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Mechanical properties of soilbags and their applications to earth reinforcement

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ABSTRACT: In this paper, we first present the mechanical properties of soilbags and their verifications by unconfmed compression tests on both model and real soilbags. Then, we report the applications of soilbags in earth reinforcement, such as the reinforcement of soft foundations where the N-values are as low as 1~2 and the construction of retaining walls. When reinforcing soft foundation, soilbags have also an effect of reducing traffic-induced vibration in addition to the increase of bearing capacity. Through this study, we believe that the reinforcing method using soilbags will become a promising method for earth reinforcement.

1 INTRODUCTION

For a long time, people have used soilbags to prevent a flow of soils from floodwater and build temporary structures in case of emergency. But, it seems no applications of soilbags in building a permanent structure. As a result of the studies on soilbags by Matsuoka et al. (1999, 2000), many advantages of soilbags, such as improving bearing capacity of soft ground, being friendly to our environment, reducing traffic-induced vibration and so on, have been elucidated and soilbags have been applied to various aspects of earth reinforcement. In this paper, we first present the mechanical properties of soilbags and their verifications by unconfined compression tests on both model and real soilbags. Then, we report several application cases in earth reinforcement.

2 STRENGTH PROPERTY OF SOILBAGS AND ITS EXPERIMENTAL VERIFICATIONS

Let us consider the stresses acting on a 2D soilbag. Figure 1(a) shows a 2D soilbag subjected to the principal stresses, σ_1, and σ_3. Under the application of σ_1, and σ_3, the total perimeter of the bag usually extends and a tension T takes place in the bag. This tension produces an additional stress that acts on the soil particles inside the soilbag, whose components are expressed as

$$\left.\begin{aligned}\sigma_{01} &= 2T/B \\ \sigma_{03} &= 2T/H\end{aligned}\right\} \qquad (1)$$

where B and H are the width and height of the soilbag, respectively. Thus, the stresses acting on the soil particles inside the soilbag are the combined result of the externally applied stresses and the additionally produced stresses by T, as shown in Figure 1(b). At failure, the following equation holds (Matsuoka et al., 2000a):

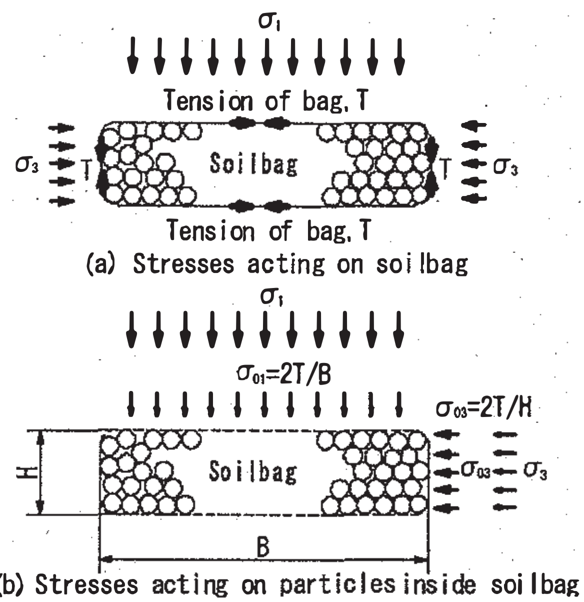


Figure 1. Stresses acting on two-dimensional model soilbag and on particles inside the soilbag.

$$\sigma_1 + \frac{2T}{B} = K_p\left(\sigma_3 + \frac{2T}{H}\right), where\ K_p = \frac{1+\sin\phi}{1-\sin\phi} \qquad (2)$$

By comparing Eq.(2) with the strength expression of $\sigma_{1f} = \sigma_{3f} K_p + 2c\sqrt{K_p}$ for a cohesive-frictional material, we can obtain the expression of the apparent cohesion c of soilbags due to their tension T.

$$c = \frac{T}{B\sqrt{K_p}}\left(\frac{B}{H}K_p - 1\right) \quad (3)$$

This suggests an interesting fact that an apparent cohesion produces in the soilbag due to the tension of bag although the original materials inside the soilbag are frictional materials such as sands and crushed stones.

In order to verify the above strength property of soilbags, a number of biaxial compression tests were performed on 2D paper-wrapped model soilbags. The model soilbag has dimensions of 15cm wide by 3.75cm high. The materials inside it are two kinds of aluminum rods with diameters of 1.6mm and 3mm and a length of S0mm that are mixed in a ratio of 3:2 by weight. The angle of internal friction, ϕ , of this aluminum rod mass is about 25°. Owing to the limitation of the loading capacity in our biaxial compression test apparatus, a very weak paper with a tensile strength of about 0.36kN/m is used in the model soilbag. To minimize the boundary influence of the apparatus, three model soilbags are piled up to construct a specimen, as shown in Figure 2. The results of these tests are expressed with the solid Mohr's stress circles at failure in Figure 3. It can be seen from these solid Mohr's stress circles that the soilbags have an apparent cohesion. From Eq. (3), it is calculated that the apparent cohesion, c, of the model soilbags is 14kPa. The solid straight line in Figure 3 is drawn by using c=14kPa and ϕ =25° . It is approximately tangent to the solid Mohr's stress circles, indicating that Equations (2) and (3) can represent reasonably the strength characteristic of soilbags. Furthermore, the broken Mohr's stress diagrams in Figure 3 represent the stresses of the material inside the soilbags at failure after combining the additional stresses that are produced by the tension, T_f = 0.36kN/m, of the paper-made bag. The envelop of these broken Mohr's stress circles is a straight line passing through the origin with an inclined angle of 25°, which is equal to the angle of internal friction of the material inside the soilbags. This indicates that the materials inside the soilbags are kept to be the frictional material although it is wrapped up.

Figure 4 shows the unconfined compression test on real soilbags with initial dimensions of 40cmx 40cm x 10cm and Table 1 summarizes the results of this test on soilbags comprising of various different bags and materials inside the bags. The load, F, of soilbag at failure in Table 1 can be predicted from Eq. (2) by taking into consideration σ_3=0 at the unconfined compression test.

$$F = \sigma_1 B L = B L\left(K_p\frac{2T}{H} - \frac{2T}{B}\right) = 2\left(\frac{B}{H}K_p - 1\right)TL \quad (4)$$

where L is the length of soilbag. For example, in the case that the bag is made of PE and the materials inside the bag is crushed stones, B=L=0.4m, H=0.1m, T = 12kN/m and K_p = 5.55 (ϕ =44°), thus F=204kN. This predicted value agrees nearly with the measured value, 230~290kN. Some discrepancy is originated from the three-dimensional effect of real soilbags and the difference in soilbag dimensions at

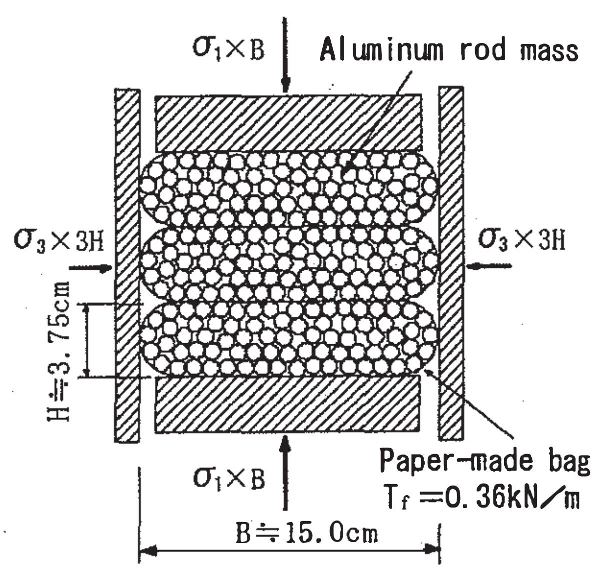


Figure 2. Schematic illustration of biaxial compression test on 2D model soilbags.

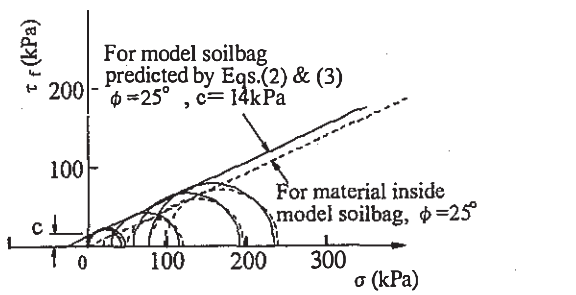


Figure 3. Results of biaxial compression tests on 2D model soilbags.

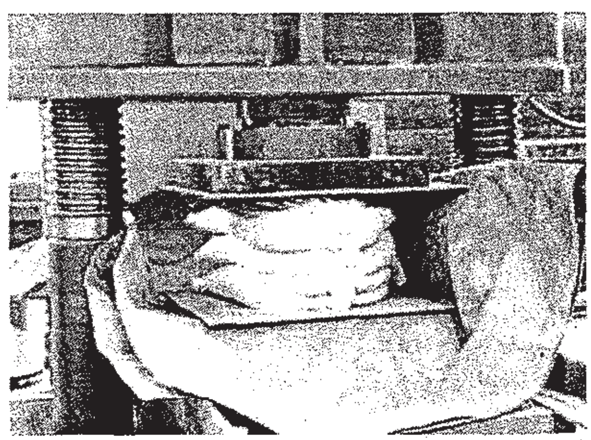


Figure 4. Unconfined compression test on real soilbags to confirm their extremely high strength to resist external forces.

Table 1. Summary of the results of unconfined compression tests on various soilbags.

Bag material	PE	PP	PP	PP	PP	PP	PE (UVR)
Materials inside soilbag	Crushed stones	Crushed stones	shirash	Dry coal ash	Wet coal ash	Volcanic ash	Volcanic ash
Load at failure (kN)	230~290	550~650	680	266	510	850	584

Note: PE - White bag made of polyethylene with tension strength of about 12kN/m; PP - Green bag made of polypropylene with tension strength of about 20kN/m; PE (UVR) - White bag made of polyethylene having a property of resisting ultraviolet ray. One soilbag has an initial size of 40cm x 40cm x 10cm.

failure from its initial ones. It is found from this prediction that the failure load of this soilbag is about 42 times larger than the tensile strength of the PE bag itself that is equal to 4.8kN (=12kN/m x 0.4m). Therefore, it is understood that the soilbag has an extremely higher strength than that originating from the tension of the bag.

3 APPLICATIONS OF SOILBAGS TO EARTH REINFORCEMENT

3.1 *Reinforcement of soft foundation*

Up to now, we have applied soilbags to reinforce more than 30 soft grounds with the N-values as low as 1~2, where one- or two-floor buildings are constructed. Figures 5 and 6 show a typical arrangement of soilbags under the building foundation and a typical real construction field, respectively. To minimize the external forces on soft grounds, the lower two layers of soilbags are connected by both sewing the bottoms and tying the openings of two bags. Under the whole raft foundation, two layers of soilbags are placed but not connected. One soilbag is about 40cm long by 40cm wide by 10cm high. The materials inside the soilbag may be crushed stones, excavated soils, asphalt wastes and so on. The bag is usually made of polyethylene that can sustain for a long time if it is protected from sunlight. The gaps between soilbags must be filled with small soilbags or soils. And, every layer of soilbags must be compacted using a vibrator to ensure the tension of bags effect quickly when the soilbags are subjected to external forces from the buildings.

To illustrate the effectiveness of this reinforcing method, we estimate the bearing capacity of ground by considering that the sliding failure would not take place within the assembly of soilbags but would take place within the soft ground below the soilbags. This assumption is based on the fact that soilbags have very high strengths as shown in Table 1 and are not easy to slide between them. The load of the upper building is assumed to act on the 40cm wide footing that is then transmitted to the soft ground through the assembly of soilbags with an spreading angle of about 45°. For a soft ground of c_u=18.6kPa, ϕ_u = 0 and γ =16kN/m^3, the bearing capacity is 38.9kN/m before the reinforcement, while it is increased to be

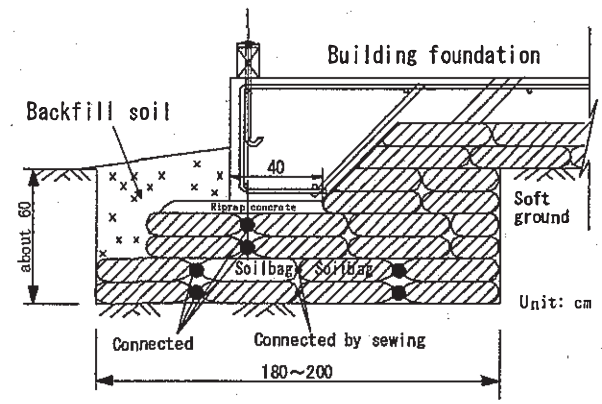


Figure 5. Typical arrangement of soilbags to reinforce soft foundation with N-values as low as 1~2.

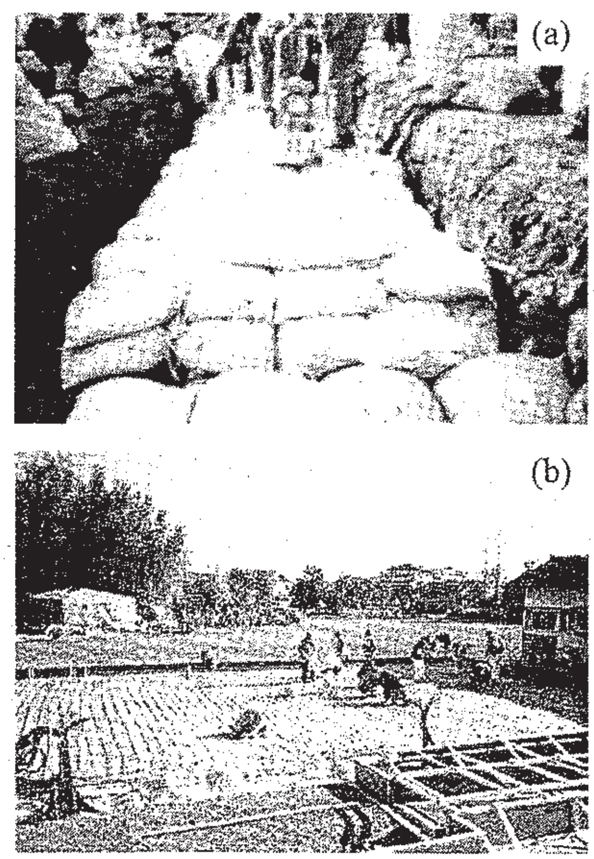


Figure 6. Typical construction field of using soilbags to reinforce soft foundation with N-values as low as 1~2: (a) soilbags under footing; (b) soilbags under raft foundation.

305kN/m after the reinforcement by soilbags. The effectiveness of this reinforcing method is thus illustrated.

In the application of this method, we have encountered an extremely weak foundation where the ground was waterlogged and a work man settled into it as deep as 30cm, as shown in Figure 7. In this case, the arrangement of soilbags as shown in Figure 8 was implemented, i.e. 3 layers of 4-connected soilbags were first placed into the ground below water level, then 5 layers of such soilbags were further placed above the ground water. The materials inside the soilbag were crushed stones. Consequently, the reinforced ground can even withstand a heavy construction machine like backhoe. Clearly, if the crushed stones were directly put in the waterlogged ground, then they would sink into the ground.

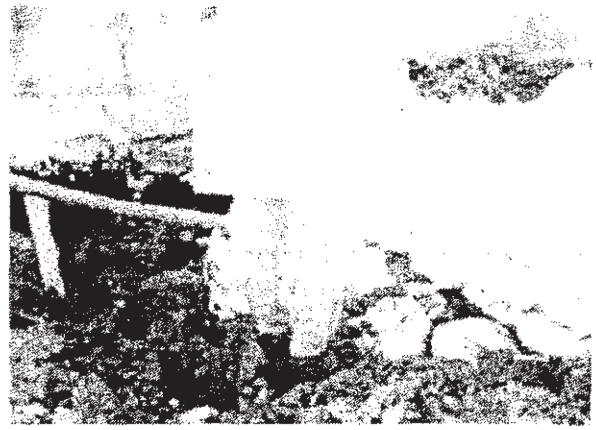


Figure 7. Waterloggedi weak ground where soilbags are to be used.

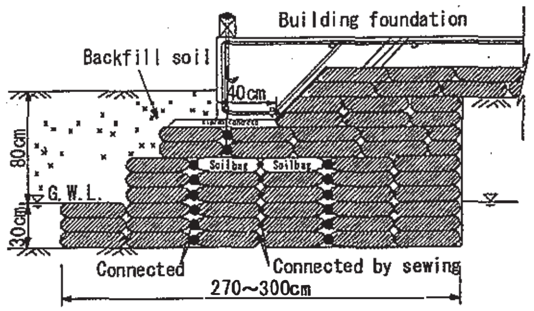
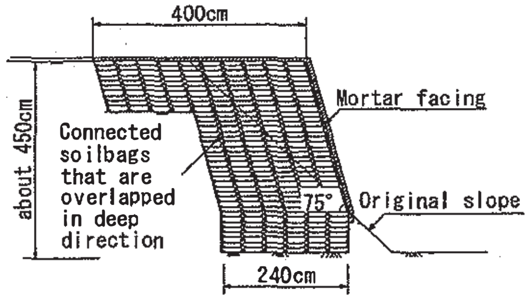


Figure 8. Arrangement of soilbags for waterlogged weak foundation of Figure 7.

3.2 *Construction of retaining walls*

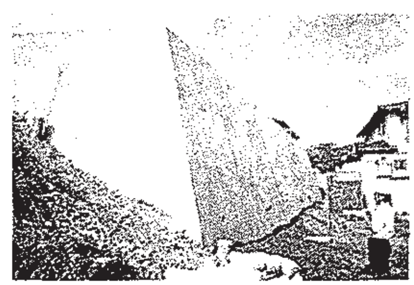
Two retaining walls have been constructed using soilbags: one was constructed such on a very weak foundation that it is impossible to build a reinforced concrete retaining wall. It is about 2m high, 50m long and inclined to horizontal with an angle of 80°; the other was constructed on a loam foundation with a height of about 4.5m, a total length of about 21m and an inclined angle of 75°. Herein, we present the latter one in detail. Figure 9 (a) shows the arrangement of soilbags of it. In this case, 6 soilbags are connected behind the wall in the lower part and 10



(a) Arrangement of connected soilbags

(b) Completion of piling up soilbag viewing in vertical direction

(c) Piling up soilbags from upper view



(d) Completion of castellated retaining wall

Figure 9. Construction of a retaining wall with 30,000 soilbags.

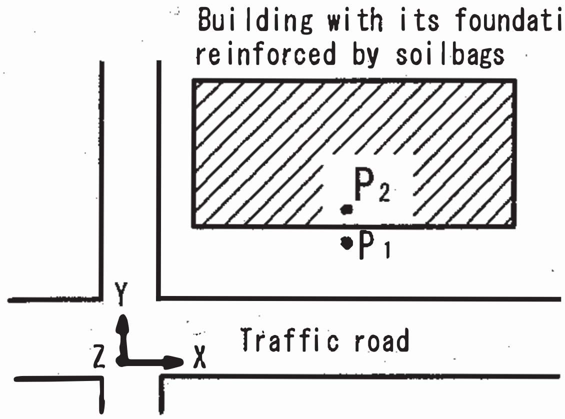


Figure 10. Locations of vibration measuring points.

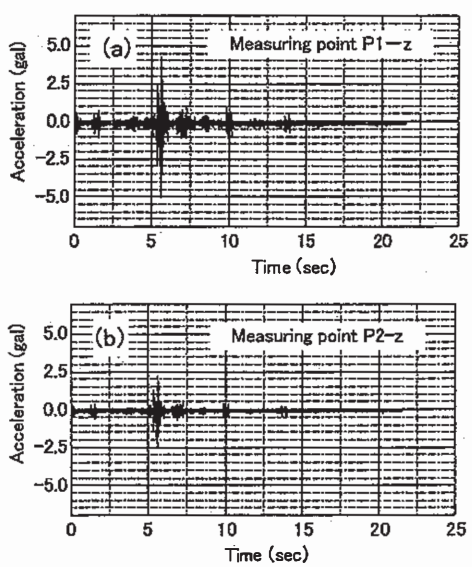


Figure 11. Measured accelerations in Z-direction: (a) no reinforcement, (b) with reinforcement.

soilbags are connected in the upper part. One soilbag has dime nsions of 40cm in length by 40cm in width by 10cm in height. The materials inside the bag are construction wastes with tiles that are in free charge. The bag is made of polyethylene. The soilbags are piled up and compacted with a vibrator layer by layer with an overlapped arrangement in vertical direction, as seen in Figure 9 (b). Figure 9(c) shows the top surface of this retaining wall before lining with asphalt. It is seen from Figure 9(c) that there are some construction wastes spread over the surface of soilbags, which serve as filling the gaps among soilbags and preventing the bags to be broken during compaction. As seen in Figure 9(c), a row of soilbags on the top surface is removed to make a trench to drain ground surface water. Since the polyethylene-made bag is sensitive to sunlight, a thin layer of steel-reinforced mortar is cast on the outside surface of the wall, as shown in Figure 9(d). In this project, about 30,000 soilbags were used.

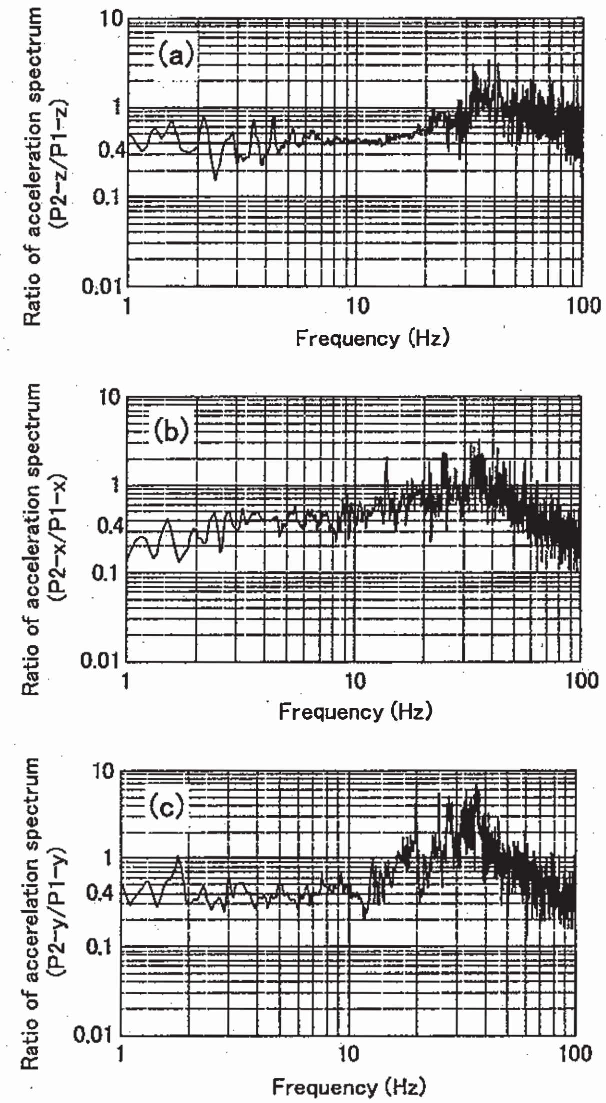


Figure 12. Relationship between ratio of acceleration spectrum and frequency in x, y and z directions measured at point P2.

4 EFFECT OF REDUCING TRAFFIC-INDUCED VIBRATION

In addition to the improvement of bearing capacity, the reinforcement by soilbags has an effect of reducing traffic-induced vibration as well. Herein, we present an example of measurement of the traffic-induced vibration in a field where the soft ground has been reinforced by soilbags (Matsuoka et al. 2000b). Figure 10 illustrates the locations of two measuring points. The measuring point P_2 is located on the 1st floor of a building where the foundation is reinforced with soilbags, while the measuring point P_1 is located on the ground outside the building that is not reinforced with soilbags. The directions along and perpendicular to the traffic road are denoted as x- and y-directions, respectively. The vertical direction is denoted as z-direction. Figure 11 presents the measured results plotted as acceleration in z direction versus time. The similar results are obtained in both x- and y-directions. It is clearly seen from Figure 11 that the accelerations induced by traffic vibration decrease greatly when the foundation is reinforced by soilbags. Furthermore, Figure 12 gives the relationship between the ratio of acceleration spectrum at point P_2 to that at point P_1 and vibration frequency in z-, x- and y-directions. It is seen from Figure 12 that, within the vibration frequency ranging from 1 to 10Hz, the acceleration spectrum at point P_2 is decreased by half less than that at point P_1 (the ratio of them is about 0.4) in any of three directions. It is said that the vibration with a frequency ranging from 5 to 8Hz is the most sensitive to human's feeling and the resonance frequency of a wood-made living house is less than 10Hz. These facts suggest that soilbags are very suitable to the reinforcement for foundations of our houses.

5 CONCLUDING REMARKS

The main results of this paper may be summarized as follows:

1) Due to the tensile force of the soilbag, an apparent cohesion, c, produces in the soilbag although the original materials inside the soilbag are frictional materials such as sands, crushed stones and so on. This can explain such a surprising test result that a single soilbag of 40cm x 40cm x 10cm, consisting of crushed stones and polyethylene bag, can sustain a vertical load of 230 ~ 290kN.
2) The soilbags can be used to effectively reinforce soft foundation and build retaining walls. This earth reinforcing method is cost saving, friendly to our environment.
3) When reinforcing soft foundation by using soilbags, there is also an effect of reducing traffic-induced vibration in addition to the increase of bearing capacity.

Through this study, we believe deeply that the reinforcing method using soilbags will become a very promising method for the earth reinforcement.

6 ACKNOWLEDGEMENTS

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