DESIGN AND CONSTRUCTION OF PAVEMENTS IN COLD REGIONS:
QUESTIONNAIRE SURVEY OF STATE DEPARTMENTS OF TRANSPORTATION

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ABSTRACT
A questionnaire survey was conducted of 23 state departments of transportation (DOTs) to investigate the state of the practice concerning certain aspects of design and construction of pavements in cold regions within the United States. In particular, the methods and standards employed for characterizing materials, improving soils and aggregates, and determining pavement layer thicknesses were explored. The survey included 15 questions specifically addressing material specifications, identification of frost-susceptible soils, stabilization techniques, geosynthetics, and spring load restrictions and winter premiums.

The information obtained in this research represents a unique compilation of standards of practice that have been developed by DOTs based on years of experience and research in their respective jurisdictions. While this research allows engineers at state DOTs to compare their pavement design and construction practices with those of other states represented in the survey, consulting engineers and engineers in local governments involved in the design and construction of pavements in cold regions can also benefit from this work.
INTRODUCTION
The effects of frost action introduce many challenges in the design and construction of roadways in cold regions throughout the United States. The penetration of frost into pavement structures can lead to differential frost heave during winter and thaw weakening during spring (1, 2), leading to premature pavement distress, structural deterioration, and poor ride quality (3, 4). For example, a pavement designed to last 12 to 15 years under non-frost-susceptible conditions may require major maintenance in 5 years when constructed in an area with frost-susceptible subgrades (5). Because the availability of naturally occurring, non-frost-susceptible, pavement base materials is rapidly diminishing in many areas while project budgets remain largely inadequate, pavement engineers are utilizing alternative materials and techniques to minimize such damage. Although individual state departments of transportation (DOTs) and other agencies have occasionally published information about specific projects (5, 6, 7, 8, 9, 10, 11, 12, 13, 14), a document summarizing the pavement design practices of transportation agencies in cold regions within the United States has not been previously available.

Therefore, the purpose of this research was to investigate and document the state of the practice concerning certain aspects of design and construction of pavements in cold regions within the United States. In particular, the various methods and standards employed for characterizing materials, improving soils and aggregates, and determining pavement layer thicknesses were explored. To this end, a questionnaire survey was conducted to investigate the state of the practice concerning identification of frost-susceptible materials and the use of soil and aggregate stabilization in cold regions within the United States. The study was directed primarily at identifying practices utilized by state DOTs in climates with freezing temperatures. Individuals most capable of describing the state of the practice concerning the identification and treatment of frost-susceptible materials were identified through telephone calls to each state DOT office.

Surveys were e-mailed to 42 DOTs (all except Alabama, Delaware, Florida, Georgia, Hawaii, Louisiana, Mississippi, and New Jersey), and responses were received from the following 23 DOTs: Alaska, Arizona, Colorado, Connecticut, Idaho, Indiana, Kansas, Maine, Maryland, Minnesota, Montana, Nevada, New Hampshire, New Jersey, New York, North Carolina, Ohio, Pennsylvania, South Dakota, Texas, Utah, Vermont, and West Virginia. The response rate associated with the survey was 55 percent. The survey responses are summarized in the following section.

SURVEY RESULTS
The survey included 15 questions related to the identification of frost-susceptible soils and the use of stabilization methods for improving frost-susceptible soils in cold regions. Most of these questions had multiple-choice answers, but others required short-answer responses. The following sections present the survey questions and a summary of the results obtained for each question. The survey questions are presented in three different sections: climate, design and construction, and policies.
Climate
This section discusses the results of two questions addressing the climate in the regions of the different respondents.

Question 1. What is the typical air freezing index for the weather in your jurisdiction?

Figure 1 shows that the air freezing indices reported by the responding agencies range from negligible to 3000°F-days. Eight surveys were received without a response.

![Figure 1: Average air freezing indices.](image)

Question 2. What is the typical depth of frost penetration in your area?

The respondents to this question generally answered with both a minimum and a maximum penetration depth for their respective regions. Figure 2 shows the minimum and maximum values of frost penetration depth. Values for both the minimum and maximum frost penetration depths ranged from 0 ft to 8 ft. Only one survey participant did not respond.
FIGURE 2 Frost penetration depths.
Design and Construction
This section discusses the results of the 11 questions regarding design and construction of roadways included in the survey.

Question 1: What kind of pavement design methodology do you use for areas that experience frost action?

As indicated in Figure 3, the pavement design methodologies listed as choices in the survey included mechanistic, reduced subgrade strength, limited subgrade frost penetration, complete protection, American Concrete Pavement Association (ACPA), Portland Cement Association (PCA), National Stone Association (NSA), Asphalt Institute (AI), and American Association of State and Highway Transportation Officials (AASHTO) procedures. The AASHTO method is used more frequently than the other methodologies. Four of the agencies that responded do not consider frost action in their pavement designs. Responses in the “Other” category include placing 2 ft of expanded foam followed by 6 in. of granular base course for areas that experience frost action. Arizona, Minnesota, New York, Pennsylvania, and Vermont each had specific in-house methodologies that were included in the “Other” response category.
Question 2: What are the layer types and thicknesses of a typical flexible (asphalt) highway pavement in your jurisdiction?

Of the 23 survey respondents, 22 reported that they use HMA for their highway pavements. The remaining survey participant did not respond. As indicated by 12 of the surveys, dense-graded aggregate is the most commonly used base material for flexible highway pavements. The next most commonly used base material is stabilized base, which is routinely specified by five of the respondents. Crushed aggregate is utilized by four respondents. Two respondents indicated the use of existing material, gravel, or asphalt, and one respondent indicated the use of sand or RAP.

Twelve responses were received regarding the type of subbase materials generally used in flexible pavement sections. Eleven of the 12 respondents indicated the use of granular material for subbases, while three of the respondents indicated the use of stabilized layers as subbases. The remaining respondents indicated that a subbase layer is not used as part of the flexible highway pavement sections in their jurisdiction.

Figure 4 shows the typical thicknesses used by the respondents for asphalt, base, and subbase layers in flexible highway pavements. Although the thicknesses of the asphalt, base, and subbase vary widely among the respondents, the survey results indicate that 4 in. to 6 in. or greater than 9 in. of HMA, 5 in. to 8 in. of base material, and 7 in. to 12 in. of subbase material are the most commonly specified thicknesses.

![HMA Surface Thickness](image)

(a) HMA surface thickness.

**FIGURE 4** Layer thicknesses in flexible highway pavements.
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FIGURE 4 Layer thicknesses in flexible highway pavements, continued.

Question 3: What are the types and thicknesses of a typical rigid (concrete) highway pavement in your jurisdiction?

Of the 23 survey respondents, nine reported the use of rigid pavement sections for their highways; the remaining 14 survey participants did not address this question. Of the eight responses received concerning the use of base materials, two indicated the use of granular
material, while two of the respondents reported the use of crushed aggregate. Stabilized base, cement-treated base, lean concrete, and asphalt bases were each used by at least one respondent.

Of the surveys received, six included information regarding subbase layers. Three of the six survey respondents indicated that subbase layers are not typically used in rigid pavement sections in their jurisdictions. Two responses indicated the use of granular subbases, while the remaining respondent reported the use of chemically-treated subbases.

Figure 5 shows the typical portland cement concrete (PCC), base, and subbase thicknesses used in rigid highway pavements. The data show that a PCC thickness of between 9 in. and 12 in., a base thickness of between 0 in. and 4 in., and a subbase thickness of between 1 in. and 6 in. are most commonly specified.

![Diagram showing PCC surface thickness and base thickness in rigid pavements.](image)

**Figure 5** Layer thicknesses in rigid highway pavements.
Question 4: How do you determine whether a given aggregate base or subgrade material is frost susceptible?

Figure 6 shows that the most commonly used methods for identifying frost-susceptible soils are field experience, laboratory testing, and particle-size distribution. Responses for “Other” were received from an agency that is currently conducting research to upgrade the existing method, as well as from an agency that uses solely granular bases to reduce the need to identify frost-susceptible soils.
Question 5: For pavement construction on frost-susceptible subgrades or reconstruction of pavements that previously exhibited frost susceptibility, what pavement construction approaches do you use?

Figure 7 displays the pavement construction practices used in areas characterized by frost-susceptible soils. Excavation and replacement of the frost-susceptible soils is the most frequently cited method of constructing pavements on frost-susceptible subgrades. Only one survey participant did not respond. The response “Other” includes use of bituminous-treated bases, underdrains, rock subgrade fragmentation, and broken rock trenches. Figure 8 presents the depths of excavation and replacement typically specified by the agencies that employ this method. Both of the respondents who cited the use of subgrade processing to remove large stones indicated removal of stones larger than 12 in. in diameter.
FIGURE 7 Construction methods used for frost-susceptible materials.
Figure 8 Depth of excavation and replacement generally used.

Question 6: When stabilization is selected, which types of stabilizers do you most commonly use?

Figure 9 clearly indicates that portland cement and lime are the two most commonly used stabilizers. Proprietary admixtures was the only choice not cited by a respondent. The responses for “Other” include that stabilization was used only for constructability purposes and that 1 to 2 percent cement was added to all treated materials. Seven survey respondents did not respond.
Question 7: How do you determine the optimum amount of chemical stabilizer to add to a given base or subgrade material?

As shown in Figure 10, field experience and unconfined compressive strength (UCS) are the most commonly cited methods for determining the optimum amount of chemical stabilizer to add to a base or subgrade material. Agencies that use UCS for determining lime content all use different target strength values in selecting the optimum content. For example, while one agency specifies strength values of greater than 50 psi at 3 days, another agency requires strengths greater than 60 psi at 7 days. A third agency adds sufficient lime to achieve an increase of 50 psi over the untreated soil strength. Target UCS values for cement stabilization ranged from 3-day values between 100 psi and 150 psi and 7-day values between 125 psi and 750 psi. The responses for “Other” include plasticity index reduction, indirect tensile strength, Virginia DOT in-house testing procedure, Eades and Grimm procedure, 10 percent by weight, and the Wirtgen process for foamed asphalt. Seven survey respondents did not respond to the question.
FIGURE 10 Methods used to determine optimum amount of chemical stabilizer.
Question 8: When geosynthetics (geogrids in particular) are used in the pavement structure, do you permit thinner surface or base layers compared to pavement structures not designed with geosynthetics?

Of the 23 surveys received, one did not respond, five indicated that they do permit thinner pavement sections to be constructed when geosynthetics are incorporated in the design, and 17 indicated that they do not allow thinner pavement sections. Of the respondents that indicated that they do not allow thinner pavement sections, many indicated that they do not have research supporting the effectiveness of geosynthetics. Many of the agencies that do not allow thinner pavement sections do apparently use geosynthetics in problematic areas and for constructability purposes, however. Those that do permit the use of thinner pavement sections reported increasing the subgrade R-value by 10 points in design, reducing subbase thicknesses by 6 in., and using Spectrapave software for designing with geogrids.

Question 9: In construction of cement-treated pavement layers, what procedures do you follow to minimize shrinkage cracking of layers? For example, please address pre-cracking procedures, if used, the type and timing of sealing, the timing of surface layer paving, use of granular layers or other features to resist reflective cracking into the surface, and other relevant practices.

Ten of the respondents indicated that the question was not applicable, and two did not respond. Of the answers received, using a curing seal was the most common, as indicated by five respondents. Maintaining moisture levels and using minimum amounts of portland cement were reported by four respondents. Using geogrids, requiring lower UCS values, pre-cracking, and only stabilizing the subbase layer were all responses given. One of the respondents indicated that no method for minimizing shrinkage cracking was required.

Question 10: Following construction of a cement-treated pavement layer, what methods or specifications are used to certify that the layer can be opened to traffic?

Figure 11 indicates that specifying a curing time is the method most frequently used by the survey respondents. Curing times of 3 days and 7 days are most common as indicated by three respondents for each curing time. A two-day curing time is used by one agency, while another agency requires that paving occur within two days of placing the cement-treated layer. Six survey participants did not respond to the question.
FIGURE 11 Methods used to determine when to open a cement-treated pavement layer to traffic.
Question 11: Overall, what are your observations regarding the performance of pavements constructed using chemically or mechanically stabilized layers in your jurisdiction?

Two survey respondents reported very good performance, and five respondents reported good performance. Six participants indicated satisfactory performance. Only one agency reported poor performance of stabilized layers. Three survey participants did not respond.

Policies
This section discusses responses to the two survey questions that addressed spring and winter pavement loading policies.

Question 1: Do you require spring load restrictions for pavements in your jurisdiction?

Thirteen of the 23 agencies that responded to the question reported that they do not require spring load restrictions in their jurisdictions. Nine of the agencies indicated that they do require some type of spring load restriction. Of the agencies that do require spring load restrictions, past experience was the most common method used to determine the timing and duration of the restrictions, as listed by four respondents. Computer modeling and use of a predetermined period of time were methods listed by two and three survey respondents, respectively. In addition, evaluations of air and soil temperatures were cited as methods used by different agencies to determine both the timing and duration of the spring load restrictions.

Question 2: Do you permit winter load premiums?

Only one of the 23 agencies surveyed allows a winter load premium. One survey participant did not respond to the question.

CONCLUSION
In this research, a questionnaire survey was conducted to investigate and document the state of the practice concerning certain aspects of design and construction of pavements in cold regions within the United States. In particular, the various methods and standards employed for characterizing materials, improving soils and aggregates, and determining pavement layer thicknesses were explored. The survey was e-mailed to 42 DOTs, and 23 responses were received; therefore, the response rate for the survey was 55 percent.

The survey included 15 questions regarding the experiences of the respondent with frost-susceptible materials, pavement design, and stabilization techniques. Air freezing indices in the various geographic areas represented by the survey participants varied up to 3000°F-days, and frost penetration ranged from about 1 ft to 8 ft. Among the regions represented by the survey respondents, the AASHTO pavement design method is most commonly used, although many agencies use their own in-house methods for pavement design. A majority of the respondents indicated the use of HMA for surface layers of flexible pavements together with the use of dense-graded aggregate base material and granular subbase material. A few respondents utilize stabilized base or subbase materials. Among the participants specifying the use of rigid pavement sections, granular, stabilized, lean concrete, and asphalt bases were all reported.
The most common methods employed to identify frost-susceptible soils include field experience, laboratory testing, and particle-size distribution. Excavation and replacement of frost-susceptible soils was the most frequently cited method of constructing pavements on frost-susceptible subgrades. Other commonly used methods include the use of edge drains, open-graded drainage layers, and stabilization. The most commonly specified stabilizers are portland cement and lime, but agencies are also using fly ash, asphalt emulsion, foamed asphalt, slag, and calcium chloride. Field experience and UCS testing are the methods most often used for determining the optimum amount of stabilizer to add to a given base or subgrade material. When geosynthetics are incorporated into the pavement structure, several of the survey respondents indicated that they permit construction of thinner pavement sections.

The survey results suggest that the most commonly used method for minimizing shrinkage cracking of cement-treated layers is placement of a curing seal. Maintaining moisture levels and using minimum amounts of portland cement were also common responses. In addition, using geogrids, requiring lower UCS values, pre-cracking, and only stabilizing subbase layers are methods employed to minimize cracking. Curing times typically ranging from 3 to 7 days are most frequently required before a cement-treated pavement layer can be opened to traffic. The majority of the respondents reported very good, good, or satisfactory performance of pavements constructed using chemically or mechanically stabilized layers.

Spring load restrictions are used by approximately half of the respondents to prevent accelerated damage to pavements during thawing, but only one agency permits winter load premiums. Among the agencies that do require spring load restrictions, past experience was the most common method used to determine the timing and duration of the restrictions. Other responses included computer modeling, use of a predetermined period of time, and evaluations of air and soil temperatures.

Although the results of the questionnaire survey reveal a variety of practices, the data suggest that many DOTs utilize similar methods for the design and construction of pavements in cold regions. The information obtained in this research represents a unique compilation of standards of practice that have been developed by DOTs based on years of experience and research in their respective jurisdictions. While this research allows engineers at state DOTs to compare their pavement design and construction practices with those of other states represented in the survey, consulting engineers and engineers in local governments involved in characterizing materials, improving soils and aggregates, and determining pavement layer thicknesses can also benefit from this work.

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REFERENCES


