

Development of a Method for Laying Geosynthetics in the Base Course with Consideration for the Long Service Life of Asphalt Pavements

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ABSTRACT: The main cause of deterioration of asphalt pavements is the infiltration of rainwater through cracks in the surface layer. The pavement is also deteriorating faster than the expected service life of the pavement. In addition, many roads deteriorate earlier than the expected service life of the pavement, which has become a social problem. Therefore, research on the application of geosynthetics in base courses is considered necessary. This study focuses on the use of geosynthetics as a base course reinforcement material, and aims to understand the effect of geosynthetics on base course reinforcement and to propose measures to extend the service life of asphalt pavements. This paper discusses the results of (1) Effect of geosynthetics on geotextile base course reinforcement using small tank, (2) Bearing capacity improvement characteristics using FEM analysis, and (3) Geotextile base course reinforcement using test construction.

KEYWORDS: Geosynthetics, Base Course, Long Service Life, Asphalt Pavements

1 INTRODUCTION

As pavements are subjected to a loss of base course bearing capacity due to the penetration of rainwater through cracks in the base course. This reduction in base course strength is believed to induce deformation of the pavement, leading to premature damage to the entire pavement structure (Wakabayashi, Y. et al., 2019, Takahashi et al., 2015). Therefore, it is considered necessary to repair the pavement from the base course, not by cutting and overlay, which only renews the surface. Hirakawa et al. have also shown that it is important to effectively control the amount of residual settlement that occurs above the base course due to traffic loading in order to extend the functional life of As pavements and to reduce maintenance costs (Hirakawa, D. et al., 2014). Therefore, this study focuses on the use of geosynthetics as a base course reinforcement material, aiming to understand the effect of geosynthetics on base course reinforcement and to propose measures to extend the service life of road pavements (Akimitsu, M. et al., 2023). Geosynthetics have characteristics such as tensile strength, deflection, permeability and water sealing properties. Mainly, many cases have been reported as reinforcement materials in embankments and soil retaining walls, and as separation materials in road pavements when soft ground is constructed. However, there are few examples of actual use as base course reinforcement. Therefore, research on the application of geosynthetics in base courses is considered necessary. Pavement reinforcement construction by placing geosynthetics on asphalt layers has been conducted in other countries. For example, Correia et al. reported that laying geosynthetics in the As layer effectively reduces cracking and increases the performance of the entire road pavement structure. Thus, there are a wide variety of applications of geosynthetics in road reinforcement (Correia, N.S. et al., 2015, Zomberg, J. G. et al., 2018). Currently, it is important to conduct full-scale field experiments to understand the effect of reinforcement on the base course and its mechanism. However, it is not easy to understand the internal deformation of the base course once it is covered with asphalt. Therefore, this study reports on model experiments conducted at the laboratory test level (Akimitsu, M. et al., 2023(a)). First, friction tests were conducted using a spring-loaded sand material and a small soil tank for the purpose of understanding the friction characteristics between the geosynthetic material and the geosynthetic material. Furthermore, since FEM analysis is considered to be effective

in predicting the deformation behavior of base courses, the degree of effect of different reinforcement materials was examined both from the perspective of small tank tests and analysis. In order to confirm the effectiveness of geosynthetic in reinforcing roadbeds, we report on the results of a test construction on an actual road.

2 THE EFFECT OF BEARING CAPACITY REINFORCEMENT BY MODEL TEST AND ANALYSIS

2.1 Model ground

Figure 1 shows soil tank used in the experiment (Akimitsu, M., et al., 2023) and Figure 2 shows mesh diagram of the soil tank model used in the FEM analysis. FEM analysis was conducted to supplement the bearing capacity reinforcement effect of geosynthetics obtained from small soil tank experiments using

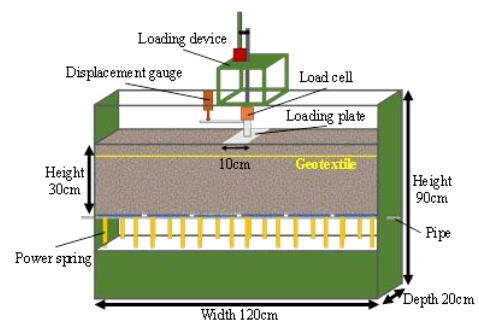


Figure 1. Soil tank

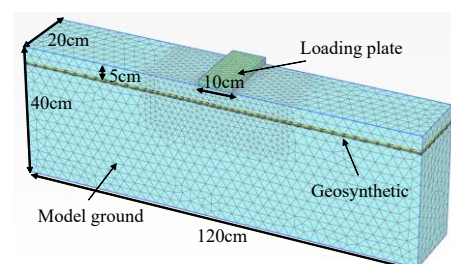


Figure 2. Mesh diagram of the soil tank model

monotonic loading. The code used was PLAXIS 3D. As with the model ground for the small tank experiment, the height, width, and depth of the geosynthetics were 40 cm, 120 cm, and 20 cm, respectively, and the depth of the geosynthetics was 5 cm.

2.2 FEM analysis conditions

The Mohr-Coulomb elasto-plastic model was used as the constitutive equation for the analysis conducted in this study. Table 1 shows the material properties. The physical properties of Mikawa Silica Sand No. 5 were set based on data obtained from triaxial compression tests (CD). The modulus of elasticity (E_{50}) is larger than the experimental level of stress when the triaxial compression test values are used in the analysis. Therefore, the set value of E_{50} was assumed to be approximately $E_{50} = 8500 \text{ kN/m}^2$ at an effective stress of 2.4 kN/m^2 at a depth of 0.2 m in the center of the model ground in the vertical direction, based on the experimental stress in the soil tank shown in Table 2 and the relationship between the elastic modulus and average effective stress shown in Figure-3. The cohesive c was assumed to be $c = 0.1 \text{ kN/m}^2$, considering that the sample used in this study is sandy soil, because the triaxial compression test results show a very high value of $c = 6.2 \text{ kN/m}^2$. For the internal friction angle ϕ , data of 39.8° obtained from triaxial compression tests were used. The dilatancy angle ψ was set to 12.0° by elemental simulation. Poisson's ratio was assumed to be $\nu = 0.33$.

Table 3 shows the mechanical properties of the geosynthetics obtained from the tensile tests conducted separately. In the analysis, woven fabrics and two types of geonets simulating geogrids were substituted to compare the effect of geosynthetic shapes on the reinforcement effect. Tables 3 show a summary of the geosynthetics used. The woven fabric is made of high-strength fibers woven in a special multi-layered, multidimensional structure, and the gaps between the fabrics are formed at an angle, resulting in a high-performance material that has all the functions of reinforcement, separation, and drainage. Furthermore, when laid between the foundation and embankment, it can be expected to be effective in various reinforcement measures, such as stabilizing soft ground, extending the service life of road pavements, and reinforcing earthquake resistance. Geonet, on the other hand, is a plastic net made mainly of polyethylene, and is available in different mesh sizes, yarn thicknesses, and shapes, which can be selected according to the purpose of the construction and soil conditions.

The constitutive equations of the geosynthetics were assumed to be linear elastic, since no load was applied to the geosynthetics at the level of rupture. The EA used in the analysis was calculated from the tensile strength at 3 % tensile strain. Since it is necessary to set A to obtain E from EA, A was calculated for the woven fabric based on the thickness t of the product. The apparent average cross-sectional area A was calculated from the unit area mass M and the mass (specific gravity) of the raw material (high-density polyethylene) of the geonet, since the geonet has a mesh shape and its cross-section is not constant. The friction angle between the reinforcement and the soil discontinuity was set to 39.8° , the same as the internal friction angle of the soil.

The displacement boundary was a vertical roller on the sides and a fixed boundary on the bottom. Although springs were used in the model experiment (Fig.1), the fixed boundaries were used in the analysis because the purpose of this paper is not to reproduce the experiment perfectly but to qualitatively understand the degree of reinforcement effect. The load condition was applied up to a forced displacement of 5 mm.

Table 1. Material properties of Mikawa silica sand

Model	γ (kN/m ³)	c (kN/m ²)	ϕ (°)	ψ (°)	E_{50} (kN/m ²)	ν
Mohr-Coulomb	18.0	0.10	39.8	12.0	8500	0.33

Table 2. The experimental stress in the soil tank

γ (kN/m ³)	Depth (m)	Vertical stress (kN/m ²)	Mean effective stress ($K_\sigma=0.5$) (kN/m ²)
18.0	0.2	3.6	2.4

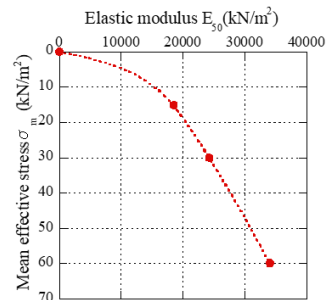





Figure-3. Relationship between the elastic modulus and average effective stress

Table 3. Summary of the geosynthetics

Material	Photo	Tensile strength (kN/m)	Permeability (1/min/m ²)
Woven fabric		89.0	-
Material	Photo	Tensile strength (kN/m)	Mesh size (mm)
Geonet①		8.5	2.5
Geonet②		2.0	10.0

2.3 Effect of geosynthetic on increased bearing capacity

Figure 4 shows the analysis results of the relationship between loading stress and settlement. Figure 5 shows the results of the monotonic loading test conducted in the small tank experiment [3]. The model with geosynthetics shows a difference in loading stress as settlement progresses compared to the model without geosynthetics. Although the loading stress and the slope of the settlement curve are different between the analysis results (Figure 4) and the results of the monotonic loading test in a small soil tank (Figure 5), the increase in bearing capacity due to reinforcement shows the same trend. In this analysis, the geosynthetic surface profile and boundary conditions with the soil material, such as interlocking effects with the soil material, were not sufficiently set up, etc. In addition, due to the very small overburden stress condition, there was a large difference in the stiffness at the initial stage of loading between the analysis results and the experimental results. Next, focusing on the type of geosynthetics, the order of the geosynthetics in the monotonic loading test was woven fabric, geonet ② and geonet ①, whereas in the analysis, the order of the geosynthetics was

woven fabric, geonet ①, and geonet ②, indicating that the order of geonet is different. This may be due to the fact that the geonet is modeled as a single sheet in the analysis, which has a large influence of EA and does not reproduce the apparent shear resistance angle φ obtained from the geometry and friction property tests. Figure 6(a)-(d) shows the stress distribution at the end of loading in the vertical stress σ_{zz} direction. Compared to the non-reinforced specimens, the woven fabric and geonets ① and ② show higher stress just below the loading plate. The woven fabric shows the largest color change. This may be due to the fact that the analysis reflects the value of tensile stiffness EA in the results.

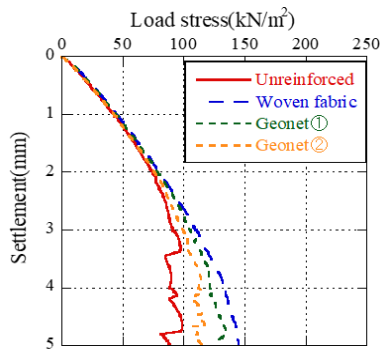


Figure 4. The analysis results of the relationship between loading stress and settlement

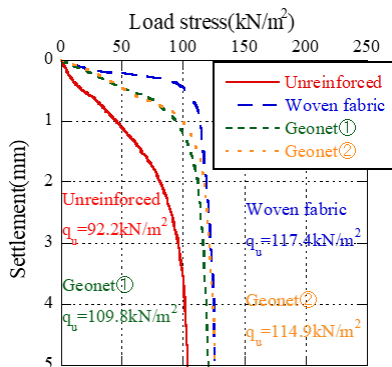


Figure 5. The results of monotonic loading test conducted in the small tank experiment [3]

Figure 7(a)-(d) shows the distribution of deviatoric strain $(\epsilon_1 - \epsilon_3) / 2$ at the end of the loading period. In the unreinforced case, the shear zone extends over the entire area and slip failure occurs. In the case of the woven fabric, the shear zone is suppressed at the top of the reinforcement. On the other hand, the stress distribution shows that the stress increases on the shallow side of the reinforcement and the stress distribution spreads on the deep side, which indicates that the support range for the load is extended over a wide range of the ground, which means that the bearing capacity has increased.

Therefore, the development of shear zones is considered to have been suppressed. In the case of the geonet, the shear zone is suppressed as in the case of the woven fabric, but the reinforcement effect is small, and the shear strain spreads from the underside of the reinforcement.

FEM analysis also confirmed the effectiveness of the geosynthetics in reinforcing the bearing capacity and reducing deformation. However, if the results of the small soil tank experiments are to be accurately simulated, improvements are

needed, such as accurately estimating the frictional resistance between the geosynthetics and the soil sample and the geosynthetics with different shapes.

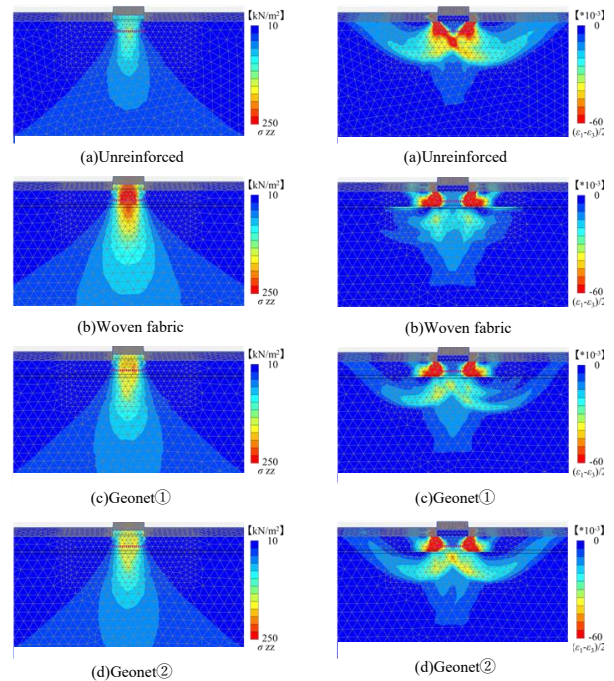


Figure 6. Stress distribution at the end of loading in the vertical stress σ_{zz} direction

Figure 7. Deviatoric strain $(\epsilon_1 - \epsilon_3) / 2$ at the end of the loading period

2.4 Effect of geosynthetic on increased bearing capacity

Monotonic loading tank tests confirmed that the bearing capacity of the base course was increased by placing a single layer of Geosynthetics in the soil. FEM analysis using the monotonic loading test as a comparison target also confirmed the effect of placing a single Geosynthetics sheet in the soil on the bearing capacity. In this experiment, Mikawa silica sand No. 5, which has a single grain size, was used as a substitute for the base course material because its deformation behavior is easy to understand in loading experiments. In actual practice, geogrids, which have a mesh shape that can suppress the deformation of the base course material (interlocking effect), are expected to be used. In this experiment, geonet, which has a smaller mesh size than geogrid, was first substituted for geosynthetics and evaluated. As a result, the reinforcing effect of geosynthetics was clarified.

3 THE FULL-SCALE TEST CONSTRUCTION

3.1 Purpose of full-scale test construction

This study focuses on the utilization of geosynthetics as base reinforcement method by laying them in the base course of asphalt pavement. The full-scale test construction was conducted to identify the effect of geosynthetics in reinforcing the base and to propose this method to extend the lifespan of asphalt pavements. By for now, the effect of the deformation resistance of the tensile reinforcement of the woven fabric and the bearing capacity reinforcement of the interlocking of the geogrids were confirmed in the previous laboratory tests, even if under the conditions of rainwater penetration. This paper refers to the results of a survey on the workability of

geosynthetics laid in the basecourse and the effect on the reinforcement bearing capacity of asphalt pavement.

3.2 Location and Conditions

The construction site was located on the Technical Research Institute of Taisei Rotec Corporation (e.g., Figure 8), where an average of 13 large vehicles passes by each month. 20 months since construction, the total number of large vehicles passing through the site reached 260. Figure 9 shows the number of large vehicles that have passed since construction began. The annual precipitation at the site is 1239mm, and the average annual temperature is 14.9°C.



Figure 8. The test construction site

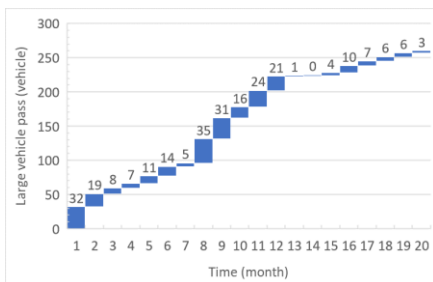


Figure 9. Total numbers of large vehicles passed each month

3.3 Materials

The geosynthetic specification are shown in Table 4. The woven fabric (Figure 10(a)) is a material that combines all functions of reinforcement, separation, and drainage. The triaxial geogrid (Figure 10(b)) is a material which makes it

Table 4. The geosynthetic specification

Reinforcement	Woven fabric	Geogrid
Tensile strength(kN/m)	89.0	10.0
Drainage volume(1/min/m ²)	3055.5	-

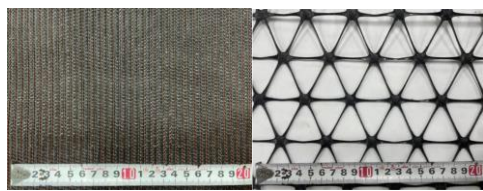


Figure 10 Geosynthetic for test construction site

possible to suppress deformation of the base that the interlocking effect of suppression and load dispersion is exerted. (Matsumoto et al. 2019). A concept of the base reinforcement method using woven fabric and geogrid is shown in Figure.11 and 12.

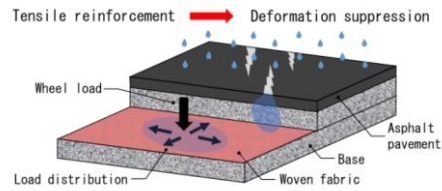


Figure 11. Concept of base reinforcement method using woven fabric

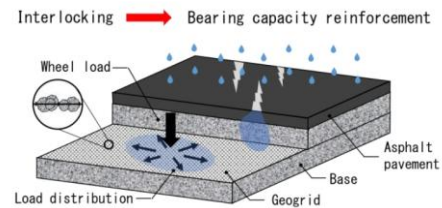


Figure.12 Concept of base reinforcement method using geogrid

3.4 Structural Design

In Japan, pavement structures are designed based on the daily one-way heavy vehicle traffic volume and the design CBR of the subgrade (Japan road association. 1989). The design conditions were set as follows: daily one-way heavy vehicle traffic volume of 100 to 250 vehicles, and the design CBR of the subgrade was 4%. The construction test site plan and cross sections are shown in Figure. 13 and 14. It is divided into three construction zones: zone 0, zone 1 and zone 2. The construction zone 0 was unreinforced as controlled section, while the zone 1 is reinforced by woven fabric and the zone 2 is reinforced by geogrid. Both geosynthetics were laid within the middle of the base in zones 1 and 2 respectively. The pavement structure consisted of a 200 mm subbase (C-30), 200 mm base (M-30) and 50 mm asphalt layer from the top of the subgrade. Previous research has shown that the reinforcement is more effective the shallower it was laid (Kitamura et al. 2019), so the geosynthetic was laid at a depth of 150 mm from the pavement surface in the middle of the base. To verify the effect of rainwater entering through cracks on the base, a porous asphalt mixture was used for the surface layer in the structure to actively guide the rainwater into the base. No emulsion was sprayed between the layers to direct rainwater and to weaken interlayer adhesion and promote pavement failure. Moisture meters, soil pressure gauges and strain gauges were equipped in the base course.

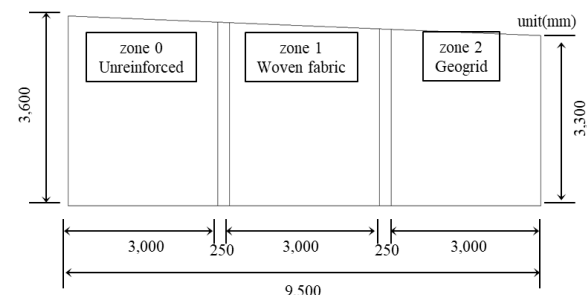


Figure 13. The test field plan

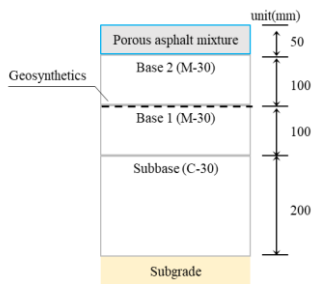


Figure 14. The test field cross section.

4 FOLLOWINGSURVEY

4.1 Deformation resistance

In Japan, damage to asphalt pavements is evaluated by the cracking rate, the amount of rutting depth, and the IRI. Of these indicators, the rutting depth is related to the deformation suppression effect, and its typical value to be repairment is generally 20 mm to 40 mm. Therefore, to evaluate the effect of deformation resistance, the displacement of the road surface was measured by a TLS (Terrestrial laser scanner), and the area ratio of the displacement of 20 mm or more was calculated.

Figure. 15 shows the measured heat maps of displacement approximately 18 months after the first measurements were conducted in December 2022. Figure.16 and Table 5 show the change in average displacement and the average displacement and the percentage of area above 20mm displacement after 18 months of construction, receptivity.

After 18 months had passed since construction, it can be seen visually that the geosynthetic laid construction zone has been reduced settlement compared to construction zone 0. The distribution of displacement of the road surface shows that settlement has developed in both construction zones. And it has increased along with the passage of time. Table 5 also shows that the percentage of area above 20mm displacement in all construction zones. From Table5, it is suggested that woven fabrics and geogrids have a deformation resistance effect.

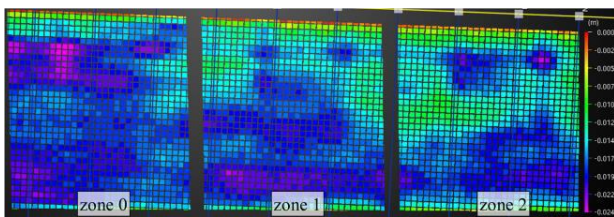


Figure 15. Heat maps of displacement approximately 18 months after the first measurements.

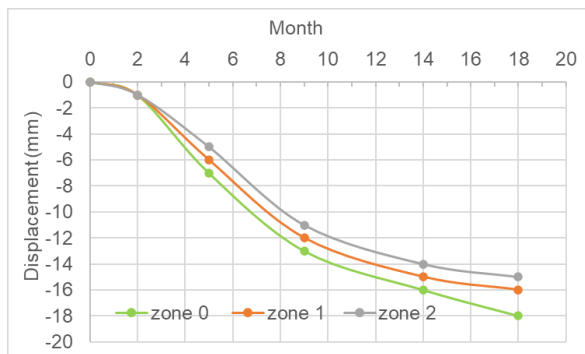


Figure 16. Change in average road surface displacement

Table 5. Area rate displacement by 20mm or more after 18 months of construction

Reinforcement	Unreinforced	Woven fabric	Geogrid
zone	zone 0	zone 1	zone 2
average displacement (mm)	-17	-16	-15
Area rate displacement by 20mm or more (%)	23	14	6

In terms of the bearing capacity reinforcement effect, in the laboratory experiments, the ultimate bearing capacity was assessed by loading tests on the base, however, in the test field it is not available to conduct loading tests directly. FWD is non-destructive test of investigating pavement bearing capacity. Result of deflection measurement with FWD can be used to judge whether pavement has a sufficient bearing capacity. (Japan Road Association, 2013). Deflection results alone can only evaluate the bearing capacity of the entire pavement. Therefore, as a method for evaluating the effect of reinforcement of bearing capacity, the deflection in the middle of the construction zone was measured by FWD, and the modulus of elasticity of the base calculated by inverse analysis of the deflection, was divided by the value immediately after construction to obtain the modulus change rate. and BALM (Japan Society of Civil engineers, 2015) was used for the inverse analysis program.

Figure. 17 shows the deflection valueD0 occurring below the FWD's loading point (D0). Figure.18 shows the elasticity modulus of base course and subbase course immediately after construction. Figure.19 shows the precipitation and Table 6 shows the change of the elasticity modulus after 20 months of construction.

The elasticity modulus change rate shows that at each measurement timings, the elasticity modulus of each base layers in zone 0 decreased from the initial value as the months passing, while zones 1 and 2 reinforced with geosynthetics have a smaller change rate than zone 0. Table 4 shows that the elasticity modulus of zone 0after 20 months from construction became less than 88% of the initial value of base layers, but that of zones 1 and 2, where woven fabric and geogrid was laid, remained more than 94%. it suggests that the woven fabric and the geogrid seemed to have a bearing capacity reinforcing effect. The reason for the decrease in the change rate of the elasticity modulus in each layer during a month between 5 month and 6 months after construction is considered that the penetration of rainwater (Akimitsu et al., 2023(b), 2023(c)) into the base during a series of heavy rains. The total precipitation during that period was 241 mm (as shown in Figure. 19), it was 2.3 times of the average monthly precipitation of 103 mm.

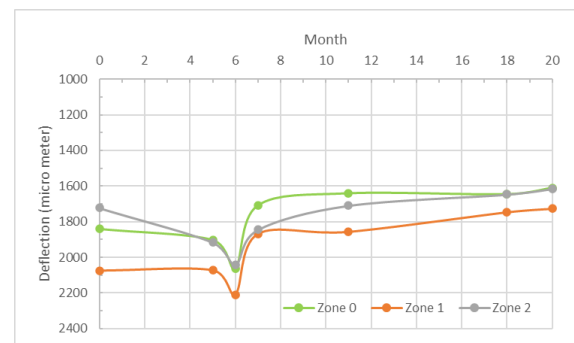


Figure 17. Deflection D0 from FWD

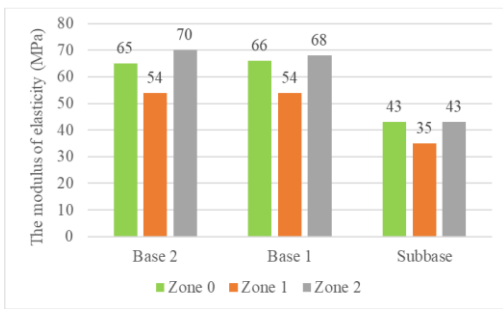


Figure 18. The modulus of elasticity of base course

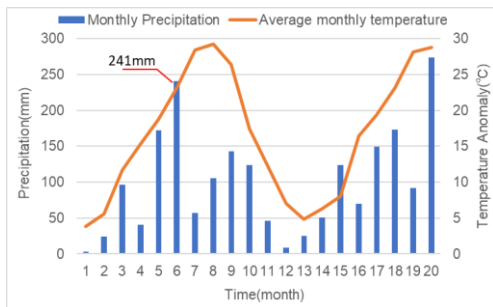


Figure 19. Precipitation

Table 6. The modulus of elasticity change after 20 months of construction.

Reinforcement	Unreinforced	Woven fabric	Geogrid
Zone	Zone 0	Zone 1	Zone 2
Base 2	87	97	94
Base 1	88	99	97
Subbase	87	101	98

5 CONCLUSIONS

- 1) The results of bearing capacity tests using small soil tanks and FEM analysis using the results showed that geosynthetic base course reinforcement could be effective. It was also found that the reinforcement effect varied depending on the type of geosynthetic.
- 2) The geosynthetic's workability was considered sufficient because it was easily laid. Construction quality could be secured even with the presence of the geosynthetic.
- 3) It is confirmed by the following surveys that the effects of laying geosynthetics for reinforcing the basecourse bearing capacity and suppressing pavement deformation. It is suggested that the base course reinforcement with geosynthetics could contribute to the extending the lifespan of pavements. As for future research topics, an open cut survey will be conducted at a time when the pavement has been more damaged and further verify the effects of geosynthetic base reinforcement.

6 ACKNOWLEDGEMENTS

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