Roller compaction behavior of short fiber reinforced gravelly soil

Daiki Hirakawa and Yoshihisa Miyata

i) Lecturer, Dept. of Civil Engineering, National Defense Academy, 1-10-20 Hashirimizu, Yokosuka 239-8686, Japan. ii) Professor, Dept. of Civil Engineering, National Defense Academy, 1-10-20 Hashirimizu, Yokosuka 239-8686, Japan.

ABSTRACT

In pavement structure, short fiber reinforcing technique is hoped as an effective method for improving the stability of the subbase or subgrade layers against traffic loads. In this paper, compaction behavior of short fiber reinforced is discussed by the results of laboratory compaction tests. As the results of roller compaction tests, it was confirmed that the value of ρd stably increases with an increase in the number of roller passing even if initial ρd value at spreading was lower. At 8 passing of roller compaction, the realized ρd value around the w_opt become higher than the maximum dry density (ρd)max obtained from the Proctor test. This results shows that the current compaction control method for the subbase of pavement structure can also be applied to short fiber reinforced soil.

Keywords: reinforced soil, short fiber, gravelly soil, roller compaction

1 INTRODUCTION

In Japan, the roadway network was rapidly developed in the past 50 years. Total extension of roadways at present is more than 1.2 million kilometers. Approximately 96% of the paved roadways in Japan use asphalt pavement system. Benefits of asphalt pavement are its workability and it allows for the application of various technologies against vehicle noise, water and heat for safety as well as environmental issues. On the other hand, flexible pavement has structural problems that low durability against traffic loads and environmental interaction. Therefore, developing of roadway network using asphalt pavement leads to increase in its maintenance and repair costs. Innovations leading to lower maintenance and repair costs for pavement structures are required in recent years.

Distortions such as rutting and cracking are caused by the instability of the asphalt mixtures or a deficiency in the bearing capacity of the subbase and subgrade layers against the heavy traffic load (Brown, 1996, 1997). In Western countries, soil reinforcing technologies using geosynthetics such as geogrid was often applied to pavement structure to improve the stability (Perkins et al. 2010). However, geogrid reinforcing technique may be difficult to apply to the subbase or subsoil of general roadway in Japan. Because the many lifeline facilities are installed under/near the road, and their maintenance works are required periodically. For general roadway in Japan, therefore, it is only possible to apply a soil reinforcing technology that is equivalent to excavating and backfilling. The short fiber soil reinforcing technique without the use of cement solidification is hoped as an effective method for improving the stability of these roadways.

Various studies have examined the contribution of short fiber reinforcement to the shear strength of granular materials (Miki et al., 1994, Ibraim et al., 2006, Diambra et al., 2008, Zornberg et al., 2010). For applying the short fiber reinforcing technique to soil structures including pavement, investigations of the following features are required; 1) the fiber mixing characteristics, 2) compaction properties of the fiber mixed granular materials and 3) reinforcing effect on mechanical properties. In this paper, compaction behavior of short fiber reinforced gravelly soil is discussed concerned with the above 2) based on the results of laboratory roller compaction tests simulated to actual construction work using smooth roller.

2 TESTED MATERIALS AND FUNDAMENTAL MECHANICAL PROPERTIES OF SHORT FIBER REINFORCED SOIL

2.1 Tested materials

Well-graded crushed andesite was used in this study. This gravelly soil is typical subbase material for asphalt pavements in Japan. The maximum particle size of the gravelly soil was 30mm in the original grading. In order to perform various laboratory soil tests especially the Proctor test and triaxial test, the grading of the gravelly soil was readjusted to a maximum particle size of 19.0...
Very good

Table 1. Index and mechanical parameters of the tested vinylon fiber.

| Parameters                  | Values          |
|-----------------------------|-----------------|
| Unit weight                 | 1.3 [g/cm³]     |
| Average diameter, d         | 0.4 [mm]        |
| Average length, l           | 20 [mm]         |
| Aspect ratio, l/d           | 50 [-]          |
| Breaking tensile strength   | 900 [MPa]       |
| Modulus of elasticity       | 23 [GPa]        |
| Acid and alkali resistance  | Very good       |

The present study. Other index and mechanical parameters of the tested vinylon fiber is summarized in Table 1. It is known that vinylon has high tenacity, high modulus, low elongation, high weather resistance, and high chemical resistance.

2.2 Fiber content

The average fiber content, \( w_f \), was evaluated by the dry weight percentage of the gravelly soil. The method of determining the \( w_f \) based on the weight ratio has an advantage in construction work, because the required amount of fiber can easily be measured at a construction site. The typical fiber distribution at \( w_f =0.5\% \) in the tested materials is shown in Figure 2. From Figure 2, it was confirmed that the fibers were distributed homogeneously in the aggregate. The characteristic of fiber mixing is very well in this fiber content.

The comparison of compaction curves obtained by the standard Proctor test is shown in Figure 3. In the conditions of \( w_f=0.5\% \), the maximum dry density \((\rho_d)_{max}\) of the fiber reinforced soil is almost same as the gravelly soil.

2.3 Mechanical properties of short fiber reinforced soil

Typical strength-deformation properties of short fiber reinforced soil are shown in Figure 4. Figure 4 was the results of conventional drained triaxial compression (TC) tests under the stress conditions at \( K (=\sigma_3/\sigma_1)=0.5 \), where \( \sigma_3=40\) kPa. The specimen size of the TC test is 100 mm in diameter and 200 mm in height. The diameter of the TC sample is same as the Proctor test. Figure 4a plotted axial strain \( \varepsilon_a \) against deviator stress \( q (=\sigma_1-\sigma_3) \) as well as volumetric strain \( \varepsilon_{vol} \) of the unreinforced gravelly soil and the fiber reinforced soil in the conditions of \( \rho_a=about 2.135 g/cm^3 \). This \( \rho_a \) value is agree with \((\rho_a)_{max}\) evaluated by the standard Proctor tests. Figure 4b summarized the maximum deviator stress \( q_{max} \) versus \( \rho_a \). From Figure 4,
it was found that the peak strength of the gravelly soil can be stably increased by mixing fiber even if the value of \( w_{\text{f}} \) is only 0.5%. The \( q_{\text{max}} \) depend on the value of \( \rho_{\text{b}} \), while the reinforcing effects is almost same in the range of \( \rho_{\text{b}}=\text{about 1.943-2.135 g/cm}^3 \). Therefore, the bearing capacity of the fiber reinforced subbase or subgrade layers of pavement structure would be also strongly affected by the realized value of \( \rho_{\text{b}} \).

3 ROLLER COMPACTION BEHAVIORS OF SHORT FIBER REINFORCED SOIL

Generally, smooth wheel roller is used at the construction of pavement structure. In the present study, therefore, a series of laboratory roller compaction tests were performed to simulate the construction of the subbase layer of asphalt pavement. An outline of the roller compaction test is shown in Figure 5. This apparatus consisted of a reaction frame, sandbox and rigid roller with smooth surface. The size of the sandbox was 120 cm-long, 30.5 cm-wide and 40 cm-high. After preparing approximately 35 cm-thick model subbase layer by spreading of gravelly and fiber mixture soils respectively, a constant wheel load of 29.4 kN/m was applied to the surface of each subbase model. Wheel load, \( F_{\text{w}} \), applied to the range of about 58 cm in the central area of the model subbase. The value of \( F_{\text{w}} \) was determined from the weight of middle subbase layer (8 applications of passing) by considering of actual construction work. Moreover, movements of the subbase aggregates near the sidewall of the sandbox were recorded using a digital video camera, and those vertical/horizontal movements estimated by the particle image analysis method.

Test conditions of each case such as water content, \( w \), and initial \( \rho_{\text{b}} \) in spreading as well as the value of \( \rho_{\text{b}} \) after roller compaction are summarized in Table 2. The conditions in water content of model subbase were set to the optimum water content at the standard Proctor test and the dry/wet sides of it, respectively. The value of degree of compaction, \( D_{\text{c}} \), shown in Table 2 were calculated by \( (\rho_{\text{b}})_{\text{max}} \) obtained from the standard Proctor test.

![Figure 4. Fundamental mechanical behaviors of the tested combined materials; a) strength and deformation properties, b) \( q_{\text{max}}-\rho_{\text{b}} \) relations.](image)

![Figure 5. Outline of roller compaction test.](image)

| Gravelly soil | Fiber reinforced soil |
|--------------|----------------------|
| \( w=6.5\% (<w_{\text{opt}}) \) | \( w=7.3\% (<w_{\text{opt}}) \) |
| \( \rho_{\text{b}}=1.811 \rightarrow 2.072 \text{ g/cm}^3 \) | \( \rho_{\text{b}}=1.786 \rightarrow 2.040 \text{ g/cm}^3 \) |
| \( (D_{\text{c}}=84.8\%) \quad (D_{\text{c}}=97.1\%) \) | \( (D_{\text{c}}=83.7\%) \quad (D_{\text{c}}=95.6\%) \) |
| \( w=8.6\% (\approx w_{\text{opt}}) \) | \( w=8.2\% (\approx w_{\text{opt}}) \) |
| \( \rho_{\text{b}}=1.961 \rightarrow 2.185 \text{ g/cm}^3 \) | \( \rho_{\text{b}}=1.796 \rightarrow 2.143 \text{ g/cm}^3 \) |
| \( (D_{\text{c}}=91.9\%) \quad (D_{\text{c}}=102.3\%) \) | \( (D_{\text{c}}=84.1\%) \quad (D_{\text{c}}=100.4\%) \) |
| \( w=9.5\% (>w_{\text{opt}}) \) | \( w=10.0\% (>w_{\text{opt}}) \) |
| \( \rho_{\text{b}}=1.933 \rightarrow 2.143 \text{ g/cm}^3 \) | \( \rho_{\text{b}}=1.801 \rightarrow 2.037 \text{ g/cm}^3 \) |
| \( (D_{\text{c}}=90.5\%) \quad (D_{\text{c}}=100.4\%) \) | \( (D_{\text{c}}=84.4\%) \quad (D_{\text{c}}=95.4\%) \) |
Roller compaction behaviors of unreinforced and fiber reinforced gravelly soils are shown in Figure 6. In the results of roller compaction tests shown in Figure 6, the compaction curves with 0 (in spreading), 1, 4 and 8 roller passes are also indicated to compare the results of the Proctor test. Figure 7 is summarized the $\rho_d$ versus number of roller passing relations. The following important trends could be seen in the compaction behaviors of the fiber reinforced gravelly soil with the 0.5% mixture, as shown in Figures 6 and 7:

1) In the beginning of roller compaction, the initial value of $\rho_d$ of gravelly soil becomes lower by mixing of short fiber.
2) Despite above, the value of $\rho_d$ stably increases with an increase in the number of roller passing. This trend was independent of the value of $w$ in the fiber reinforced soil.
3) The roller compacted $\rho_d$ of the fiber reinforced soil exhibited the highest value around the $w_{opt}$ obtained from the Proctor test. At 8 passing of roller
compaction, the realized $\rho_d$ value using smooth roller around the $w_{\text{opt}}$ become higher than the maximum dry density ($\rho_d_{\text{max}}$) obtained from the Proctor test. This result shows that controlling of the water content of fiber reinforced soil at the construction site leads to effective soil compaction.

With respect to the above 1), decrease of the $\rho_d$ value before soil compaction has a possibility to lead a reduction in the running of compaction equipment due to significant sinkage of the roller. It was considered, therefore, understanding of the initial $\rho_d$ value of fiber mixture soil is important to keeping of workability. In this experimental study, significant roller sinkage is not observed in any case of the fiber reinforced soil. Figure 8 is a comparison of the sinkage behavior of the roller during first passing of test case of $w_{\text{opt}}$. There is not large difference in the roller sinkage between the gravelly soil and fiber reinforced soil.

In this study, deformation characteristics of the model subbase layer during roller compaction are investigated. Figure 9 shows typical movements of the subbase aggregate during roller compaction.

Figure 11. The results of CPT; a) typical distribution of the end resistance of CPT at before/after roller compaction, b) the end resistance of CPT – dry density relations.
and number of roller passing. From Figure 10, it can be seen that deformation characteristics of the gravelly soil and fiber reinforced soil during roller compaction are similar. The \((\varepsilon_{0})_{\text{ve-res}}\) number of roller passing curves exhibited a hyperbolic shape. This trend is in common at the unreinforced and fiber reinforced gravelly soils. The results obtained in this study as shown in Figures 5 to 9 indicates that compaction mechanism using rigid roller does not change even when short fiber mixed in the soil.

Figure 11 shows the results of the cone penetration test (CPT) to investigate the changing of mechanical behavior of the model subbase at before/after roller compaction. Typical distribution of the end resistance, \(q_c\), at before and after roller compaction are shown in figure 11a. The gradient of the distribution of the end resistance, \(\delta q/\delta \varepsilon\), were calculated and plotted it against the \(\rho_0\) as shown in Figure 11b. CPT has the advantage of being able to easily investigate the mechanical stability of the soil layer in the depth direction. The \(q_c\) increased linearly with respect to the depth direction in all cases of the present study. It was considered that, therefore, the current compaction control method for soil can be applied to short fiber reinforced soil without any modification.

4 SUMMARY

The roller compaction behaviors of the fiber reinforced subbase were investigated by performing of the laboratory roller compaction tests simulated to construction of pavement structure. The fibers were selected to the discrete and flexible linear vinylon fibers that have a length of 20 mm. The following important conclusions were obtained in this study;

1) The initial value of dry density \(\rho_0\) at spreading of fiber reinforced soil become lower compared to those for unreinforced gravelly soil. However, the value of \(\rho_0\) stably increases with an increase in the number of roller passing. At 8 passing of the roller compaction with smooth roller, the \(\rho_0\) value at the optimum water content condition become higher than the maximum dry density \((\rho_d)_{\text{max}}\) obtained from the Proctor test. Therefore, controlling of the water content of fiber reinforced soil at the construction site is important to realize effective soil compaction.

2) The movements of the aggregates in the fiber reinforced subbase during roller compaction as well as the characteristics of residual vertical strain of the fiber reinforced subbase caused by roller compaction are similar to those of unreinforced gravelly soil.

3) It found that the end resistance of cone penetrometer, \(q_c\), increases linearly with respect to the depth direction in the fiber reinforced subbase at before and after roller compaction.

From the results described above, it was confirmed that mixing of short fiber to the subbase materials don’t have adverse effects to the construction phase of soil structure. The current compaction control method for the subbase of pavement structure can also be applied to short fiber reinforced soil.

ACKNOWLEDGEMENTS

This study was supported by Grants-in-Aid for Scientific Research (C). The authors gratefully acknowledge the cooperation provided by Dr. A. Ogawa, Kuraray, LTD., Japan.

REFERENCES

1) Brown, S.F. (1996): Soil mechanics in pavement engineering, 36th Rankine Lecture, Geotechnique, 46(3), 383-426.
2) Brown, S.F. (1997): Achievements and challenges in asphalt pavement engineering, Proceedings of 8th International Conference on Asphalt Pavements, 1-23.
3) Diambra, A., Ibraim, E., Wood, D. M. and Russel, A. (2008): Fiber reinforced sands: Experiments and modelling, Geotextiles and Geomembranes, 28(3), 238-250.
4) Ibraim, E. and Fournont, S. (2006): Behaviour of sand reinforced with fibers, Soil Stress-Strain Behavior: Measurement, Modeling and Analysis, Springer, 807-818.
5) Miki, H., Hayashi,Y., Mori,K. and Katsu, N. (1994): Development of fiber-reinforced soils and its application to practical use, Tsut -to-Kiso, 42(11), 11-16 (in Japanese).
6) Perkins, S.W., Christopher, B.R., Thom, N., Montestruque, G., Korkiala-Tanttu, L. and Want, A. (2010): Geosynthetics in Pavement Reinforcement Applications, Proceedings of 9th International Conference on Geosynthetics, 165-192.
7) Zornberg, J. G. and Gupta, R. (2010): Geosynthetics in pavements: North American contributions, Proceedings of 9th International Conference on Geosynthetics, 379-398.