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LITERATURE REVIEW
ON FROST HEAVING

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16. Abstract

This literature review and report is in response to a problem statement for research. The problem statement proposed the installation of salt reservoirs as a low cost solution to seasonal frost heaves in the Colorado Rockies. The literature review includes: 1. The mechanics of frost heaving, 2. Mitigating measures, 3. Chemical treatment, 4. Insulation and finally, 5. Conclusions and Recommendations.

Implementation

This report and researcher assistance be extended to District personnel to aleviate their frost heave problems.

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LITERATURE REVIEW ON FROST HEAVING

Frost heaving on S. H. 40 on Rabbit Ears Pass prompted the submission of a problem statement to the Research Council in the spring of 1984. Several areas on the pass develop severe frost heaves which are hazardous to motorists and result in higher annual maintenance costs. Some previous efforts to alleviate the problems, which were not very successful, included excavation and improvement of drainage. Drainage is very difficult because the grades are very flat for several miles across a tundra environment on the pass. The problem statement proposed the installation of salt reservoirs as a low cost solution to the seasonal upheavals. The problem statement was evaluated by the Research Council and was placed high enough on their list to warrant funding for a research project.

An HRIS (Highway Research Information Service) file search and review is required before a formal research proposal can be submitted to the FHWA. That HRIS search, a search of the Highway Department Library and a search of documents in the Technology Transfer file provided a multitude of titles, abstracts and reports on Frost Heaves. This short informal report is the result of the literature review on pertinent materials from this collection.

A. THE MECHANICS OF FROST HEAVING

It has been established that frost boils or frost heaving is not a result of freezing of moisture present in one spot in the soil capillaries but of the building up of ice lenses through migration of moisture from shoulders and subgrade water table. An extra supply of water is the cause of excessive frost heaving (12). The supply of free water can be from the top, sides or from beneath. Water vapor can add to the free water supply but must first be condensed in order to flow to the ice lenses. Freezing water vapor forms individual ice crystals in the voids and is not accumulated in large quantities in the form of ice lenses. Maximum frost heaving does not occur simultaneously with the maximum depth of frost penetration. Frost heaving is dependent on soil moisture content resulting from precipitation or ground water (5). Free water flows to the freezing front (13).

The forces such as capillary action and ionic attraction by which water is retained in the soil lower the freezing point (16 & 17). In lean clay soils the freezing temperature of soil moisture is not constant, but decreases by several degrees below 32^{o}F (1, 16, & 17). Smaller capillary pores require lower temperatures before freezing can occur. This provides a means for supercooling of pore water in the vicinity of an actively growing ice lens. The subsequent release of energy in such a system is utilized to create a moisture suction gradient to the ice front. The quick freezing of super cooled water upon contact with the ice lens along with part of the energy released during latent heat of crystallization perpetuates the moisture suction gradient and produces positive pressure to raise the overburden (3).

Highways are good thermal conductors, especially when clear of insulating snow cover. Frost penetration will be abnormally deep as compared to adjoining surfaces. Solar heat absorbed by highways in the daytime and intensive outward radiation at night intensifies the freeze-thaw action of the vernal active zone (1 & 15). Accumulation of soil water in the "vernal active zone" above the horizon of winter frozen ground, at temperatures below 32°, feed the ice lenses and steadily increase their volume. Water accumulation can come from vertically downward gravitational action from surface moisture, horizontal migration from accumulation elsewhere, or vertically upward migration by either capillary action or by vapor deposition processes (1). The primary source of water is snow melt from the surface and adjacent areas (2 & 12). Normal gravitation drainage is blocked by an impervious ice horizon below the active zone (1).

The migration of water in the soil is accompanied by a change in volume resulting from changes in pore water pressure (17). The extent to which water will move into the frozen zone to cause the phenomena known as frost-heave, depends on the suction of the surrounding unfrozen soil, as well as that of the frozen soil. High suctions are present during freezing (3 & 17).

B. MITIGATING MEASURES

The following list is a composite of remedies or corrective measures taken from many of the sourse documents which were reviewed.

1. Drainage may be improved and soil may be compacted to a greater density (4 & 14).
2. Undesirable soil may be removed and replaced with better quality material (5, 10, 13, & 14).
3. The grade line may be raised by placing better quality materials over the weaker soil. Increase base course thickness (3, 5, 10, & 13).
4. The water table may be lowered. Deep Drainage (1, 5, & 14).
5. Frost-susceptible base-course soils may be blended with coarser grained soil to reduce the percentage of fines (3 & 10).
6. A frost-susceptible soil may be completely encapsulated within a plastic membrane to curtail the availability of moisture and thus reduce frost effects (4).
7. Application of a layer which will prevent capillary conduction (14).
8. Insulation, usually styrofoam or other nonbiodegradable insulation placed at one or more levels below the pavement surface and above frost susceptible soil layers (1, 5, 6, 7, 8, 10, & 14).
9. Chemical Treatment involving the addition of salts or ice retardants to the soil or water (4 & 14).

C. CHEMICAL TREATMENT

The best area for possible application of chemical treatment and additives lies in the borderline frost-susceptible materials (3). Salt may be added to lower the freezing point of soil water. Lowering the freezing point may preclude freezing or reduce the number of freeze-thaw cycles under a given set of temperature conditions, but does not affect the soil's propensity for heave if and when freezing occurs. The main disadvantage to the use of soluble salts for void-water treatment is that they are removed by leaching. It has been suggested that this problem might be avoided by complete encapsulation of the salt-treated soil within a plastic membrane (4).

Calcium chloride has been mixed or added to subgrade soils in Minnesota, Indiana, Michigan and Massachusetts, in an attempt to minimize frost heave. In several of the installations no apparent benefit resulted (4). In Massachusetts, there was a reduction in the heaving due to the use of calcium chloride however, the chemicals caused surface damage to the highway requiring reconstruction (4). The main disadvantage to use of soluble salts for pore fluid treatment is their non-permanency (4).

Influx of salt water from the surface will tend to form a dish shaped reservoir containing a solution with a lower freezing temperature. With such a condition of salt concentration, the soil tends to freeze upward. This upward progressing frost line (also dish shaped) can produce lenses which are subsequently supplied with additional salt water (melt water) and permits continued ice lens growth (4). A freezing front is developed below the pavement in the shape of a dish near the depth of deepest frost penetration for that particular freezing cycle. Dish shaped isochloride concentration solution levels are developed below the surface or salt water entry area. The ice lenses are also dish shaped and freeze upward (18).

As a result of these largely negative results, the committee on frost heave and frost action in-soils feels that it is not worthwhile to continue the field experiments (4).

Addition of 1 % sodium sulfate can significantly increase strength and durability of soils and decreases frost heaving (14).

(note: the above was taken from a report which was primarily concerned with soil stabilization)

D. Insulation

Insulation layers have a two part effect.

1. freezing resistance
2. maintaining a frozen condition (9)

It has been observed that water on top of lake ice but protected by snow insulation can remain unfrozen for days at a time even when the air temperature was recorded as low as -50° F (1). This confirms the earlier statement that thin film or capillary water freezes at temperatures below 32° F. and supports the fact that insulation layers reduce the effects of daily temperature changes. Insulation of roadways prevent rapid freezing of subgrade water at the beginning of the season, but tend to keep the entire subgrade colder and solidly frozen during mid and late winter seasons. This dampening out of daily, weekly or even monthly fluctuations effectively eliminates the "vernal active zone" and most of the free water and therefore the soil suction forces.

Frost damaged roads can be repaired easiest by laying insulation on the existing pavement and a new pavement on top of this (20). This corrective measure has the added effect of raising the grade, or, effectively placing the water table farther from the surface and increasing the thickness of granular material, thus reducing the effectiveness of the frost susceptible material.

E. CONCLUSIONS AND RECOMMENDATIONS

Chemical treatment including salt reservoirs have only been marginally effective in a small percent of field tests. In several tests they have had a detrimental affect.

Two other remedial measures are generally accepted and effective throughout northern regions of the world where frost heaving is a significant problem. They are: 1) excavate all frost susceptible soil to below the level of maximum frost penetration and replace with a granular material, and 2) install insulation layers within the highway structure covering the problem areas.

It is recommended that either remedial measure 1) or 2) or a combination of both be utilized in one or more of the problem areas on Rabbit Ears Pass.

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