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Introduction

Guy Doré

Frost action detrimentally affects pavement structures in two ways: pavement heaving by segregation freezing in frost-susceptible soils, and loss of bearing capacity of the pavement structure once the ice contained in the base course, subbase, and subgrade soil thaws. There are several mitigation measures used to attenuate the effects of these phenomena, all based on empirical procedures (Dysli 1991). However, the use of pavement design approaches based on rational and physical models and on analytical and numerical techniques is increasing.

Most of the agencies managing road networks in northern Europe, Asia, and North America use design criteria related to frost action. But surprisingly, several agencies do not use specific design procedures to mitigate frost action, despite frost action significantly affecting their road network.

The following chapters synthesize the principles, criteria, and methods used for frost protection of pavement and other structures in cold climates.

Reference

Dysli, M. 1991. *Le gel: Et son action sur les sols et les foundations*. Lausanne, Switzerland: Presses polytechniques et universitaires romandes.

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CHAPTER 6

The Design Principles

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There are a wide range of approaches to structural design in freezing conditions. Most use one or both of these two main strategies:

- Design the structural components of the pavement and verify how the structure will be affected by frost heave or frost penetration. If frost heave or frost penetration exceeds allowable values based on criteria adopted by the highway agencies, the structure must be improved.
- Design the structural components of the pavement without considering frost action but verify the design for adequate bearing capacity during spring thaw. The structure must be improved if it cannot sufficiently withstand traffic load during the thaw season.

The designer must first establish which mechanism, frost heave or thaw weakening, is likely to have the greatest impact on a specific pavement. The designer may then choose to focus on the control of frost heave or only consider the loss of support capacity during the thaw season.

In the first case, the strategy will involve controlling one of the three factors essential to the segregation freezing process: the frost susceptibility of subgrade soil; temperatures below the freezing point for a significant period of time, allowing frost to penetrate the pavement structure and the subgrade soil; and the availability of water in the soil near the frost front. In the second case, the designer will focus on the bearing-capacity loss during spring thaw, and seasonal (mainly spring) variation of mechanical properties of subgrade soil and pavement materials will be a determining factor in the design. The designer can also try to account for both phenomena, knowing that control of the segregation freezing process will help mitigate the loss of bearing capacity due to thaw.

The designer can also choose between two levels of pavement protection. One is to attenuate the effects of freeze–thaw cycles and to adapt the pavement structure to resist these attenuated freeze–thaw effects. This is generally referred to as a partial protection approach. Partial protection implies accepting a seasonal loss of functional or structural capacity of the pavement associated with frost action. In partial protection, the pavement structure can be made stiffer or more flexible as a function of the significance of the frost heave during winter or the bearing-capacity loss due to thaw. Consequently, the objectives of the design, lifetime expectancy, and service level offered to users must be adjusted.

The other option is the total protection approach: trying to neutralize the damaging effects of freeze–thaw cycles. This strategy focuses on controlling one of the three factors essential for segregation freezing. Total protection aims to maintain the functional performance and structural capacity throughout the year. The design must be made in consideration of the worst annual conditions (freeze or thaw), which generally leads to systematically overdesigned pavements. In all cases, it is beneficial for the pavement to be thicker to reduce frost action in the subgrade soils, to better distribute strains, and to absorb deformations. Table 6-1 summarizes the design strategies, including some examples of applicable techniques.

Furthermore, the designer may choose to intervene locally or over an entire project. For example, transitions or frost tapers are often used in locally severe cases where there is contact between frost-susceptible and non-frost-susceptible soil. General protection measures will be adopted in cases where pavements are underlain by highly frost-susceptible soils. The choices depend on local conditions and on the classification of the road considered.

Indicators are measurable values or indices related to the response of the pavement structure to climatic factors in a given geological and hydrogeological context. They can be compared to a reference value, or criterion, linked to the desired performance of the pavement. This type of design criterion is based on local experience, suggesting that pavements that do not meet the criterion will not have acceptable performance. Frost depth is an indicator frequently used in verification methods. Many methods use an empirical criterion related to this indicator to verify the adequacy of the pavement structure. For example, the total thickness of the pavement structure should correspond to 70% of the expected frost depth (Kono et al. 1973). Some agencies have raised the sophistication of this simple criterion by adding soil and road classification correction factors to take into consideration different levels of frost susceptibility of subgrade soils and different levels of risk tolerance depending on the functional classification of the road (St-Laurent 2006).

Indicators can also be used as weighting factors for other design variables. For example, the original AASHTO method used a “regional factor” to weight the effect of traffic as a function of frost conditions (Johnson 1973). Lastly, the indicator can be directly used as a design factor. This is particularly the case in the Finnish design method (Jämsä and Orama 1990, Dysli 1991), which uses a spring soil support modulus as a basis for pavement structural design. But this type of approach can be overly conservative and lead to overdesign of the pavement structure.

There is a large range of types and qualities of indicators and criteria for frost verification of pavement structures. Table 6-2 shows a tentative classification of these indicators according to their design application and quality. Indicators of the first order are ones that constitute a direct measure of pavement response to frost

Table 6-1. Structural Pavement Design Strategies to Counter the Effects of Freezing.

Mechanism considered	*Approach*	*Examples of applicable mitigation approaches*
Frost heaving	Structural adaptation	• Thicken the subbase (to reduce frost action in the subgrade soil). • Improve flexibility of the asphalt layer (to resist frost-related cracking).
	Neutralization of the mechanism	• Add pavement drainage (only deep drainage will have a significant effect). • Add pavement insulation. • Homogenize subgrade soils to reduce the risk of differential heaving. • Remove frost-susceptible soil and replace with granular material (to the depth of frost penetration). • Neutralize the frost susceptibility of subgrade soils with chemical treatments.
Bearing capacity	Structural adaptation	• Stiffen the structure (stabilize base materials and/or thicken the asphalt concrete layer). • Thicken the granular layers for better load distribution.
	Neutralization of the mechanism	• Add pavement drainage (only deep drainage will have a significant effect). • Use granular materials with low susceptibility to water and frost action. • Add pavement insulation. • Homogenize subgrade soils to reduce the risk of differential heaving and frost heaving. • Remove frost-susceptible soil and replace with granular material (to the depth of frost penetration) • Neutralize the frost susceptibility of subgrade soils with chemical treatments.

Table 6-2. Indicators and Criteria Used in the Verification of Permafrost Structures.

Considered mechanism	*Indicator quality*	*Indicator*	*Criteria used (admissible values)*
Frost heaving	First order	Heave	40–200 mm, depending on road classification (Finland)[1] 50–80 mm, depending on road classification (Québec) 50–300 mm, depending on road classification (Sweden)[2]
		Change of slope	4% to 15%, according to the road type (Finland)[12]
		Loss of serviceability	Δ PSI (AASHTO)[3] Δ RCI (Ontario)[2]
Loss of bearing capacity during thaw	First order	Stress Strains Deflections	Resilient modulus and damages integrated over the year (AASHTO)[3] Springtime bearing capacity (Finland)[1,4] Based on representative subgrade resilient modulus (Ontario)[2] or based on saturated CBR (Saskatchewan)[5] Note: these values are directly used in response and damage models based on fatigue cracking, rutting, or deflection.

Heaving and loss of bearing capacity	Second order	Frost penetration Allowable freezing index	$D = 0.4$ to $0.6 \times X_{30}$ (Switzerland)[1] $D = 0.8 \times X$ (CRREL)[6] $D = 0.7 \times X$ (Japan)[7,8] Allowable FI at the subgrade line (France)[1]
Heaving and loss of bearing capacity	Third order	Freezing index Frost sensitivity of the soil Regional factor	D = function of FI, SG, and road classification (Québec)[9] D = function of FI_x and SG (Norway)[1] $0 < SB < 600$ mm, according to the engineer's judgment (New Hampshire and New York)[5]

Source: Doré (1997).

Notes:

[1] Dysli (1991)
[2] Ontario Ministry of Transportation and Communications (1990)
[3] AASHTO (1993)
[4] Jämsä and Orama (1990)
[5] Johnson (1973)
[6] Ladanyi (1996)
[7] Kono et al. (1973)
[8] Kubo and Takeichi (1992)
[9] Transports Québec (1995)

B = Subbase
CBR = California bearing ratio
D = Total thickness
FI = Freezing index
PSI = Pavement serviceability index
RCI = Ride comfort index
SG = Frost susceptibility of subgrade soil
X = Frost depth

action. Second-order indicators are an indirect indication of the effect of frost or climate. Such values are specific to the structure considered. Third-order indicators are indicators of the effect of climate on the pavement but are not specific to a given structure. The table also includes some criteria used in the methods summarized in the next chapters.

References

AASHTO. 1993. *AASHTO guide for the design of pavement structures*. Washington, DC: AASHTO.

Doré, G. 1997. "Deterioration des chausses en conditions de gel: une nouvelle approche previsoinelle." Ph.D. thesis, Département de Génie Civil, Université Laval.

Dysli, M. 1991. *Le gel: Et son action sur les sols et les fondations*. Lausanne, Switzerland: Presses polytechniques et universitaires romandes.

Jämsä, H., and R. Orama. 1990. "The measurement of seasonal subgrade properties under existing pavements and the Finnish pavement design method." In *Proc., 69th Annual Meeting TRB Preprint 890619*, Washington, DC.

Johnson, T. C. 1973. "Calcul des chaussées dans les régions de gel saisonnier d'Amérique du Nord." *Compte rendu du symposium sur l'action du gel sur les chaussées*, Oslo, Norway, 124–131.

Kono, F., T. Takahashi, H. Kubo, and H. Hiraoka. 1973. "Pavement design in cold areas." In *Proc., Symp. of Frost Action on Roads*, 138–141. Oslo, Norway.

Kubo, H., and K. Takeichi. 1992. "Seasonal nondestructive evaluation of frost-heave prevention layers in asphalt pavements." *Transp. Res. Rec.* **1362**: 90–94.

Ladanyi, B. 1996. *La conception et la réhabilitation des infrastructures de transport en régions nordiques*. Direction des Communications, RTQ-94-07. Montréal: Québec Ministry of Transportation.

Ontario Ministry of Transportation and Communications. 1990. *Pavement design and rehabilitation manual*. SDO-90-01. Toronto, Canada: Surveys and Design Office.

St-Laurent, D. 2006. *Chaussée 2: Logiciel de dimensionnement des chaussées souples. Guide de l'utilisateur*. Québec: Québec Ministry of Transportation.

Transports Québec. 1995. *Normes: Ouvrages routiers, Tome I: Conception routière Ministère des Transports du Québec*. Québec: Les publications du Québec.

CHAPTER 7

Pavement Design Methods in Cold Climates

Guy Doré

This section describes several frost design or verification methods and illustrates several approaches to pavement design in frost conditions. It summarizes for the United States methods developed by AASHTO and the US Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL), and for Canada the methods from the Ontario Ministry of Transportation and the Québec Ministry of Transportation. For Europe, it describes methods used in France and the Nordic countries. Lastly, the Doré and Zubeck method is presented.

7.1 METHODS USED IN THE UNITED STATES

The CRREL method (Departments of the Army and Air Force 1985, Berg and Johnson 1983, Ladanyi 1996) is essentially an empirical method that includes two specific verification procedures:

1. Take into consideration the reduction of pavement bearing capacity during spring thaw (reduced subgrade strength, RSS).
2. Control differential frost heaving based on the control of frost penetration in the subgrade soil (limited subgrade frost penetration, LSFP).

Factors this method considers are the average freezing index of the three coldest winters in the last 30 years or the coldest in the last 10 years, the annual average temperature, the duration of the freezing season, the dry density of pavement materials, the water content, and the granular layer thickness. The RSS procedure uses an effective annual California bearing ratio determined by the correlation with the frost susceptibility of the subgrade soil. The total thickness of the pavement is determined empirically in the LSFP procedure using an equation or the design chart replicated in Figure 7-1. The method includes a recommendation to homogenize the subgrade soil to a depth equal to two-thirds of the frost depth or 600 mm, whichever is smaller (Berg and Johnson 1983), although