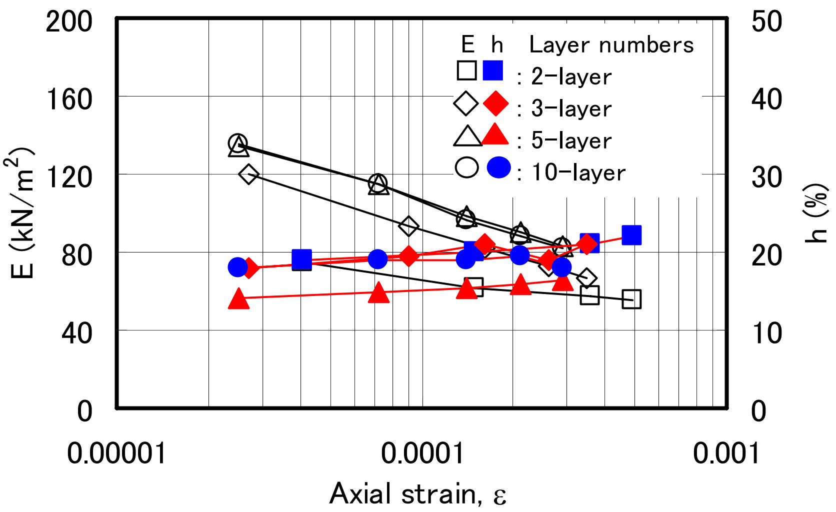

Figure 7 Strain dependency of E & h in case 5

5. CONCLUSION

A new geomaterial, plant-base vibration-damping block, was developed and the mechanical properties under cyclic loading are dealt with in this paper. The major findings are as follows.

(1) When the specimen contains much emulsified asphalt, its value of the hysteresis damping ratio shows great.

(2) The Young's modulus and the hysteresis damping ratio of filler material, RF case, showed the largest value of any other case. In addition, when the mix proportion of RF to WC was large, the Young's modulus was large too and the hysteresis damping ratio showed approximately the same value.

(3) The Young's modulus and the hysteresis damping ratio showed approximately the same value after curing for 14-days, but that of the curing for 7-days does not indicate as large a value as curing for 14-days or 28-days.

(4) The Young's modulus was showed a larger value after the compacted layer number grew. The hysteresis damping ratio of all cases was approximately the same value, independent of compacted layer numbers.

From the results above, wood-chip with recycled fine component was an excellent mixture for the geomaterial with vibration damping capability. In addition, recycled fine component was hardly reused in its present state. Furthermore, it was that the control of curing days and compacted layer numbers (i.e. bulk density) was very important.

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