

NEEDED RESEARCH PERTAINING TO FROST ACTION

REPORT OF QUESTIONNAIRE ON RESEARCH NEEDS

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Few engineers are aware of the vast amount of information developed in the study of frost action in subgrades and base courses during the past 20 years. Much of this information is widely scattered in the engineering literature, and it is only recently that a sincere effort has been made to assemble significant information on frost and its related highway problems. There is an urgent need for making a systematic appraisal of this knowledge so that remedies and treatments can be made available to the practicing engineer for design and maintenance purposes.

The Highway Research Board, through its Correlation Service and committee activities, has made considerable progress during the past several years by assembling and reporting significant research on the highway frost problem. Periodic visits to state and university laboratories, questionnaires, solicitation of technical papers for the annual meeting of the Highway Research Board, compilation of bibliographies, abstracts of technical articles, and the committee discussions of significant phases of frost research are some of the devices which have been used to collect, assemble, and organize this frost information on a nation-wide basis.

It is recognized that even with the research work that has been completed there will be certain aspects of the frost problem that need additional study. For this reason a nation-wide survey was made to obtain the opinions of a selected group of engineers and scientists to ascertain which phases of the frost problem should be considered in future research which will be of interest to a majority of engineers working with this problem.

A questionnaire was sent to 238 engineers and scientists located in state highway departments, government organizations and engineering schools to obtain as complete a cross-section of opinion as possible by this method of survey. More than 68 percent of these questionnaires were returned with complete answers. About 10 percent returned the questionnaires stating that they were not in a position to answer the questionnaire or they failed to rate the six categories of research. Only questionnaires with complete answers were considered in summarizing the results of this study. In most instances the opinion of at least one state or government engineer and one professor of civil engineering was obtained from each state. In some of the frost states more than one opinion was obtained from each of the three groups previously mentioned.

Questionnaire

We have directed this questionnaire to you because the Committee on Frost Action wishes to obtain your opinion. Your name will not be used in the tabulation of these data.

We want you to rate the following six categories A through F by assigning numbers, one through six, in the order of importance to the frost problem in your area. In case you have additional frost problems in your area which are not included in the categories listed, add them to the questionnaire and give them a numerical rating so that we can obtain your relative rating of all the categories:

(A) Soil Temperature

Research work within this category includes the tabulation of actual temperature measurements over a long period of time which will be correlated with local climatic conditions, local soil conditions, surface cover conditions, and the effect of the soil moisture on the movement of temperature within the subgrade of pavements. Included

will be the studies of the effect of various thicknesses of insulation courses to reduce frost penetration.

(B) Soil Moisture and Moisture Movement

Research work within this category includes the collection of factual information on subgrade moisture content data together with information on soils, pavement structure, and climate; the development and improvement of moisture-measuring devices for subgrade soils; and the study of theories of moisture movement in soils.

(C) Climate and Distribution of Soils

Research work within this category includes the development of a generalized soil map and the development of a climatic map for the United States with special reference to the damage of highways due to freezing.

(D) Frost Heave, Basic Data, and Definitions

Research work within this category includes the fundamental study of the phenomena of frost action, the collection of basic data on the effects of frost action in various types of soils and the definition of terms associated with the problem of frost action.

(E) Frost Action and Spring Breakup

Research work within this category includes the collection of field data on loss of stability of subgrade soils during the spring breakup together with data on soils, moisture changes, climate and pavement structure; and laboratory investigation of the action of freezing upon moisture in soils as related to stability.

(F) Remedies and Treatments

Research work in this category includes the collection of information on the design and construction practices that are followed to remedy or minimize the frost problem in various parts of the United States, such as, drainage, use of base course, making the soil more uniform, etc.

(G) Other Fields of Research

Research work in this category includes research studies on problems not included in the six categories, or additional comments on the frost problem, if necessary.

Results of Questionnaire

The data obtained from the questionnaires were tabulated by states and the ratings for each of the six categories of research were summarized under three subheadings so that comparisons could be made among the ratings assigned to those six categories by professors of engineering schools and government and state highway engineers located in various parts of the country. The results of this study are summarized in Table 1 on a percentage basis so that direct comparisons can be made between the various opinions. In this table the data have been summarized on a nationwide basis to show the consensus of opinion expressed by the three different groups answering the questionnaire. These data have been subdivided into two areas, non-frost and frost, to indicate the influence of climatic conditions on the opinions of these three groups.

The percentage distribution based on the number of papers presented in this symposium is shown to indicate the relation of this symposium to the consensus of opinion found by the questionnaire.

A study of the data in Table 1 warrants the following general conclusions:

(1) It appears to be the concensus of opinion on a nationwide basis that the most important categories for research studies are (F), (E), and (B). These three are about of equal importance. There is a slight trend toward placing more emphasis on (F) - "Remedies and Treatments." The next category of importance is (D) which is about 70 percent as important as (F), (E), and (B). The least important are (A) and (C) which are about 40 percent as important as the highest rated categories of frost research.

TABLE I.

RELATIVE IMPORTANCE OF THE SIX CATEGORIES OF FROST RESEARCH (A THROUGH F) LISTED IN QUESTIONNAIRE							
Classification of Groups Questioned	No. in Groups	Rating of 6 Categories on Percentage Basis *					
		A	B	C	D	E	F
Academic ^{1/}	44	12	21	12	16	19	20
Gov. Engrs. ^{2/}	50	11	19	9	18	21	22
Highway Engrs. ^{3/}	53	13	23	11	13	16	24
Av. of Total Group ^{4/}	147	12	21	11	16	18	22
Av. of Engrs. in Wash. D.C. ^{5/}	16	8	22	9	18	23	20
Subdivision of above data							
(a) Nonfrost area ^{6/}							
Academic ^{1/}	13	9	21	20	15	17	18
Gov. Engrs. ^{2/}	19	10	19	9	18	21	23
Highway Engrs. ^{3/}	19	12	23	11	13	18	23
Av. Nonfrost area		10	21	13	15	18	22
(b) Frost Area ^{6/}							
Academic ^{1/}	31	14	21	9	16	20	20
Gov. Engrs. ^{2/}	31	13	19	8	17	21	22
Hwy. Engrs. ^{3/}	34	12	21	5	15	26	21
Av. Frost area		13	20	7	16	23	21
Percentage Distrib. of Papers ^{7/}		11	19	8	24	19	19

^{1/} - Academic includes College and University Professors.

^{2/} - Gov. Engrs. includes B.P.R. and other Gov. Bureau Engrs.

^{3/} - Highway Engrs. includes State Highway Engineers.

^{4/} - Av. Total Group does not include those from Washington D.C. area

^{5/} - This group classified separately because of their national viewpoint.

^{6/} - Frost and nonfrost areas based upon J.A. Sourwine's climatic map.

(See PUBLIC ROADS Magazine, Vol. II, No. 8, 1930.)

^{7/} - Distribution based on papers presented in this symposium

*A, soil temperature; B, soil moisture and moisture movement; C, climate and distribution of soils; D, frost heave, basic data and definitions; E, frost action and spring break-up; F, remedies and treatments.

(2) It appears that on the average there is very little difference between the relative importance of these six categories of research as expressed by the nonfrost and frost areas. However, from the academic viewpoint of those from the nonfrost area, (B) and (C) are considered the most important for doing additional research work. Whereas, the engineers in the same area place considerably less emphasis on the importance of (C). This probably can be attributed to the potential usefulness of this category of research material for instruction purposes in areas where serious frost damage is not a highway problem.

(3) It appears that the papers presented in this symposium reflect quite closely the national viewpoint found for most of the six categories of frost research. The major difference appears to be in (D) -- "Frost Heave and Basic Data." The national viewpoint appears to place less emphasis on research on basic frost heave theory and more emphasis on the importance of research work in (E) -- "Frost Action and Spring Break-up."

Other Research Categories and Comments

As previously indicated, a part of the questionnaire was for additional research and for comments regarding the problem of frost action. The following remarks cover

some of the comments obtained by this nationwide questionnaire on frost research. These comments and other phases of research are tabulated by states. In most cases they are excerpts of statements made by one or more of the groups in the state and they are presented in random order to conceal the source of information. These opinions and suggestions were treated in this manner since it was stated in the questionnaire that personal names would not be used in this report. Consequently they may or may not reflect design practices in the states.

Arizona - Research studies should be made to determine (1) which component of the pavement structure is primarily responsible for most frost damage (applicable only, of course, in pavement structure that is otherwise completely adequate); (2) which factors are causing the damage in the distressed pavement components; and (3) a practical test method which can be used in the field to detect the factors responsible for frost damage. These field and laboratory studies should be confined to roads built in accordance with modern design practice with respect to thickness and quality of the materials used for each structural component of the pavement.

California - Frost heave is a minor problem confined to the northeasterly mountainous regions. We are, however, interested in the factors affecting the development and movement of soil moisture.

Georgia - Frost damage is a very minor problem. Some damage is experienced with base courses of roads built in the northern part of the state during extremely cold winters.

Idaho - There is a need for the development of a control test that can be used to predict the susceptibility of base course materials to frost damage. It also is desirable to study the form taken by frost in penetrating and heaving base and subgrade. Additional information is needed on the accumulation of moisture beneath bituminous surfaces with untreated shoulders and some study should be made of snow removal methods in relation to the penetration of frost.

Illinois - The effect of soil moisture on the movement of temperature has been studied and can be computed. Research is needed to determine the thickness of pavement and base necessary to carry highway loads over a frost melting subgrade.

Iowa - Research work is needed in the study of vapor movement of soil moisture through the subgrade and base course.

Kentucky - It is desirable to obtain additional data on the minimum thickness of pavements with bituminous surfaces for use on lightly traveled roads.

Louisiana - The temperature rarely falls below 25 F. and stays too short a period to make frost action a serious factor in the life of pavements. Our problem is high water table and saturated subgrades. A study of pavement pumping in connection with movement of moisture in soils and their corrective treatments is needed.

Maine - Additional information is needed concerning the effect of frost action on culverts and minor structures. Studies should be made on the relative displacement of structures and adjacent soils due to the freezing of soil moisture and on the effect of thawing on the stability of culverts and minor structures displaced by frost action.

Research work is needed in "Frost Action and Spring Breakup," in "Remedies and Treatments," and in "Soil Moisture and Moisture Movement" as it ultimately will show the relative efficiency of various construction types in resisting frost action. The improvement in pavement design to resist frost action is one of the paramount needs in this area. Experience has indicated that highway damage is not necessarily dependent upon the overall severity of a given winter, but rather upon the details of temperature fluctuations and moisture conditions and traffic characteristics. It is the accumulation

of excess moisture that causes trouble regardless of what the climatic conditions may be, even though subfreezing temperatures produce the most accumulation of moisture. The past winter has demonstrated that extremely severe damage may occur during the course of a winter of moderate severity.

Maryland - Additional studies should be made in the use of chemical admixtures to provide for protection of pavements against frost heave. Information is needed on what percent of chemical would be required, to what depth the treatment should be and how long it will be effective after placement.

Massachusetts - There are too many independent investigations made by various organizations. It is highly desirable in the interest of progress to coordinate these efforts and to make a better dissemination of the results of these studies.

A study should be made of the colloid chemistry of soil constituents, their interaction, and how they can best be stabilized to offer a basis for highway construction unaffected by moisture frost, etc.

Michigan - Climate and the distribution of soils are very important to the highway industry as a whole. There are some conflicting ideas on basic frost heave data that need clarification. Field practices are well established and the pressure for research is, therefore, not too great. There is a need for economic studies in connection with the design of highways to prevent frost damage. How much money can be spent to protect highways against frost damage considering construction and maintenance costs and traffic loads?

Missouri - Research studies are needed in soil moisture and the movement of moisture as this information is needed for other purposes. Remedies and treatments become important after the others have been determined.

Montana - Studies should be made in soil moisture movement and frost action to determine the effect of lowering the free water table in frost conductive soils by means of drainage facilities, such as, open ditches, underdrains, etc.

New Jersey - A critical analysis from a fundamentally scientific viewpoint of available information in these six categories of research and coordination into theoretical structure is needed to show the futility of much of the presently planned work, and it would render more valuable the really more important investigations.

There is a need for studying the intermediate frost action zone where the freezing index ranges from 0 to possibly 300. Studies recently made indicate that pavement subgrades are weakened considerably by the presence of excess moisture throughout the winter period. Such conditions appear to exist even when the subgrade soil is frozen relatively few days during the critical period.

New Hampshire - There is need for field studies on the destructive effects of frost heave with respect to cracking and joint failures and their relation to pumping under the action of traffic. Also, studies should be made to determine the relation of ground water level to frost action in various types of soils.

North Dakota - A study of frost action in soils at culverts in northern climates is needed to determine corrective measures in bedding, backfill, etc. to prevent grade subsidence that occurs frequently from 2 to 5 years after construction in fills less than 5 ft. in height. No trouble is found in deep fills where the cover over culverts is greater than 5 ft. A study is needed in local load restrictions applied during spring breakup. This should include the determination of the best method of restricting local limits to prevent damage to various types of pavement surfaces because of loss in stability or load-carrying capacities in subgrades and bases during the spring breakup period. Should such restrictions be based on maximum allowable loads per inch of tire width,

per wheel load, per axle load, or by gross weight of vehicle or combination thereof? The collection of information on such practices throughout those states confronted with the spring breakup problem would assist in the solution of this highway problem.

Ohio - "Frost Action and Spring Breakup," and "Remedies and Treatments," should be expanded to include base courses, such as, soil-aggregate, macadam or soil-cement.

Pennsylvania - There is a need for the collection of basic data on the effect of frost action in various types of soils; and for the study of the effects of various thicknesses of insulation courses to reduce frost penetration. It is desirable to acquire as quickly as possible any information which would qualify or disqualify remedial measures now generally in use. This would make available useful information for immediate application while the long term research studies are underway.

Virginia - There is a need for relating spring breakup to soils and climatic factors and for accumulating information on remedies and treatments which can be correlated with data on frost action such as, temperature and soil moisture movements. Studies should be made to determine the effect of freezing in well-graded granular soils which have high percentages passing the No. 200 mesh sieve and high liquid limits and plasticity indexes. More emphasis should be placed upon the evaluation of information collected and tabulated. This is the link for bridging the gap between scientific research and engineering practice. For example, the collection of information on remedies and treatments should be relatively simple, but, the evaluation of the effectiveness of various remedies will be difficult and probably controversial. Yet it is evaluation that the practicing engineer wants.

Washington - It is believed by some engineers that in most cases, if sufficient granular base is constructed to meet strength requirements, it will also take care of the local frost problem. Some local research may be in order to determine the accuracy of this belief. Studies are needed to correlate the frost hazard with ground water table and soil properties as a means of determining the frost susceptibility of soils used for highway construction purposes.

Wisconsin - Research is needed to establish the potential of water tables in the soil column below the pavement structure, the potential manners in which moisture can accumulate or have access to soil column and geological influence contributing to such potential.

Wyoming - It is suggested that studies be made of the profile shape taken by the top of the frost layer, under various types of pavements and shoulders, as the frost leaves the road, to provide data on why some roads give satisfactory performance during some winters and go to pieces in others. This information would be useful for determining corrective measures for design purposes.

Washington, D. C. Area - If remedies are to be applied, and if designs are to be improved, fundamental understanding of the laws of physics involved must first be obtained. Research is needed to determine the effect of freezing and thawing on the stability of base courses and subgrades in border line areas where prolonged freezing is not considered a factor in design. Studies should be made to determine the soil characteristics which make a soil susceptible and to determine the effect of gradation (silt and clay content) on frost action. Suggest a follow-up questionnaire to state and federal organizations concerning their research in the categories listed in the questionnaire to obtain brief statements of results obtained to date from work now in progress. Research is needed to study in particular the phenomenon of thermo-osmosis in connection with temperature studies, soil moisture movements, and the distribution of climate and soils.

mate and soils.

The following fields of research are suggested: (a) Effect of grain size, rock content, density, and gradation on frost action; (b) Effect of alternating freezing and thawing, water table, and degree of saturation on frost action; (c) Effect of permeability, rate of frost penetration, and thermal properties of soil on frost action; (d) Study the length of thaw period or time the bearing capacity is reduced and determine methods to remedy conditions; (e) Development of freezing index data for areas studied; and (f) Prepare soil and climatic map showing areas of different types of frost damage or spring breakup.

It would be desirable to assemble all information as to areas where frost damage is a problem on a map or maps and then select the problems which are of most importance for an accurate and intense study of all conditions related to the frost damage. "Soil Moisture and Moisture Movement (Category B)" and "Frost Heave and Basic Data (D)" can be studied simultaneously and "Frost Action and Spring Breakup (E)" could be studied in conjunction with "Temperature (A)". After all these conditions have been tabulated and studied, conclusions may be reached and remedies and treatments prescribed.

Attention is directed to the fact that the mileage of highways reached for construction or reconstruction each year is insignificant when compared with the total mileage in our highway transportation system. It will, therefore, be many years before these improved practices, developed as a result of research and correlation studies of factors related to frost damage, will result in any relief to the maintenance forces and funds from the costly annual problem of repairing damage from frost action on many miles of roads.

Summary

There is an urgent need for the correlation of frost research now in progress in this country and means must be developed to obtain and disseminate more freely the results of investigation so that future research can be directed into the phases that need additional development.

It appears that considerable research has been reported without an organized attempt to evaluate this information so that it can readily be applied to the improvement of highway design and maintenance practices. The bibliography on frost prepared by the Highway Research Board is an excellent initial step as it organizes the available information, but, considerable more work must be done in the appraisal of this information so that recommendations can be made to minimize frost heave and frost damage in our existing highways.

Not all the future frost research should be directed to laboratory studies. There appears to be a real need for field research in connection with soil moisture and moisture movement and freeze damage in border line areas where frost action has not been considered a major problem.

The practicing engineer needs a field control test which can be used to predict the susceptibility of base course and subbase materials to frost damage.

The accumulation of excessive moisture in the subgrades due to temperatures at or near the freezing point and the subsequent loss of subgrade support appears to be an important field of research for both frost and nonfrost areas. Research reported by some states indicates that a moderately severe winter may cause considerably more road damage than a severe winter. It suggests that more attention must be given to influence of variations in climate on frost damage. A study of freezing indexes over a long period of years should assist in the solution of this frost problem.

Attention is directed to the need for studying frost heave of culverts and minor structures especially with reference to the type of material used for bedding and backfill as well as the minimum cover needed to protect these minor drainage structures against frost damage.