FREEZE-THAW EFFECTS IN NEW ZEALAND PAVEMENTS

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AN IMPORTANT NOTE FOR THE READER

CONTENTS

EXECUTIVE SUMMARY

Assessing freeze-thaw effects in New Zealand pavements will allow engineers to improve the design of frost-resistant pavements.

The design of frost-resistant pavements is discussed, for which the effect of freezing and thawing on pavements, the mechanism of frost heave, loss of strength during and after thawing, and the symptoms of frost damage are described.

Aspects of good design for frost-resistant pavements that are described cover:

- Selection of suitable frost-resistant material for the basecourse, including methods for their assessment and the use of additives;
- Increasing the thickness of the basecourse, in relation to the depth of frost penetration into the pavement;
- Provision of appropriate subsurface drainage;
- Control of traffic during thawing.

The use of geotextile composites and the application of seal coats are also discussed.

For special designs, laboratory testing using a freeze-thaw cabinet is recommended. For routine designs, a modified TNZ M/4:1985 "Specification for Crushed Basecourse Aggregate" can be adopted.

ABSTRACT

The design of frost-resistant pavements are discussed. Aspects of design include: the effects of freezing and thawing on pavements; selection of frost-resistant basecourse materials, including methods for their assessment and the use of additives; increasing the thickness of basecourse in relation to depth of frost penetration; provision of subsurface drainage; control of traffic during thawing; use of geotextile composites; and the application of seal coats.

1. EFFECT OF FROST ON PAVEMENTS

1.1 General

A general overview of freeze-thaw effects in soils is given in Mitchell (1976). The influence of frost on pavement performance is a major consideration for the design of pavements in colder parts of New Zealand. The principal two phenomena of frost damage in pavements are:

- Frost heave
- Post-thaw bearing strength loss.

These two phenomena depend on the simultaneous presence of several factors:

- Frost-susceptible pavement materials, used for basecourse and subgrade;
- Sub-zero pavement temperatures;
- Water supply to help form and feed the ice lenses within the pavement materials.

1.2 Frost Heave

Frost heave occurs when frost penetrates below the pavement surface in zero or sub-zero temperatures. Unbound water within the basecourse and subgrade layers may become frozen. When it is frozen, water is no longer available to humidify the pavement materials, and a humidity gradient (or negative pore pressure) is developed across the depth of the pavement. This causes a flow of water from the lower unfrozen layer upward to the underside of the frozen layer (frozen front).

During the freezing period the water that accumulates at the frozen front in the pavement also starts freezing. The water transforms into ice lenses that then expand. The expansion results in either an internally increased induced pressure or heave (uplift) of the pavement materials. In either case, the effect is not necessarily uniform, so cracking of the pavement may occur.

1.3 Post-thaw Bearing Strength Loss

On thawing, the ice lenses within the pavement materials melt. As a result, water contents in the basecourse and subgrade materials are higher than water contents before freezing. If this water cannot be readily dispersed the material may become unstable under traffic loading.

During thawing, the pavement rebounds elastically from the heave displacement. However, some permanent deformation will remain. The freezing and thawing process results in loosening of the inter-particle bonds between the roading aggregate and the subgrade materials, thus lowering the bearing strength of the pavement. The California Bearing Ratio (CBR) is normally used to measure the bearing strength of the basecourse materials. Laboratory investigations by Cheung and Sutherland (1995) have shown that the post-thaw CBR values of basecourses can be as low as 30% of their original values before freeze-thaw testing.

1.4 Distress

According to Bisset and Salt (1989), frost damage normally has the following visual characteristics for sealed roads:

- Surface cracks;
- Smooth surface texture where chip has been pushed down through the binder;
- Rutting within wheeltracks.

For sealed roads, the deterioration symptoms of the pavement can also include small weeping cracks, "alligator" or "chicken wire" cracking, loss of seal coats, and shear failures. Cracking of the surfacing allows water to infiltrate the basecourse and subgrade, generally resulting in rapid deterioration of the pavement.

For unsealed roads, the symptoms show first as slushing of the surface and rapid deterioration of the pavement as traffic passes over the road. Eventually, deep wheel ruts are formed.

2. DESIGN OF FROST-RESISTANT PAVEMENTS

2.1 General

In some countries, such as the United States and Canada, with very long and severe winters, pavements are surfaced with thick asphaltic concrete to resist the frost damage. However, such pavements with thick seal coats are very expensive and are not warranted for the relatively mild winters of New Zealand.

Good pavement design and management practices aimed at resisting frost damage should consider the adverse effects caused by the climate, temperature, materials properties and traffic. In New Zealand Fong and Cheung (1995) found, from a survey of roading practitioners, that successful control of pavement damage in frost-prone areas involved one or a combination of the following practices:

- Selection of suitable frost-resistant basecourse materials;
- Increasing the basecourse thickness, to ensure that pavement subgrade is below the depth of frost penetration;
- Provision of subsurface drainage systems;
- Control of traffic load during the thawing period.

2.2 Selection of Frost-resistant Basecourse Materials

Frost-resistant basecourse materials can be prepared and assessed using one of the following methods:

- TNZ M/4:1985 Specification;
- Freeze-thaw cabinet test;
- Laboratory classification tests;
- Additives to the basecourse materials.

2.2.1 TNZ M/4:1985 Specification

Basecourse materials satisfying the Transit New Zealand M/4:1985 "Specification for Basecourse Aggregates/Materials" are widely used in pavements to resist damage in frost-prone areas. Materials meeting the TNZ M/4:1985 specification are also used when replacing pavements which were built before 1985 and have been damaged by frost action. Where frost damage is still occurring in some pavements constructed using basecourse meeting the TNZ M/4:1985 specification, alterations to the specification as described in Section 2.2.3 are recommended.

2.2.2 Freeze-thaw Cabinet Test

Correlations between the field performance and the laboratory findings of basecourse materials that are subject to frost action have been developed. The laboratory results were based on the freeze-thaw testing on 10 different basecourse samples. The freeze-thaw cabinet test procedure is detailed in Cheung and Sutherland (1995), and Cheung et al. (1992). Although the findings are based on tests from such a limited number of samples, it is recommended that the following criterion be met for selecting acceptable frost-resistant basecourse materials:

> The average heave displacement of four CBR size specimens after four days freezing within the freeze-thaw test cabinet shall be less than 14 mm.

2.2.3 Laboratory Classification Tests

Because the freeze-thaw cabinet test is an expensive test procedure, alternative measures to estimate the frost resistance of basecourse materials using routine laboratory classification test procedures involving the sieve analysis of the aggregates can be applied. The basecourse should satisfy the requirements of the TNZ M/4:1985 specification, except that:

- Sand equivalent value shall exceed 50;
- Fines content (particle size smaller than 0.075 mm) shall be less than 5% by weight.

The presence of fines is detrimental to the performance of a pavement to resist frost damage. Thus care should be taken to minimise the following effects during construction (Bisset and Salt 1989):

- Segregation of materials;
- Degradation in the size of materials;
- Addition of surface fines.

Bisset and Salt (1989) also recommend that crushing resistance is applied, in association with maximum fines criteria, to limit the degradation of the TNZ M/4:1985 basecourse, thus providing a limit to any increase in the fines content of the basecourse during construction. These classes and limits are presented in Table 1. However, it is recommended that the maximum fines content should not exceed 5%, consistent with the Bisset and Salt criteria, and as shown in the right hand column of Table 1.

Table 1. Crushing resistance versus maximum fines content proposed by Bisset and Salt (1989), and the recommended maximum fines content (Fong and Cheung 1995).

Crushing resistance (kN)	**Bisset and Salt criteria maximum fines content (% passing 0.075 mm)**	**Recommended Fong and Cheung maximum fines content (% passing 0.075 mm)**
> 300	7	5
250 - 300	6	5
200 - 250	5	5
150 - 200	4	4
< 150	3	3

2.2.4 Additives to Basecourse Materials

Stabilising agents (e.g. lime, cement or bentonite) may be used to reduce frost heave in basecourses. However, experience in the application of stabilising agents to control frost damage in New Zealand is very limited and the results have not been conclusive (Fong and Cheung 1995). If additives are to be considered, it is recommended that their performance should first be evaluated with the proposed basecourse material using the freeze-thaw cabinet test.

2.3 Increasing Basecourse Thickness

Even if the basecourse layers are frost resistant, permanent distress can occur in the pavement if freezing of the subgrade below the basecourse occurs. In most countries where frost damage problem is severe, the commonly employed technique is to prevent the frost from penetrating too far into the subgrade (OECD 1988). This is achieved by increasing the thickness of the frost-resistant basecourse layer to below the anticipated depth of frost penetration.

The freezing index is the sum of the degree days of frost for a given period and is usually computed from the mean daily temperature (e.g. a mean daily temperature of –5 °C would give a freezing index of 5 degree-days Centigrade for that day). Various methods for computing the freezing index for an entire winter are given by Linell et al. (1963), Straub and Wegmann (1965), and McCormick (1991).

Figure 1 must be used with care because the pavement will affect the ground temperature, and therefore the freezing index, and also the effects of thermal radiation may be significant. Any specific recommendation is not possible without further studies on the effect of frost penetration depth and its determination.

2.4 Provision of Subsurface Drainage

Drainage is not only important for mitigating the effects of freeze-thaw, but it is also part of a good pavement design practice. Removing the water beneath the pavement will minimise the moisture within the voids that is available to form ice lenses during freezing. It will also reduce the detrimental effects of heaving and weakening during thaw of the pavement.

In areas where rainfall is high, or the subgrade is believed to be within the frost penetration zone, the use of drainage blanket layers below the basecourse is recommended. In some cases, the use of a sand layer or a coarse sub-base layer as a drainage blanket, has been successful in reducing the amount of water available which can form ice lenses underneath the pavement.

Overseas, geotextile composites and drainage wicks as capillary barriers have been used in pavements to reduce frost heave (D'Andrea and Sage 1989, Henry 1990). A thin layer of granular material, such as sand, sandwiched between geotextile materials can also be used. The aim is to break the rise of moisture through capillary action in the soil, thereby reducing the supply of water, and thus reduce frost heave. The long-term performance of a geotextile as a capillary barrier depends on its ability to resist clogging and blinding of its pores. If the method is used, drainage at the depth that the geotextile is placed is essential.

2.5 Control of Traffic During Thawing

Imposing traffic access restrictions on low traffic volume roads is a common practice in North America during the spring thaw period. Placing traffic restrictions on sealed state highways and on local authority sealed roads in New Zealand is not a practical option because these roads are main routes with relatively high traffic volumes connecting different parts of the country. Therefore, the use of appropriate pavement materials, basecourse depths and drainage techniques are generally the most effective measures available to minimise frost damage.

Traffic control is recommended in New Zealand only on low volume unsealed roads. The presence of traffic during thawing can cause the pavement to deteriorate quickly and deep wheel ruts to develop. This often makes the road virtually impassable and reduces driving safety. To minimise the damage, traffic restrictions may be applied during the critical period when thawing occurs.

Methods to determine the critical period have not been determined for New Zealand conditions, and the practice of applying restrictions on the weight and size of vehicles, and on times that traffic may use the roads, changes from one region to another. At present, only local knowledge and experience can be applied.

2.6 Application of Seal Coats

The appearance of "alligator" or "chicken wire" cracks in the wheeltracks is often the first sign of a frost problem on sealed roads. Also, a sound of hollowness in the basecourse, detected when a chain or pick axe is dragged across the pavement, is an indication of the presence of frozen water within the basecourse.

It is recommended to seal the cracks with an emulsion before winter. This is an effective way of waterproofing the pavement, and prevent excess water from entering the basecourse and subgrade from the surface.

3. CONSTRUCTING OVERLAYS

For sealed pavements with minor frost damage the placement of an overlay of frost-resistant basecourse over the old pavement is an effective and economical method of repair. The surface is then sealed to ensure that it is waterproof.

Since detailed information on the depth of frost penetration in New Zealand roads is not well understood at present, overlay thicknesses from 70 to 130 mm have been used in different areas. The purpose of the overlay is to extend the thickness of the basecourse layer to prevent freezing of the subgrade.

Even though an existing seal coat may act as a membrane to stop the rise of water in the pavement caused by capillary action, frost damage may still occur in the overlay and it is recommended that a frost-resistant basecourse is always used for the overlay.

4. RECOMMENDATIONS

- The following alterations to the TNZ M/4:1985 specification for selecting acceptable frost-resistant basecourse materials are recommended:

  - Average heave displacement of four CBR size specimens after four days freezing within the freeze-thaw test cabinet shall be less than 14 mm;
  - Sand equivalent value shall exceed 50;
  - Fines content (particle size smaller than 0.075 mm) shall be less than 5% by weight.

- If additives are to be used, their performance should first be evaluated with the proposed basecourse material using the freeze-thaw cabinet test.

- Any specific recommendation for thickness of basecourse is not possible without further studies on the effect of frost penetration depth and its determination.

- In areas where rainfall is high, or the subgrade is believed to be within the frost penetration zone, the use of drainage blanket layers below the basecourse is recommended.

- Traffic control in New Zealand is recommended only on low volume unsealed roads, and may be applied during the critical period when thawing occurs.

- Cracks should be sealed with an emulsion before winter to waterproof the pavement, and to prevent excess water from entering the basecourse and subgrade from the surface.

- As freeze-thaw damage may occur in the overlay, a freeze-thaw resistant basecourse should always be used for the overlay.

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