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Effect of rainwater infiltration from pavement surface on base course bearing capacity

Effet de l'infiltration de l'eau de pluie à la surface de la chaussée sur la portance de la couche de base

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ABSTRACT: Japan has a huge stock of road pavements, exceeding 1.2 million km. However, road pavements require constant maintenance and repair work because they gradually progress in deterioration due to various factors immediately after the operation. In particular, the deterioration of base course bearing capacity due to rainwater infiltration through cracks from the asphalt layer is said to have a significant impact on the durability of road pavements. However, it is difficult to observe and investigate the deterioration in the base course while it is in service, and there are only a few cases where detailed investigation and analysis have been attempted. This study reports the results of CBR tests on the effects of water content ratio at the time of sample preparation and rainwater infiltration time on the bearing capacity reduction behaviour of base course using two types of pavement materials.

RÉSUMÉ: Le Japon dispose d'un énorme stock de chaussées routières, dépassant 1,2 million de km. Cependant, les chaussées nécessitent des travaux d'entretien et de réparation constants car elles se détériorent progressivement sous l'effet de divers facteurs immédiatement après leur mise en service. En particulier, la détérioration de la portance de la couche de base due à l'infiltration de l'eau de pluie à travers les fissures de la couche d'asphalte est considérée comme ayant un impact significatif sur la durabilité des chaussées routières. Cependant, il est difficile d'observer et d'étudier la détérioration de la couche de base pendant qu'elle est en service, et il n'y a que quelques cas où une étude et une analyse détaillées ont été tentées. Cette étude rapporte les résultats d'essais CBR sur les effets du rapport de la teneur en eau au moment de la préparation de l'échantillon et du temps d'infiltration de l'eau de pluie sur le comportement de réduction de la capacité portante de la couche de base en utilisant deux types de matériaux de chaussée. Je suggère d'inclure des conclusions plus détaillées si possible.

Keywords: Bearing capacity; base course; rainwater infiltration; CBR tests.

1 INTRODUCTION

Japan's road pavement stock exceeds 1.2 million km. In the future, it will be important to establish maintenance management methods for road pavements. However, in recent years, Japan has been facing a declining birth-rate and an aging population, and road maintenance and management costs are facing a very difficult situation. In the future, road managers will be required to perform maintenance management with high economic and technical effectiveness. Road pavements are structures that gradually deteriorate by the passage of years in service. In particular, the loss of base course bearing capacity due to rainwater infiltration through cracks in the asphalt layer is known to significantly affect the durability of road pavements [1].

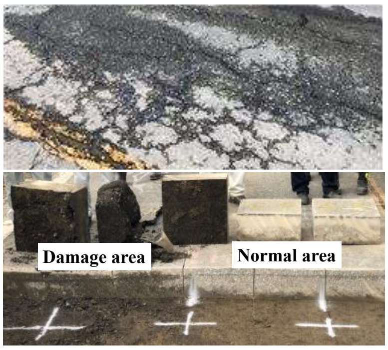


Figure 1. Early deterioration of asphalt pavement.

The process of base course bearing capacity reduction is as follows: (1) cracks occur in the asphalt layer due to age-related deterioration (Figure 1), (2) rainwater infiltrates through the cracks, (3) the fine grains in the base course are released by the pumping phenomenon when large traffic loads act on the pavement under rainwater infiltration, and (4) Pavement bearing capacity decreases due to the change in the pore structure caused by the change in the grain size of the base course material and rainwater infiltration (Figure 1). This decrease of base course bearing capacity is a major factor in the early deterioration of road pavements. When deterioration progresses rapidly, the base course needs to be replaced. However, replacement of the base course material is rarely implemented due to traffic obstructions caused by construction regulations, construction period problems, and high repair costs. In the future, appropriate maintenance and repair technology will be required before premature deterioration of pavements progresses. However, it is difficult to understand the details of base course damage of pavements with early-stage deterioration, and very few research have attempted to investigate and analyse the damage. The water content ratio of the geomaterial at the time of base course material placement and density control after compaction are considered to have a significant effect on the base course bearing capacity [2]. Therefore, it is considered effective to obtain an experimental understanding of the mechanism of base course deterioration due to rainwater infiltration to investigate the early stage of pavement deterioration. This study reports the results of CBR tests on the effects of water content ratio at the time of sample preparation and rainwater infiltration time on the bearing capacity reduction behaviour of base course using two types of pavement materials.

2 TEST PROCEDURE

2.1 Experimental samples

Two types of pavement materials were used in this study: M-25, which was mixed and prepared from No. 4-7 crushed stone, sand, and stone dust, and RM-25, which was recycled concrete material purchased from a construction materials company. Table 1 shows the physical properties of the two materials. Figure 2 shows the particle size distribution curves of the samples before and after compaction. Figure 3 shows the compaction curve. Particularly, for RM25, particle crushing by compaction occurred, indicating that it was affected by the water content ratio. This is considered to be due to the effect of the cement content attached to the aggregate of RM-25, which was crushed by compaction.

2.2 Testing conditions

The E-b method was used in accordance with the Soil Compaction Test Method by compacting (JIS A 1210). Here, the E-b method for soil compaction is used a meld inner diameter of 15 cm (volume: 2209 cm3) and a rammer of 4.5 kg dropped from a height of 45 cm without repeated use of a soil sample with adjusted water content. In addition, the number of times of compaction was reduced to 82 times for each sample at the optimum water content ratio in order to achieve a uniform dry density of Dc=99% for each specimen. In the case of RM-25, Dc=99% was set to 1.70 x 0.99 = 1.68 Mg/m^3 at about 3% before and after the optimum water content ratio in consideration of the implementation of the project. In the same way, M-25 was set to 2.28 × 0.99 = 2.26 Mg/m^3, where Dc=99%. Table 2 shows the experimental conditions. The water content ratio of M-25 was set to 1.6 (dry side), 2.8 (optimum water content), and 3.6 (wet side) % at Dc=99%. In the case of RM-25, three different water content ratios w = 9.9 (dry side), 13.5 (optimum), and 17.4 (wet side) % at Dc=99% were used in the study.

In order to investigate the change in base course bearing capacity due to rainwater infiltration, water was sprayed from the top of the specimen after the specimen was prepared. The amount of water sprayed was set so that the water content ratio of each specimen increased by w=4.0%.

The CBR penetration tests were conducted immediately after all the sprayed water had infiltrated from the top of the specimen (t=0h) and after 6 hours(t=6h) and 24 hours (t=24h). Table 3 shows the time required to complete infiltration under each condition. The CBR penetration test was conducted after removing the water from the top of the specimen because the water did not infiltrate even after 96h in the wet side of RM-25 with 150 ml of water sprayed.

Table 1. Physical properties of base course materials.

sample	M-25	RM-25
Appearance		
Soil particle density ρ_s(Mg/m^3)	3.056	2.642
Uniformity coefficient U_c	35.10	58.37
Coefficient of curvature $U_c{}'$	2.81	1.33
Abrasion loss R(%)	14.30	30.70
Water absorption (%)	0.40	9.02

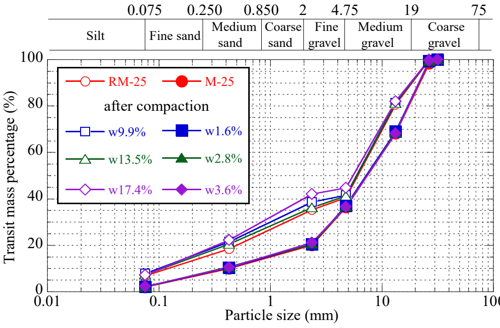


Figure 2. Grain size distribution curves of the samples before and after compaction.

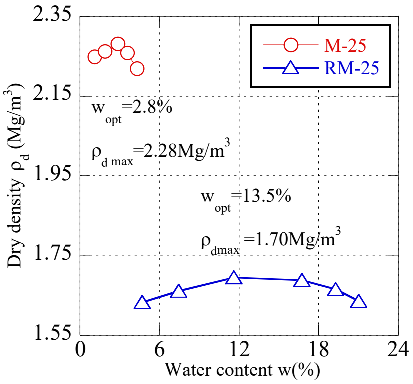


Figure 3. Compaction curve.

Table 2. Experimental conditions.

Sample	Specific water content w(%)	Compacted times	Amount of water sprinkled	Dry density ρ_d(Mg/m^3)	Standby time
M-25	1.6 (Dry) 2.8 (Optimum) 3.6 (Wet)	92times (E-b) 82times (Optimum)	0 ml 200 ml	2.26 (Dc=99%)	0 h 6 h 24 h
RM-25	9.9 (Dry) 13.5 (Optimum) 17.4 (Wet)	92times (E-b) 82times (Optimum)	0 ml 150 ml	1.68 (Dc=99%)	

Table 3. Time to the end of infiltration.

Specific water content	Sample (Amount of water sprinkled)	
	M-25 (200ml)	RM-25 (150ml)
Dry	3min	40min
Optimum	3min	1.5h
Wet	3min	96h

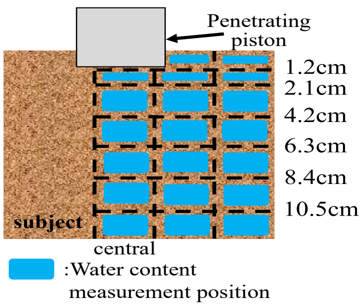


Figure 4. Location of water content measurement.

In this study, water content was measured at the locations shown in Figure 4 immediately after the CBR penetration test in order to evaluate the behaviour of bearing capacity reduction due to rainwater infiltration from the state of pore water inside the specimens. Measurements were taken at a total of 20 locations, 7 in the vertical direction and 3 in the horizontal direction, without the penetration position.

3 RESULTS AND DISCUSSIONS

Figures 5 and 6 show the distribution of water content inside the specimens after the CBR test for M-25 and RM-25 at (a) the dry side, (b) the optimum water content, and (c) the wet side, for each elapsed time after water sprayed. The average water content and saturation of the entire specimen are also shown. Figure 7 and Figure 8 show the CBR test results for M-25 and RM-25. Here, the results of experiments conducted by the authors using Decomposed granite soil under the same conditions are also shown in each figure.

3.1 Dry side

Just after water sprayed, both specimens showed a significant decrease in bearing capacity with water sprayed, similar to the results for Decomposed granite soil. This is considered to be due to the decrease in suction caused by the increase in saturation due to water infiltration. As time elapsed after water sprayed,

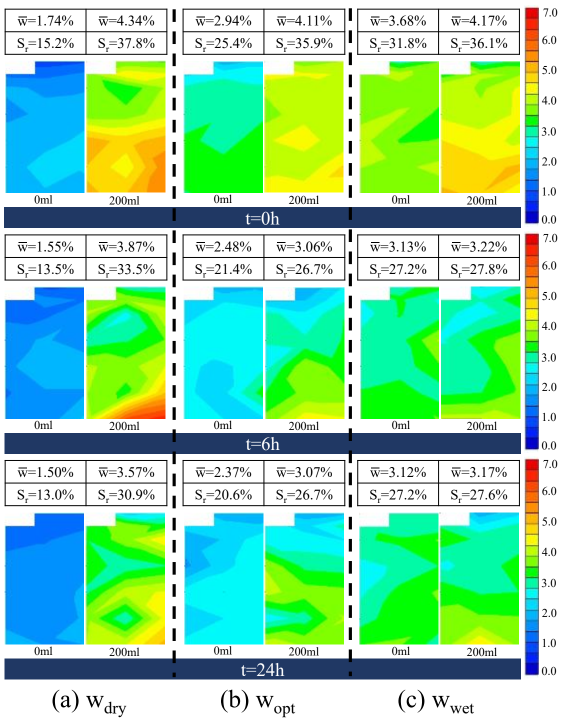
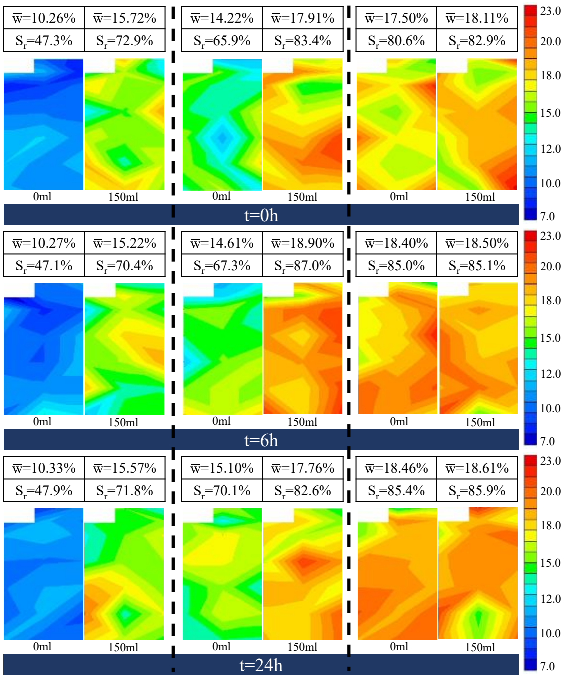


Figure 5. Distribution of water content in the specimen (M-25).



(a) w_{dry} (b) w_{opt} (c) w_{wet}

Figure 6. Distribution of water content in the specimen (RM-25).

the bearing capacity of M-25 increases compared to that of the bearing capacity just after infiltration (Figure 7(a)), similar to that of Decomposed granite soil. On the other hand, the bearing capacity of RM-25 decrease (Figure 8(a)). This is caused by the good permeability of M-25 and the decrease in water content in the upper part of the specimen with elapsed time, and the high water absorption of aggregate in RM-25 and the high water content maintained in the upper part of the specimen.

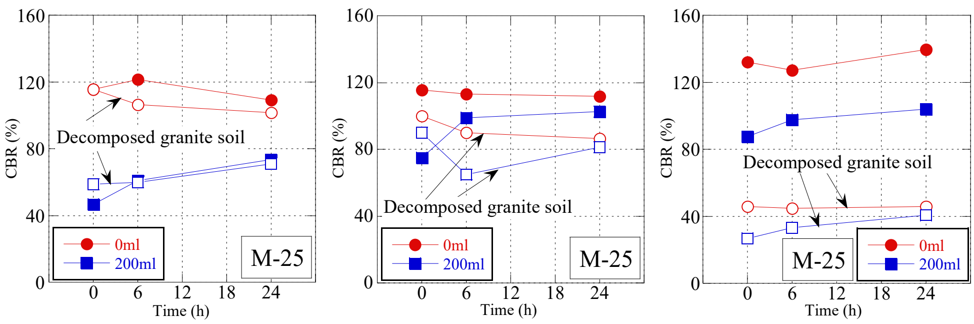
3.2 Optimum water content ratio

In both samples, the rate of decrease in bearing capacity due to water sprayed is smaller than that of the dry side. In addition, the bearing capacity of M-25 increased with the elapsed time immediately after water infiltration and approached the bearing capacity without water sprayed (Figure 7(b)), as is the case for the dry side. This is due to the assumption that the water content in the specimen approached the optimum water content with the elapsed time, as shown in the water content distribution in Figure 5(b), and that the specimen was not easily affected by the water flowing down the specimen. In comparison, the bearing capacity of RM-25 decreased after 6 hours and did not change thereafter (Figure-8(b)), as was observed for the dry side. This is considered to be due to the fact that water runoff does not occur after 6 hours and the upper part of the specimen was kept at a high water content ratio due to water absorption by the aggregate.

3.3 Wet side

M-25 shows high bearing capacity as well as other initial water content ratios, and the effect of water sprayed on the bearing capacity is similar to that of the optimum water content ratio. With the elapsed time, the bearing capacity gradually increases and recovers compared to that immediately after water sprayed (Figure-7(c)). This is caused by the distribution of the water content ratio returning to almost the same level as that before water sprayed over time, in spite of the wetted side.

On the other hand, the bearing capacity of RM-25 before water sprayed is the smallest among the other water content ratios, showing the same level of bearing water content ratios, showing the same level of bearing capacity as decomposed granite soil. This suggests that RM-25 was crushed by compaction as shown in Figure-2, causing a significant decrease in bearing capacity due to the increased water retention of the aggregate. This effect also caused a slight decrease in bearing capacity after 6 hours, after which no change was observed (Figure-8(c)). This is considered to be due to the gradually infiltrating water sprayed into the specimen, which increased the degree of saturation.



(a) Dry (b) Optimum (c) Wet

Figure 7. CBR test results (M-25).

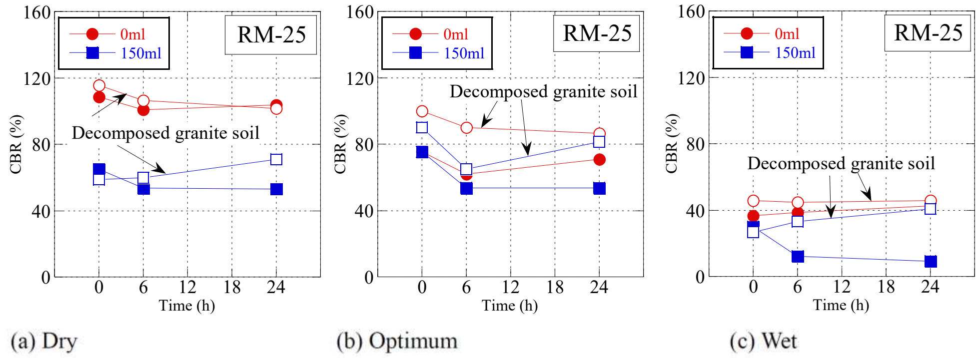


Figure 8. CBR test results (RM-25).

4 CONCLUSIONS

1) The water content of the base course at compaction has a significant effect on the strength reduction after rainwater infiltration.
2) The change of water content in the base course with the passage of time after rainwater infiltration has a significant effect on the bearing capacity behavior of the base course.

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