Frost Considerations in Highway Pavement Design: Western United States

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The western United States highway departments all seem to have a similar approach in their consideration of frost effects in soils for the design of pavements. Geographically, all the western states' area with the exception of parts of California, Arizona, and Texas is considered subject to frost effects. Generally all roads are designed for all-season unrestricted loading and operations with the exception of very low traffic roads of secondary classifications in three states.

Soil characteristics considered as setting a criteria to frost susceptibility are generally silt by classification and any material having in excess of 10 percent finer than a No. 200 sieve. No special tests are reported as being used to measure susceptibility.

The location of soils considered frost susceptible within the horizon and with respect to the grade line varies. Some states are endeavoring to waste or otherwise dispose of frost-susceptible soils within an arbitrary zone with respect to the finish grade line of the highway, whereas others report no consideration given this condition. Similar considerations appear to be given the elevation of the water table with respect to the grade line.

No special geometric section or drainage feature or controls are attributed to frost effects in soils. It appears that generally accepted sections and treatments were developed with this feature considered as all present designs are believed adequate. Admixtures have been used only in very few instances as a means of controlling frost. Flexible pavement design criteria vary considerably. Some states appear to make no differentiation for frost susceptibility or their standards of design have "built in" a factor that is not identifiable directly. Others do give special consideration to frost by requiring added thickness, or set a minimum thickness of pavement structure depending on the depth of frost penetration, or the frost susceptibility of the soil. Designs for structure thickness are not varied for embankments or cut sections.

Rigid pavement designs seem to apply very similar criteria for the total thickness design. Subbase materials must meet general requirements similar to those for flexible pavements. Present designs are for all-season loading and operations of the pavement except for the very lowest traffic volumes on secondary highways in three states for either rigid or flexible pavements.

No special treatment of soils in foundations for structures is reported. Generally footings are carried well below frost line. Backfill material is required to meet general criteria for cleanness and free-draining properties. It appears that the frost considerations are so much a part of each department's routine oper-

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ation that it is hard to separate specific considerations in design due to frost. All recognize frost problems and their design methods appear to provide a pavement structure considered adequate.

•THE western United States geographically encompasses an area of climatic extremes. Elevations for regularly used highways range from below sea level to over 11,000 ft. The latitude varies from semitropical areas to the 49th parallel, or an area where winters can be very severe except as modified by the Japanese current along the Pacific Coast. Rainfall varies from less than 1 in. per year to more than 150 in. per year. With these variations in precipitation and temperature, it is apparent that frost effects would likewise vary through very great extremes.

Figures 1 and 2 show the mean minimum and maximum temperatures for January. Figure 3 shows the range of the mean annual precipitation. Figures 1 and 2 indicate the extensive areas subject to daily freeze and thaw conditions.

The questionnaire submitted to all highway departments in the WASHO, with the exception of Alaska and Hawaii, requested clarification geographically of the areas within their state requiring special consideration for frost effects.

A different approach to the frost effect problem appears immediately. All of the western states acknowledge that frost must be given consideration throughout a part of their state, however, only Colorado, Idaho, and Washington report that 100 percent of their state systems require special consideration due to frost.

The remaining states report limiting design considerations because of frost:

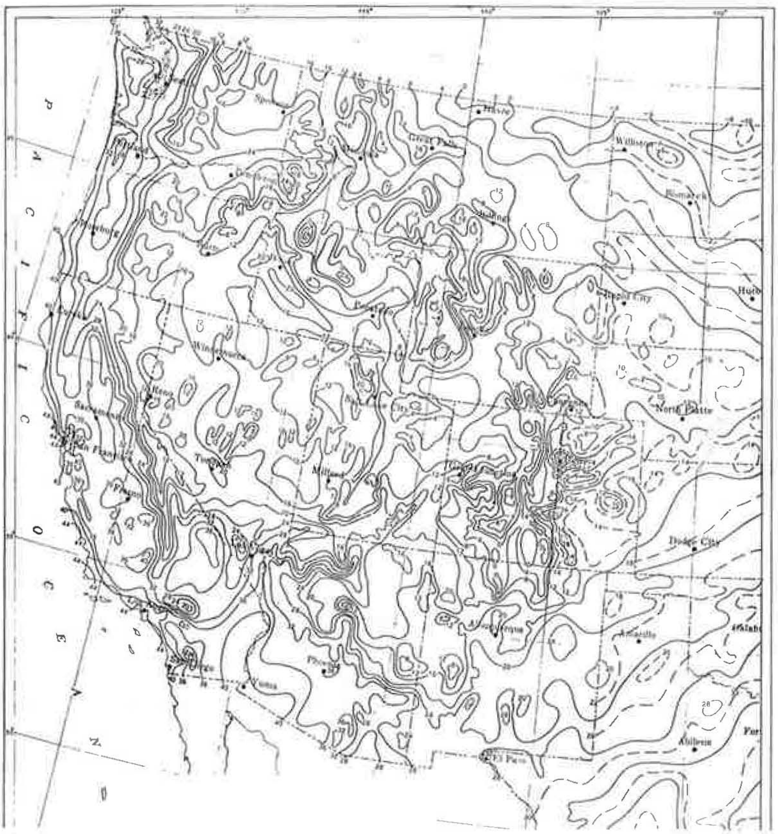


Figure 1. Mean daily minimum temperatures (°F) January.

Arizona	Northern half.
California	Mountain regions.
Montana	Area west of the Continental Divide, north central area and any area of silty soil having a high water table.
Nevada	Northern half.
New Mexico	Elevations above 6, 500 ft.
Oregon	East of the western foothills to the Cascade Mountains.
Texas	Northwestern part.
Utah	Areas where moisture and frost are conducive, about 25 percent of state.
Wyoming	Only irrigated areas.

Thus, the approach to the frost problem varies greatly, and the degree of frost susceptibility considered to require attention varies.

Land use of land, that is, forested, cultivated, irrigated, etc., is not recognized by Arizona, California, Idaho, Nevada, New Mexico, Oregon, and Texas. However, Colorado, Montana, Utah, Washington, and Wyoming recognize land use as it affects the elevation of the water table.

As expected, all states are designing their heavy-duty concrete highways for all-season unrestricted legal axle loadings.

All states except Wyoming consider their asphaltic concrete pavements adequate for

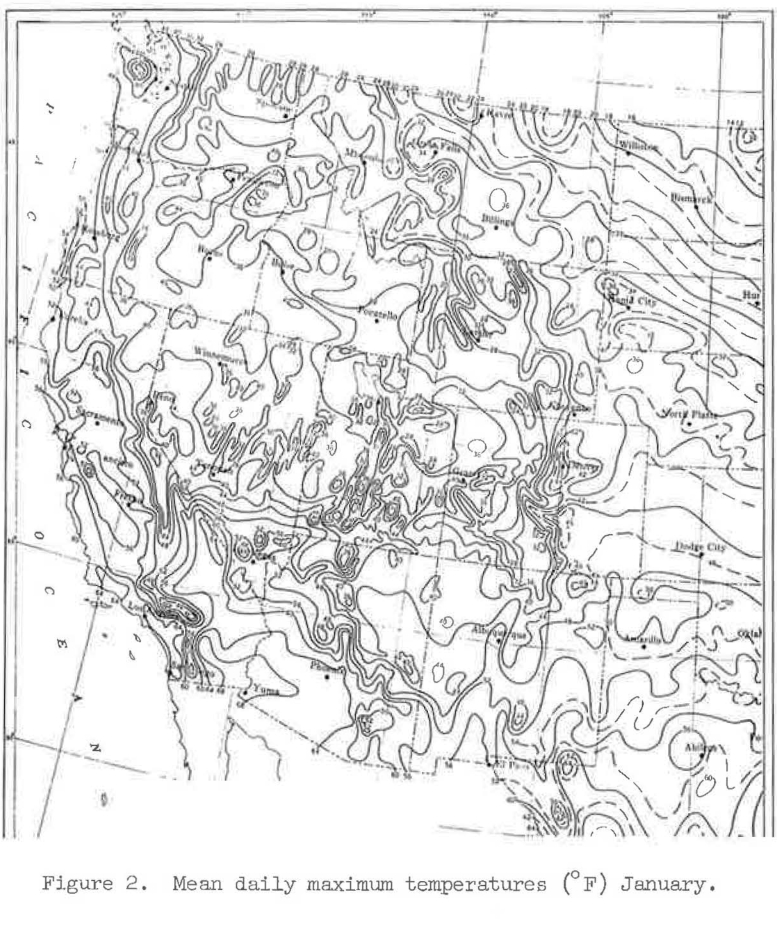


Figure 2. Mean daily maximum temperatures (°F) January.

Figure 3. Mean annual total precipitation (in.).

unrestricted legal axle loadings. Wyoming uses the 5,000-lb equivalent wheel-load method of evaluating axle loading and does not believe this method adequately provides for frost. Other states using the 5,000-lb equivalent wheel load for axle loading either believe it adequate or provide other means of adjusting thicknesses because of frost.

All states except Wyoming and Texas provide for unrestricted legal axle loading and operation for their intermediate roads. Again, Wyoming feels the 5,000-lb equivalent wheel loading is inadequate. Texas, without further clarification, reports that restrictions are applied to some roads.

Several states have designed parts of the secondary road system for springtime load restrictions. Montana applies load limits if the ADT is more than 100 vehicles per day. New Mexico and Texas apply restrictions to some roads and not to others.

Oregon and Idaho report studies for strength loss of soils or softening of the road bed during the spring. Oregon has reported work in previous HRB Proceedings and bulletins. This work was conducted for the Committee on Load Carrying Capacity of Roads and Airfields as Affected by Frost Action. Idaho conducted Benkelman beam deflection measurements during summer 1954 and spring 1955 with a few isolated tests since then. Their original work was reported at the WASHO Conference at Phoenix in 1956.

SOIL CONSIDERATIONS

The western states were asked if they had established any criteria for a "frost-susceptible soil" and any test or combination of tests to measure the degree of susceptibility. Conversely, they were also asked if they had any criteria or tests to assure that soils were not susceptible to frost. Answers vary from "No" to all questions to some interesting and apparently practical considerations.

The percentage passing the No. 200 sieve, together with liquid limit and plasticity index tests, appears to be the most accepted approach for determining if a material is frost susceptible. The classification "silt" was also noted as being a criterion for frost susceptibility.

The percentages passing the No. 200 sieve varied from a maximum limit of 8 to a maximum limit of 25 for a non-frost-susceptible soil. Generally, values less than 12 percent were reported as the maximum percentage passing the No. 200 sieve for base courses. Limiting values for liquid limit or plasticity index were not reported.

Colorado considers all its soil as frost susceptible. Arizona has established maximum percentages passing the No. 200 sieve for base materials depending on elevations with 12 percent permitted to an elevation of 2, 500 ft, 10 percent to 3, 500 ft, and 8 percent for elevations above 3, 500.

Montana considers A-1a(o), A-1-b(o), and A-2-4(o) soils least susceptible to frost. Utah reports that any sand or silty soil is susceptible if more than 25 percent passes the No. 200 sieve. Washington limits passage of the No. 200 to 10 percent for base courses and considers lesser percentages as non-frost susceptible.

SOIL PROFILE AND HORIZON CONSIDERATIONS

Consideration of the location of the frost-susceptible soil within the soil profile and the subgrade is given by all but four states. It appears possible that other considerations such as the depth to the water table are the governing factors in these four states.

States that consider the frost-susceptible soils to require special consideration base their action on the positon of the soil with regard to the subgrade. Idaho takes precautions to remove all top soil at the grade point and to further reinforce this area with granular materials. Montana uses a minimum of 2 ft of selected granular materials in the top of the embankments together with a thicker surfacing section. Other states report raising the grade line and wasting the frost-susceptible soils or burying them in the lower portions of embankments.

The depth to the water table is given special consideration by seven states and four report the water table presents no problem. Most states reported raising the roadway grade line if the water table was high. It appears that the dividing line between a high and low water table is considered to be about 4 or 5 ft.

The states giving consideration to the water table elevation remarked that their consideration was based on the influence of the water table on the moisture content of the soil.

Selective placement of soil is given consideration by nearly all states. Reasons given by several are to reinforce or strengthen the subgrade and to reduce the quantities of high-type base. Several report that the poor soils are buried low in the embankment. One state reports that it is too costly to consider selective placement. Another reports that uniformity of the subgrade is stressed, and still another that the poor soils are merely given added reinforcement with base.

The general specifications appear to be about evenly divided in requiring or not requiring selective placement of soil. Several states reported that the special provisions or plans provided for selective placement when desired. Only two states made a special note that payment for cross-haul was made, although the question was not asked. Several other states may also do this.

Five states show on the plans the soils to be excavated and replaced due to frost susceptibility. Others remarked this was done to increase the structural strength of the subgrade. It is important to note that several states report the soil areas are too extensive for this type treatment.

The quality of backfill material is mentioned in only two specifications, but several states provide for central laboratory, material engineer's, or another engineer's approval of the material to be used. It appears that this is not a specification-described material.

The use of a material to prevent intrusion of fine-grained soils into the coarser base or subbase materials is reported by six states; three of which use the Corps of Engineers D15/D85 ratio of less than five as their control. One state uses a A-3 sand if available, otherwise a bituminous membrane in the bottom surfacing course. Another specifies a material at least 15 percent finer than the No. 40 sieve and 25 percent finer than the No. 10 sieve. This is required only when the soil has more than 65 percent passing the No. 200 and a PI or linear shrinkage greater than 5.

GEOMETRIC DESIGN CONSIDERATIONS

None of the states appear to have special geometric designs due to frost considerations. Several note widened or deepened ditches to provide for snow storage. A few made occasional slight changes for short sections.

None of the states have any special drainage design features specifically for frost areas, although occasionally special drainage using perforated pipe underdrains is used for lowering the water table.

USE OF ADMIXTURES

None of the states appear to have used admixtures in any general way to control frost-susceptible soils. One state reports occasional use of sodium chloride in an attempt to prevent frost heaves. Another reports using portland cement and lime to control PI and upgrade aggregates. Several western states have used portland cement and bituminous materials to upgrade or stabilize base courses, although not specifically to reduce frost affects.

DESIGN OF FLEXIBLE PAVEMENTS

Seven states have provisions for varying their design thickness requirements because of frost. The others use a standard design throughout, but make variations in design due to type of soil, water table, and other considerations.

The criterion used for design is geographic in five states, i.e., regions wherein frost is no problem are noted and not given any consideration for frost. Three states use the maximum measured frost penetration. Two of these set a minimum thickness of the pavement structure, pavement, base, and subbase equal to one-half the frost penetration unless the soil strength calls for a greater thickness. Colorado has a table of factors which gives added thickness requirements depending on the penetration of frost and moisture conditions (see Appendix B).

Two states report an arbitrary thickness increase where frost considerations dictate—one state providing 2 in. of base, the other 4 in.

Apparently design considerations are applied to all soils as only two states made reference to this factor. One reported designs applied to all soils having more than 10 percent passing the No. 200, and the other remarked they wasted soils of high PI or "bentonite" type soils.

Limitation of axle loads apparently is not considered in design for frost except by Wyoming where it is believed that the equivalent wheel load method is insufficient to provide for all-season legal loads.

The use of material to prevent intrusion of fines into the subbase or base courses as a part of the total design thickness is common to all states except two. Further comments indicate that the material was considered in the design only if it was better structurally than the subgrade material.

None of the states report making any change in the design thickness for cuts or embankments. One state increases the thickness in cuts if the tendency toward a wet situation exists, then backfills with selected granular materials.

Embankments constructed from rock are capped with granular materials by 8 states. One reports using selected material only for construction purposes, and another reports inferior materials are avoided. Only two states report that no special materials were provided or attention given.

DESIGN OF RIGID PAVEMENTS

Only two states have any different considerations in the design of concrete pavement over frost- versus non-frost-susceptible soils. Both states add additional subbase over frost-susceptible soils even though both have used base material beneath the slab.

Two states use the same frost penetration criteria for rigid pavement designs as for flexible pavements using base or subbase to obtain the necessary thickness.

Four states consider the base and subbase as a part of the thickness design but furnish no details as to the manner applied.

Two states treat the base or subbase with portland cement beneath the concrete pavement to prevent pumping. Another state does this, but not because of frost. Pumping is caused by water and not necessarily frost, but spring thaws seemingly provide the greatest water supply at any time and in this way can be associated with spring breakup.

States using portland cement concrete pavements do not make use of any special material to cap rock embankments other than suitable material for a leveling course.

SUBBASE AND BASE COURSES

Four states reported on their criteria for measuring frost susceptibility of subbase and base courses. Three used the same criteria as for crushed-base materials, i.e., gradation, LL and PI. Only one state reports any specific test, that developed by McDonald (1). The state reports that although the test is not very precise, it has provided considerable information.

All states apparently pretest and designate sources of materials for subbase and base during the preliminary engineering phases. Approval is given to sources, but one state reports frost considerations are not included.

Seven states report that the gradation taken with the Atterburg limits or the sand equivalent determines the quality of the materials to be used. Some report that their standard specifications require the same limitations for percent passing the No. 200 and for LL and PI for subbase material as they require for crushed-base materials.

Ten states report that subbase and base courses are carried full width, and one other reports this is done when necessary for drainage. The ditch is also carried below the subgrade in 9 states with depths reported from 0.5 to 3 ft. Two states did not answer.

Only one state reports using any admixture to control frost susceptibility of base or subbase courses. In this instance, they permit 20 percent passing the No. 200 sieve and use cement or lime to stabilize the material if it is above 12 percent or the plasticity index is more than 6.

STRUCTURES

Limited information was obtained regarding frost-susceptible soils or backfill materials. Those reporting placed footings below the frost line and considered drainage of backfill materials of sufficient importance to mention.

GENERAL COMMENTS

The results of the questionnaire show that all the western states have some criteria that they use in design for frost-susceptible soils. Most of the factors are incorporated into their overall design criteria, but it is not always evident that certain requirements are essentially because of frost. This is particularly true in those states having a definite winter season throughout the entire state. Only those states having areas with limited or no winters apparently have recognized any major difference in designs.

Even though criteria differ throughout the states, it appears to be mostly the means to the end that differs. Essentially all states strive to keep the better soils in the subgrade, elevate the grade line to reduce effects of the water table and keep a free-draining subbase and base material over the subgrade. Criteria for the gradation limits and other properties do vary. However, as was pointed out previously, when the extremes of precipitation and climate are considered, this certainly must be no surprise. States having moderate to heavy precipitation with definite winters tend to have the most restrictive requirements for their subbase and base materials. Others with equally cold winters but limited precipitation apparently have found they can be less restrictive.

One factor that appears to be limiting special treatments of frost-susceptible soils is the extensive areas of materials that can be classified as definitely susceptible. In these instances, the design must be such that the roadway structure can carry all-season traffic even though these materials are used. The use of a pavement structure, i.e., subbase, base, and surfacing equal to half the frost penetration, is one approach used by two states. Others apparently find this uneconomical or not necessary.

Realizing that the availability of materials for use in subbase and bases is limited in many areas, it is understandable that available local material, which experience has shown to give acceptable service, is used extensively. Attention to the quality of bases and subbases and the upgrading of these materials by cement, lime, and bituminous materials is gaining in importance. All of the states apparently want to build roads capable of carrying legal axle loads all seasons of the year.

The factors involved in frost susceptibility are numerous. No one has developed a specific test for frost susceptibility as such, but reliance is placed on soil-identification tests, depth to water table, position of the soil within the roadway grade, etc., in determining the design. This approach appears to be giving good results.

REFERENCE

1. McDonald, C.H., "Investigation of a Simple Method of Identifying Base Course Material Subject to Frost Damage." HRB Proc., 29: p. 392-400 (1949).

Appendix A

QUESTIONNAIRE
HIGHWAY PAVEMENT DESIGN IN FROST AREAS—DESIGN CONSIDERATIONS

Questions asked the various State Highway Departments are answered in the Tables below. The numbers at the head of the columns of the tables refer to the question numbers below.

1. GENERAL INFORMATION

(a) What is the geographical extent of areas within your state wherein special consideration is given to frost effects in the design of pavements?

(b) Does land use (irrigated tracts - forest lands, etc.) provide a guide or limit to the geographic areas given special consideration? If so, please explain.

(c) Are pavements designed for all season unrestricted loading and operations on:

Heavy Duty Roads
Intermediate Roads
Secondary Roads

If other classification is used, please explain

(d) Have you made any special studies regarding the loss of strength of soils or of the softening of the roadbed during the spring. Please give reference to any reports.

2. SOIL CONSIDERATIONS

(a) Have you established any criteria for a "Frost susceptible soil"? If so, please furnish criteria.

(b) Have you any criteria or specific tests or combination of tests to measure the degree of frost susceptibility? Please furnish details.

(c) Have you any criteria or specific tests or combination of tests to assure that soils are not susceptible to frost? Please furnish details.

State	1(a)	1(b)	1(c) H	1(c) I	1(c) S	1(c) Other	1(d)	2(a)	2(b)	2(c)
Arizona	Practically ½ state high enough elevation to require frost consideration	No - Altitude and soil analysis	Yes	Yes	Yes		No	Cover frost susceptible soils with sufficient material that frost no longer is considered. Specify use of non-frost susceptible base	Base materials to have maximum percent passing No. 200 sieve Elevation Feet / Maximum Percent Under 2500 — 12 2500- 3500 — 10 Over 3500 — 8	Grading and plasticity index
California	Primary Routes in Mountain Regions	No	Yes	Yes	Yes		No	No	No	No
Colorado	Entire State	Yes - irrigated lands or other land where ground saturated when frost present. Ref. Colorado Dept. of Hwys. Design Manual, Table 5-606.4 (See Appendix B)	Yes	Yes	Yes		None	All soils considered susceptible	None	None
Idaho	Entire State. Doubt special consideration given but do have few "built in" controls like percent 200 in base and an empirical soil number.	No	Yes	Yes	No		Periodic Benkleman Beam Deflection measurements	A-4 - A-5	No	No
Montana	Northwest area west of Continental Divide. North central area in Milk River drainage & areas of high water table.	Yes - irrigated and flood irrigated areas Combination excess water, high water tables, and heavy silty clayey soils can cause heaves.	Yes	Yes		Yes on secondary roads if over 100 ADT.	No - observation of past performance	No	Past experience with individual soil types	Consider A-1a(o), A-1-b(o), and A-2-4(o) soils least frost susceptible. Percent passing No. 200 sieve, liquid limit plasticity index on both No. 40 and No. 200 fractions usual guide.
Nevada	Northern ½ State	No - generally severity climate is guide - irrigated tracts considered where encountered.	Yes	Yes	Yes		No	No	No	No
New Mexico	Northern State, elevations over 6,500.	No - See 1(a)	Yes	Yes		Secondary roads - varies	No	Yes - Silt tested to verify	Permeability and freeze-thaw	No
Oregon	East of Cascade Mtns. western foothills	No	Yes	Yes	Yes		Yes - See HRB Proceedings Vol. 28 & 34, Research Report 10 D - Bulletin 40, 54, & 96.	Soils having more than 10% passing No. 200 sieve	No	No
Texas	Northwestern area only	No	Yes			Some intermediate & secondary are restricted	None available	No	No	No
Utah	Limited to areas where frost and moisture are conducive - 20-25% of State. Aridity of State not conducive to detrimental frost action.	Provided use furnishes moisture to frost susceptible soils.	Yes	No Ans	No Ans		No	Non - or slightly permeable fine sands and silts with more than 25% passing No. 200 sieve	No	Field experience - believe tests alone will not show areas susceptible.
Washington	Entire State	Yes - irrigation water effect on ground water has increased areas where frost must be considered.	Yes	Yes	Yes		No	Soil or aggregate with more than 10% Passing No. 200 sieve	No	No
Wyoming	Areas with light to heavy irrigation	Yes - irrigated areas only ones with high water table.	Concrete Yes Asphalt No	No	No	Asphalt pavement std. Section based on traffic count.	No	No	No	No

3. SOIL PROFILE OR HORIZON CONSIDERATIONS

(a) Does the location of a frost susceptible soil in a horizon influence your design? Please explain.

(b) Does the water table elevation with relation to the frost susceptible soil influence your design? Please explain.

(c) Are requirements for selective placement of soil considered and provided for in design? Please explain and if possible illustrate.

(d) Does your standard specifications provide for soil types (granular material) to be used selectively?

(e) Do you show on your plans areas of frost susceptible soils which are to be excavated from below subgrade and replaced with suitable backfill?

(f) Is the quality of backfill material used to replace frost susceptible soils specified in your general specifications or is choice of material left to your field engineers?

(g) Do you have any criteria for the use of a choker or blanket course immediately over fine grained soils to prevent intrusion into a subbase or base material? If so, please give details.

State	3(a)	3(b)	3(c)	3(d)	3(e)	3(f)	3(g)
Arizona	No	Water table is usually too low to influence frost action	No	In base and subbase only	Not necessary	No answer	Varies with available material controlled by PI & No.200 specification.
California	Only in special cases such as I-80 in the mountains.	No	No - for structural requirements only.	No	No	Where applicable included in specifications for project.	No
Colorado	No	Refer Colorado Design Manual Table 5-606.4 (See Appendix B)	Yes - when practical poor soils placed in lower portions of embankments.	No	No	Neither	No
Idaho	Yes - Topsoil or frost susceptible soils at transition cut and embankments excavated, backfilled with granular material - drainage provided. Depth below finished grade is to bottom topsoil or twice depth of "ballast" section whichever is least.	Keep ditch bottom 0.5' below base or any select granular material.	Specifications require saving granular material for selective placement. Project design may call for use in capping embankments.	Yes, see 3(c)	Yes, See 3(a)	Only that it be granular sources investigated during project development. Field engineers choice.	Yes - If percent passing No. 22 exceeds 65 & PI or linear shrink exceeds 5. Blanket material must have at least 15% passing No. 40 & 25% passing No. 10. Place 0.25' to 0.40' thickness.
Montana	Yes - Use selected granular soils in top of embankment (Min. 2') also thicker surfacing section.	Yes - Construct higher embankment or protect surfacing course with sand choke or bituminous membrane.	No - Poor soils in lower horizons. Best soils on top. Pay crosshaul - placed in 8" layers.	No - covered by special provisions	Yes	Left to field engineers judgment	Yes - Use 5" of A-3 sand when economically feasible based upon piping ratio of 5. When sand not available use a bituminous membrane full width in bottom of surfacing courses consisting of 3" - 4" depth roadmixed with SC4 or MC3 plus top and shoulders of surfacing courses given 2 applications Bituminous treatment down through membrane course.
Nevada	Silt pockets or layers are removed or covered by free draining material.	Yes - Roadway elevated above water table elevation and placing free-draining base material above subgrade in low surfacing.	No - Control is in base Thickness - poor soils given greater thickness.	Yes - Thicker base courses	Yes - Generally in high water table areas.	Quality of backfill specified - obtain from roadway cuts or borrow sources.	No
New Mexico	Yes - Grade line kept high to avoid moisture in embankment - special pitrun material may be used.	Yes - Higher water tables cause greater susceptibility. See Question 2.	Yes - uniformity cannot otherwise be obtained.	No - Plans have notes indicating where conditions warrant selective placement.	No - See 3(c) for method used.	No - selection by project engineer based upon criteria from preliminary soil testing.	No standard - on high type roads a layer of cement treated base is often used over fine silty clays.
Oregon	Yes - If soil in subgrade zone.	This is not a problem	Yes - if free-draining granular material is used in subgrade to reduce base rock requirements.	Yes	Yes - in particular instances	General Specifications	Corps of Engineers criteria for filter material.
Texas	Yes - where experience indicates.	No	Yes - where economically feasible.	Yes	Yes - under special conditions.	Not in General Specifications.	No specific criteria
Utah	If location of soil and moisture conditions are such as to require. If soil 4' below final grade not considered.	Yes - frost penetration without available moisture does not produce serious subgrade failures.	Yes - Well graded granular materials as subgrade reinforcement. Thickness these materials plus base and surfacing roughly equivalent frost penetration	Yes	No - Generally areas are too extensive - Treatment is prescribed in design recommendations.	No - When specified central laboratory determines type and quality.	Not in Specifications. Central laboratory determines if warranted and based on type and quality of materials economically available.
Washington	Yes - Avoided, wasted or buried or covered with adequate depth frost free material where they must be used.	Yes - If water table is expected within 5 feet of subgrade elevation frost design called for if frost susceptible soils involved.	Yes - See 3 (a)	Not specifically for frost - Usually covered in special provisions for project.	See 3 (d)	Not in General Specifications. Approval of Materials Engineer required. Quality see 2(a).	15% size of Surfacing less than 4 to 5 times 85% size foundation material.
Wyoming	No	Yes - Water table elevation used determine where soils could be susceptible. Rainfall, frost action, water table and general conditions used to determine final design.	No - Would make costs prohibitive	Yes - Special granular backfill used around culverts and specified drainage areas.	Generally No	No	No - However, used in certain areas.

4. DRAINAGE

(a) Are different geometric sections used in areas subject to frost problems than in non-frost areas (ditch depths, shoulder slopes, etc.)? If any, please describe.

(b) Are any special drainage features or controls, if any, used in conjunction with your subgrade in frost areas versus non-frost areas? If so, please explain.

(c) Are any special drainage features or controls, if any, used in conjunction with your subbase or base materials? If so, please explain.

5. USE OF ADMIXTURES

(a) Have any admixtures been specified to control frost susceptible soils?

1. Calcium Chloride
2. Sodium Chloride
3. Bituminous materials
4. Portland cement
5. Lime
6. Sulphite Liquors
7. Other

(b) Please describe your success with the use of admixtures, i.e., degree of increased support attained, duration of effectiveness, control frost heave, etc.

State	4(a)	4(b)	4(c)	5(a) 1	2	3	4	5	6	7	5(b)
Arizona	No	No	No	No	No	No	No	No	No	No	None used
California	No	No	No	No	No	No	No	No	No	No	No answer
Colorado	No	No	Under drains where moisture conditions require	No	No	No	No	No	No	None	None
Idaho	No	No	See 3(a) for gradepoint treatment	No	Yes	No	No	No	No	No	NaCl placed in frost heave areas by drilling through pavement.
Montana	No - consider snowfall and snow storage in geometric design. Can expect 5 feet of frost penetration.	All sections designed for good drainage.	No	No	No	Yes See 3(g)	Yes	Yes	No	No	Have used soil cement where aggregates are scarce and hydrated lime to reduce PI in poor gravels - Reduces susceptibility to frost with satisfactory results.
Nevada	No - Ditches constructed below bottom of base course	In extreme cases perforated under drains carry water from base and subbase - bedding and backfill aggregate sand or sand-gravel with less 2% pass No. 200.	See 4(b)	No	No	No	Yes	No	No	No	One project stabilized with cement to prevent decomposed granite from heaving. Completed in 1961 - Satisfactory to date.
New Mexico	No - In general adopted wider roadway cut ditch to eliminate excessive water.	No - Use perforated pipe for sub-drains.	Cement treated bases tends keep moisture from working into underlying surfacing and subgrade.	No	No	No	No	No	No	No	None
Oregon	Emphasis on good drainage	Not in particular	None other than free draining specification material.	No	No	No	No	No	No	No	None
Texas	No answer	No answer	No answer	No	No	No	No	No	No	No	No experience
Utah	To date only some section changes in short road sections. Primarily of side ditch interceptions of water by cut widening, drain ditches, or drain pipes.	4(a)	4(a)	No	No	No	No	No	No	No	None
Washington	Deeper ditches used where snow may remain in ditch and plug them.	Not for frost	4(b)	No	No	No	No	No	No	No	None
Wyoming	No	No	No	No	No	No	No	No	No	No	None

6. DESIGN OF FLEXIBLE PAVEMENT STRUCTURE THICKNESS (Pavement, base, and subbase)

(a) Do you have any differing criteria for total pavement structure thickness in frost areas versus non-frost areas? Please explain.

(b) If any differing criteria is used, is it applied to soils types generally or to any specific soil type? Please explain.

(c) If limited axle loadings are provided for, how are these adjustments made in your design?

(d) Do you consider any choker or blanket course used as a part of your total pavement structure thickness?

(e) Do you vary pavement structure thicknesses for embankments versus cuts for the same soil types? Please give criteria if any.

(f) Are any special materials specified to be used in capping rock embankments? Please give details.

State	6(a)	6(b)	6(c)	6(d)	6(e)	6(f)
Arizona	Standard design thickness	No answer	Not limited	Considered part of total thickness.	No	Attempt to avoid inferior materials - Material used depends upon material available.
California	No	No answer	No adjustments	Yes	For drainage purposes primarily; frost effects considered only in special cases.	Only for structural and construction purposes
Colorado	Total thickness of subbase, base course and surfacing is partly determined by depth of frost penetration (Ref. Colorado Design Manual - 5-606.4) (See Appendix B)	None	See Table 5-606.4 Appendix B	No	No	Yes - we use subbase material for leveling course.
Idaho	No			Yes	Extra thickness of granular materials provided in cuts if wet conditions are anticipated.	No - Specifications provide for using "approved granular materials".
Montana	No - Use HRB Group Index for thickness design with thicker bases over poorer soils.	Applied to all soil types & group indexes modified by local soil and moisture conditions.	Design for 20 years Projected traffic type and volume.	Yes - for choke course but not for blanket course of granular material.	No - Use same thickness	Variable - Depending on local conditions and type of rock.
Nevada	On Interstate projects total base and surface thickness is increased 4 inches in northern ½ of State or in frost areas.	Total base thickness is increased over minimum where poor soils are encountered. Determined during design from soil samples.	No	No	No	Yes - granular material specified and used as a cushioning material to cap rock fills and cuts.
New Mexico	Regional factor for thickness of Pavement Structure.	Applied to soils generally	Reflected in Traffic Index	Yes 3(g)	No	Yes - subbase or base course is used to level out rock cuts and fills, to profile grade.
Oregon	In frost areas total pavement structure equal to ½ frost penetration if exceed "R" Value for Soil.	All soil, if 10% or more material passes No. 200 sieve.		Yes	No	No
Texas	No - due to limited depth of frost problem.				No	
Utah	No - Extra thickness is applied in subgrade. Reinforcement with granular materials.			No - See 6(a)	No	Only a base leveling course.
Washington	Frost design thickness equal to ½ frost penetration in area for frost susceptible soils.	Only to frost susceptible soils.		If it is of better quality or higher "R" value than subgrade on which placed.	No	No
Wyoming	Yes - Frost areas noted on soils profile by field engineers - total thickness designed will be increased 2" over that required by Stabilometer.	Only on specific type such as "Bentonite". Soils having extremely high PI are noted on soils profile to be wasted.	Axle loading are limited and design done accordingly	When recommended included as part of total pavement structure thickness	No	Yes - Rock kept at least 2 ft. below profile grade on embankments. Special material used limited in maximum size and clay type soils are not to be used in the top 6" of the grade.

7. DESIGN OF RIGID PAVEMENT STRUCTURE THICKNESS
(Pavement and Sub-base)

(a) Do you have differing criteria for total pavement structure thickness in frost areas versus non-frost areas? Please explain.

(b) If differing criteria is used, is it applied to soil types generally or to any specific type? Please explain.

(c) If limited axle loadings are provided for, how are adjustments made in your design?

(d) Is the sub-base course, blanket or choker courses considered as imparting any structural strength?

(e) Are you providing for treating of the sub-base material with admixtures to prevent pumping? Please explain.

(f) Do you vary the pavement structure thickness for embankments versus cuts for the same soil types? Please explain if used.

(g) Are any special materials specified to be used in capping rock embankments? Please give details.

State	7(a)	7(b)	7(c)	7(d)	7(e)	7(f)	7(g)
Arizona	No		Not limited	Problematical	No	No	Attempt to avoid inferior materials - Material used depends upon types available.
California	No			No	Yes - All projects have 4" - 6" cement treated material directly under the PCC.	No	No
Colorado	None			Yes	No	No	Yes - Sub-base material used for leveling course.
Idaho	Have no design Standards		*				
Montana	Usually Minimum 1 ft. of base course over free-draining embankment soils - Over frost susceptible soils 2 ft. blanket or sub-base or good granular material placed.	Soil types generally	Slab designed to carry expected traffic volumes with a 6" cement treated base - Additional base and sub-base courses are used to protect from frost heave with thicknesses based upon soil types or local conditions.	Yes - Slab is designed to carry traffic volumes and loads without additional base.	No	No	Use available material
Nevada	No answer						
New Mexico	No		Not limited legal only	Yes	Yes - 4" of cement treated base under PC pavement	No	Yes - See 6(f)
Oregon	Frost areas - Total pavement structure equal to at least ½ frost penetration.	See 6(b)		Yes	No	No	No
Texas	No				Yes - Not in connection with frost.	No	No
Utah	No			No	No	No	Gravel base materials as a leveling course.
Washington	See 6(b)	See 6(b)	No	Yes - See 6(b)	No	No	No
Wyoming	Yes - Areas of frost action thoroughly investigated. Standard rigid pavement designed and 4" of crushed base provided where frost is detrimental - additional sub-base to above used.	Yes - Applied to specific soil types in relation to water table.	Standard pavement design based upon overloadings as outlined in PCA manual "Concrete Pavement Design".	No	No - Sub-base is a specification material.	No	See 6(f)

8. SUBBASE AND BASE COURSES

(a) Do you have any criteria for frost susceptibility of subbase or base materials?

(b) Are sources of subbase materials pretested and designated for use?

(c) Are sources of base materials pretested and designated for use?

(d) What test methods and test limitations are specified to control quality of subbase and base materials for frost susceptibility?

(e) Are subbase and base courses constructed full width from subgrade shoulder to subgrade shoulder?

(f) Are ditch bottoms carried at a level lower than the subgrade on which any subbase is placed in frost areas? How far?

(g) Are admixtures ever specified for use to control frost susceptibility of subbase or base materials? If used, what is your criteria, testing procedures and test value limitations?

State	8(a)	8(b)	8(c)	8(d)	8(e)	8(f)	8(g)
Arizona	Use test reported in Highway Research Board Proceedings, Vol. 29, 1949, Page 392. Investigation of a simple method of identifying base course material subject to frost damage	Yes	Yes	Maximum % Pass No. 200 and plasticity index.	Yes	Usually	No
California	No	Not for frost action	Not for frost action	None	When necessary for drainage.		No
Colorado	No	Yes	Yes	None	No	Not in all cases	No
Idaho	No	Yes	Yes	No quality criteria for frost. Have gradation and sand equivalent controls otherwise.	Yes	Yes 0.5 feet	No
Montana	Yes - limit % Pass No. 200 to 12% and LL to 35, PI to 6 by special provisions.	Yes	Yes	% Pass No. 200, LL & PI	Yes	Usually 1 foot	No
Nevada	No answer						
New Mexico	No	Yes	Yes	None	Yes	No	No
Oregon	Yes	Tested and recommended for use	Tested and recommended	Standard Specifications for crushed materials	Yes	Yes - in special instances to 3 feet	No
Texas	No	Yes	Yes	None	Yes - generally	Yes	No
Utah	No	Yes	Yes	Use Standard AASHO tests for gradation. Limit percentages fine sand and silt fractions in soils designated to use.	Yes	Yes	No
Washington	See 2(a)	Yes	Yes	Grading only See 2(a)	Nearly always except when special free-draining shoulder section is used	Ditch bottom carried 6 inches below subgrade elevation frost or no frost	No
Wyoming	Use Specification materials - these considered not susceptible.	Yes	Yes	Subbase crushed to pass 1½" square sieve with less 20% pass No. 200 LL & PI meet base specifications. LL less 25 PI less 6.	Yes	Yes - ditch bottoms always below subbase.	Yes - when subbase or base has PI greater than 6, cement or lime used to improve quality.

9. STRUCTURES

(a) Are any special criteria employed for structures in areas subject to frost effects? If so, please explain.

(b) Do you use a special backfill or embankment material that is non-frost susceptible adjacent to structures or culverts? If so, please give details.

(c) Are any other treatments of soil made due to frost with regard to structures and pipe?

10. OTHER

Please add any comments you wish regarding Design Considerations relative to frost action in soils.

State	9(a)	9(b)	9(c)	10
Arizona	No	All backfill for structures both in or out of frost areas shall have the sum of the % passing No. 200 and plasticity index not to exceed 23.	No	
California		Granular material is required for all structure backfill.	No	
Colorado	Bridge footings placed below frost line.	No	No	
Idaho	No	Yes - granular material with less 5% pass No. 200 and Sand Equivalent of at least 70.	No	
Montana	No	Permeable granular material, less 15% pass No. 200	No	Good embankment construction by layer placement with compaction control and selective placement of poor soils in lower horizons producing embankment uniformity together with adequate surfacing courses can eliminate detrimental frost action. We have found no cheap method of frost heave control, but have generally eliminated this condition by good embankment construction and adequate depths of surfacing materials.
Nevada	No Answers			
New Mexico	Footings below frost and use granular backfill.	Yes - Specifications require a specified granular backfill.	No	
Oregon	No	Yes - Backfill with a free-draining material.	No	
Texas	No	No	No	
Utah	Foundations below frost elevation.	Backfill conforms to Specifications for imported borrow.	No	
Washington	No	Yes - Standard backfill materials are non-frost susceptible.	No	
Wyoming	Footings are a minimum of 4 feet below ground line.	Yes - Replace poor material due to consolidation rather than frost.	No	Considerations are given in design to frost action in soils even though specific tests to determine this are not run. By having specifications on subbase and base and having embankment placed at 95% compaction we believe detrimental frost action is at a minimum.

Appendix B

The Colorado Department of Highways, Design Manual, Section 5-606, Design Procedure for Flexible Pavements provides for varying the total thickness as follows:

"When (CBR) values are used on basement soils, the following procedure shall be used to determine the required thickness of subbase material:"

"The design curve to be used is determined by summing up the values assigned to the FROST conditions, moisture conditions and traffic conditions on Table 5-606.4."

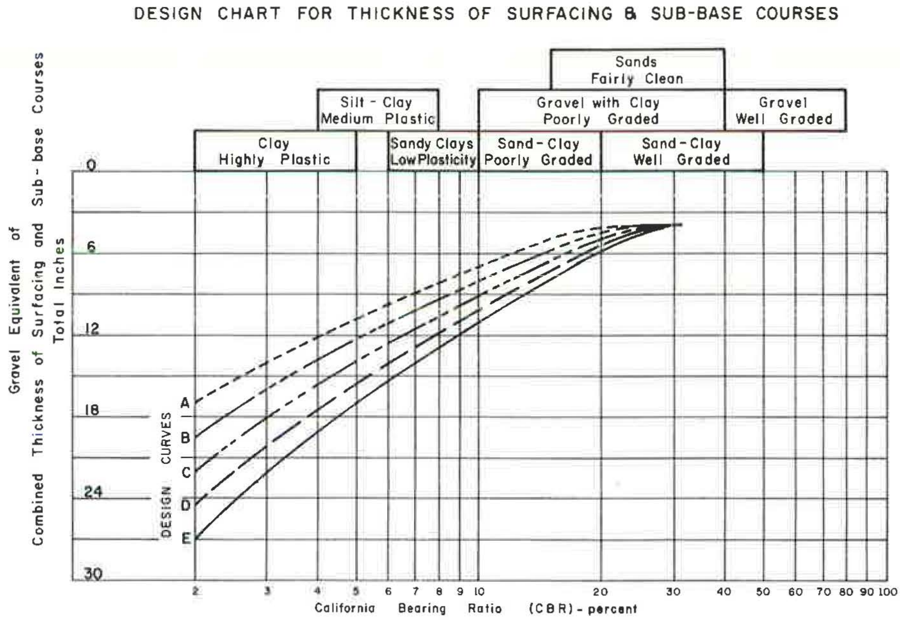
"The gravel equivalent of the total thickness of subbase, base course surfacing and pavement is determined from Figure 5-606.4 by drawing a vertical line from the indicated (CRB) to an intersection with the designated design curve. From this intersection point, a horizontal line drawn to the left side of the chart will indicate the gravel equivalent of the combined thickness."

"The required subbase thickness is determined by subtracting from this gravel equivalent, the gravel equivalent of the base course surfacing and pavement."

Table 5-606.4

Design Curve Selection

FROST CONDITIONS	ASSIGNED VALUE
Penetration of 0" to 12"	3
Penetration of 13" to 24"	5
Penetration of 25" to 36"	7
Penetration over 36"	10
MOISTURE CONDITIONS	
Arid or high table land not subject to standing water	2
Ground subject to occasional standing water during storms	4
Ground subject to saturation only during periods when frost is not present	7
Ground subject to saturation during periods when frost is present	10
TRAFFIC CONDITIONS	
Traffic of 0 to 400,000 EWL	0
Traffic of 400,001 to 800,000 EWL	1
Traffic of 800,001 to 1,600,000 EWL	2
Traffic of 1,600,001 to 2,400,000 EWL	3
Traffic of 2,400,001 to 3,200,000 EWL	4
Traffic of 3,200,001 to 5,600,000 EWL	5
Traffic of 5,600,001 to 8,000,000 EWL	6
Traffic of 8,000,001 to 12,000,000 EWL	8
Traffic from 12,000,000 EWL	10
SUM OF ASSIGNED VALUES	
From 0 to 8	Use Curve A
From 9 to 13	Use Curve B
From 14 to 18	Use Curve C
From 19 to 24	Use Curve D
25 and over	Use Curve E



Discussion

R. V. Le CLERC, Washington Department of Highways—Mr. Erickson has summarized a rather voluminous amount of information into a form which can be easily read and assimilated. As such, he has made it possible for the utmost benefit to be derived from such a questionnaire. The summary text will enable the reader to see what others are doing and perhaps obtain a few new ideas—further details can be found in the questionnaire or from the state source of the information.

Most of the frost design methods appear to be based on recognition of the three basic conditions nearly always associated with frost problems (frost-susceptible soil, available water, freezing temperatures) and removal of one or more from consideration by various means.

Opposite ends of the scale of frost design methods might be the design which seeks to prevent any freezing or frost heave at all, and the design which ignores the frost prevention and provides a structural section to accommodate the weakened, thawed subgrade. Most of the methods, by plan or happenstance, fall somewhere between these--at least it is believed that the Washington approach does. It falls into the group which calls for a depth of frost-free cover equal to one-half of the maximum depth of frost penetration in the location concerned. This is used only where the three elements of frost potential are evident, and the depth of cover to provide this frost protection is considered together with that called for by the stabilometer "R" value and that indicated by swell pressure in arriving at the design cover depth for the subgrade soil. A depth necessary to meet all these requirements is used.

The depths of maximum frost penetration were obtained by field measurements during an exceptionally cold winter of 1949-50. The measured depths and their locations were spotted on a state map and rough contour lines of equal frost penetration drawn through these points. The maximum frost penetration depth used in the design is taken from this map.

Frost susceptibility is judged by the amount passing the U.S. No. 200 sieve—any soil having more than 10 percent passing this size sieve is considered frost susceptible.

If water table at the onset of freezing temperatures is within 5 ft of roadway elevation, water is considered available for frost damage through formation of lenses and frost heave.

Although the above criteria are somewhat classic and deal with frost heave and its consequent damage, it is believed that frost contributes to roadway deterioration in another manner which is less obvious and which does not require the classic conditions listed heretofore.

The sequence of events occurs in this manner:

The rains in the fall season are somewhat continuous and contribute to an increase in the water content of the underlying base, subbase, and possibly subgrade. A prolonged cold spell moves in with freezing temperatures prevailing for approximately a week or ten days. During this period, particularly if there is snowfall, the thawing which might occur during the day does not penetrate to a depth sufficient to permit vertical drainage, and lateral drainage is hardly ever present, even in unfrozen shoulders. The alternate freezing and thawing tends to accumulate water under the roadway, and promotes an abnormally high water content in the surfacing (base and subbase) courses. Also, the freezing contributes to some expansion and consequent loss of density in these materials. The freezing temperatures need not be exceedingly severe, just 15 or so degrees below freezing, to bring about this condition.

With the warming trend that follows, the accumulation of water plus the loss in density, however small, is manifested in increased amplitude of roadway surface deflection under load. Before the water can be dissipated and the density of the affected base and subbase courses regained, the fatigue life of the pavement surface has been seriously shortened or surpassed.

The sequence of events has been noted often in Washington and no doubt occurs in other states. The rapid appearance of surface cracking is usually noted, and close observance will show that the extent of cracking increases with each cycle of similar freezing conditions.

The work of Oregon and Idaho in measuring loss of strength in roadbeds during spring is directed to the solution of this problem—particularly the studies which involve measurement of deflection. It is believed that the continued studies of roadway deflection and behavior during this critical period will lead eventually to a much better understanding of this problem and give design engineers more tools with which to work, or at least another factor to add to the list of those which must be considered in designing a roadway for reasonable life expectancy.