Cold Weather & Concrete Pavements:
Troubleshooting & Tips to Assure a Long-Life Pavement

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ABSTRACT

To prevent cold weather-related problems in concrete pavements, both the designer and contractor must be aware of a few key considerations, so that the inherent long life of a concrete pavement can be fully realized. These considerations must occur in all stages of the concrete pavement's life: design, construction, and maintenance, and they include subgrade preparation, paving during cold weather, using deicing chemicals, and allowing studded tires.

Subgrades and subbases must be designed and built to prevent frost heave in the soil. Paving in cold weather often requires the use of insulating blankets to keep the concrete temperature high enough to allow the hydration reaction to occur and prevent the water in the concrete from freezing. The maturity method is an excellent technique to monitor not only the strength gain of the concrete, but also the internal temperature of the slab during cold weather placement. Snow and ice control often require using deicing chemicals and salts, which have the potential to be harmful to concrete pavements, if the pavements are not designed and constructed correctly. Though it is quite costly, concrete pavements can also be designed to withstand the wearing and abrasion from studded tires, but it is best to ban their use.

INTRODUCTION

Cold weather not only inhibits construction and rehabilitation of transportation infrastructure, but it also accelerates weathering and deterioration of the infrastructure system. Roadways in particular are subject to a very harsh environment. Regardless of pavement type, the construction season for paving generally only lasts from spring to fall. In fact, many northern US states and Canadian provinces have a construction season of just five or six months.

Cold weather also takes a toll on pavements. In fact, most pavements do not “fail” because of design factors such as thickness, but usually because of materials problems or environmental distresses such as oxidation, thermal cracking, and subgrade softening in asphalt pavements, and freeze-thaw damage, joint deterioration (spalling), and scaling in concrete pavements.

To prevent cold weather-related distresses in concrete pavements, both the designer and contractor must be aware of a few key considerations, so that the inherent long life of a concrete pavement can be fully realized. These considerations include subgrade preparation, paving during cold weather, using deicing chemicals, and allowing studded tires.

SUBGRADE PREPARATION

Pavements are built upon the existing soil, and it is that soil which supports the pavement, even where stabilization treatments are employed. Flexible (asphalt) pavements depend more on soil support conditions for structural capacity than rigid (concrete) pavements, but nonetheless, subgrade and subbase support is still vital to a well-performing concrete pavement. [1]

The key to subgrade preparation and subbase construction is uniform support. A concrete pavement can be designed and constructed on top of a very poor soil, but certain characteristics need to be addressed, particularly for soils susceptible to frost heave (or frost action). Frost action is best described as the expansion and eventual consolidation of fine-grained soils due to freezing. A number of factors must be present for frost action to occur including:

- A "frost susceptible" soil (generally a silt, silty clay, or sand)
- An adequate supply of moisture (due to infiltration, ground water movement, capillary rise, and other sources)
- Sustained temperatures below freezing (the soil must freeze - ambient air temperature can be used as a predictor, as can historic climatic data) [2]

Asphalt pavements are affected by the thawing of the frozen subgrade in the spring, which weakens the subgrade and reduces support. Concrete pavements, however, are not influenced by seasonal weakening of the subgrade during spring thaw. [3] Figure 1 shows the U.S. states that have load restrictions on asphalt roadways. The primary concern for subgrades under concrete pavements subject to freezing is frost action.

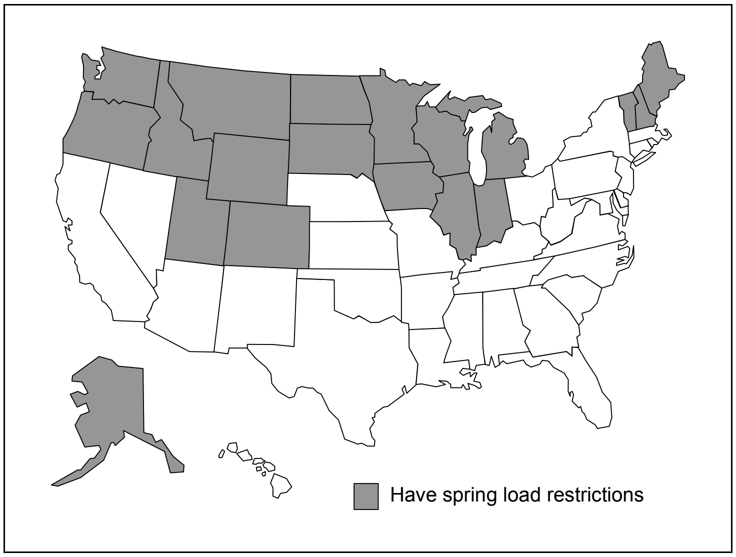

Figure 1. Load restrictions are used in 19 states, primarily during the spring and early summer. [3]

Figure 2 shows the relationship between capillarity and permeability of soils and the potential for frost action. Soils with high permeability and low capillarity such as sands and gravels have very little frost action potential, while soils with high capillarity and very low permeability such as clays also have little frost action potential. The soils most susceptible to frost action are silts, silty clays and sands, and very fine sands, due to their capillarity and permeability.

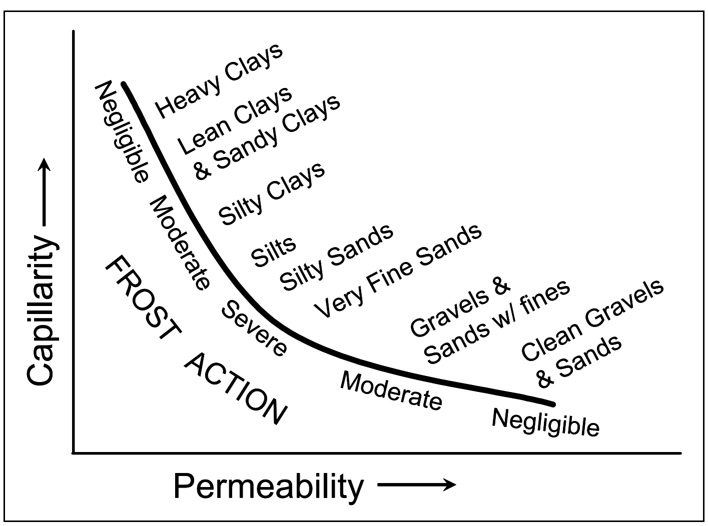

Figure 2. Relation between frost action and hydraulic properties of soils. [1]

Practically all surface soils undergo some frost action, the magnitude of which is dependent upon the locally prevailing climate and precipitation. Frost action divides into two phases: freezing the soil water, and thawing the soil water. For pavements, frost action becomes critical when either the freezing phase is accompanied by noticeable heaving of the road surface, or the thawing phase is accompanied by a noticeable softening of the roadbed.

Heaving of the road from frost action is termed "frost heave." Frost heave, particularly when in isolated areas, induces uneven support of a pavement. When a heavy load passes over the area of uneven support, a crack may form in the pavement surface layer (Figure 3). Cracks will typically begin and end at the pavement edges and have a noticeable change in elevation across the crack. [4]

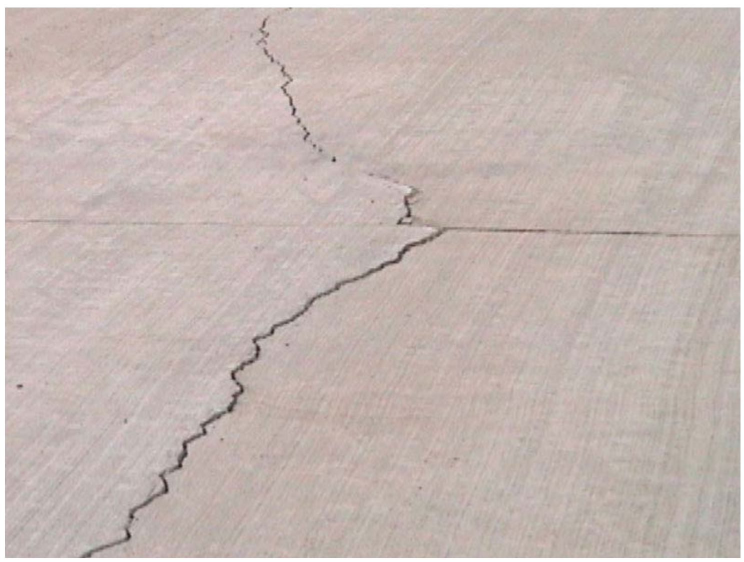

Figure 3. Crack from frost heave with characteristic difference in slab surface.

The heaving itself is caused by the formation of “ice lenses” in the soil below the pavement (Figure 4). Water expands 9% by volume when frozen. The size of the ice lens depends upon the quantity of free water available within the soil and from the water table, and time. When the soil freezes, the free water freezes and expands. Once started, ice lenses continue to grow as long as a source of free water is available. Free water migrates through the soil to a forming ice lens by capillary action (akin to wicking). This migration of water can be as far as 6 m (20 ft) for certain frost-susceptible soils. When the soil thaws, the ice lenses melt and consolidation of the soil occurs. [5]

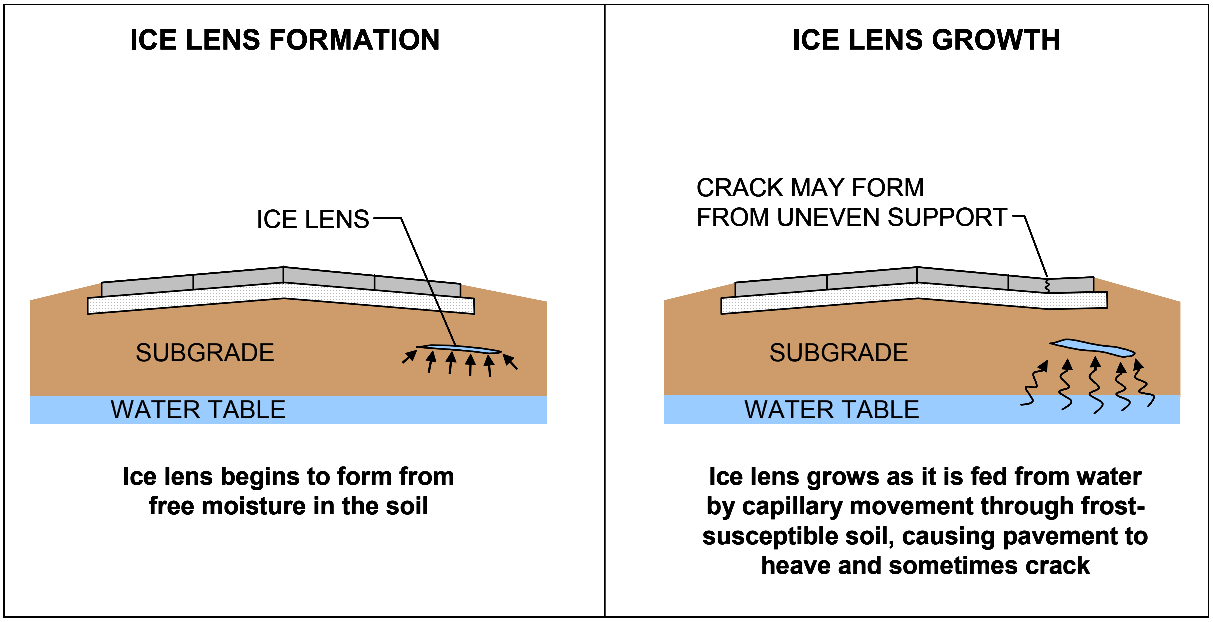

Figure 4. Formation of ice lens and frost heave in frost-susceptible soil.

Frost action affects all pavement types, although concrete pavements are less susceptible to it than asphalt pavements. It is most detrimental during the formation of the ice lenses, which result in expansion of the soil. Pavement distress typically involves longitudinal cracking and differential vertical movement of the slabs. The consolidation phase during thawing is not as critical because concrete pavements distribute load stresses over a wide area. The most problematic areas are transition zones between materials of different frost susceptibility.

Eliminating the supply of water to the soil below the pavement is virtually impossible. However, good drainage can partially reduce the quantity of water available to feed an ice lens and cause frost heave. Much of this supply of water from below can be cut off with combinations of sand blankets and tile drains.

Some soils are more susceptible to the formation of ice lenses than others. Silts or silty clay soils are considered amongst the most frost susceptible. Silt, because of the extremely small size of its particles, or gradation, permits and encourages the flow of water by capillary action through its pores. Consequently, silts supply the water necessary to promote the formation of ice lenses in the freezing zone. Other soils considered frost susceptible include fine sands, clayey gravel and rock flour. Moderately frost susceptible soils include dirty sands and gravels and glacial tills.

The only soils that can be considered to be non-frost susceptible are very clean mixtures of sand and gravel. These soils drain freely by gravity and do not create capillary moisture movement.

Frost heave is most often found at the following locations:

- Transitions from cut to fill
- Where ditches are inadequate or non-existent
- Over culvert pipes
- Adjacent to driveways that dam roadside ditches and/or collect water
- Wherever there is an abrupt change in subgrade material

Not all frost heaving is detrimental to a pavement. Uniform heaving will likely not be noticeable to the eye or to vehicle passengers. There are no bumps or rolls, the whole road has heaved uniformly and therefore presents no maintenance problem. Heave is destructive and troublesome only during the freezing or frozen phase, when it varies sharply, causing uneven support to the pavement.

To prevent frost heave, highly susceptible soils should be replaced or stabilized. Frost heave spots should be drained with tile drains and/or ditches should be kept clean and free of clutter that prevents flow of water away from the pavement.

Reducing the effect of frost action can be accomplished through a few simple, cost-effective techniques. These include:

- Removal of the frost-susceptible soil and replacement with a more suitable material
- Cross hauling to eliminate differential frost susceptibility
- Addition of soil modifiers such as lime, fly ash, cement, or cement kiln dust to reduce frost susceptibility (Figure 5)
- Minimizing the level of moisture present through proper drainage, pavement maintenance, and design features [6]

Figure 5. Soil stabilization can improve the soil's properties for both construction and pavement performance, including frost action.

A non-frost susceptible cover above the subgrade will also reduce frost heave by insulating the subgrade from freezing temperatures and providing a cushion for a small amount of expansion to occur in the soil. The non-frost susceptible cover is usually the subbase layer, which is often added for increased support for both design and construction reasons. The subbase provides additional support to the pavement, which reduces design thicknesses and provides a stable platform for construction equipment.

COLD WEATHER PAVING

Paving in cold weather is often necessary due to tight construction schedules, liquidated damages, incentives, and expedited project requirements. Existing guidance on cold weather concreting such as ACI 306 has not changed substantially in recent years, although the knowledge about concrete's early age behavior has increased.

Cement hydration in a freshly placed concrete mixture is an exothermic reaction, which means that it gives off heat. Most of the heat of hydration is generated during the first three days after placement and finishing. However, the concrete must be protected from freezing, so that the free water can combine with the cement in the mixture and form the hardened paste. [7]

ACI 306R-88 recommends that concrete should be protected from freezing if air temperature is expected to fall below 4°C (40°F) in any of the three days following paving [8]. The Colorado Department of Transportation recently released a new cold weather paving specification allowing contractors to maintain the *concrete* temperature above 4°C (40°F) until the pavement reaches 13.8 MPa (2000 psi) compressive strength [9], to continue the cement hydration reaction. To date, experience with and results of the new specification have been very positive.

Insulating blankets (Figure 6), mats, or foam sheets are commonly used in cold weather concreting to protect fresh concrete from freezing and maintain its temperature at a higher level. This allows hydration to occur at a more rapid rate, generating higher temperatures and promoting faster strength gain. However, insulation blankets do not negate the need for curing compound, which should be applied prior to the blankets, to form the membrane required to hold in moisture.

Figure 6. Insulating blankets in place on freshly-placed concrete slab.

Insulation blankets are capable of holding concrete slab temperatures around 49-60°C (120-140°F), even in cold weather. A concrete pavement repair project constructed in the late fall of 1999 on Highway 401 near Toronto, Ontario used insulation blankets for curing and maintaining the concrete temperature. The full-depth repairs were constructed at night starting at 10 pm and opened each morning at 6 am. When the blankets were removed to open the lanes for traffic, a thermal shock occurred, because the average slab temperatures were 59°C (138°F) and the average ambient temperatures were 13°C (55°F). Combined with traffic loading, the thermal shock caused most of the patches to crack. [10]

The results of the Highway 401 project do not discourage the use of blanket insulation, but they do indicate that a certain amount of caution should be used when deciding when to remove the blankets. The temperature of the young, still-hydrating concrete should be allowed to dissipate slowly under the curing blankets until the concrete temperature cools.

ACI 306R-88 also recommends that concrete be cooled gradually. Pavements less than 300 mm (12 in.) thick should not experience more than a 28°C (50°F) drop in temperature. It also states that concrete placed and cured at a low temperature (4-13°C [40-55°F]) is more durable, as long as it is protected from freezing and frost. [8]

Maturity meters are beneficial for cold weather paving. Maturity meters are primarily used for strength determination, but they can also monitor the concrete's internal temperature. The maturity method is a non-destructive approach for estimating the strength of concrete. It accounts for the combined effects of time and temperature on concrete strength development. The strength of a given concrete mixture that has been placed properly, consolidated, and cured is a function of its age and temperature history. [11]

The maturity concept has been around for many years and has proven to be a useful tool in several specialties within the concrete industry. This is especially true among fabricators of prestressed and other prefabricated concrete products where it is essential to obtain strength information at an early date and with minimal cost.

Early research on the maturity method was conducted in 1951 by Saul [12] who introduced and defined the term “maturity” as follows, during his investigation on steam curing of concrete: “the maturity of concrete may be defined as its age multiplied by the average temperature above freezing that it has maintained.” From this definition, he went on to develop the law of strength gain with maturity: “Concrete of the same mixture at the same maturity (measured as temperature-time) has approximately the same strength, whatever combination of temperature and time goes to make up that maturity.” Over the years, Saul’s work has been confirmed and refined by other researchers. [11]

If the temperature of a freshly-placed concrete pavement is measured over time, and those data points are plotted on a graph, the area under the curve can be called the time-temperature factor (TTF), which is a measurement of the concrete's maturity. The logarithm of the TTF correlates directly relates to the strength of the concrete (Figure 7).

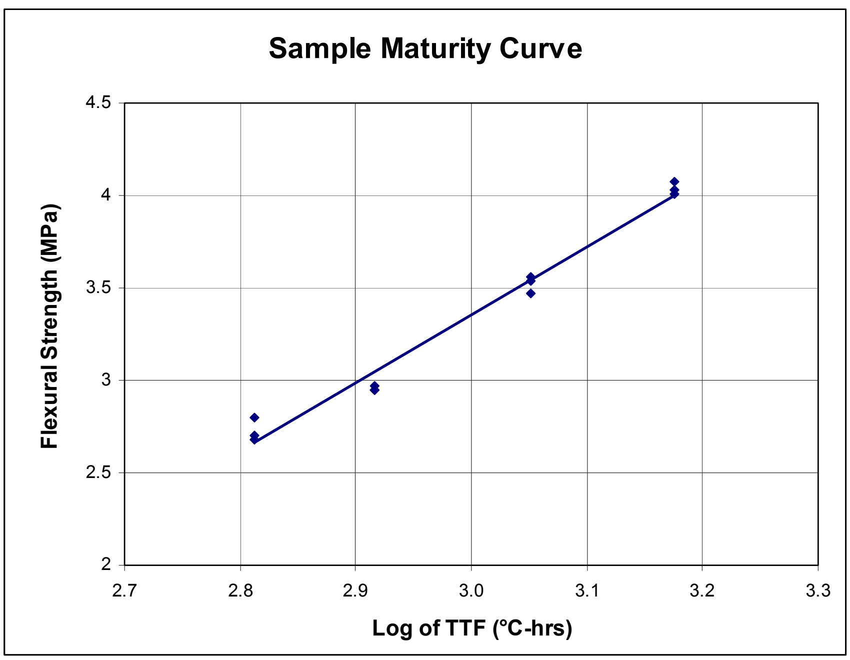

Figure 7. Sample maturity curve showing relation to flexural strength. [13]

In developing the maturity curve for a particular concrete mixture, multiple specimens must be cast, their temperatures measured over time, and their strength determined by conventional destructive testing (flexural or compressive) at various intervals to determine the maturity-strength relationship. This relationship is then valid for that mixture in any condition.

The benefits of maturity include: [11]

- Identifies earliest possible opening to both construction and public traffic
- Allows determination of optimum time to sawcut joints
- Facilitates both fast-track and cold-weather construction operations
- Requires fewer specimens to fabricate and test, thereby reducing QC/QA costs
- Facilitates earlier agency acceptance and contractor payment

Using the maturity method with cold weather paving allows contractors to not only monitor the strength gain to determine when a pavement is strong enough to support construction traffic, but also to monitor the internal concrete temperature. Armed with this information, contractors can better determine how to manage the concrete insulating blankets, paving operation, and when to suspend operations.

DEICING CONCERNS

Roadways must be kept safe for motorists, which in cold weather means keeping the roads free of snow and ice. Deicing chemicals and salts are used throughout most of the northern states and Canada for melting the ice and snow on highways, runways, taxiways, and streets. Although most concrete pavements less than 12 months old should have resistance to any detrimental effects of deicing salts, a certain amount of caution should still be exercised before salting a “new” concrete pavement.

The concern with putting deicing agents on concrete is based on the ability of the salt-water solution to penetrate into the surface of the concrete and then re-freeze. The basic reaction is mechanical – freeze-thaw – and not chemical. Regardless of the deicing chemical, it still melts the ice/snow, which can penetrate the concrete, re-freeze, and make it susceptible to scaling (the pavement distress that results from freeze-thaw damage at the surface). However, concrete pavements are designed to be resistant to this effect.

Deicing salts are not detrimental to concrete pavements if the following criteria are met: [7,14]

1. Minimum cement content is 335 kg/m^3 (564 lb/yd^3).
2. Maximum water-cementitious ratio is 0.45.
3. Adequate air entrainment is provided. It is best to have around 6 percent (no less than 3.5 percent) for harsh freeze-thaw environments.
4. Air bubble spacing factor, L, is less than 0.200 mm (0.008 in.).
5. Surface area of the air voids, α, is 24 mm^2 / mm^3 of air-void volume (610 in.^{2} / in.^{3}), or greater.

6. A sufficient curing regimen is utilized. Acceptable curing methods include curing compound, plastic sheeting, or misting, among others.
7. The new pavement has undergone an air drying period of 30 days after placement. The 30-day period of air drying allows the concrete to "seal" and prevent a water-salt solution from penetrating into the concrete.

Supplementary cementitious materials such as fly ash and ground granulated blast furnace slag (GGBFS, or just “slag”) can also be beneficial by making the concrete less permeable. Normal dosages of fly ash (up to 25% replacement) and slag (up to 40% replacement) do not negatively affect the scaling resistance of concrete. [7]

In regard to pavement color, some studies have theorized that snow and ice melting rates are higher on darker-colored pavements due to their heat retention characteristics. However, there is no clear relationship that darker pavements (new asphalt or dark-colored concrete) will affect ice and snow control to an advantage over lighter surfaces.

Older, previous reports have shown a possible 3 to 4°C (6 to 8°F) temperature differential between concrete and asphalt surfaces exposed to sunlight in cold climates. However, this is primarily applicable to high altitude locations where sunshine is predominant during cold temperatures. Many northern U.S. states and Canadian provinces receive very little sunshine during the winter months, especially during snowfall events, reducing the effect of solar radiation.

A snow/ice-covered roadway or runway has the same heat retention characteristics, regardless of pavement type, until the snow and ice are melted by deicing chemicals. The pavement surface is exposed and able to absorb and/or retain heat according to its makeup. If a darker colored pavement surface enhances snow melt, it might also cause a hazardous situation, due to re-freezing overnight, causing black ice.

In general, other factors such as temperature, wind velocity and direction, sunshine, terrain, roadway grade, and deicing chemicals have a larger influence on snow control than pavement surface color. In fact, the few studies [15, 16] have shown that salt demand is slightly higher on asphalt surfaces than on concrete.

STUDDED TIRE WEAR

In the past, many northern U.S. states and Canadian provinces allowed the use of studded tires, primarily between the months of October and April. In the 1970’s, many of the states and provinces banned their use, primarily due to the damage caused to roadway surfaces by the wearing and abrading action of the steel studs. [17-21]

Studded tires only give traction on ice or hard-packed snow. There is no added benefit to the road user when the driving surface is wet or dry pavement. Studded tires are a problem for both concrete and asphalt pavement types, although the damage appears more quickly in asphalt pavements. The steel studs embedded in the tires cause rapid abrasion and wearing of the pavement surface in the wheelpath. This can lead to standing water during rainfall events and increased possibility of hydroplaning, as well as "black ice" during winter months.

The first step in trying to eliminate the problem is to ban the use of studded tires altogether. Numerous studies [17-21] have shown that the added benefit studded tires offer is far outweighed by the additional cost to repair the pavement damage.

To address problems on existing pavements, diamond grinding will remove the pavement surrounding the worn wheelpaths, in addition to other benefits, including smoother ride, excellent friction, and longitudinal texture for low tire-pavement noise.

If studded tires are allowed in the state or region, concrete pavements can be designed to withstand the abrasion from the studded tires. Abrasion resistance is directly related to the strength of the concrete [7], so a higher strength concrete will be more resistant to the wear from studded tires. A study in Norway using an accelerated road-wear simulator showed that a concrete surface layer with compressive strength in the range of 100 to 117 MPa (14,500 to 17,000 psi) had the same abrasion resistance as granite [22], which would not abrade from studded tires.

A high abrasion-resistant concrete mixture would usually contain high-quality aggregate, between 320 and 450 kg/m^3 (540 and 760 lb/yd^3) of cement, plus silica fume, fly ash, or slag, with water-cementitious ratios of 0.22 to 0.36 and would achieve compressive strengths in the range of 83 to 131 MPa (12,000 to 19,000 psi). [7,22] However, these abrasion-resistant mixes are very costly, and it is usually more cost-effective to eliminate studded tires by statute, as most U.S. states have done.

SUMMARY

Concrete pavements are well-suited to cold weather. They can be designed, constructed, and maintained in cold weather, as long as a few important factors are considered. Poor soil in the subgrade that is susceptible to frost action must be addressed to prevent frost heave and pavement damage. Paving in cold weather is acceptable, as long as the concrete does not freeze and gains adequate strength before construction and public traffic are allowed on the pavement. The maturity method is a helpful tool for paving in cold weather, as it allows both temperature monitoring and strength determination. Deicing chemicals and salts are not harmful to the pavement if the concrete has been designed and paved properly. Though it is quite costly, concrete pavements can also be designed to withstand the wearing and abrasion from studded tires, but it is best to ban their use.

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