Revising the Method for Calculating the Subgrade Bearing Capacity of Paved Roads on Embankments during the Thaw Season

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ABSTRACT: In cold, snowy regions in Japan, subgrade bearing capacity (described by design CBR) has been calculated in consideration of a possible drop in the capacity during thawing periods. However, because the bottom of the subgrade of a pavement on embankment is at a relatively great distance from the groundwater level, it is assumed that groundwater supply to subgrade that causes freezing is unlikely to occur. Therefore it is estimated that the subgrade bearing capacity of pavements on a high embankment may not drop even during thawing periods. This study describes a design method for design CBR of pavements on embankments in consideration of embankments heights. By introducing design CBR values that correspond to various embankment heights, pavement can be designed in a more cost-effective way. The study found the following: 1) on embankments with a height of 6 m or more, thawing periods were found to have only a slight impact on the subgrade bearing capacity. The field CBR can be used directly as the design CBR, 2) on embankments with a height of 3 - 6 m, the bearing capacity was confirmed to have dropped during thawing periods. The field CBR should be multiplied by 0.77 to obtain the design CBR, 3) on embankments with a height of 3 m or less, as the subgrade bearing capacity showed significantly varying degrees of deterioration, freezing/thawing tests should be made before CBR tests are conducted to decide the appropriate multiplication factor.

KEY WORDS : Design CBR, Embankment heights, Thawing periods

1 INTRODUCTION

In cold, snowy regions of Japan, especially Hokkaido, the subgrade bearing capacity greatly decreases from softening in spring due to thawing of frozen soil. To cope with this, the design value of subgrade bearing capacity (design CBR) in such regions is set lower than that used in warmer regions, under the assumption that the subgrade bearing capacity will decline in the spring.

Frost heave is said to occur only when groundwater level, soil type, and temperature gradient all meet conditions that promote that phenomenon (Japan Road Association, 1987). Mitigating any one of these can prevent frost heave. Because the subgrade of roads built on high embankments is relatively high above the groundwater level, it is logical to assume that groundwater is not readily supplied to the subgrade. Therefore, the reduced design CBR may be too low at those locations.

Using in-situ survey results on the subgrade bearing capacity of roads built on high embankments, this paper revises the method for calculating the design CBR in cold, snowy Hokkaido. The revised calculation method obtains design CBR values according to embankment height and enables a more rational and economical pavement design than the traditional one.

2 FROST HEAVE COUNTERMEASURES FOR EMBANKMENTS

On relatively high embankments, the upper surface of the subgrade is far above the groundwater level, so the subgrade is largely free from frost heaving. According to Yokota et al. 1997, the frost heave ratio is very small where the groundwater level is below the subgrade by 2 m or more, though the ratio differs by soil type, and the frost penetration depth is affected by water content (Figure 1). For expressways, many of whose sections are on high embankments, different frost heave countermeasures have been specified for three embankment height ranges (Table 1) (Japan Highway Public Corporation, 2001).

For sections of national highways in Hokkaido on embankments 6 m or higher and whose water content of subgrade soil is below 25%, thickness of the frost blanket, a frost heave countermeasure in which the subgrade soil is replaced, can be reduced by approximately 15% (Ikeda, 1987). These indicate that frost heave is less likely to occur in the subgrade of high embankments, so it is reasonable to assume that the subgrade bearing capacity there does not decrease very much during the thaw season.

Table 1: Frost heave countermeasures for embankments[3)]

Embankment height	Frost heave countermeasures
Greater than 6 m	None taken
3 - 6 m	Taken (thickness of frost blanket: 15 cm)
Less than 3 m	Taken (Examine the applicability of the same countermeasure taken for the cut section.)

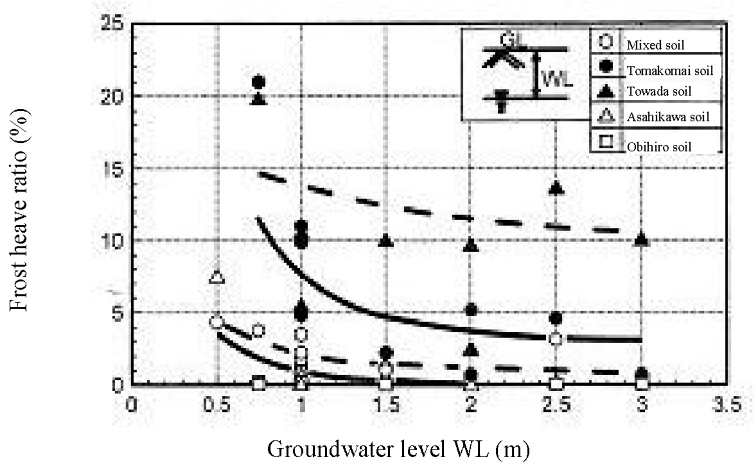


Figure 1: Relationship between groundwater level and frost heave ratio[2)]

3 FIELD SURVEY ON SUBGRADE BEARING CAPACITY

3.1 Survey Outline

To find whether or not the subgrade bearing capacity on high embankments decreases during the thaw season, we conducted a survey on national highways in Hokkaido using a Falling Weight Deflectometer (FWD). Survey sites with embankments of various heights were selected (Figure 2).

Figure 2: FWD survey sites

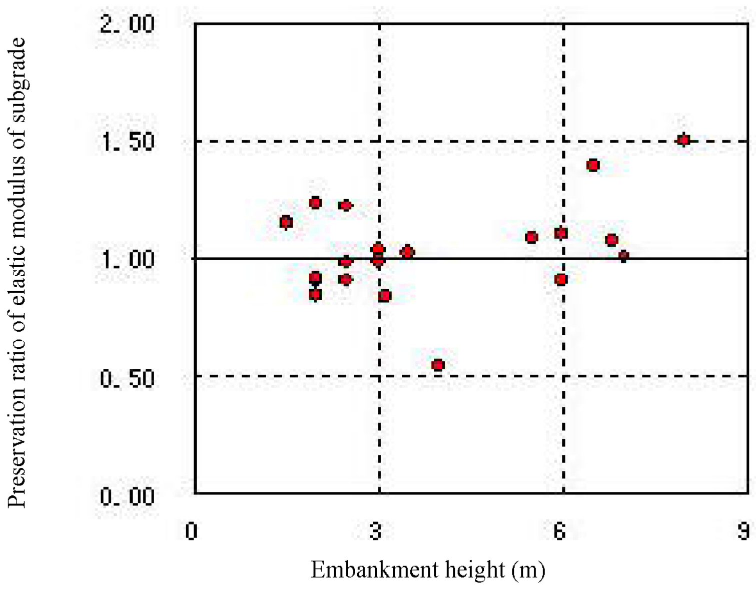


Figure 3: Embankment height and preservation ratio of elastic modulus

The embankment height of survey sites ranged between 1.5 m and 8.0 m. The types of subgrade soil included psephite, fine-grained soil, and volcanic ash. The frost heave ratio was 1% to 22% in a laboratory test.

FWD measurement was made in the fall of 2002 and in the spring of 2003 (thaw season). The elastic modulus of the asphalt mixture layer, base course, and subgrade were calculated from measurements of the deflection of the asphalt surface using an inverse analysis computer application called the Layer Moduli Backcalculation System (LMBS). It was developed by the Department of Civil Engineering, Faculty of Science and Engineering, Chuo University.

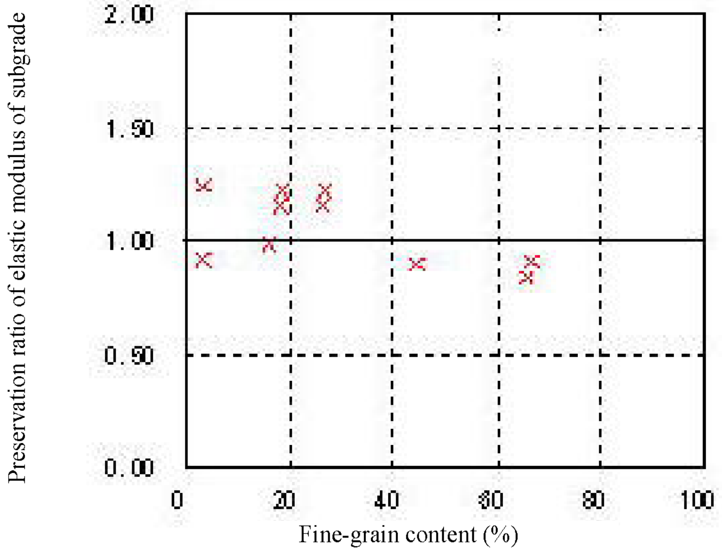
The preservation ratio of elastic modulus of subgrade was calculated using the Equation (1) from the calculated subgrade elastic modulus values of the fall (before freezing) and the spring (after thawing).

Preservation ratio of elastic modulus of subgrade
= (Elastic modulus after thawing) / (Elastic modulus before freezing) (1)

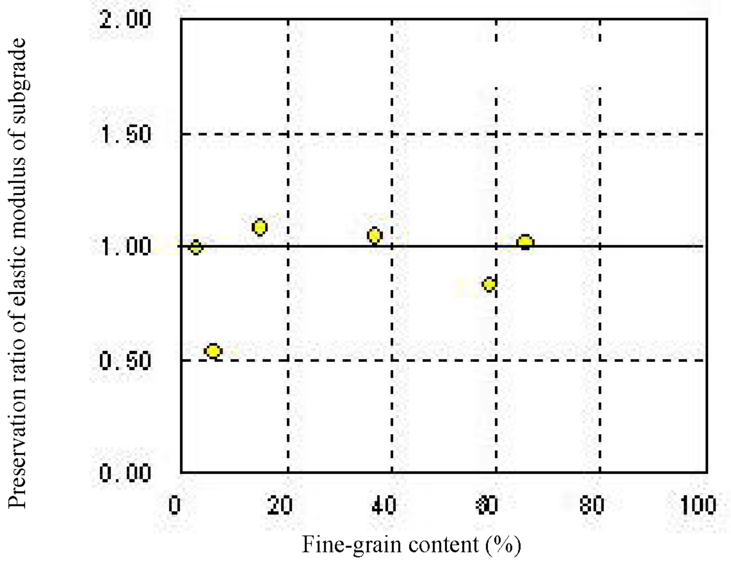
3.2 Survey Results and Analysis

Figure 3 shows the relationship between the embankment height and the preservation ratio of elastic modulus of subgrade. In Figure 3, the embankment height is the distance between the upper surface of the subgrade and the foundation ground. Although the embankment height differs from the distance between the subgrade and the groundwater level, it is regarded as the distance between the upper surface of the subgrade and the groundwater level because measuring the groundwater level at all the survey sites is extremely laborious. Since frost heave depends on soil type, no clear relationship can be seen between the embankment height and the preservation ratio of elastic modulus of subgrade. However, in many cases where the embankment height was less than 4 m, the preservation ratio of elastic modulus of subgrade was below 1 (meaning that the bearing capacity is reduced after freezing-thawing).

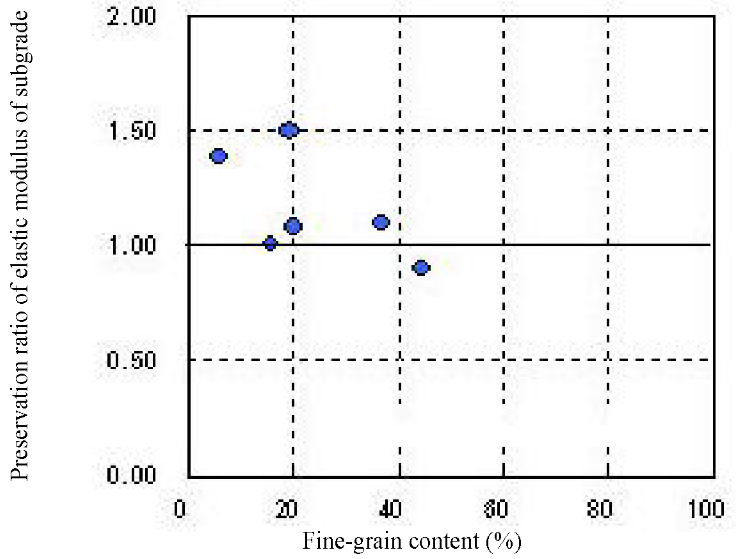
Figures 4(a), 4(b), and 4(c) show the relationship between the fine-grain content and the preservation ratio of elastic modulus of subgrade for embankment height ranges of less than 3 m, 3 - 6 m, and greater than 6 m, respectively. There is no clear relationship between the fine-grain content and the preservation ratio of elastic modulus of subgrade for any of the embankment height ranges. In the embankment height range of greater than 6 m, almost all the preservation ratios of elastic modulus of subgrade equal or exceed 1.0 regardless of the fine-grain content.



(a) Embankment height of less than 3 m



(b) Embankment height of 3 - 6 m



(c) Embankment height of greater than 6 m

Figure 4: Fine-grain content and preservation ratio of elastic modulus

4 SURVEY AT TEST INSTALLATION SITES

4.1 Survey Outline

A bearing capacity survey was conducted at the ramp of the Mukawa Interchange on the Hidaka Expressway to find the conditions under which subgrade bearing capacity declines in the thawing seasons in a road section built on an embankment. Test sections were prepared on the ramp where the embankment height was 3 m and 9 m. The frost blanket of 60-cm replacement thickness was installed in each section in addition to the standard frost blanket of 80-cm replacement thickness.

The survey items on the embankment material were soil type, presence of surface uplift by frost heave, degree of such uplift, frost penetration depth, and the in-situ CBR value. The in-situ CBR values were measured in the thaw season and in summer to calculate CBR preservation ratio.

4.2 Survey Results and Analysis

The soil test found that the embankment material was volcanic ash with a fine grain content of 14.7%, and the frost heave ratio was 11%.

Figure 5 shows the maximum surface uplift by frost heave in the 2002/2003 winter and the frost penetration depth measured on the day when the maximum surface uplift was observed. The maximum surface uplift by frost heave ranged from 0.6 cm to 0.8 cm with no difference with respect to replacement thickness or embankment height.

The frost penetration depth in the subgrade increases as the replacement thickness decreases.

The frost penetration depth in the subgrade of the 3-m embankment is greater that in the 9-m embankment.

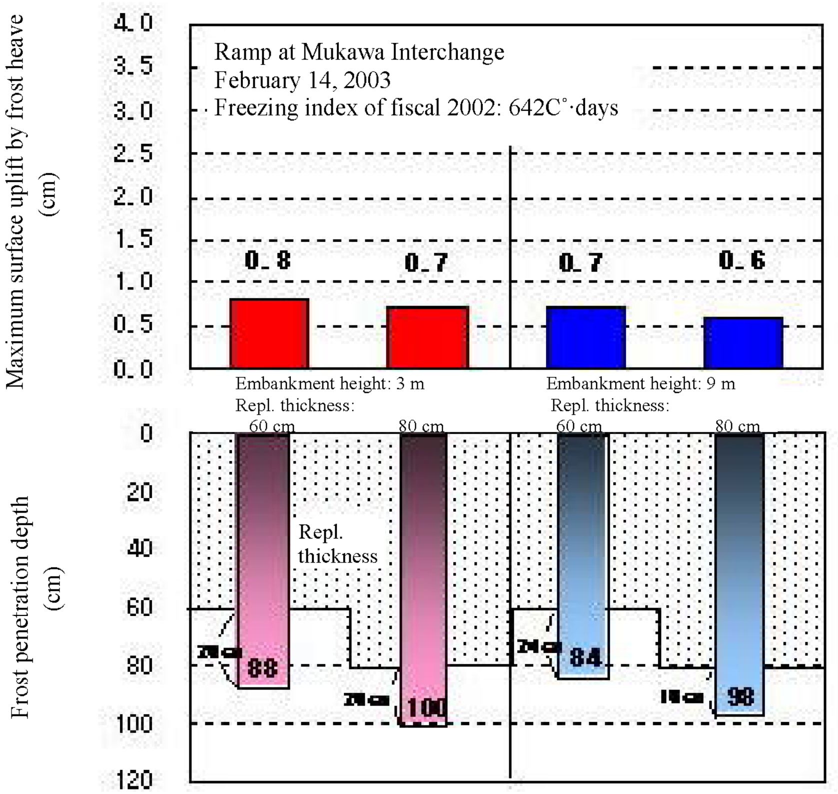


Figure 5: Maximum surface uplift by frost heave and frost penetration depth

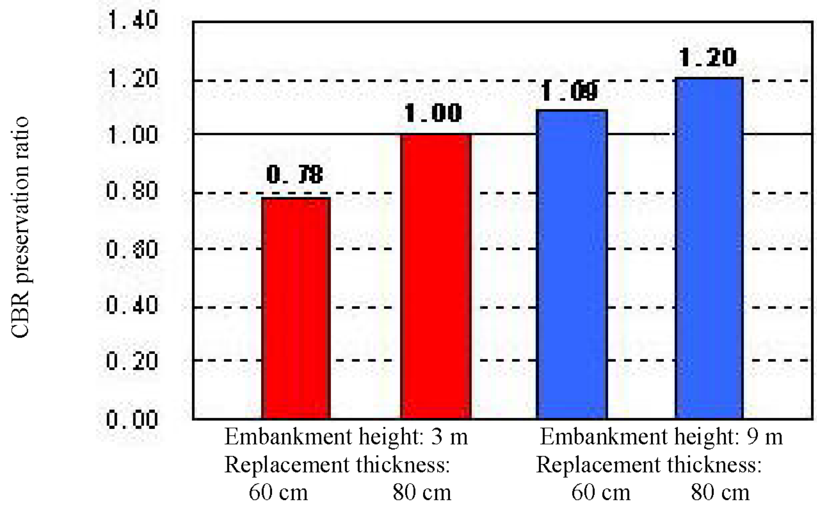


Figure 6: In-situ CBR value test results

Figure 6 shows the CBR preservation ratio acquired from the in-situ CBR test. When the embankment height is 9 m, the CBR preservation ratio is greater than 1.0 regardless of the replacement thickness. It is smaller than or equal to 1.0 when the embankment height is 3 m.

The results confirmed that subgrade bearing capacity does not decrease during the thaw season for embankments 9 m in height.

5 REVIEW OF THE DESIGN CBR FOR SUBGRADE

Based on the results of the field survey and in-situ test installation, the CBR before freezing and after thawing was estimated for three different embankment height ranges. To estimate the CBR from FWD measurements, Equation (2), which is drawn in Figure 7, was used:

$$E = 100\ CBR\ (kg/cm^2) = 10\ CBR\ (Mpa) \qquad (2)$$

Where, E is the elastic modulus of subgrade.

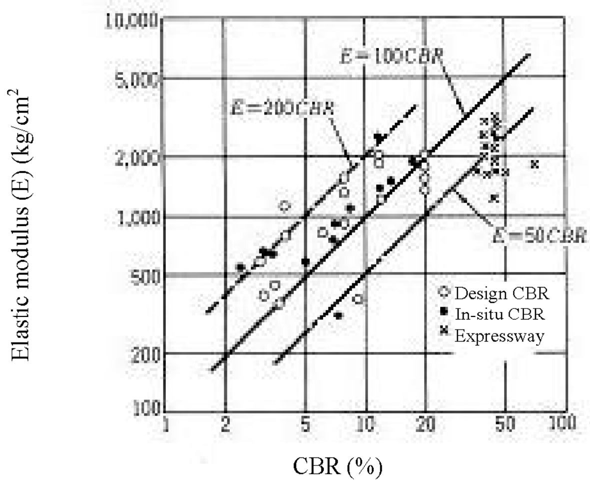
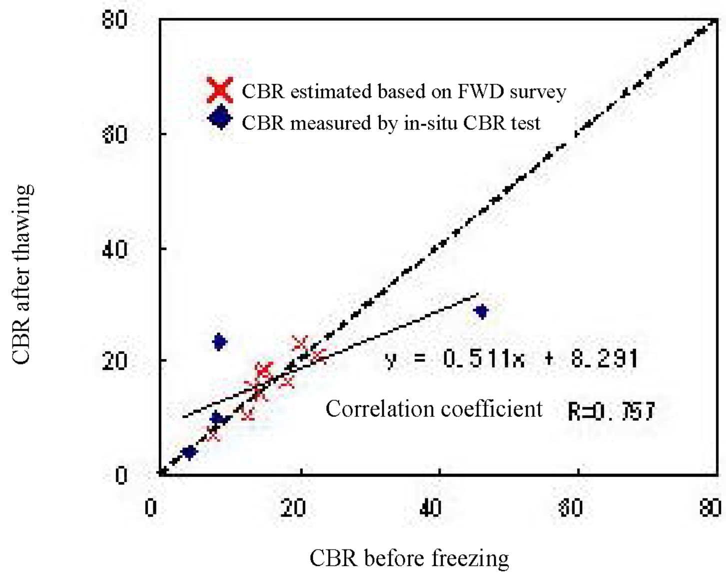
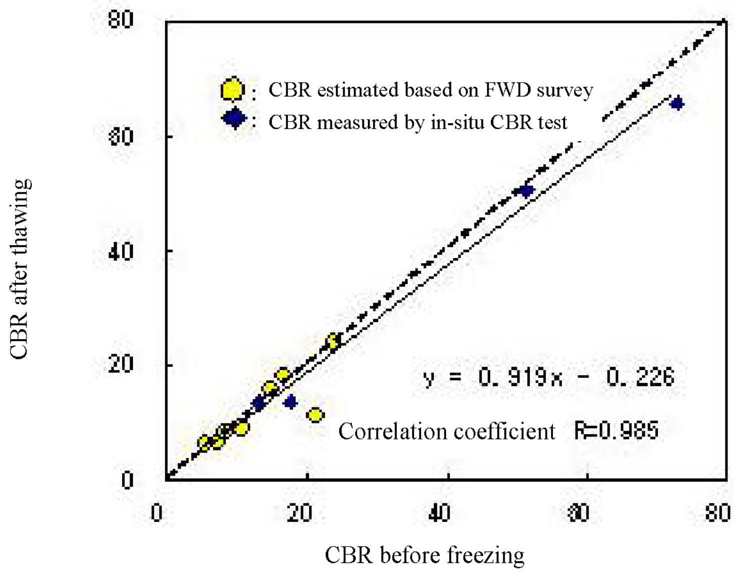


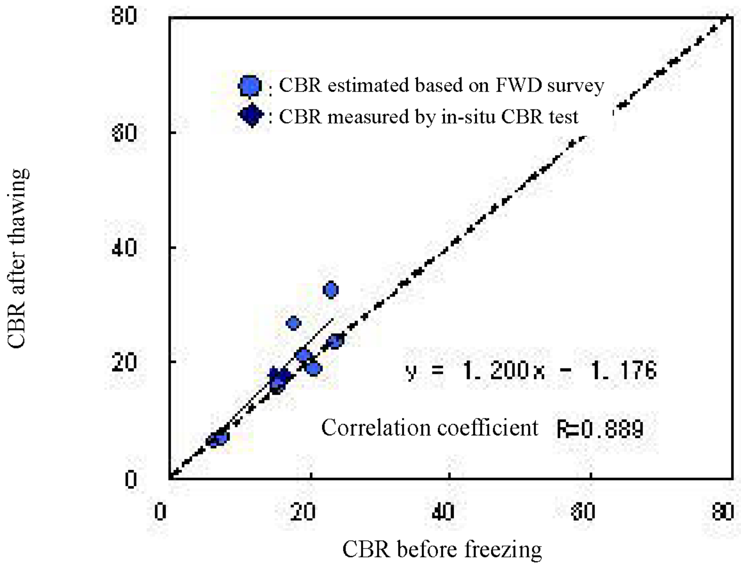
Figure 7: Relationship between CBR value and elastic modulus (E) calculated from FWD deflection (Maruyama, 1989)



(a) Embankment height of less than 3 m



(a) Embankment height of 3 - 6m



(a) Embankment height of greater than 6m

Figure 8: CBR before freezing and after thawing for three different embankment height ranges

Table 2: CBR preservation ratio by embankment height range

Embankment height range	Number of data	CBR preservation ratio of subgrade (%)		
		Average $\bar{x}$	Standard deviation σ	$\bar{x}$-σ
Embankment height of less than 3 m	(n=14)	1.15	0.506	0.647
Embankment height of 3 - 6 m	(n=12)	0.92	0.152	0.767
Embankment height of greater than 6 m	(n=10)	1.12	0.189	0.932

Figures 8(a), 8(b), and 8(c) show the relationship between the in-situ CBR before freezing and that after thawing for three different embankment height ranges.

Where the embankment height is below 3 m, the subgrade CBR before freezing shows a low correlation with that after thawing. Due to the low embankment height, the subgrade is readily affected by the groundwater and the soil type. The CBR values we obtained are largely inconsistent.

Where the embankment height is between 3 m and 6 m, the subgrade CBR before freezing closely relates to that after thawing. The slope of the regression line is approximately 1.

Where the embankment height is greater than 6 m, the subgrade CBR before freezing closely relates to that after thawing. The slope of the regression line is also approximately 1.

The CBR preservation ratio calculated from the in-situ CBR before freezing and after thawing is shown in Table 2. We categorized the design CBR for the three embankment height ranges based on the table:

a) Embankment height over 6 m

The effects of bearing capacity decrease during the thaw season are minimal, so the design CBR does not need to be reduced.

b) Embankment height between 3 m and 6 m

Decrease in the bearing capacity during the thaw season has been confirmed, so the design

CBR needs to be decreased. Because of the inconsistency in CBR preservation ratio, the average value of CBR preservation ratio less the standard deviation (0.767, from Table 2) is deducted from the design CBR.

c) Embankment height below 3 m

The values of CBR preservation ratio are inconsistent, so the CBR after thawing needs to be measured to determine the design CBR.

The results above are based on in-situ tests and surveys. At the pavement design stage, it tends to be difficult to conduct an in-situ test. For a) and b) above, it is recommendable to collect samples from the site, to conduct a laboratory CBR test on them, and determine the design CBR.

For c) above, it is recommended either to conduct a frost heave test on soil samples taken from the site, and then measure CBR by laboratory test, or to determine the design CBR from fine-grain content and frost heave ratio given in the literature (Takemoto, 2003).

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