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The Stability of Gravel Roads in Volcanic Ash-soil Regions

Stabilité des Routes en Gravier dans les Régions de Cendres Volcaniques

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Summary

This report gives the results of the investigations on the stability of gravel roads carried out in Iwate district located in the north-eastern part of Japan.

Consideration is given to the estimation of critical soil stability for gravel roads during the spring thaw, using the moisture (CBR and moisture) suction relations.

Relevant investigations on CBR tests were performed in connection with the unconfined compression tests on this soil. Finally, the load-carrying capacity of the base course is considered.

Introduction

Volcanic ash-soil which is quite widely distributed throughout Japan has given rise to difficulties in road construction and maintenance due to its unsuitable property as subgrade soil. This hazard is especially felt in the north-eastern districts of Japan where freezing and thawing occur in winter and spring. As the elements of gravel roads, which consist of the soil-aggregate surfacing and base-course, are exposed to the atmosphere, the moisture content and, therefore, the stability of base and subgrade are greatly influenced by weather conditions in comparison with paved roads. When the roads become very wet and of low stability, the surface is usually made up with granular materials in order to preserve the transportation in these districts.

A new road has been constructed along the old national road, and this investigation was performed in parallel with the construction.

Subgrade Soil Characteristics in Iwate District

The sites investigated are the national road in Takizawamura, northward of Morioka-city in Iwate district, and sites I and H, where the examination was mainly carried out, are about 2 km distance from each other. The subgrade soil at these sites, composed of volcanic ashes, belongs to MH in Casagrande's soil classification, and the total depth of the surface and base courses is from 25 to 30 cm. The materials in the surface course are little different from those in the base course. Owing to the fact that the road surface is exposed to the atmosphere, the moisture content of subgrade soil is influenced to about 70 cm depth from the road surface by seasonal variations, changing from 80 to 140 per cent by dry weight. If the subgrade soil is tested without drying prior to the test, the Atterberg limits are influenced by the initial moisture content; for example, tests on a sample taken from site I in the summer gave LL = 114 and PI = 55, whereas the test values for a sample taken in winter were LL = 154 and PI = 60. On both sites the ground water level is 2 m beneath the road surface all through the year and the frost penetration depth is from 30 to 40 cm.

Effects of Soaking the Subgrade Soil

Undisturbed samples, which were taken from the subgrade about 30 cm beneath the surface of the roads running through Takizawamura and its neighbourhood, were tested by the

Sommaire

Cette communication expose les résultats de recherches entreprises sur la stabilité des routes en gravier construites dans la région d'Iwaté, au nord du Japon.

On indique les considérations qui sont intervenues pour fixer la stabilité critique du sol, notamment la variation du CBR et de la succion capillaire avec la teneur en eau, au cours du dégel du printemps.

Les mesures de CBR ont été effectuées simultanément avec des essais de compression simple des échantillons de sol. Enfin la force portante de la couche de base a été examinée.

CBR test method. Fig. 1, which gives the CBR test results, shows that on undisturbed specimens with CBR values above 3, the CBR is reduced by about 25 per cent as a result of soaking for four days, while the effect of soaking is not recognized when undisturbed CBR is less than about 3. In Fig. 1 the low CBR values were measured on specimens taken in the thawing period

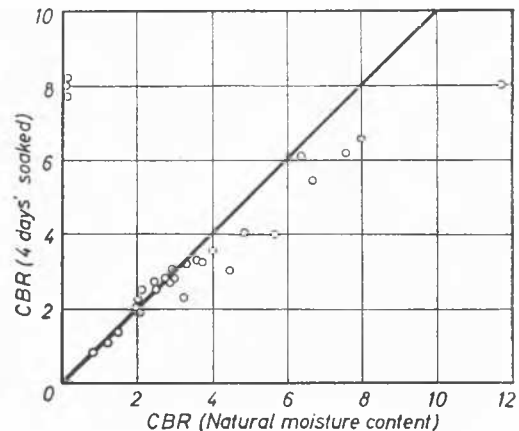


Fig. 1 Relation between undisturbed CBR and 4-days' soaked CBR
Relation entre CBR et CBR après 4 jours d'imbibition

in spring, the high values in summer, while the intermediate values were obtained in the autumn.

CBR Values, Measured Undisturbed and *in situ*

It is well known that the CBR method is very good for designing the total thickness of flexible pavement, and the shear strength method has also been used in Great Britain. Both methods, it is said, are suitable for design purposes. In order to show the relation between CBR and unconfined compressive strength required for the same total thickness of flexible pavement for a 12,000 lb. wheel-load, the *R* curve in Fig. 2 is obtained. In Fig. 2 the circles indicate the relation between CBR and unconfined compressive strength measured by undisturbed samples. They are on the *R* curve fairly well, while the crosses which show the relation between the *in situ* CBR and the unconfined compressive strength deviate considerably from the *R* curve.

It is sometimes said that the thickness of flexible pavement designed by the shear strength method agrees fairly well with the result of *in situ* CBR. In the subgrade soil of Iwate district, however, the thickness designed by the former is not in accord with that of the latter. In the subgrade soil, the values of the *in situ* CBR are greater by 1.9 ± 0.3 times than those of the undisturbed CBR.

Critical Bearing Capacity of Subgrade Soils in the Gravel Roads in the Cold Northern District

It is essential for designing road structures to have a good knowledge of the variation of moisture content and, accordingly, of the variation of bearing capacity of the subgrade for a long period of time after the construction of the road. Many methods of determining the thickness of road structures have

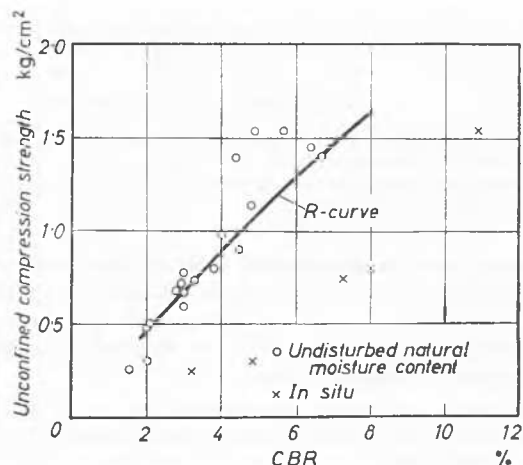


Fig. 2 Relation between CBR and unconfined compression strength
Relation entre CBR et résistance à la compression sans contrainte latérale

been reported, and they are divided into two groups: the methods based on the loading test in the field and those on the measurement of soil strength in the laboratory. However, in either case, those methods of design are not good enough which do not take into consideration the fact that the bearing capacity may vary with variation of moisture condition of the subgrade soil under the finished structure. Therefore, the CBR method of testing the soil strength after soaking for 4 days is considered to be a reasonable way of determining the critical bearing capacity of the subgrade soil. However, concerning the method in which the samples are soaked for 4 days, there are some objections on the one hand that it is too long and on the other that it is too short. It is, therefore, questionable to determine the critical bearing capacity by an easy method.

A. Mori has suggested that the equilibrium moisture content under the pavement is that under which soil moisture suction is equal to 0.1 kg/cm^2 in warmer districts. This is interesting, but in soil-aggregate surface roads in cold northerly districts the bearing capacity of subgrade is extremely decreased during the spring thaw, and the equilibrium moisture condition may not be expected as the roads are of open-type surfacing.

Fig. 3 shows the results of the loading tests measured by the Tohoku Regional Construction Bureau at Takizawa-mura using a 30 cm diameter steel plate. A tendency is observed in this illustration for the K value to increase a little in winter compared with in autumn, because the base and a portion of the subgrade are frozen in winter. However, the K value decreases quickly in the thawing period of early spring, and rises gradually in the latter half of spring and early summer.

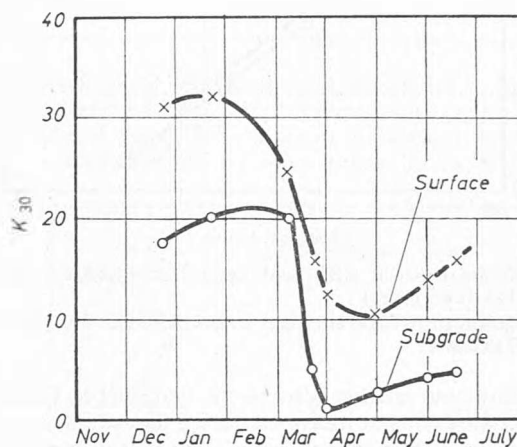


Fig. 3 Variation of K value measured at Takizawa-mura
Variation de la valeur K mesurée au village de Takizawa

According to the calculation of Mori by the equation suggested by Croney and Coleman (*Proceedings of the 3rd International Conference on Soil Mechanics and Foundation Engineering*) four days' soaking is aimed theoretically at the soaking and swell of the soil to such an extent that the soil moisture suction of the sample would reach 0.02 kg/cm^2 . However, the soaking and swell of the subgrade soil in Iwate district is not over in 4 days or so; this is shown in Table 1. As will be seen, CBR of 4 days' soaking on an undisturbed sample in a normal season (autumn) is 2.3 in the site I, while CBR in natural moisture content is 3.3. However, the CBR at natural moisture content is 1.5 in spring, that is, CBR of 4 days' soaking in normal season is considerably higher compared with the undisturbed CBR in spring. Thus, in the subgrade soil in the

Table 1
Seasonal changes in CBR
Variation saisonnière dans CBR

Season	Summer			Autumn			Spring		
	CBR <i>in situ</i>	Undisturbed sample		CBR <i>in situ</i>	Undisturbed sample		CBR <i>in situ</i>	Undisturbed sample	
		Natural moisture content	4 days' soaking		Natural moisture content	4 days' soaking		Natural moisture content	4 days' soaking
Site I	10.9	4.9	4.0	7.2	3.3	2.3	3.2	1.5	1.4
Site II				8.0	3.8	3.2	4.8	2.0	2.2

Iwate district, the effect of soaking is different according to the time of year. When the undisturbed CBR is less than 3 it is not affected by soaking as shown in Fig. 1; in the spring thaw, especially, the undisturbed CBR reaches a value which has never been attained by artificial soaking. This seems to be because of the volume expansion of subgrade soil during the freezing period in winter.

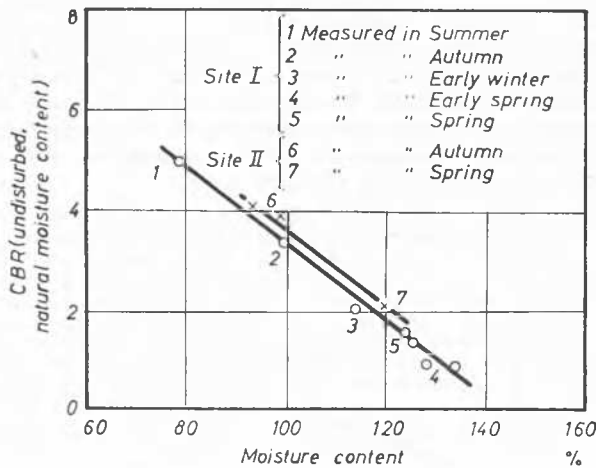


Fig. 4 Relation between CBR and natural moisture content (at Takizawa-mura)
Relation entre CBR et teneur en eau naturelle (au village de Takizawa)

Fig. 4 shows the relation between the undisturbed CBR and natural moisture content measured during the various seasons. According to this, both in sites I and II, the CBR value declines when the moisture content increases with the change of the season of the year, being particularly low in early spring. The relations between soil moisture suction and moisture content on the subgrade soil at sites I and II are shown in Fig. 5.

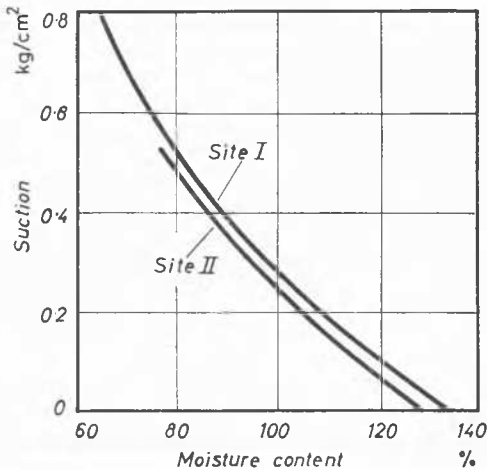


Fig. 5 Relation between soil moisture suction and moisture content on the subgrade soil (at Takizawa-mura)
Relation entre suction du sol et teneur en eau sur le sol de fondation (au village de Takizawa)

Combining Figs. 4 and 5, the relation between the undisturbed CBR and the corresponding soil moisture suction is shown in Fig. 6.

The least value of undisturbed CBR measured at site I is 0.8, which corresponds to the suction being zero. Except the sites disturbed by the traffic ruts in the site I, CBR values have never been measured lower than this value. In site II, the CBR value

corresponding to zero suction has not been measured. Considering that the soil conditions are similar to those of site I, however, the expected least value may be estimated to be 1.2, which corresponds to zero suction. For this reason, if the bearing capacity is to be estimated by CBR, it seems reasonable

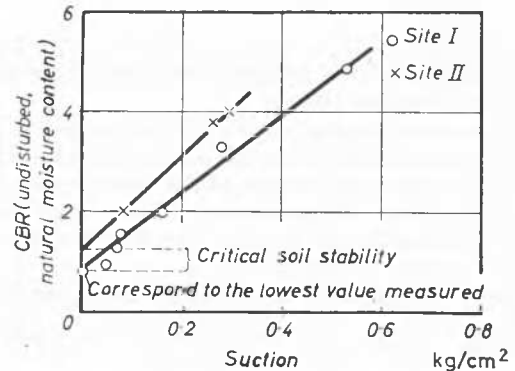


Fig. 6 Relation between CBR and soil moisture suction (subgrade soil at Takizawa-mura)
Relation entre CBR et suction de sol (sol de fondation au village de Takizawa)

to consider that the undisturbed CBR at zero suction is the critical bearing capacity in the north volcanic ash-soil regions.

The Modulus of the Top Layer and Subgrade Reaction by Seasonal Variations

If the load is applied on the subgrade by means of a rigid circular plate, the modulus of subgrade reaction by elastic theory, assuming Poisson's ratio to be equal to 0.5, is given by:

$$K_2 = \frac{p}{\rho} = \frac{E_2}{1.18a} \quad \dots (1)$$

where K_2 = the modulus of subgrade reaction ($\text{kg/cm}^2/\text{cm}$); ρ = the displacement of the plate (cm); p = the average vertical pressure under the plate (kg/cm^2); a = the radius of the plate (cm); E_2 = the modulus of elasticity of the subgrade soil (kg/cm^2).

According to Burmister's analysis, the vertical displacement of the plate at the surface of a two-layered system is obtained from the following equation, assuming Poisson's ratio of both layers is equal to 0.5:

$$\rho = F_w \frac{1.18pa}{E_2} \quad \dots (2)$$

where F_w is the displacement factor and is a function of the thickness of the top layer (h) and the ratio of E_1/E_2 , in which E_1 is the modulus of elasticity of the top layer. Therefore, if the modulus of the top layer reaction is shown by K_1 , the following is then obtained:

$$K_1 = \frac{p}{\rho} = \frac{E_2}{1.18a} \cdot \frac{1}{F_w} \quad \dots (3)$$

If K_1 and K_2 are determined using the same plate under the condition of the same displacement, the displacement factor is given from equations 1 and 3 above, that is:

$$F_w = \frac{K_2}{K_1} \quad \dots (4)$$

Using the data of Fig. 3, Table 2 is obtained from Burmister's theory. In Table 2 the thickness of the top layer has been taken to be 30 cm in calculation, which is the average thickness in Takizawa-mura. In spring the displacement factor is low, which shows that the decrease of the modulus of subgrade reaction is conspicuous compared with that of the top layer

(soil-aggregate base course). According to the elastic theory, the value of E_1/E_2 is high and consequently the modulus of elasticity of the top layer in spring is excessively high compared with the other seasons. It is inconsistent with experience, because the top layer is saturated in spring and the modulus of elasticity must be low in comparison with that of the dry seasons. This seems to show that the elastic theory may not be applied under such road conditions.

Table 2

Calculation of the modulus of elasticity of the top layer from the data of Fig. 3 by elastic theory
Calcul des modules d'élasticité du sommet de couche selon les données de la Fig. 3 par la théorie élastique

	(1)	(2)	(3)	(4)	(5)	(6)
	K_1 (kg/cm ²) (Top layer)	K_2 (kg/cm ²) (Subgrade)	$F_w = \frac{K_2}{K_1}$	$E_2 = 1.18aK_2$ (kg/cm ²)	E_1/E_2	E_1 (kg/cm ²)
Jan. (early)	31.5	18.5	0.589	328	2.6	853
Jan. (middle)	32.0	20.0	0.625	354	2.3	814
Feb. (early)	32.0	20.5	0.641	363	2.25	817
Feb. (middle)	30.0	21.0	0.700	372	1.9	707
Mar. (early)	27.0	20.5	0.758	363	1.65	599
Mar. (middle)	21.0	9.0	0.429	159	5	790
Mar. (late)	16.0	3.0	0.188	53.1	34	1800
Apr. (early)	12.5	1.0	0.080	17.7	300	5310
Apr. (middle)	10.7	1.5	0.140	26.6	72	1920
May (early)	10.5	2.5	0.238	44.2	18	795
May (middle)	12.0	3.2	0.267	56.7	13	737
June (early)	14.0	4.0	0.286	70.8	11.5	815
June (middle)	16.0	4.5	0.281	79.7	12	957

Load-carrying Capacity of The Base Course

For the purpose of investigating the ability of base course to distribute the load to the subgrade, loading tests were carried out with steel plate of 30 cm and 50 cm diameter. The pressure cell was installed 1 to 2 cm beneath the level of the subgrade. Laying the subgrade soil on the pressure cell, the base course materials were compacted to a thickness of 10 to 60 cm. The maximum size of the base course materials was 25 mm and the grading was within the AASHO specification for base course.

In Table 3, column 5 shows the ratio of the moduli of elasticity of base course and subgrade by Burmister's chart, column 6 shows the ratio of the vertical pressure at the interface to the applied pressure by Fox's calculation, and column 7 the ratio of vertical pressure measured by a pressure cell to the applied pressure. E_1/E_2 figures in column 5 do not differ much from one another, while they are scattered within the limits of 8 and 22 with respect to all data of this test.

Table 3

The results of loading test on the test base course with 30 cm diameter steel plate
Résultats de l'épreuve de charge sur une couche inférieure du revêtement exécutée avec une plaque d'acier de 30 cm de diamètre

(1)	(2)	(3)	(4)	(5)	(6)	(7)
h (cm)	h/a	K_{30}	F_w	E_1/E_2	$\frac{\sigma_h/p}{\text{by theory}}$	$\frac{\sigma_h/p}{\text{Measured value}}$
0	0	4.32				
10	0.67	6.8	0.636	10	0.49	0.37
20	1.33	9.5	0.455	8	0.21	0.28
30	2.00	12.5	0.346	8	0.12	0.16
40	2.67	16.0	0.270	10		0.115
50	3.33	19.8	0.218	11		0.08
60	4.00	23.0	0.188	12		0.065

The results of the loading tests are plotted in Fig. 7, and these lie on a curve fairly well. In this illustration, the results of the calculation of the elastic theory in a two-layer system for a perfectly rough interface by Fox are given in the dashed curve,

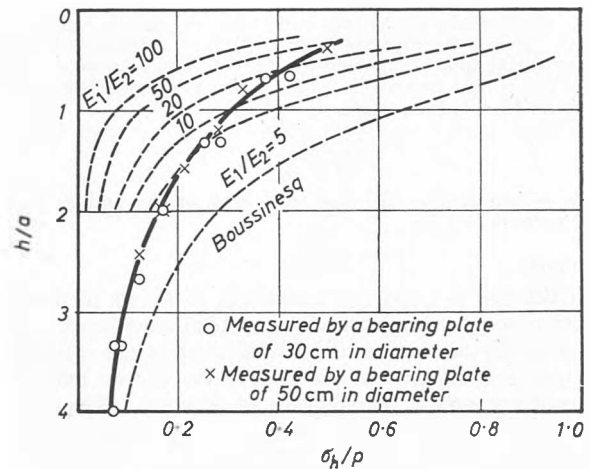


Fig. 7 Relation between σ_h/p and h/a
Relation entre σ_h/p et h/a

but the measured data are considerably different from those given by the elastic theory. In other words, if $h/a < 1$, namely in the shallow depth, the ability of the base course to distribute the load to the lower part is greater than that expected in the elastic theory. The increase of the load-carrying capacity of a gravel layer is comparatively large until such a point is reached that the thickness of the gravel layer gets to the radius length of the contact area of wheel load, after which the increase becomes relatively small as the thickness gets larger.

The load-carrying capacity of the base course in the interface of base course and subgrade is given in equation 5, within the limit of this investigation:

$$\frac{\sigma_h}{p} = 0.31 - 0.456 \log_{10} \frac{h}{a} \quad \dots (5)$$

where σ_h = the vertical pressure in the interface of base course and subgrade (kg/cm²).

In the thawing period E_1/E_2 is considerably different from the normal seasons, while the ratios of the vertical pressure measured by means of pressure cell and the applied load were not so different from equation 5. However, in order to make sure of the validity of equation 5 in the thawing period, a more extensive investigation should be conducted, since the data used above are limited.