Frost Heave of Roads in Hokkaido and Its Countermeasures

Michiyoshi KOYAMA and Harumi SASAKI
小山道義　佐々木晴美
Civil Engineering Research Institute
Hokkaido Development Bureau, Sapporo, Japan

Abstract

For preventing frost damages from paved roads in Hokkaido, the so-called replacement method has been adopted with the aid of the current specifications provided by the Hokkaido Development Bureau. However, there still remain some problems to be solved to obtain the rational design criteria for paved roads. Particularly, the frost preventing effect and load carrying capacity in thawing period are urgent to be solved at the present time in Hokkaido.

This paper contains the following items.

1. Frost Heave of Roads in Hokkaido.
2. Replacement Method in Hokkaido.
3. Research Outline on This Subject.
4. Bibi Frost-Heave Test Road.

I. Introduction

Frost heave, essentially caused by cold weather, is one of the greatest problems in roads and road construction at cold areas. Since 1951 the Hokkaido Development Bureau (HDB) has conducted research and studies on frost heave of roads in co-operation with the Hokkaido University, the Hokkaido Prefectural Government and other organizations concerned. For the paved roads to be newly constructed, the so-called replacement method providing nonfrost-susceptible subbase is adopted and recommended in Hokkaido. In road construction practice, the current specifications provided by the HDB are available. However, there still remain some problems to be solved.

This paper describes the outline of frost heave of roads in Hokkaido, its countermeasure provided by HDB, and Bibi road test being conducted to make clear frost problems concerning road construction.

II. Frost Heave of Roads

Roads of Hokkaido are under such severe weather and frost conditions as shown in following figures.

Figure 1 shows the maximum freezing index most closely related to the freezing of ground at representative cities of the island. The city of Hakodate has the lowest with −328 °C·day and the city of Obihiro, the highest with −874 °C·day, while in mountainous parts it often goes beyond −1 000 °C·day.

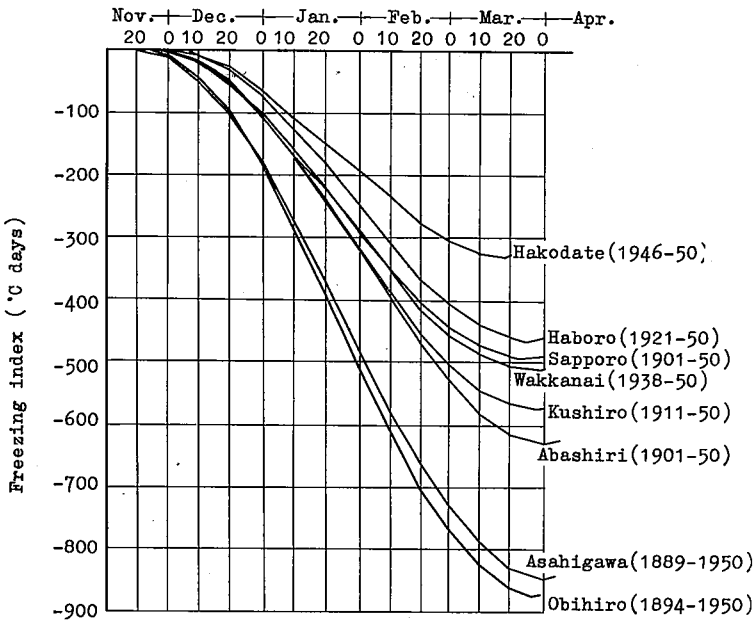


Fig. 1. Freezing index in Hokkaido (statistical value)

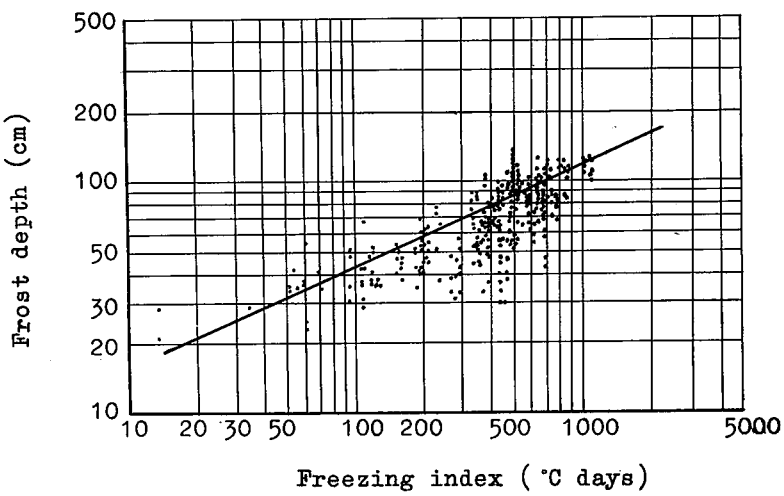


Fig. 2. Relationship between freezing index and frost penetration depth in existing gravel roads in Hokkaido (1955, 1956)

Figures 2 and 3 show frost data for the island (Ifukube, 1962; Miyakawa and Koyama, 1962).

III. Replacement Method for Frostpreventing

Much has to be yet discovered about the frost heave mechanism. However, several methods for preventing frost heave are: replacement, heat insulation, water interception and chemical treatment. In Hokkaido, the replacement method is the most popular:

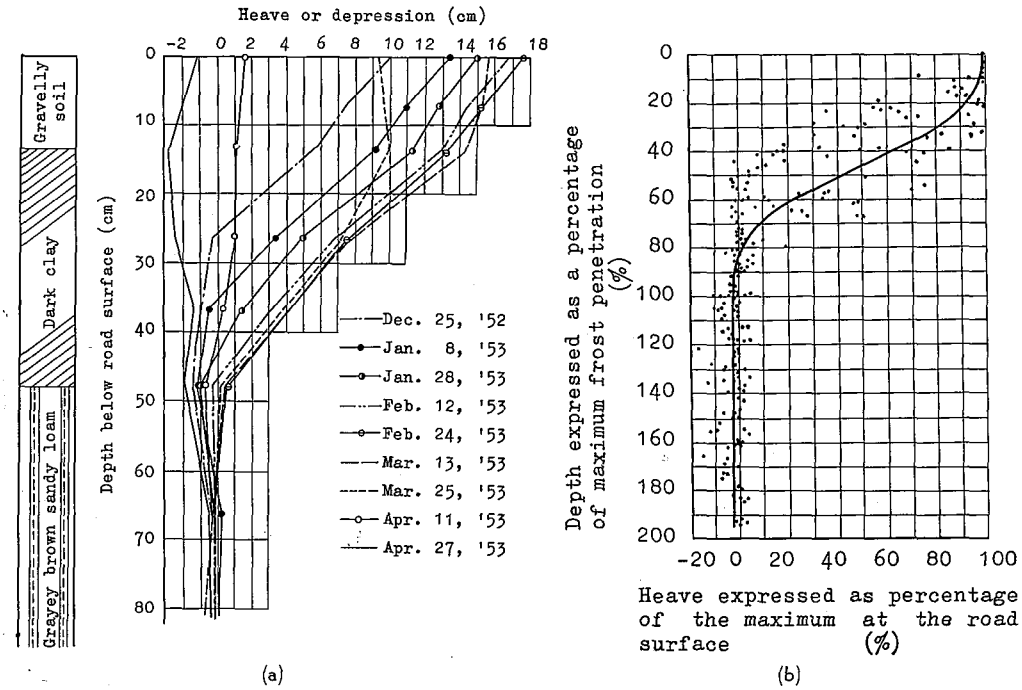


Fig. 3. (a) Frost heave profile at Nina, Hokkaido (1952–53)
(b) Profile of frost heave, at its max. value, of existing gravel roads in Hokkaido (1952–54)

frost-susceptible subgrade soil within the freezing depth is replaced by nonfrost-susceptible materials. The chemical method is adopted only as a subsidiary step to the replacement method. Heat insulation and water interception methods are not used except experimental adoptions.

The following design criteria on the replacement method, provided by the HDB, are based on the results of both field investigations and laboratory tests conducted there hither-to, and might be revised and supplemented.

Replacement depth. Generally, it is uneconomically to replace the whole frost-depth. As replacement materials, sand and unscreened gravel are used, and replacement by such coarse-graind materials further lowers the frost line as compared with existing frost depth of subgrade before replacement, and so much expense is needed if replacement is to be made down to the estimated frost depth. In practice, therefore, it becomes important to set the minimum depth of replacement for preventing frost heave damage—that is, for reducing the frost heave to the amount that will not damage the surface layer but will secure a necessary subbase bearing capacity at the thawing season.

The requirements for the subbase as to bearing capacity and its uniformity vary according to whether the surface layer is rigid or flexible. Therefore, the replacement depth and the selection of materials are closely related to the kind of pavement. One reason for adoption of flexible pavement in Hokkaido is that this kind of pavement has been found by experience to be best fitted for the partial replacement technique. The HDB recommends a replacement ratio (the depth ratio of select replacement material to

original frost depth) of about 80% (HDB, 1966, p. 17), considering that only a small percentage of the surface heave of existing gravel roads is attributable to the soil below 80% of the original frost penetration depth as shown in Fig. 3. It is also expected that the adopted depth of select fill may provide sufficient bearing capacity, even if the accumulation of extra water and resultant weakening might damage the underlying layer. In the districts having a shallow frost depth, therefore, the depth of select fill may be concerned only with bearing value.

The standard depths of paved structures in various districts have been adopted as follows: in Hakodate, 60 cm; Asahigawa and Obihiro, 90~100 cm; and the others, 80 cm. In the districts having a deep frost depth, however, the frost heave often damages the surface layer of bituminous pavement.

Figure 4 shows the frost damage at Obihiro district. For preventing these damages of roads, chemical treatment and heat insulation have been experimentally adopted there.

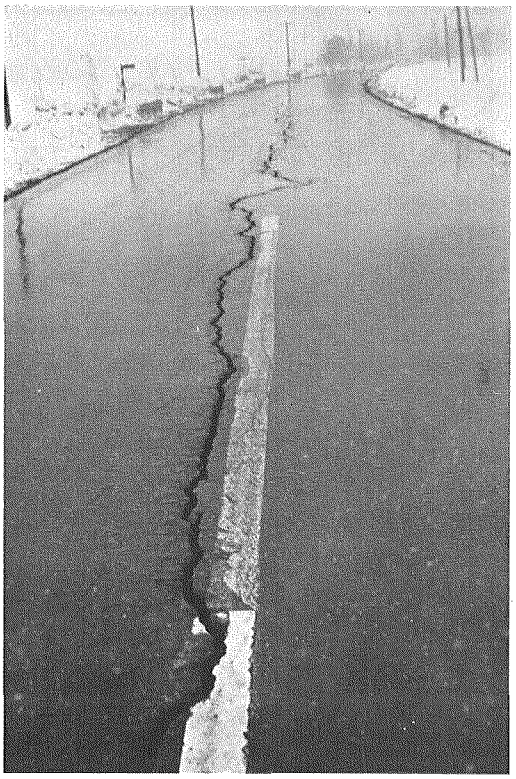


Fig. 4. Frost damage. Longitudinal crack at the center having qualified structure of 100 cm thickness

Quality of replacement materials. Materials used for a subbase should be nonfrost-susceptible and maintain the necessary bearing capacity. A subbase usually consists of two layers: a subbase course and a frost preventing layer. Since replacement materials are needed in large quantities, it is important to obtain inexpensive materials. When qualified materials for a subbase course are available at low prices, a frost preventing layer can be made of the same materials. When more than two kinds of materials are used from the economical point of view, they should be classified according to qualities demanded in road structural functions. As for frost-susceptibility of materials usually utilized such as sand, unscreened gravel, volcanic ashes etc., the HDB has provided the following standards in its specifications (HDB, 1963, p. 57–p. 59). Frost-susceptibility of unscreened gravel is checked by the amount of the fraction passing the 74 μ sieve in the sand fraction passing the 4 760 μ sieve and a weighted amount less than 9% is tolerable. Crusher-run is generally used for the subbase course, and the specifications above mentioned are applied correspondingly. Frost-susceptibility of the sand is checked by the amount of the fraction passing the 74 μ sieve; and in the case of the amount less than 6% it is allowed to consider nonfrost-susceptible. Volcanic ashes at local areas are so inexpensive and readily available that they are often used. Materials should not

have any signs of efflorescence, the fraction content passing the 74 μ sieve more than 20% and ignition loss more than 4%. Standards for fine fraction content and ignition loss were temporarily set as a simple method of judging frost-susceptibility of volcanic ashes. Even volcanic ashes out of the standards, however, can be used when they are ensured to be nonfrost-susceptible by frost heaving test.

IV. Bibi Road Test

Since 1960 frost experiments and surveys have been successively conducted on a test road at Bibi, City of Tomakomai (along National Highway Route No. 36) to obtain data for rationally designing a road structure in a cold area, and the investigation will be continued until 1968. The period of investigation is divided in two terms. The investigation in the first term (1960–1965) was conducted to check how antifrostheave effects and subbase bearing capacity vary according to the kind, quality and thickness of replacement materials under various weather and traffic conditions. On the basis of its findings, the investigation of the latter (1966–) has been conducted with the aim of establishing the road design and construction method in a cold area. The outline of the investigation of the first term is described below.

Outline of the test road

The test road is 1 250 m long and 7.5 m wide. It consists of the frost test section 480 m long, the stabilization test section 300 m long and the access road 470 m long. The longitudinal cross section of the frost test section is shown in Fig. 5, which illustrates the arrangement of each test block and the structural component of the road. The test road was completed with laying the surface course of Topeka in 1961.

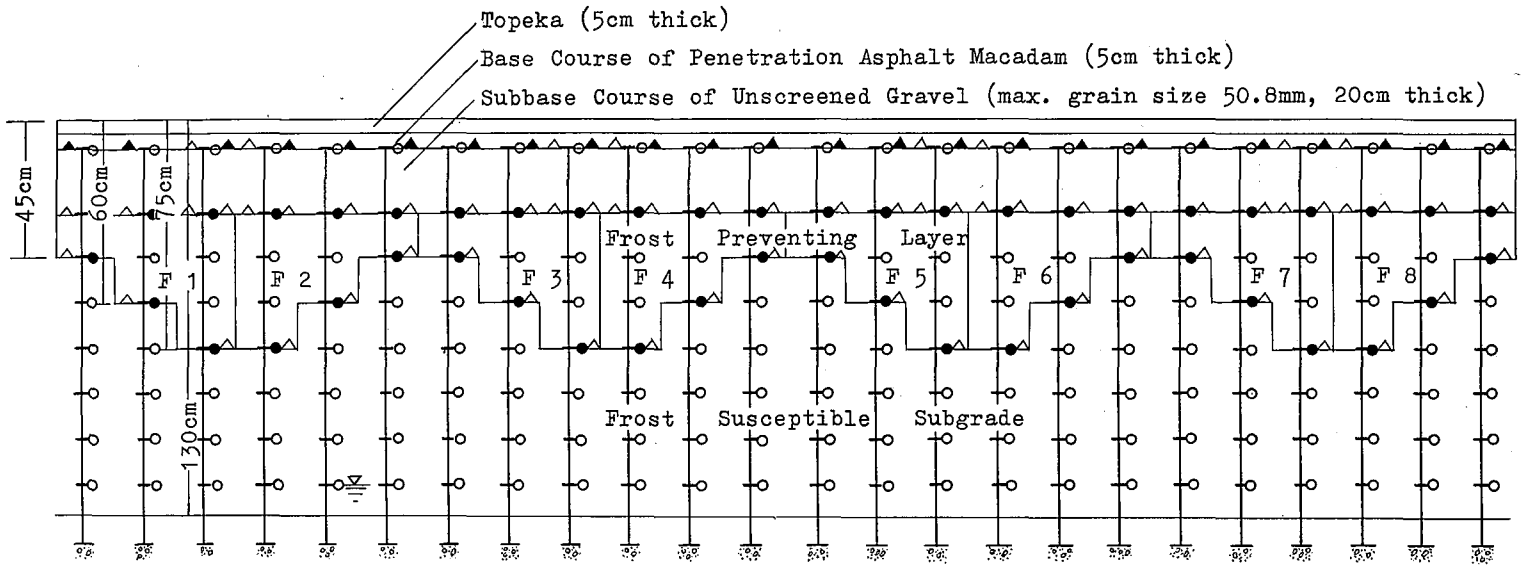
The frost test section

This section is divided in 24 test brocks with 8 kinds of material and with 3 kinds of thickness for the frost preventing layers: 2 kinds of volcanic ashes, 2 kinds of sand and 4 kinds of gravel. As for sand and gravel under distinction in their maximum grain sizes such as 4.76, 25.4 and 50.8 mm, were selected respectively both of the materials which conform to or not to the specifications. Then, one kind of the volcanic ashes was coarse-grained and the other fine-grained.

The road is in 3 kinds of thickness; 75 (the standard value in this district), 60 and 45 cm. Throughout the section, were adopted the uniform kind of subbase course (gravel subbase course, 20 cm thick), base course (penetration asphalt macadam, 5 cm thick) and surface course (Topeka, 5 cm thick), and frost preventing layer have 3 kinds of thickness of 45, 30 and 15 cm.

The subgrade was built with the remarkably frost-susceptible soil. The frost-susceptible subsoil was laid and compacted to 10 cm thick for the lowest layer and 15 cm thick for the layer above, so that it could be compacted uniformly with the compaction value of 70% for the lowest layer, 75% for the second, 80% for the third and 95% for the layers above, of the maximum dry density by the JIS soil compaction test.

The frost preventing materials were laid and compacted to 15 cm thick at each layer respectively. As for the coarse-grained materials, special care was taken in laying them, so as not to get these coarse and fine grains separated. The CBR test and the



Instrument for Investigation

Symbol	Instrument	Remarks
▲	Apparatus for Bearing Test	
△	Pressure Cell	Carlson Type (0~6 kg/cm^2)
┼	Measuring Apparatus for Frost-Heave	
●	Thermometer	Pt 50Ω/0 °C Self Recording
○	Thermometer	Pt 50Ω/0 °C

Used for Frost Preventing Layer

Block	Materials	Maximum Grain Size (mm)	Percentage Passing 0.074mm Sieve in Fraction Finer than 4.76mm (%)
F 1	Unscreened Gravel	50.8	17
F 2	Unscreened Gravel	50.8	5
F 3	Unscreened Gravel	25.4	17
F 4	Unscreened Gravel	25.4	7
F 5	Sand	4.76	11
F 6	Sand	4.76	5
F 7	Volcanic Ash	Coarse Grained	
F 8	Volcanic Ash	Fine Grained	

Fig. 5. Explanatory chart on the frost test section of the Bibi test road

plate bearing test were carried out after the JIS method for management of the compaction at each layer.

Subbase course was built, after the same tests, with a layer of 20 cm. After the construction of subbase course, the subbase course and frost preventing layer were dug open for the confirming test of the density, moisture content, plate bearing and CBR.

Item of investigation

The main items of the investigation for the frost test section are as follows:

(a) The difference in frost controlling effects from the variation of the kind and thickness of the frost preventing layer.

(b) The difference in load dispersing of the frost preventing layer, resultant bearing capacity measured on subbase course and their seasonal fluctuations, particularly the loss of the bearing capacity at the thawing period, from the variation of the kind and thickness of the frost preventing layer.

Results

The construction work was completed up to the base course in November, 1960. Therefore, the test road was not opened to the traffic for the first year, but kept its base course exposed to the cold air with snow cleared at all times. Soil temperature, frost heave amount, bearing capacity of subbase course and soil pressure stress were periodically measured every month. At the same time, the additional survey was carried out on weather, underground water level and other matters.

In 1961, the road was opened to the general traffic after the surface layer was

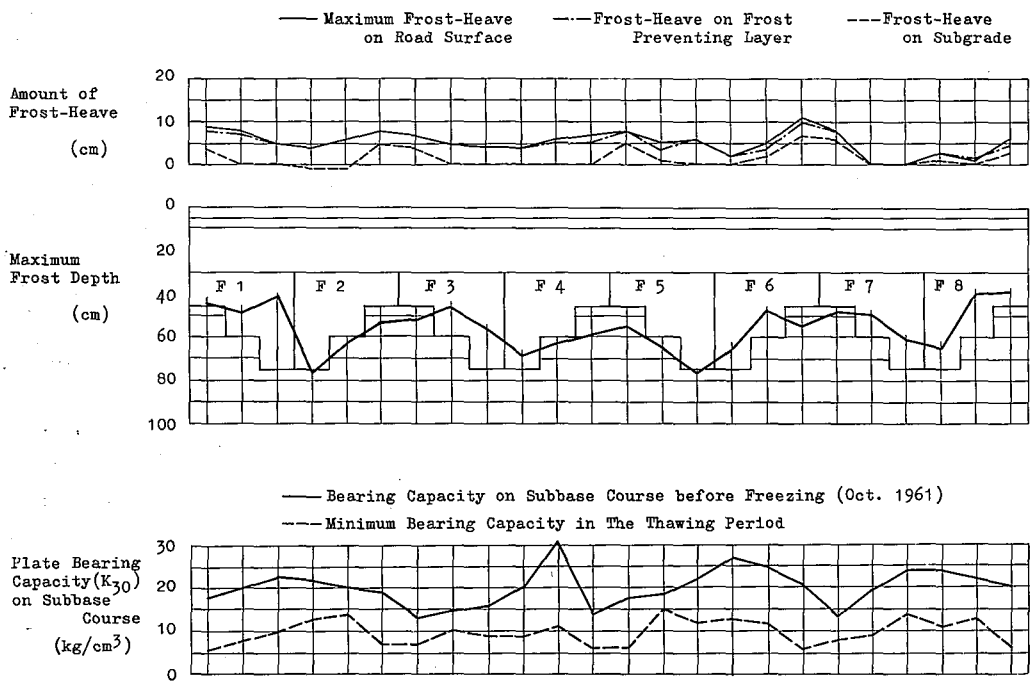


Fig. 6. Maximum amount of frost heave, maximum frost depth and plate bearing capacity on Subbase course at the Bibi test road in 1961–1962

completed, and then were done similar investigations. Since 1962, the investigations have been successively carried out from autumn to next spring.

Figure 6 shows the maximum frost heave amount, maximum frost depth and the seasonal fluctuations of bearing capacity of subbase course at each test block of the frost heave test sections, that were extracted from the data of investigation.

The findings of the investigations are as follows:

1) Frost depth

In this investigations, maximum frost depth is inclined to grow up in proportion to the thickness of frost preventing layer. This coincides with that obtained by the experience.

2) Frost heave amount

(a) Maximum frost heave amount measured on road surface decreases when the thickness of frost preventing layer becomes larger. When the frost affects severely subgrade, frost heave of subgrade contributes to that of road surface.

(b) The frost heave of frost preventing layer is considerably large, comparing with that of subbase. When frost does not penetrate into the subgrade or affects slightly subgrade, frost heave amount of road surface mostly consists of that of frost preventing layer.

3) Plate bearing capacity

(a) The bearing capacity measured on subbase decreases at the thawing period and it is caused by frost heave phenomenon. On this subject it must be emphasized that the loss of bearing capacity measured on subbase is caused by not only the decrease of density and the increase of moisture content of subgrade, but also those of frost preventing layer.

(b) In general, the larger the total thickness of frost preventing layer and subbase course is, the larger the bearing capacity is at the thawing period. However, it is occasionally found from some data that the effect of increasing the total thickness on subbase bearing capacity decreases when the thickness reaches beyond a certain value. Such a result is found when the loss of bearing capacity is regarded to be mainly caused by subbase or frost preventing layer.

(c) At the location of this test road, replacement of 75 cm is almost rational for frost preventing and it is expected that the increasing replacement thickness may bring a good effect on frost preventing. However, it must be noted that the residual bearing capacity measured on subbase at the thawing period is only 8–16 kg/cm^3 in K_{30} for the whole thickness 75 cm of road structure above subgrade, and even in the case of the whole thickness more than 75 cm, the residual bearing capacity does not reach the value required for asphalt pavement for such materials of the subbase course and frost preventing layer as used in this test road.

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* HDB: Hokkaido Development Bureau.

† In Japanese.