ECONOMIC ASPECTS OF HIGH SPEED GRAVEL ROADS

FINAL REPORT

by

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16. Abstract

The report examines the comparative costs of gravel-surfaced and paved roads capable of carrying traffic safely at 55 m.p.h. Gravel surfaces are found to be a practical alternative to asphalt concrete pavement for rural highways in many areas in Alaska. Construction costs are significantly less as a result of the elimination of paving costs and differences in the requirements for embankment material quality and thickness. Maintenance costs are found to favor paved roads where the embankment and original ground conditions are very good, but favor gravel surfaces where these conditions are fair to poor, and especially where permafrost thaw settlement is a maintenance problem.

Dust control treatment of gravel-surfaced roads is found to be necessary for providing safe, high speed travel. The expense of such treatment is found to be partially, if not entirely, offset by the resulting reduction in the need for maintenance grading and surfacing gravel replacement.

The report recommends that gravel-surfaced roads be given greater consideration in transportation planning for Alaska. It further recommends that the state adopt standard specifications for gravel surface course material, that a regular regraveling program for unpaved highways be initiated, and that Alaskan design limits on road embankment fines content be reexamined where the highway will not be paved.

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I. INTRODUCTION

At the present time the same basic design process is followed for nearly all state road projects in Alaska. One of the underlying assumptions of this process is that all roads may eventually be paved and the designs are developed to accommodate this. Unpaved roads, then, are simply paved roads without the pavement; in many cases, there is little likelihood that there will be a pavement within the design life of the structure.

This design procedure may not be the best practice for roads which are not expected to be paved for two basic reasons; first, it may lead to unnecessary costs in road construction, and second, it may not produce the best gravel-surfaced road.

The deliberate design, construction and maintenance of some roads as upaved structures thus has the potential for both reducing costs and improving performance. This practice would be applicable to two general situations. The first of these is in areas where new roads, or improvements in old roads, are desirable but traffic volumes do not justify the expense of a paved road. As construction costs rise, especially for paving materials and fuel, this situation may become increasingly common. The second situation is in areas where paved roads have performed poorly even though large amounts of maintenance effort and money has been spent on them. These areas include roads which experience severe frost heave problems and/or permafrost thaw settlement. Because of the relative ease of releveling gravel surfaces, such roads might provide better service at less cost if they were not paved.

It has been demonstrated that gravel roads can provide good, high speed performance in northern climates. This has been shown often in the Yukon Territory and other parts of Canada, and to a limited extent in Alaska. Much of the Canadian portion of the Alaska Highway is maintained as a high speed gravel road, using soil fines in the surface layer and intermittant treatment with calcium chloride as a dust palliative. The performance of this road has been good, considering the terrain and climate it passes through.

Climate may, in fact, make unpaved roads more desirable in high latitudes than elsewhere. During the long winters, when paved and unpaved roads alike are frozen, most of the advantages of pavement are lost. Many people even prefer the packed snow or ice-cemented gravel surface of an unpaved road to a pavement in winter driving conditions.

This report was undertaken to examine the design standards, maintenance needs and performance levels of gravel-surfaced roads in comparison with paved ones. The effects of differences in the two types of road were then analyzed. For both types of road the objective was the same--to provide safe, high speed travel for light to moderate traffic volumes in rural areas.

II. SUMMARY AND CONCLUSIONS

Gravel surfaces for high speed rural highways can be a practical alternative to asphalt concrete pavement. Gravel-surfaced roads are cheaper to build than paved roads; this cost difference can be large in areas of ice-rich ground or where clean gravels are scarce and consequently expensive. They are also likely to be cheaper to maintain in areas where foundation conditions are poor (i.e. where a pavement will require a lot of patching and leveling). Gravel roads may also provide superior performance in areas with poor foundation conditions since surface repairs can be made more quickly and easily.

Even in areas where a paved surface is likely to provide better performance than gravel, traffic volumes may not justify the expense of building a paved road. "High speed" gravel roads--with good surface course material and dust control treatment--may provide a practical "mid-range" alternate between a paved and a dirt road in such situations.

User costs are difficult to analyze with any accuracy but are likely to be greater for gravel roads than for paved ones in the summer. In areas with very poor foundations and/or embankments, the opposite may be true because of higher travel speeds possible on a gravel surface and the reduction or elimination of spring load restrictions.

A good unpaved road is not inexpensive. Just as in the case of a paved road, good performance requires good construction and maintenance practices. Many of the major design criteria should, in fact, be identical for both paved and unpaved roads.

The use of dust control agents on high speed unpaved roads, although costly, is almost mandatory to ensure a high level of performance.

First Costs (Road Construction)

The most obvious savings in the cost of unpaved vs. paved roads is the pavement layer itself. At current prices this is typically about $75,000 per mile of two-lane road, including incidentals.

The fines content of the road embankment is less critical on a gravel road than on a paved one, and this can result in large cost savings in areas where clean gravels are scarce and expensive. As discussed in the design chapter of this report, the effect of this may be to reduce costs by as much as $100,000 per mile.

A similar magnitude of savings may occur in areas where road alignments are over ice-rich ground. While the thermal behavior of roads in permafrost is not completely understood, analysis indicates that unpaved roads can be built on embankments one to two feet thinner than paved roads for thawing indices typical of Interior and Western Alaska without causing greater degradation of permafrost (the amount is about half as great on the North Slope).

Recurring Costs (Road Maintenance)

Maintaining a high speed gravel road can be either more or less expensive than maintenance of an equivalent paved road. The major factor affecting the maintenance costs of paved, rural roads in Alaska appears to be the quality of the original ground and the road embankment. Pavement on a strong and frost stable embankment can have a life of more than twenty years with little need for patching. Under such conditions a paved road is cheaper to maintain than a gravel road. The "best case" estimate made for this report showed paved road surface maintenance costs of about $3400 per 12' lane mile annually including periodic overlays in contrast to about $5300 for a gravel road including periodic regraveling.

When a road embankment is susceptible to frost heaving and/or thaw settlement, however, much more maintenance is required to keep a paved road in good condition. Costs for gravel roads in similar conditions are also higher than they would be on good ground but the cost increases are much less than for paved ones. Gravel roads therefore are cheaper to maintain under these conditions. For the worst ("very poor") conditions considered in this report, annual costs were about $9100 and $18,800, respectively for gravel and asphalt surfaces. As with the previously cited figures, this includes the cost of periodic rebuilding, reconditioning, regraveling and/or pavement overlay as needed.

The "crossover" point for maintenance costs between paved and unpaved roads appears to be somewhere between the "good" and "fair" conditions studied. Such conditions are probably typical of a large fraction of Alaskan highways.

III. RECOMMENDATIONS

Surface Course Specifications

The State of Alaska maintains approximately the same number of lane-miles of unpaved road as of paved road, yet there is no standard specification specifically for gravel surface course material. The creation and use of such a materials specification would improve the performance of unpaved roads whether or not these roads were treated with dust control agents. American Association of State Highway and Transportation Officials (AASHTO) Specification M-147 as it applies to surface courses could be adopted verbatim as a standard Alaskan specification.

Regraveling Program

Alaskan unpaved roads would benefit from a regular regraveling program wherein a shallow (3"-4") layer of surface course material was placed as necessary to renew what was lost from traffic and blading. This regraveling might be necessary at about five or six year intervals depending upon conditions such as traffic volume and the use of dust control agents.

Gravel Surface Field Trials

The Department of Transportation and Public Facilities (DOTPF) should select one or more sections of paved highway which have historically had very high maintenance costs and serious performance problems. These sections should be converted to a gravel surface with dust control treatment. Sections of gravel roads should also be chosen for upgrading with a good surface course and dust control treatment. Trial sections should be several miles in length.

The extent of further use of "high speed" gravel surfaces should be based on the results of the trials.

New Roads in Permafrost Areas

The economic benefit of allowing a new road over poor ground to stabilize for several years before paving has been shown in this study and in field observations. The length of this stabilization period should be determined by observation of road settlement in each case.

Areas for Further Study

1) The heat transfer calculations performed for this report indicated that road embankments with unpaved surfaces can be one to two feet shallower than those with paved surfaces without causing greater permafrost degradation. This was calculated for thawing indices typical of Interior and Western Alaska. Current programs to measure actual thaw depths below existing road embankments should be continued to confirm and refine this conclusion as it could have a large effect on the cost and design of Alaskan highways.

2) The effect of dust palliatives on the frost susceptibility of road embankment material needs to be studied in greater depth. There are indications that calcium chloride and lignins in particular may greatly reduce frost heaving in soils. This could not only make them more valuable as dust control agents on gravel roads, but may also have large economic benefits in many types of embankment construction. Inexpensive and plentiful materials which cannot now be used because of their frost susceptibility might be sufficiently improved by treatment with these additives to make them usable, with large savings in costs as a result.

3) Investigations to determine whether surface-applied palliatives leach or migrate into embankments should be performed. If they do, a dust control program might have the major effect of base stabilization at no added cost. After a sufficient period, this could result in a road embankment sufficiently thaw-stable to warrant paving.

4) The limited information available indicates that the benefits of requiring "clean" (low fines content) subbase material is much smaller on an unpaved road than on a paved one. In areas where price differences between "clean" and "dirty" materials are large, current strict limits on subbase fines may greatly increase construction costs with little or no improvement of the performance of unpaved roads. Such large price differences are common in many parts of Alaska; further investigation of this topic would thus be very useful.

IV. DESIGN OF UNPAVED HIGHWAYS

One of the objectives of this study was to examine differences in the preferred design criteria and related costs of paved and unpaved highways. The current DOTPF practice is, with few exceptions, to design all major highways based on a single "rational pavement design method". As a result, the only difference between a paved and unpaved highway is that the pavement layer, and sometimes the crushed base course, is omitted on an unpaved road.

In many ways this is a good procedure. No evidence was found in this study to indicate that the type of surfacing should affect the preferred alignments, grades or surface widths of rural highways.

There are several design factors which may be significantly affected by the type of road surface, however. These include embankment material quality, embankment thickness, amount of crown and specifications for the top layer of gravel (the base course of a paved highway and the surface or wearing course of an unpaved highway).

Embankment Material Quality

High fines contents in Alaskan road embankments have been shown to correlate with pavement weakness at breakup and the consequent early fatique cracking of asphalt concrete surfaces.[7] This is thought to be a result of the greater capillarity of "dirty" materials which contributes to frost heaving (the development of ice lenses during freezing) and thus high moisture contents and excess pore pressures when thawing occurs.

The objective of the current tight limits on fines content, then, is to prolong pavement life. This objective is not applicable to unpaved roads. An increase in rutting due to higher fines content would be of concern; Reference 7, however, found "no significant correlations...between rut depth and soil gradation." Surface repairs, moreover, are cheaper and easier on an unpaved road (grading) than on a paved one (asphalt patching or overlay). It therefore seems likely that a higher limit on subbase fines would be acceptable on an unpaved road. Limits on fines contents apply as deep as 42 inches below the pavement in the new (Feb. 1982) Alaska pavement design manual.[8]

Relaxed limits could result in considerable savings for an unpaved road compared to a paved one in areas where clean gravels are in short supply. Such areas include much of Alaska's highways located in upland terrain. In the Yukon-Tanana Uplands near Fairbanks, for example, Birch Creek Schist predominates. This rock can contain more than 20% fines after excavation, placement and compaction. In recent contracts, cleaner, harder gravels hauled from borrow pits for use as subbase have cost four to six times as much (on a unit basis) as unclassified excavation of the schist. In addition, locating and gaining access to borrow pits for the higher quality material has become increasingly difficult. The substitution of schist for the cleaner borrow, then, would clearly reduce the cost and difficulty of road construction in this area. In areas where clean material is abundant, of course, this does not apply.

Higher fines content in a gravel road embankment will undoubtedly lead to a greater amount of frost heaving in winter. On a well built road with uniform materials this heaving should be relatively uniform, and thus winter performance should not be seriously affected. The associated higher moisture contents at breakup, however, could result in less strength at this time of the year accompanied by rutting problems. This may be at least partially offset by the greater ability of unpaved roads to drain since, unlike paved roads, moisture is free to move to the surface where it can run off or evaporate. A better understanding in this area would be useful.

In any case, a higher fines content in the embankment of an unpaved road should result in no noticeable difference in performance except during breakup. On the other hand, the damage to a pavement during breakup will result in poorer performance throughout the remainder of the life of the pavement.

It may be desirable at some future time to pave a gravel highway even if that time is not within the original design life of the structure. In such a case, a higher fines content in the embankment might result in the need for subbase stabilization or a substantial new lift of cleaner material. A lift of material may be needed anyway in permafrost areas to preserve the ground thermal regime as discussed elsewhere in this chapter. Outside of such areas, however, the need for new embankment material would make future paving of a gravel road considerably more expensive. It is possible, however, that some dust palliatives used on gravel roads may also stabilize the subbase, making new material unnecessary before paving. This is discussed in Chapter VI, and further study of this is recommended.

Embankment Quantity

The amount of fill required to build an unpaved highway may be less than that for a paved highway in some types of terrain. One of these is in areas where unclassified excavation from the roadway contains significant fines after handling, and therefore cannot be used near the top of a paved embankment. Another case is in areas where the alignment is over ice-rich permafrost.

In the first of these types, large cost differences may result from the quality of materials used in the roadway as was discussed under the heading "Embankment Material Quality". The quantities of material required, however, may also be affected. In a paved road cut section, for example, excavation might have to be made to as much as three feet below finish grade and the road prism rebuilt with a clean borrowed subbase topped with a base course. Current design practices would allow in situ material to remain if pavement thickness were increased and/or design life shortened. This too is an expensive alternative. If the same road section were not paved, however, more of the original material might be left in place with little or no subbase placed below a surface course. The quantity of borrowed subbase, then, would be greatly reduced or eliminated.

On a road with a 24 foot surface, the elimination of one foot of subbase would amount to a savings of more than 5,000 cubic yards of this material per mile. If limits in subbase fines content were relaxed for unpaved roads, extreme cases might allow for the savings of more than twice this amount of subbase.

In areas where clean gravels require long haul distances, their cost may exceed $10 per cubic yard even in large quantities. Allowing higher fines content in the subbase of gravel roads, then, could result in savings of as much as $100,000 per mile. At the other extreme, of course, there might be no savings at all. In an area of abundant clean gravels, a road built mostly or entirely of borrowed material would realize little or no benefit from changes in the upper limit on fines. Similarly, such a change in the limitation on fines would have no effect if the material taken from road cuts contained few fines anyhow.

Design in Permafrost Conditions

It is well known that road construction can cause thawing of permafrost beneath the embankment causing severe settlement if the permafrost is "ice-rich". Thaw consolidation causes some of the worst highway maintenance problems in Alaska.

The analysis in Appendix B, using typical values for ice-rich silt in the Interior, shows what has been observed on some sections of Alaskan highways, namely that average settlements of three to four feet and differential settlements of as much as five feet can occur where the embankments have been placed over warm permafrost (30°F).

This creates severe problems for any highway, although less so for unpaved ones, as repairs to a gravel surface are simpler and cheaper than repairs to pavement. Reference 16 suggests three basic ways to avoid thaw settlement problems for highways:

" - locate on thaw stable subgrades

- remove permafrost
- place sufficient fill or use artificial insulation to maintain the ground thermal regime".

To this list one may add thawing and consolidating the ground prior to building the roadway.

Unfortunately thaw-unstable subgrades cannot always be avoided and are often too deep to make sub-excavation to stable material practical. In this situation the third alternative above often appears the best.

Fill depths necessary to keep thaw from penetrating the permafrost beneath a roadway are dependent on many factors. Among them are the temperature of the permafrost, the conductivity, density and moisture content of the embankment material, the local weather conditions (temperature, length of thaw season, wind speeds, cloudiness and precipitation) and whether or not the road is shaded from the sun.

The type of surface also affects the depth of thaw, and it is this factor which is of importance in this report. Gravel surfaces have been consistently shown to be cooler in summer than paved surfaces although the magnitude of this difference varies.[17] This is probably due to the lighter color and porous nature of these surfaces. The former results in less solar energy absorbed, while the latter results in more water evaporating from the surface which has a cooling effect.

Calculations using the Modified Berggren Equation were performed to investigate the effect of these cooler surface temperatures. This work is summarized in Appendix D.

The data indicate that an unpaved embankment can be one to two feet thinner in most of Alaska and still provide equal performance with regards to thaw settlement. This is true even if fill depths are relatively thin and some permafrost is melted. Any reduction in consolidation due to a smaller overburden would compound this characteristic of unpaved roads.

The material and cost savings of a reduced embankment thickness are large. For example, a reduction from eight feet to seven feet in total fill depth reduces the embankment cross sectional area by about 18 percent, saving over 13,000 cubic yards of material per mile (assuming a 24 foot roadway over level ground and 3:1 slopes). A reduction to a six foot embankment under similar circumstances saves nearly 26,000 cubic yards of material per mile. The deeper the fill depth and the flatter the slopes, the greater these savings become.

The thermal characteristics which would allow thinner embankments on unpaved roads also account for observed situations where "the addition of pavement to a gravel road that has an apparently stabilized thermal regime (results) in renewed permafrost degradation."[16] The results of the thaw depth analysis imply that a one to two foot fill of new material over the old road before paving should avoid these problems. While this is costly, it is preferable to the expenditure of effort and money on an "improvement" which results in worsened driving conditions.

The conclusions drawn from the thaw penetration analysis performed for this report are preliminary. A more detailed study, including field work, seems warranted.

Crown

Steeper transverse slopes (crowns) are recommended for unpaved highway design than for paved highways in order to ensure adequate drainage. Rain water must be able to drain quickly and easily from the relatively porous unpaved surface in order to avoid saturation of the structure which leads to excessive rutting, potholes and slipperiness. If an insufficient crown is used on unpaved roads, the minor profile irregularities which can develop between bladings (e.g. rutting) may hold water, resulting in a rapid deterioration of the road surface.

Alaska DOTPF designs for unpaved highways generally specify a 3% rate of crown. This is greater than the 2% normally specified for paved structures but less than the 4% frequently suggested in the literature for unpaved highways.[1 & 2] Designers are understandably hesitant to specify large rates of crown due to their tendency to pull moving vehicles toward the highway shoulder, but experience and literature suggest that this is outweighed by the deterioration in performance of inadequately drained gravel roads.

Surface Course

The surface course of a gravel highway should have a higher fraction of fines (material passing a No. 200 sieve) than the base course of a paved road. At the present time, however, the material used for surface courses in Alaska is generally quite "clean". The material specified is normally either base course grading D-1 (with 0-6% fines content) or subbase grading C (with 4-10% fines content). There are no standard Alaskan specifications specifically designed for gravel surface course material. This seems to be a result of the policy of designing all highways with the assumption that they will ultimately be paved.

The advantages of a higher fines content in the surface course of an unpaved highway include the following:

- the surface is more waterproof and drains more effectively, yielding a harder and drier road in moderate rains;
- the surface retains moisture better in dry weather, yielding a more cohesive surface with less loose gravel on the road surface. This provides smoother riding quality, lessens the amount of gravel lost over the side of the road from traffic and reduces the damage to vehicles from flying rock;
- the surface is less prone to potholing (if there is proper drainage, i.e. sufficient crown) and washboarding.

Surfaces with a high fines content have the disadvantage of greater rutting and slipperiness when very wet. If the road is properly drained, this becomes a problem only at breakup and during periods of prolonged heavy rains. This presents a greater problem in Southeastern Alaska than in the relatively dry Interior. The moisture retaining characteristics of the higher fines contents is also obviously less needed in the damper coastal climates.

AASHTO M-147 "Standard Specification for Materials for Aggregate and Soil Aggregate Subbase, and Surface Courses" recommends a minimum of 8% fines for surface courses, with an upper limit between 15% and 25%.[9] They further recommend a plasticity index for the fraction passing the No. 40 sieve of 4 to 9. The AASHTO specifications are nearly identical to those for surface course material used by the Yukon Department of Highways except that the latter's minimum fines content is sometimes as high as 15%.[5 & 6] The Yukon gradation specifications from reference (5) are very similar to what Alaska's subbase grading D would be with the addition of 15% fines (see Table 1).

TABLE 1

Comparison of Gradation Specifications of Yukon Surface Course and Alaska Subbase Grading D

	Percent of Material Passing Sieve		
Sieve Size	Alaska Subbase Grading D(1)	Alaska Subbase Grading D Plus 15% Fines	Yukon Surface Course(2)
3/4"	100	100	100
3/8"	-	-	70-100
No. 4	45-80	52-83	50-85
No. 10	30-65	39-70	40-70
No. 40	-	-	25-45
No. 200	4-12	17-23	15-25

NOTES: 1 From Standard Specifications for Highway Construction, AK DOTPF, 1981.

2 From reference (5). Other Yukon contracts may have different surface course gradation specifications.

V. MAINTENANCE AND PERFORMANCE

This report attempts to compare gravel surfaced and paved highways under the assumption that both are "high speed" facilities, i.e. safely driveable at speeds in excess of 50 mph. The performance of these two types of roads, however, are not exactly the same and this is especially true when they are performing poorly. Even the best gravel surfaced road may never perform as well as a paved road on a good foundation. The reverse may be true on a poor foundation.

Winter Performance

The performance of paved and unpaved roads is most alike during the winter. This is particularly notable in Alaska where "winter" driving conditions prevail so much of the year. Many people feel that unpaved roads are superior during the winter. Under certain conditions, snow plowing leaves a rough-textured surface of ice-cemented gravel on an unpaved road which provides better traction than that on a paved surface. These conditions do not always occur; both paved and unpaved roads can be entirely free of snow in the winter months, or iced over or covered with packed snow. A study of highway accident statistics on the two surface types for winter months would be of interest in this comparison; such a study was beyond the scope of this report.

Paved Road Performance

The principal performance problems of paved roads during the warmer months are potholes and the distortions ("humps, bumps and dips") caused by differential settlement. Minor cracking in the road usually does not seriously affect performance in itself, but maintenance forces often try to seal these in an attempt to prevent water from getting beneath the pavement, weakening the base and leading to more serious problems. Localized potholes are repaired individually, but when larger areas of pavement start to break up full lane width patching, often hundreds of feet long, is done.

Distortions in paved surfaces due to settlement are usually ignored until they become severe. The depressions are then filled with gravel to level the road and new pavement laid. In some bad spots on Alaskan roads, there are half a dozen layers of pavement sandwiched with layers of gravel. When these problems are severe, highways cannot be kept in a condition for safe travel at high speeds. Even when maintenance forces have sufficient funds, equipment and manpower (they often don't), there is a time lag between when potholes and dips appear and when they are repaired. Sometimes severe pavement pothole or distortion problems are "solved" temporarily by overlaying the road with gravel until such time as a new pavement can be laid down. As a result, some of the worst sections of "paved" road in Alaska end up being gravel-surfaced much of the time.

Eventually, highways which are in very bad shape must be "reconditioned" or "rebuilt". In areas with poor foundation conditions, even this is often only a temporary solution. In some of the worst stretches of Alaskan highways, reconditioning or even rebuilding of the roadway returns it to a "high speed road" condition for only a year or two.

Another major performance problem in paved roads is large, longitudinal cracks which appear not only in the pavement but in the embankment itself which typically, although not always, occur in permafrost areas. Patching the cracked pavement in this situation serves only to bridge over the void in the embankment below. As settlement continues, the crack in the pavement reappears (and is patched) repeatedly. Cracks over ten feet deep have been observed in Alaska highways bridged over by asphalt patching. Given sufficient settlement and/or traffic loads, these asphalt bridges will fail leaving not a crack but a large hole in the roadway.

Since stopping the settlement is impractical, the "solution" to this performance problem is to fill the crack in the embankment (preferably with gravel and not passing vehicles). This "solution" is obviously only temporary in nature until the foundation stabilizes, which may take decades.

Unpaved Road Performance

These longitudinal cracks also occur in unpaved roads since the same sort of differential settlement can occur. The effects on performance, however, tend to be less severe, and the cost of dealing with them tends to be less. Routine maintenance blading, as well as traffic, tends to keep these cracks in the embankment filled so little extra effort is required. In addition, there is no expensive asphalt patching to perform.

The same can be said of differential settlement which causes surface distortions. On a gravel road, these can be graded out if they are minor in nature. If the problem is more severe, blading these distortions out becomes difficult and will expose the subbase material in the high spots where the surface course has been scraped away. Since a "high speed gravel road", as defined in this report, assumes a good surface course, the placement of new gravel will be needed just as in the case of a paved road. Unlike a paved road, however, no new pavement is required.

Another performance problem common to both paved and unpaved roads is potholes. As with the settlement problems, these are more easily repaired in an unpaved road than in a paved one, but unlike settlement problems, they may appear with greater frequency on an unpaved road. Potholes are often caused by irregularities in the road material, i.e. pockets of loose or poorly graded gravel which are easily kicked out by traffic. Proper construction will avoid much of this problem. Reoccurrence of potholes can be avoided by maintenance blading at least to the depth of the potholes rather than by merely scraping loose surface gravel into them to fill them up. Potholes frequently occur where water is trapped in low spots on the road surface; the maintenance of proper crown can minimize this.

Other common problems with unpaved roads include mud, dust and washboarding. Muddiness usually indicates excessive fines and/or poor drainage of the road surface. Proper surface course gradation and the maintenance of the road crown will minimize the problem. Washboarding is generally indicative of insufficient fines, fracture and/or compaction in the surface material. This problem can also be minimized by good construction and maintenance practices.

Dust problems can also result from insufficient fines, fractures and/or compaction. Any of these can make the road surface less able to stand up to traffic abrasion. Greater amounts of material--gravel as well as dust--end up being thrown from the road surface. Ironically, excessive fines can also cause dust problems.

Dust problems can be greatly reduced or eliminated by the use of dust palliatives. These materials can also reduce other problems--washboarding and potholing in particular--since they help to bind or cement the road surface together. These materials are discussed in Section VI of this report.

Alaska Highway Performance Testing

The high speed gravel road most familiar to Alaskans is the Alaska Highway in the Yukon Territory of Canada. The maintenance of this highway includes a regular program of renewing surface course gravel as well as the use of calcium chloride as a dust palliative.

In July 1980, the surface condition of the Alaska Highway was investigated on both sides of the border using a Mays Ride-Meter. This device records and sums the vertical movements of an axle relative to the body of a vehicle. For this investigation, a passenger vehicle was driven at 50 mph over representative sections of the road. Data was recorded for 39 miles of paved road (on the U.S. side of the border) and 62 miles of gravel road (on the Canadian side).

The average axle movement per mile was 13% less on the gravel (Canadian) portions of the road than on the paved (U.S.) portions. Large individual axle movements (indicative of severe dips, bumps or potholes) were almost seven times as frequent on the paved segments as on the gravel segments. The data are summarized in Table 2.

TABLE 2

Mays Ride-Meter Data Summary--Alaska Highway

	Paved (U.S.) Segments (Total 39 miles)	Gravel (Canadian) Segments (Total 62 miles)
Average axle movement (inches/mile)	113.0	98.7
Highest axle movement, single mile (inches/mile)	246.4	247.7
Lowest axle movement, single mile (inches/mile)	37.1	46.7
Average large axle movements (1")	2.41	0.35

The axle movements over gravel road segments were on the whole consistent and of relatively small amplitude. These axle movements might not even be perceptible to the driver of a vehicle but are accompanied by road noise from the vehicle's tires. Greater road noise is typical of gravel roads and can increase driver fatigue.

The axle movements on the paved segments also were small and consistent most of the time but were interspersed with short stretches with large axle movements. The much greater frequency of large axle movements on paved segments indicates many more severe surface problems--potholes, dips, etc.--which would certainly be felt by drivers. Many drivers of the Alaska Highway have reported being unable to maintain as high a speed on the paved parts as on the unpaved ones because of these dips and potholes in the pavement. They have also reported being more tense while driving on the paved parts due to constantly being on the lookout for these problems.

One cannot confidently draw too many conclusions from the single set of Ride-Meter tests conducted for this report even though it seems a good case for comparison. The road was only tested at one point in time, and the paved and unpaved parts do not traverse identical ground. In addition, the precise amount of maintenance work performed on each road segment is not known.

It seems clear, however, both from this test and from long experience with this road, that a high speed gravel road can be successfully maintained in sub-arctic conditions. Moreover, in the particular test done for this report the performance of the gravel portion of the Alaska Highway was superior to the paved portion. In the opinion of many, this has long been the case.

VI. DUST PALLIATIVES/CEMENTING AGENTS

Products which help to control dust problems on roads do so by binding loose aggregate particles together. They can thus be considered as "cementing agents" with varying degrees of strength, stability and longevity. The cheapest, though shortest lived, dust palliative/cementing agent is plain water which evaporates so fast that it is not very useful except on a day-to-day basis (i.e. during construction). At the other extreme, one can consider asphalt and portland cement concrete pavements as effective long-lived "dust palliative/cementing agents."

Usually, however, when dust palliative/cementing agents are discussed, treatements which last from a few months to a few years are considered. Many products have been tried on roads with varying degrees of success including, it seems, virtually any sticky, gummy or caking byproduct of manufacturing which is not wanted elsewhere. Included in this group are such things as vegetable oils, animal fats, molasses residues, vanilla extract residues, vegetable gums, fly ash, waste oil, plantago seed husk derivatives, lignins and byproducts of fertilizer manufacturing.[24] More specialized and expensive products include various polymers; even epoxy is sold for this purpose.

The specialized chemical products are generally too expensive to be considered for widespread and continuous use, although good results have been achieved with some.[23,24] They have not been investigated in depth for this report. Many of the byproduct-type substances have been used with some success, but they tend to be impractical unless a source of sufficient quantity can be found at low cost near the point of use. In Alaska, this limits this group to waste oils and possibly lignins (in the form of wood pulping liquors).

Dust palliative/cementing agents considered here are limited to these two byproducts and to calcium chloride, emulsified asphalts and cutback asphalts.

These products provide several benefits to the treated road. Reduced dust levels improve visibility and thus safety as well as increasing the life of air and oil filters on vehicles. Driver satisfaction with roads is also improved. The cementing action of these products allows an adequate road surface to be maintained with much less effort. The hard surface has less raveling and better drainage. The reduction in loose surface gravel can decrease the hazard of damage to passing vehicles from thrown rocks.

Another important benefit from dust palliatives is a reduced loss of surfacing gravel from the road. Less frequent grading, less dust and less gravel thrown by passing vehicles combine to produce this effect. Calcium chloride manufacturers claim reductions in gravel loss as much as two-thirds[2] although Yukon Highway personnel question this in their experience.[6] This contention was supported, however, by a study in Iowa which concluded that "annual aggregate replacement could be reduced by a factor of 2 to 4 by various types of palliatives and application methods."[23] Such savings are likely to represent about a half an inch to as much as an inch of surface material annually, based on studies of the amount of gravel and dust lost from roads.[23,26] One-half an inch over a two lane surface is equivalent to about 200 cubic yards per mile; at current prices for crushed material such a savings could more than pay for the cost of purchasing and applying dust palliatives.

Calcium Chloride

Calcium chloride is the type of salt most frequently used by DOTPF for winter ice control. It is also used in Alaska as a dust palliative to a limited extent and is commonly used for this purpose in the Yukon.

In a report on trial use of calcium chloride on the Whitehorse Keno Road (Yukon Territory) in 1969, the treatment's performance, typical of this material, is described:

> The immediate effects of the surface treatment were dramatic; the road gained a smooth, firm, hard packed wearing surface with the exception of some minor potholes and ruts with a completely dust free surface.......Two months after the surface treatment, minimal amounts of dust were noticeable. Four months after the surface treatment, there was a definite increase of dusting. However, nothing in the order of being hazardous to the travelling public. Along with the gradual appearance of dust as time went along, there was a gradual deterioration of the wearing surface. (i.e. approaching the conditions of the road surface prior to the application of the calcium chloride surface treatment.)[1]

This performance was achieved even though the rainfall during this period was greater than normal and the grading and shaping of the road prior to treatment "left a lot to be desired."

Calcium chloride can be applied by any of several methods. It can be mixed with surface course material prior to placement during construction, sprayed onto the road in brine form, spread in flake form prior to maintenance blading or spread in flake form after blading onto a moist surface, followed by water as needed to dissolve the salt. The latter method is the most frequently used in the Yukon[10]; brine application is the usual method used by DOTPF Maintenance forces.[15,25]

The amount of calcium chloride needed is greater when the road aggregate has few fines, and the frequency of application required is greater in wetter climates. The Department of Highways in the Yukon normally uses 10 tons per mile initially, followed by five tons per mile applied twice annually. Enough salt is retained that, after a year or two, application rates can sometimes be reduced below this level.[6] DOTPF experience is similar. In the Anchorage area, application rates are roughly five to eight tons per mile; although it is not used often as a dust palliative.[15] Good retention of salt has been noted from one year to the next in the Southeastern Region, even though their rainfall excceds that of the rest of Alaska and the Yukon.[25]

Current (early 1982) prices for calcium chloride are about $207 per ton in bulk and $370 per ton in 100 pound sacks, F.O.B. Anchorage.[13] Freight costs to Fairbanks are roughly $60 per ton by rail and $80 per ton by truck.[14] Loading, unloading and storage costs will add to this as will shipment to more remote locations.

Cost for applying calcium chloride to a roadway using a sand spreader and a water truck have been estimated at roughly $85 per lane mile. These costs are more than offset by the reduced amount of grading required on the road (estimated at about $100 per lane mile). Yukon Department of Highways personnel report a reduction in road grading from eight to ten passes per year without salt to two with salt (i.e. grading just before salt application) in most areas. On some roads in the Haines, Alaska area, grading requirements have been reduced from as much as three times per week to as little as three times per year by the use of calcium chloride and some added fines in the roadway.[25] Some reworking of salted roads can be done if needed when the road is moist without a major loss of salt benefits since, as moisture evaporates from the road, the salts tend to migrate to the road surface again. During dry weather, the road surface becomes too hard to grade successfully.

Users generally have favorable reactions to driving on calcium chloride treated roads due to the smoother, harder surface and the reduction or elimination of dust. The principal disadvantages to drivers of this dust palliative are its corrosive action on vehicles and its slipperiness in extremely wet conditions. Both of these disadvantages are less severe in drier climates. The slipperiness reported during very wet periods is probably a combination of both the calcium chloride and the fine particles (clay or silt sizes) in the surfacing course. Light and even moderate rainfall will not create this problem if the proper crown is maintained in the roadway and ponding of water prevented. The corrosive effect of salts cannot be avoided, however, except by washing it off vehicles.

Petroleum-based Products

Several petroleum-based products have been used as dust palliatives on unpaved roads including waste oil, cutback asphalt and asphalt emulsions.

Both good penetration and a stable aggregate base are necessary for these dust palliatives to work well. Warm, dry weather during application is important for waste oil and cutback asphalt treatment. A slight amount of moisture in the road improves results, however, by keeping the oil or cutback from forming dust-coated beads on the surface which prevents penetration. Good results, then, depend on good judgment in application; there's an "art" to their use as well as a "science".

Good penetration of asphalt emulsions is achieved by diluting the emulsion with large amounts of water. The Asphalt Institute recommends dilution with "five or more parts water by volume."[11] Poor results have often been reported with simple spray application; better results are likely if the emulsion is road mixed with at least the top inch or two of the road surface material.

Application rates for all of these materials range from about 0.2 to as much as 0.5 gallons of residual bituminous product per square yard of treated road surface. The cost of waste oil varies with time and location; current prices range from about 35 cents to nearly a dollar per gallon. Alternative uses for waste oils have recently been driving the price up and reducing its availability. Current (May 1982) price quotes for asphalts are $206 per ton for emulsions and $261 per ton for cutbacks, F.O.B. Anchorage. Freight charges from Anchorage to Fairbanks run approximately $70 per ton by truck.

Low viscosity asphalts are recommended on dense, fine-grained road surfaces (i.e. 30 and 70 grade), while higher viscosities (i.e. 250 grade) are preferable on looser, open-textured surfaces.[12] Similar reasoning implies that better results would be achieved with less dilution of emulsified asphalts on the open-textured surfaces.

There are mixed reports on the performance of these dust palliatives. In some cases, they have yielded good results through an entire summer with residual benefits seen the next spring. More frequently there are reports of "pitting" and pothole problems. Reworking the road surface to cure these problems destroys most of the benefits of this treatment and requires new application of the palliative.

These problems may result from several factors. One of these is soft spots in the roadway; if the roadway yields excessively under load it breaks up the weak cementing action of these materials. Another factor is variations in the texture of the road surface which precludes any single type and rate of application from producing successful results in all parts of the road. Yet another possible cause is the presence of large amounts of fines (particularly clays) in the roadway, which can absorb petroleum-based palliatives. This reduces both the palliative's effectiveness as a binder and the natural cohesiveness of the fines.[23] Application during bad weather conditons, of course, detracts from performance.

Lignin

Another material which has been widely used as a dust palliative/cementing agent is lignin, usually obtained as a byproduct of the wood pulping industry in the form of spent sulfite liquor. Several commercial palliatives sold under trade names are basically the same thing. Lignin sulfonates and sugars in the spent liquor act to cement road aggregate achieving results similar to other palliatives.[20] Recommended application rates for sulfite liquor are about 1/2 gallon per square yard for surface treatment.

Lignins were tried in the Anchorage areas as a dust control/cementing agent several years ago. The results ranged from very good to very poor performance with the variability blamed primarily on existing road conditions and surface materials. The presence of a stable base and considerable surface fines was considered to be even more important for success with lignins than with other palliatives.[25] The importance of fines in the surface course is also supported by outside experience.[23]

Most of the volume and weight of spent sulfite liquor is water, and this tends to make shipping costs to Alaska excessively high. If it were available in a more concentrated form, or if larger scale pulping operations existed in Alaska, this treatment might be a practical alternative.

The reported results with all the dust palliative/cementing agents discussed here have been better when they were mixed through the entire surface course (4" to 6") rather than merely applied to the surface. An exception to this may be brine application of calcium chloride which results in good penetration without road mixing. The quantities required for road-mix application are roughly equal to that for surface treatment alone multiplied by the number of inches treated, i.e. a 6" layer treatment would require about six times the quantity as a surface treatment alone. This is obviously a much more costly operation than mere surface treatment. The benefits, however, are reported to be not only better but also much longer lasting.

A significant amount of fines in the surface course improves the performance of calcium chloride and liquor treatments by aiding in binding larger aggregate together. High fines contents, however, may detract from the performance of petroleum-based palliatives as discussed above.

Effects on Frost Heaving

Any significant effect of dust palliatives on the frost susceptibility of gravel roads may be an important factor in decisions about their use. No extensive work on this subject could be performed within the scope of this project. Reference 23 describes the results of a limited amount of freeze-thaw testing of soils containing emulsified asphalts and lignosulfonates (among other additives), but not calcium chloride. A freeze-thaw test of soil containing various amounts of calcium chloride was performed in the DOTPF Research Section lab to supplement this information. The DOTPF test and its results are presented in Appendix A of this report.

The tests described in Reference 23 and the DOTPF test were performed by freezing compacted cylinders from the top down, while maintaining a supply of water to the bottom of the samples to allow for capillary absorbtion of moisture. This simulates typical conditions in a roadway.

In the Reference 23 tests, ten freezing periods of 18 hours each were made at 20^{0}F, separated by 6 hour thawing periods at room temperature. Both better and worse behavior was found with emulsified asphalt treatments, depending upon the soil type. Some benefit apparently resulted when emulsified asphalt was used on an A-2-4(0) soil (sand and gravel with low plasticity fines).

No heaving at all was noted when the same soil was treated with 2% ammonium lignosulfonate; in fact, slight shrinkage occurred. The same soil without treatment exhibited considerable heaving. This dramatic result would be of great importance if it occurred under real winter road conditions. It may be, however, that this palliative depressed the freezing point somewhat, and that the test's conditions were neither long enough nor cold enough to initiate freezing of soil moisture. This was found to be the case in the DOTPF test with calcium chloride at 17^{0}F temperatures.

The DOTPF test was conducted on four samples with calcium chloride contents ranging from 0 to about 0.5% (by weight of soil). Even at the lowest $CaCl_2$ concentration, no heaving was observed after a week at 20^{0}F, although the sample without $CaCl_2$ heaved considerably. Three more freezing cycles were then performed at $0^{o}F$. At this temperature all samples heaved, but the amount of heaving was much less in the samples containing $CaCl_2$. Heave reduction was greater than 50% even with only 0.1% $CaCl_2$; with 0.5% $CaCl_2$ the reduction was over 85%.

None of the testing described was comprehensive enough to draw firm conclusions regarding the effects of dust palliatives on the frost heaving characteristics of road aggregate. The test results available do indicate, however, that calcium chloride, lignins and perhaps emulsified asphalts may reduce frost heaving and therefore lessen thaw weakening. Lignin-derived grouts have been injected into subgrade material in the past in order to reduce frost heaving.[20] Further investigation of these properties seems to be warranted.

Even if beneficial effects occur, it is not clear that palliatives applied to a road surface will penetrate an embankment far enough to make much difference. Chemical analysis of cores taken from roads which have been treated with palliatives for an extended period would help to determine this.

It is thus possible that the use of dust palliatives could help to stablize an embankment with regards to frost heaving over a period of time. If this were the case, a frost-prone road on which pavements cannot be justified economically (see Chapter VI) might, after a period of years, become stable enough to pave. Two major objectives--dust control and embankment stablization--might be accomplished on a gravel road by one procedure.

VII. COSTS

The costs of building and maintaining paved and unpaved surfaces on "high speed" rural roads are examined in this section. This is done for a range in quality of the original ground from very good (e.g. bedrock or dense gravel) to very bad (e.g. ice-rich silt or peat). Similar costs are also examined for a new road built on initially poor ground which stablizes over time.

A two lane rural road with a 24-foot surface is assumed in these analyses. The costs of snow and ice control, signs, guardrails, embankment construction and other factors are ignored if they would not be affected by the presence or absence of pavement. Traffic volume and composition are also ignored for the most part too since most rural Alaskan highways have relatively light traffic loads.

Every highway is unique, and there may be none which perfectly match the "typical" conditions examined. While this does not mean that the theoretical analysis is without value, it is useful to look at the experience with particular highways for comparison. This has been done for some of our roads, and the results of this are presented.

Maintenance of Established Roads

The annual costs of maintaining safe, high-speed travel on a two lane rural highway for an indefinite period were estimated as described in Appendix C. The costs were determined as a function of the foundation quality, which represents a combination of the embankment quality and that of the original ground the road traverses. These costs are summarized in Table 3 for both paved and gravel surfaces.

TABLE 3

Average Annual Costs (1982, $/lane mile)
Reconstruction and Maintenance of Two Lane, 24' Wide Surface
on a High Speed Rural Highway

	Foundation Condition				
	Very Good	Good	Fair	Poor	Very Poor
Paved Surface					
Reconstruction	2,343	3,343	4,520	6,935	10,336
Maintenance	1,056	1,584	2,640	5,280	8,448
Total	3,399	4,927	7,160	12,215	18,804
Gravel Surface					
Reconstruction	3,363	3,426	3,665	4,092	5,640
Maintenance	1,981	2,064	2,332	2,854	3,460
Total	5,344	5,492	5,997	6,946	9,100

These totals are illustrated in Figure 1, in which a shaded area is also shown for both types of surface, reflecting costs 15% more or less than those estimated. The cost estimates cannot be expected to be exact, but costs for most roads would probably be within the indicated range in Figure 1.

It should be noted that these levels of work are those which were estimated to be necessary to maintain the road in good condition. They do not necessarily reflect the amount of work which is currently performed on Alaskan highways.

Figure 1 indicates that the total surface related costs of a paved road are less expensive where foundation conditions are good or very good. Gravel surfaced roads appear to be less expensive when poorer foundation

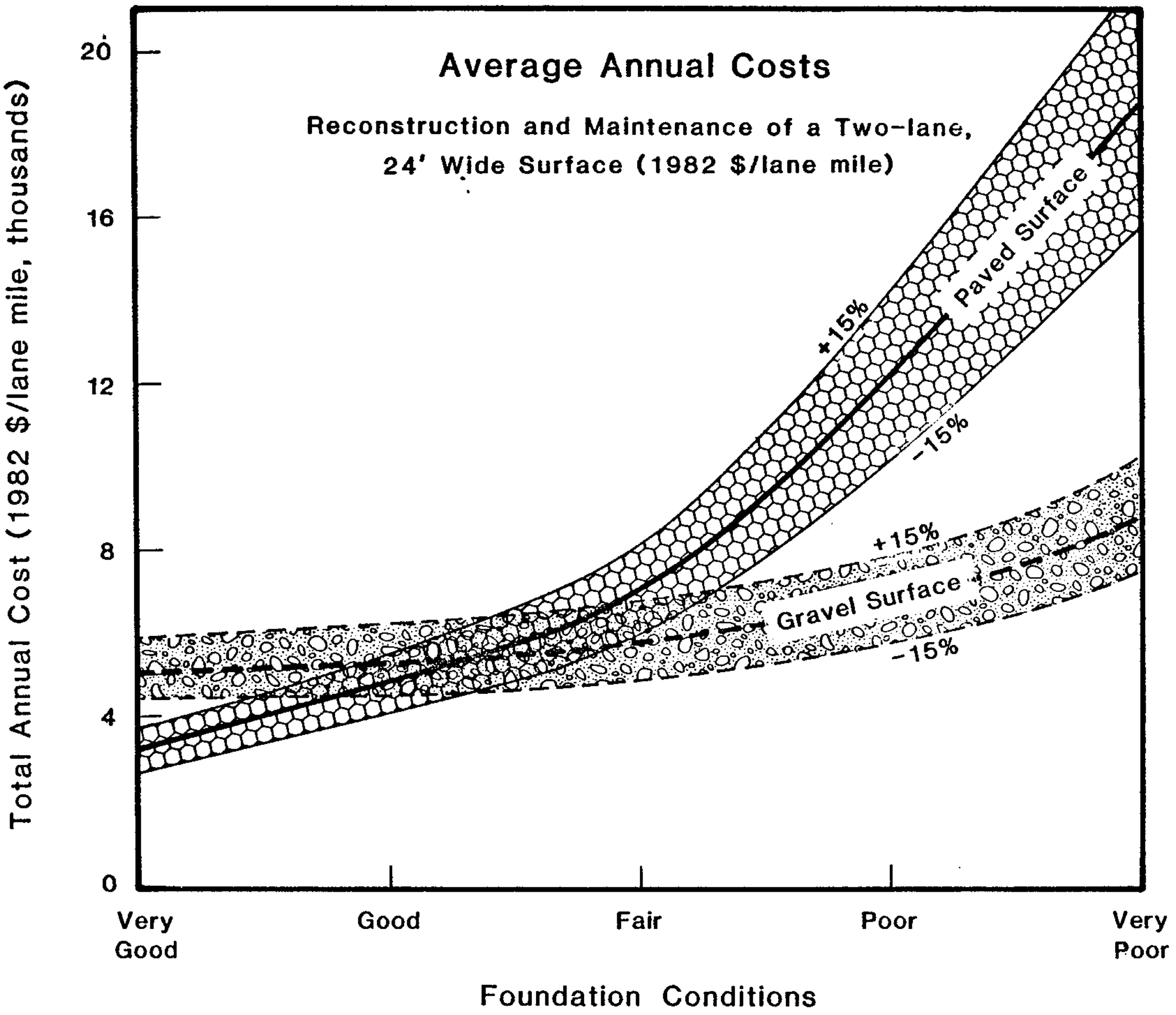
Average Annual Costs
Reconstruction and Maintenance of a Two-lane, 24' Wide Surface (1982 $/lane mile)
Total Annual Cost (1982 $/lane mile, thousands)
20
16
12
8
4
0
Paved Surface
+15%
-15%
Gravel Surface
+15%
-15%
Very Good
Good
Fair
Poor
Very Poor
Foundation Conditions

Figure 1

conditions exist. In short, where pavements can be expected to be long-lasting and require little maintenance, they appear to be a more economical choice than gravel surfaced roads with their continual maintenance and regraveling needs. On the other hand, paving roads which have continual foundation problems appears to be a very costly choice.

The foundation quality categories are somewhat subjective in nature. A good understanding of what they imply can be had by the work schedules of Tables C-2 through C-6 in Appendix C.

New Road Construction Costs

Where a smaller embankment is possible if a new road over permafrost is to be gravel surfaced (see Chapter 4), the cost savings can be significant. The quantity of material saved by a one to two foot reduction in embankment height for moderate fills on a two lane road over level ground will range from about 10,000 to 20,000 cubic yards per mile of roadway. Unit prices for borrow and unclassified excavation vary from less than two dollars per cubic yard to more than ten.

Total cost savings from reduced fill heights can thus vary by an order of magnitude, from about \$20,000 per mile for a small reduction of cheap materials to \$200,000 per mile for a large reduction of expensive material. These reductions for gravel surfaced roads are only possible, of course, where concerns about the rate and magnitude of permafrost thawing are the primary factor in designing embankment heights.

Some new roads experience severe settlement problems for a number of years and thereafter become stable. This stabilization can occur when compressible foundation materials (clay, peat, etc.) approach their ultimate level of consolidation, when thaw penetrating previously frozen ground reaches a thaw stable stratum (clean gravel, rock, etc.), or when the thaw zone beneath the roadway approaches a new state of equilibrium.

Recommended practice has often been to leave roads such as this unpaved until stabilization occurs to avoid the high costs of pavement repair. This practice may not work well in permafrost areas since the pavement itself may induce a new thermal instability to the embankment as was discussed before. Better success in such areas is likely if a new layer of fill is added at the same time as the pavement. New fill is inadvisable in areas of thawed, compressible materials, such as muskeg.

A cost comparison of paved and unpaved roads was performed for this condition and is summarized in Tables 4 and 5. These are based on the unit costs shown in Table C-1. It was assumed that the road would have three feet of average ultimate settlement, with differential settlements as great as four feet. It was further assumed that the rate of settlement would begin at a high rate and decline expoentially such that 90% of the ultimate settlement would occur within 15 years of construction.

The average costs in current dollars are $15,690 and $8,175 per lane mile per year for the paved and unpaved roads, respectively. These are about midway between the cost levels for "poor" and "very poor" foundation

TABLE 4

New Paved Rural Road During 15 Year Stabilization Period Surface Related Costs Per Mile @ 24 Foot Surface Width

Year	1 Fill Dips with base Course Material	2 Asphalt Surface Patching	3 Paving	4 Roadbed Rebuilding	5 Total (1982 $)	6 Present Worth (3% Real Discount Rate)
0	3,000	(5.0%) 7,040	42,240		52,280	52,280
1	6,490	(15.0%) 21,120			27,610	26,805
2	5,425	(12.7%) 17,880			23,305	21,965
3	4,855	(3.1%) 4,365	73,920	73,875	157,015	143,690
4	4,080	(9.2%) 12,955			17,035	15,135
5	3,470	(7.8%) 10,980			14,450	12,465
6	3,020	(6.6%) 9,295			12,315	10,315
7	2,570	(5.6%) 7,885			10,455	8,500
8	2,120	(4.7%) 6,620			8,740	6,900
9	1,960	(4.0%) 5,630			7,590	5,815
10	1,510	(1.0%) 1,410	73,920	73,875	150,715	112,145
11	1,510	(2.9%) 4,085			5,595	4,040
12	1,060	(2.5%) 3,520			4,580	3,210
13	1,060	(2.1%) 2,955			4,015	2,735
14	900	(1.8%) 2,535			3,435	2,270
15	775	(1.5%) 2,110			2,885	1,850
Total	43,805	120,385	190,080	147,750	502,020 ($15,690/ lane-mi-yr)	430,120 ($13,440/ lane-mi-yr)

Notes:

- The original cost of the road is neglected except for the cost of the pavement itself.
- Column 1 assumes a total of 3.5" of base course (avg.) @ $32/yd ; $3,000 in initial year plus amounts proportional to settlement in following years.
- Column 2 assumes % of road patched as indicated @ $10 per yd^2.
- Column 3 assumes BST initially @ $3 per yd^2, 2" hot asphalt in later years @ $5.25 per yd^2.
- Column 4 assumes reconditioning @ $172.50 per station plus 6" base course @ $27.60 per yd^3.
- All figures are rounded to the nearest $5.
- Settlement rate is assumed to decline exponentially; settlement assumed to reach 90% of ultimate amount of 3' by year 15.

TABLE 5

New Gravel Surface Rural Road with Calcium Chloride Treatment During 15 Year Stabilization Period
Surface Related Costs per Mile @ 24 Foot Surface Width

Year	1 Fill Dips with Surface Course Material	2 Grading and Salt Application	3 Regravel Road	4 Roadbed Rebuilding	5 Total (1982 $)	6 Present Worth (3% Real Discount Rate)
0	3,500	5,270			8,770	8,770
1	8,400	4,285			12,685	12,315
2	7,025	4,285			11,310	10,660
3	6,285	4,190			10,475	9,585
4	5,280	4,095	32,385		41,760	37,105
5	4,490	4,190			8,680	7,485
6	3,910	4,095			8,005	6,705
7	3,330	4,095			7,425	6,035
8	2,745	4,000			6,745	5,325
9	2,535	5,350		73,875	81,760	62,660
10	1,955	3,905			5,860	4,360
11	1,955	3,905			5,860	4,235
12	1,375	3,810			5,185	3,635
13	1,375	3,810			5,185	3,530
14	1,160	3,715	32,385		37,260	24,635
15	1,005	3,620			4,625	2,970
Total	56,325	66,620	64,770	73,875	261,590	210,010
					($ 8,175/ lane-mi-yr)	($ 6,565/ land-mi-yr)

Notes:

- The original cost of the road is neglected except the cost of 10 tons/mile of $CaCl_2$.
- Column 1 assumes a total of 4.5" of surface course (avg.) @ $32/yd^3; $3,500 in initial year plus amounts proportional to settlement in following years.
- Column 2 assumes 10 tons/mile of salt and grading declining from 6 to 2 passes annually by maintenance; plus 5 tons/mile extra salt in years 0 and 9.
- Column 3 assumes a 3" layer of surface course @ $27.60 per yd^3.
- Column 4 assumes reconditioning @ $172.50 per sta. plus 6" of surface course @ $27.60 per yd^3.
- Other assumptions are the same as made for Table 4.

conditions in Table 3. The ratio of costs is even greater ($13,440 to $6,565) when expressed in discounted present values, due to the very high costs of the paved road in the first years.*

By the last year of this analysis, maintenance levels have fallen to about that found for the "good" foundation conditions in Table C-3. Under these conditions, the earlier analysis indicated that the paved surface should be less expensive than the gravel surface. The lowest total costs, given the stabilization pattern assumed here, would be found if the road were paved in the 13th or 14th year. Given other settlement patterns, the optimum year for paving might be greater or smaller than this. Moreover, present knowledge is insufficient to accurately predict this optimum year for specific sites in most cases.

The time at which sufficient stabilization had taken place to make paving economically advantageous would thus be best determined by observation. The period might be only a few years for roads on thawed peat, clays, etc., where differential settlement is normally less than that for ice-rich permafrost. It could also be short if only a few feet of ice-rich ground existed over thaw stable material. It is clear, however, that such a delayed paving has major cost advantages in such cases.

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*A 3% "real" discount rate was used in Tables 4 and 5. If one assumed a 7% rate of inflation, this is equivalent to a 10.2% nominal discount rate (1.03 x 1.07 = 1.102). DOTPF uses a 10% nominal discount rate for its life cycle cost analyses.

In areas with deep deposits of ice-rich ground it may never be economically advantageous to pave roads. One reason for this, of course, is that the "stabilization period" may continue, apparently, indefintely. Even where stabilization occurs, however, the cost of the additional fill required before paving in order to preserve the underground thermal regime may outweigh any cost savings which might accrue due to pavement placement. For the type of road considered here, an extra foot of borrow on the embankment at typical prices might cost $40,000 per lane mile ($80,000 per mile). The savings of a paved surface over a gravel surface, if "good" foundation conditions exist, has been estimated to be about $565 per lane mile annually ($1,130 per mile annually). This is a poor rate of return on the investment in additional embankment material.

Historical Costs

Maintenance cost records were reviewed to supplement the theoretical analysis already discussed. Historical costs for particular roads are difficult to work with as each road has its own peculiar characteristics. Costs for particular years can also give unreliable results since any unusual problems (or lack thereof) in one year will not reflect longer term averages. Nonetheless, the historical cost records appear to support the conclusions of the theoretical analysis.

Table 6 shows average cost in FY81 (for equal surface areas) of four types of roads in three maintenance regions. The road types are those from Reference 21. The Southeastern and Western regions are not included: the former has little rural highway mileage, while the latter has virtually no paved rural roads to compare with gravel roads. The Dalton Highway (or Prudhoe Bay Haul Road) was also excluded as its heavy truck traffic and remote location make it an unusual case.

TABLE 6

Surface Maintenance Costs - FY 1981
$/12' lane-mile ($/7040 yd^2 surface)
Dalton Highway Excluded

	Maintenance Region			
	Interior	So. Central	Central	Combined
Type IV 2 lane paved rural primary	1,671	2,097	936	1,525
Type V 2 lane rural secondary	1,805	2,296	1,347	1,599
Type VI 2 lane gravel arterial	713	761	1,382	909
Type VII gravel road 20' width	1,352	1,545	1,050	1,313
Types IV & V combined	1,702	2,115	1,074	1,543
Types VI & VII combined	7,998	944	1,321	977

Source: Ref. 21

The table shows that in the three regions nearly 60% more was spent on the paved roads than on gravel roads per unit of surface area. In the Interior and Southcentral regions, paved road surface maintenance costs were more than twice that of gravel roads, while in the Central Region they were almost 20% less. Lower costs for paved roads and higher ones for gravel roads combined to produce this result in the Central Region. Factors which may have affected this result include:

- little or no permafrost underlying Central Region roads, leading to lower costs for paved roads
- gravel roads in the Central Region are generally more urban in nature, with resulting larger traffic volumes and maintenance costs
- some gravel roads in the Central Region are oiled or salted while fewer or none are in the other regions
- in general, the "summer" season is longer and wetter in the Central Region than in the others, so grading requirements are greater on gravel roads
- Central Region highways are, in general, newer and were therefore built to higher standards than in the other regions, leading to less need for pavement repairs
- asphalt products are cheaper in the Central region.

It is not known how much each of these factors contributes to the cost levels shown. It is also not known how closely other years' costs would match those for FY81 since the data has not been compiled in a sufficient manner.

The overall average surface maintenance costs shown in Table 6 for paved rural roads (Types IV and V) are very close to the theoretical costs calculated for "good" foundations conditions ($1,543 vs $1,584 per lane mile annually). For unpaved roads (Types VI and VII) the FY81 costs were much less than was calculated for "good" conditions ($977 vs $2,064). The calculated amount, however, included dust control/cementing agent applications, while the FY81 amount reflects almost none of this. If the estimated cost of biannual calcium chloride application were added to the FY81 figure and credit given for reduced grading needs, it too would be very close to the amount calculated for "good" foundation conditions.

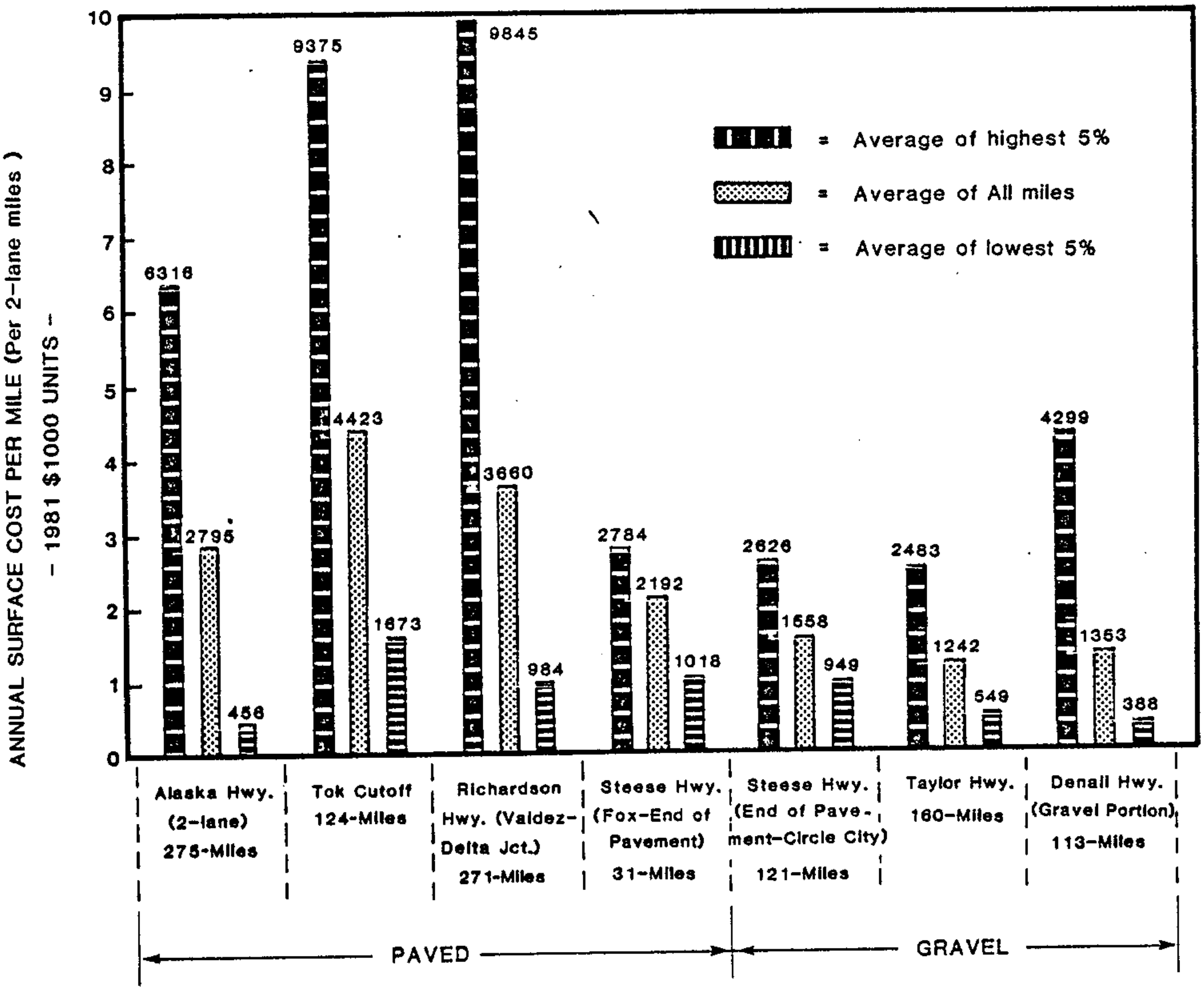
This does not prove that the average Alaskan highway is built on a good foundation. It may be that the average foundation is something less than "good," and that the overall level of maintenance is something less than was assumed in the calculations. It does lend some assurance, however, that the calculated costs for paved and gravel roads are reasonably accurate relative to each other.

Longer term average surface maintenance costs have been determined for each mile of selected Alaskan highways.[22] Eight year averages (FY74-81) were found for the Richardson, Tok Cutoff, Steese, Denali and Taylor Highways, and for the Alaska Highway excluding the four lane section between Eielson Air Force Base and Fairbanks. The average costs per mile for these highways are shown in Figure 2, along with the average cost of the most expensive and least expensive 5% of the mileage. The figures do not include the cost of ice and snow removal.

The data in Figure 2 shows, in general, an extremely large range in costs between the best and worst sections of the paved roads, and a smaller

Figure 2: Average Annual Surface Maintenance Costs

Data From FY 1974-1981 Expressed in 1981 Dollars Source: Ref 22



range for gravel surfaced roads. This supports the conclusions of the theoretical cost analysis (see Figure 1). The Denali Highway and the 31 mile paved portion of the Steese Highway seem to be exceptions; the former a gravel road with a large variation in maintenance costs, and the latter a paved road with a small variation.

The historical cost extremes shown in Figure 2 are somewhat greater than the calculated cost extremes shown in Figure 1 and Table 3. More maintenance money has been spent in the worst cases than was determined theoretically necessary for "very poor" foundation conditions. Conversely, less money has been spent in the best cases than was theoretically necessary for "very good" foundation conditions. This may indicate that the extreme conditions considered in the theoretical analysis are not extreme enough. It may be the case, however, that the construction activities (road reconstruction and/or pavement overlays) are long overdue in the areas with very high historical maintenance costs, and that the lowest historical costs are a result of a lower overall level of maintenance than was assumed.

The historical frequency and extent of construction activities on paved roads in Alaska is generally within the theoretical extremes listed in Tables C-2 through C-6. The foundation conditions of the first few miles of the Alaska Highway in Alaska, for example, are considered to be very poor. Records indicate that the first 13 miles of this road were first paved in 1959. The stretch was paved again in both 1967 and 1975, and is currently under consideration for paving again. This eight year cycle of construction work agrees with the schedule for "very poor" conditions found in Table C-6. Despite this frequent construction activity, maintenance costs for this part of the highway have remained high and performance has remained poor. Similar examples can be found on other stretches of Alaskan highways.

Construction activities on Alaska's unpaved highways have not, in general, been as frequent as would be required to maintain them as "high speed" roads as defined in this report. In particular, there has not been a routine reshaping and regraveling program for these roads, although some work of this nature has recently been done on the Dalton Highway. The general trend for unpaved roads, however, has been to either undertake a major rebuilding program (including realignment), or to perform the bare minimum of maintenance. Dust control treatment has not been undertaken to any significant degree.

The average annual surface maintenance costs of reference 22 were compared with Alaska DOTPF traffic volume figures. Little or no correlation was found between the traffic volume on a given part of a rural road and the cost of its maintenance. It may be concluded from this that traffic volume on rural Alaskan highways is light enough that it is not the primary determinant of maintenance costs. Instead, maintenance needs on these roads result mainly from other factors (e.g. frost heaving and differential settlement). There may be exceptions to this, such as the Dalton Highway, where truck traffic volumes are high.

User Costs

The study of highway user costs is difficult and imprecise, and these costs were not examined closely for this report. Accurate quantitative comparisons of such costs as wheel alignments from hitting potholes with the replacement of broken windshields from flying gravel are nearly impossible.

Factors which would tend to make user costs higher on high speed unpaved roads include the following:

- slipperiness in very wet weather (increased accident rates and slower travel speeds)
- dust (engine wear, more frequent oil and air filter changes)
- mud, salt, and oil (more frequent washing of vehicles, corrosion)
- gravel (broken windshields, headlights, etc.)

Factors which would tend to make user costs higher on paved roads include the following:

- severe potholes (more frequent blowouts, wheel alignments, and greater accident rates)
- surface distortion (slower traffic speeds, higher accident rates)
- slipperiness in icy conditions (slow traffic speeds, higher accident rates)
- spring season load restrictions (higher costs, delays, and loss of business to the trucking industry)

Obviously some of these factors can occur to some degree on both types of road. Paved roads can be slippery in wet weather too, as can gravel roads in icy conditions. Potholes occur in gravel roads as well as paved ones and there can be flying gravel on paved roads (especially from sanding icy roads) as well as on unpaved ones.

While unsupported by empirical findings, it is the author's opinion that user costs will be greater for unpaved roads than for paved ones, primarily as a result of the dust and gravel factors cited above. These problems are reduced but not eliminated by the use of dust control/cementing agents, and do not apply in winter. Overall road roughness should not be of great importance since a well-built and maintained unpaved road can give as smooth a ride as all but the newest pavement. Similarly, dust levels should not be great enough to cause danger from impaired vision if dust control agents are used.

There are several factors which influence user satisfaction with a highway which are almost impossible to quantify. Among these are the road noise of tires, which tends to be greater on gravel surfaced roads, and the effect of seeing and breathing airborne dust. A similar effect is motion sickness which can be caused by surface distortions even if they are not severe enough to cause safety problems. This problem tends to be more severe on paved roads. Still more subjective is many people's feeling that pavement --any pavement--represents "progress." While an economic value could be given to these, they are more accurately social or political costs. Although not strictly economic factors, they are not unimportant; they are often the basis on which a decision "to pave or not to pave" is actually made.

On the other hand, tourists commonly express more satisfaction with the ALCAN Highway than with the large heaves and dips on Alaska's paved routes. This is probably because gravel roads can easily be kept free of large-scale roughness.

APPENDIX A

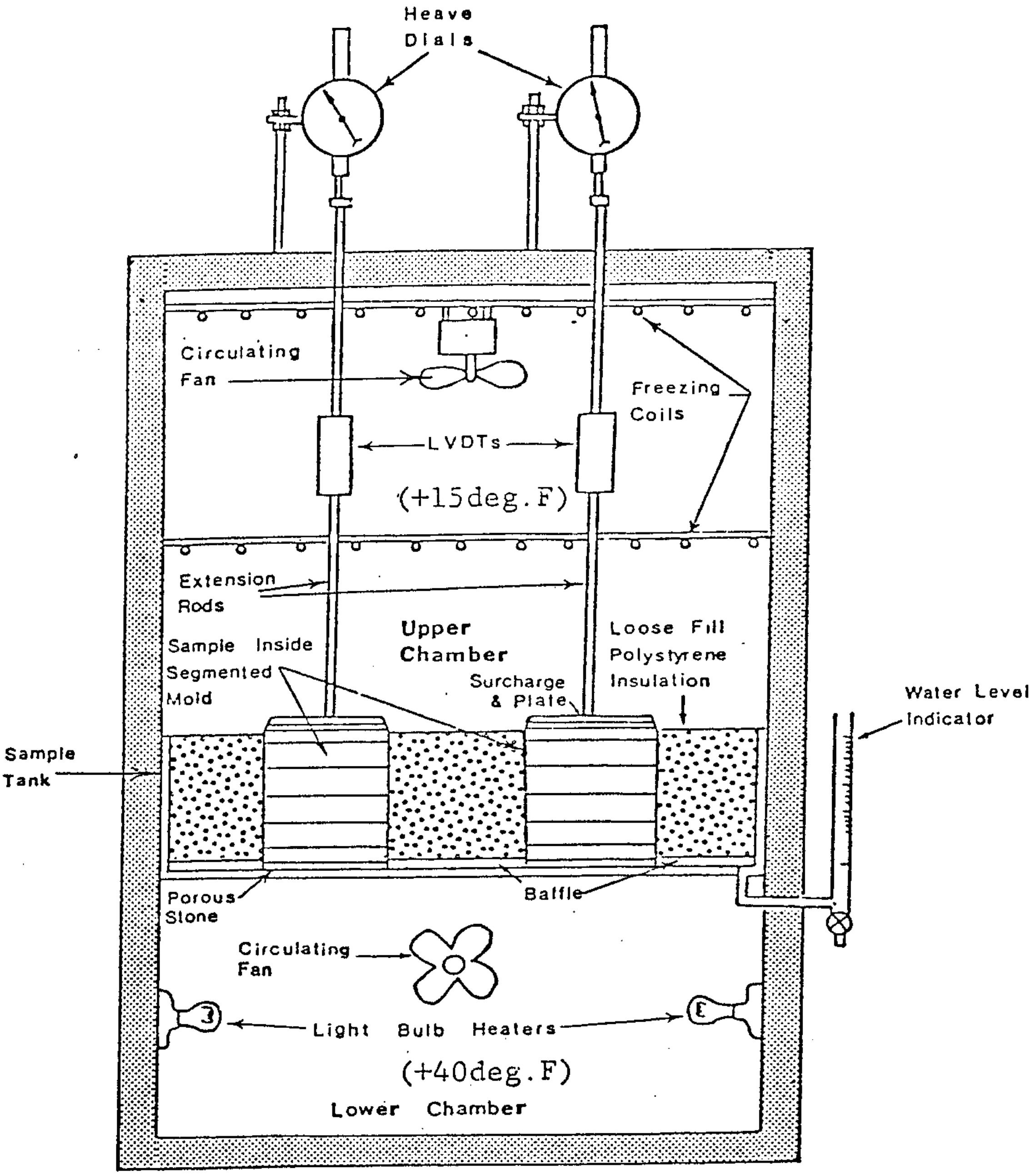
Testing of Calcium Chloride Effects on Frost Heave

The frost heave testing conducted for this report consisted of preparing compacted cyclindrical soil samples containing different amounts of calcium chloride and subjecting them to four freeze-thaw cycles. The test apparatus allowed the freezing of samples from the top down, and the amount of heave was measured throughout the test period. Samples were analyzed after completion of the test to determine the final depth of freeze and the moisture contents and densities of the frozen and unfrozen portions of the samples. The testing generally followed a standardized methodology which has been extensively used by the DOTPF Research Section.

Test Equipment

Soil samples were confined within a stack of plastic segmented rings which allow relatively unrestricted vertical movement as the heave progressed. The rings were each 1" high and had a diameter of 6", total sample height was approximately 5 1/2" (i.e. a stack of 6 rings).

A diagram of the heave test cabinet is shown in Figure A-1. The heave test cabinet contains heating coils which maintain the temperature below the samples at a minimum of 40°F. The temperature above the samples may be alternated between freezing temperatures and thawing ones. Loose polystyrene beads are packed around the sides of the samples. The samples are set on porous stones in the cabinet. Water level can be controlled around



INTERIOR DIAGRAM OF HEAVE TEST CABINET

Figure A-1

the samples; during testing it is maintained at the level of the bottom of the samples; the sample can thus absorb water by capillary action through the porous stone.

Heave of the samples may be logged by hand from readings of the heave dials (see diagram). It may also be read electronically and recorded on a data logger along with upper and lower chamber temperatures.

Procedure

Soil samples were made from "Goldstream Tailings", a schist material representative of common soil types often used for road construction in the Yukon-Tanana Uplands. The gradation of the sample material was that of a "dirty" base course; it is shown in Table A-1.

TABLE A-1

Goldstream Tailings Gradation

Size	% Passing
3/4"	100
1/2"	81
3/8"	71
#4	54
#10	38
#16	31
#40	21
#100	16
#200	12

The samples were compacted in three lifts with a vibratory hammer; the method and compactive effort are similar to those used in Proctor density determinations; densities in heave test samples are typically close to Proctor maximum values.

The first sample was prepared with 6.5% by weight of water (approximately optimum moisture content). Samples 2,3 and 4 were prepared with 6.5% by weight of solutions containing 1.5%, 3.75% and 7.5% calcium chloride by weight of water respectively. This is equivalent to a calcium chloride content by weight of soil of 0, 0.1%, 0.24% and 0.49% for samples 1,2,3 and 4 respectively. Dry densities obtained are listed in Table A-2, along with sample heights.

TABLE A-2
Sample Densities (Before Heave Testing)

Sample No.	%$CaCl_2$ moisture	Dry density (lb/ft^3)	Compacted sample height (in.)
1	0	149.1	5.53"
2	1.5	149.5	5.54"
3	3.75	151.5	5.55"
4	7.5	151.3	5.57"

After compaction, the samples were immersed for 24 hours in buckets of water containing the same concentrations of calcium chloride as was used in compaction (i.e. 0%, 1.5%, 3.75% and 7.5%). The samples were then placed in the heave test chamber.

Research Section procedures for heave tests normally freeze samples at about 15°F four times for 48 to 72 hours each, separated by 24 hour periods of thaw at 40°F.

During the first freezing in this test, however, it was noted that only the sample without any calcium chloride was heaving, even after nearly a week at 17° $\pm$2°F. It was assumed that the salted samples were not freezing significantly due to the depressed freezing point of the calcium chloride solutions.

The remaining three freezing cycles were therefore conducted at 0°F; at this temperature some heaving was noted in all four samples. The second through fourth freezing cycles lasted about three days, two days and four days, respectively; all were separated by periods of thaw of about one day.

After the four freeze-thaw cycles were completed, the samples were immediately removed from the test chamber and their total height was noted. The samples were then separated into frozen and thawed sections, and the height, moisture content and dry weight of each was determined.

Results

The total height of the samples after testing is listed in Table A-3. This table also lists the heights of the frozen and thawed portions of the samples, along with their dry weights and moisture contents. It will be noted that the sum of the measured heights of the frozen and thawed portions do not equal the measured total heights. It was difficult to separate the thawed portions of the samples intact and to measure them (the frozen portions, being cemented with ice, could be removed and measured with little disturbance to the material). The error in height measurements was thus felt to be most likely in the measurement of the thawed portions; Table A-3 therefore also lists a "computed thawed height" which is the remainder of the total minus the frozen heights.

TABLE A-3
Soil Sample Properties After Frost Heave Test

	Sample No. 1	2	3	4
Measured Height, Total (in)	6.217	5.880	5.805	5.598
Measured Height, Frozen (in)	5.414	4.055	4.865	2.540
Measured Height, Thawed (in)	1.006	1.397	1.074	3.211
Computed Height, Thawed (in)	0.803	1.825	0.940	3.058
Wet Weight, Frozen (grams)	4971.6	4076.4	4635.0	2499.9
Dry Weight, Frozen (grams)	4487.0	3744.0	4303.0	2360.0
Moisture Content, Frozen (%)	10.80	8.88	7.72	5.93
Wet Weight, Thawed (grams)	1001.9	1797.0	1263.7	3301.4
Dry Weight, Thawed (grams)	932.1	1679.0	1182.1	3110.4
Moisture Content, Thawed (%)	7.49	7.03	6.90	6.14

Notes: Measured heights are average value of three measurements.
Computed Height, Thawed is measured total minus measured frozen.

The relative volume of the samples after testing compared to that before is illustrated in Figure A-2. The moisture content of the samples before and after testing is illustrated in Figure A-3. The values listed are those for water content alone, not water-calcium chloride solution content.

The total heaving of the samples is plotted against time in Figure A-4. The data logger was not operating properly during the first part of the test, and a limited number of manually recorded values were extrapolated to form the curve for this period.

Figure A-2: FINAL HEAVE RATES

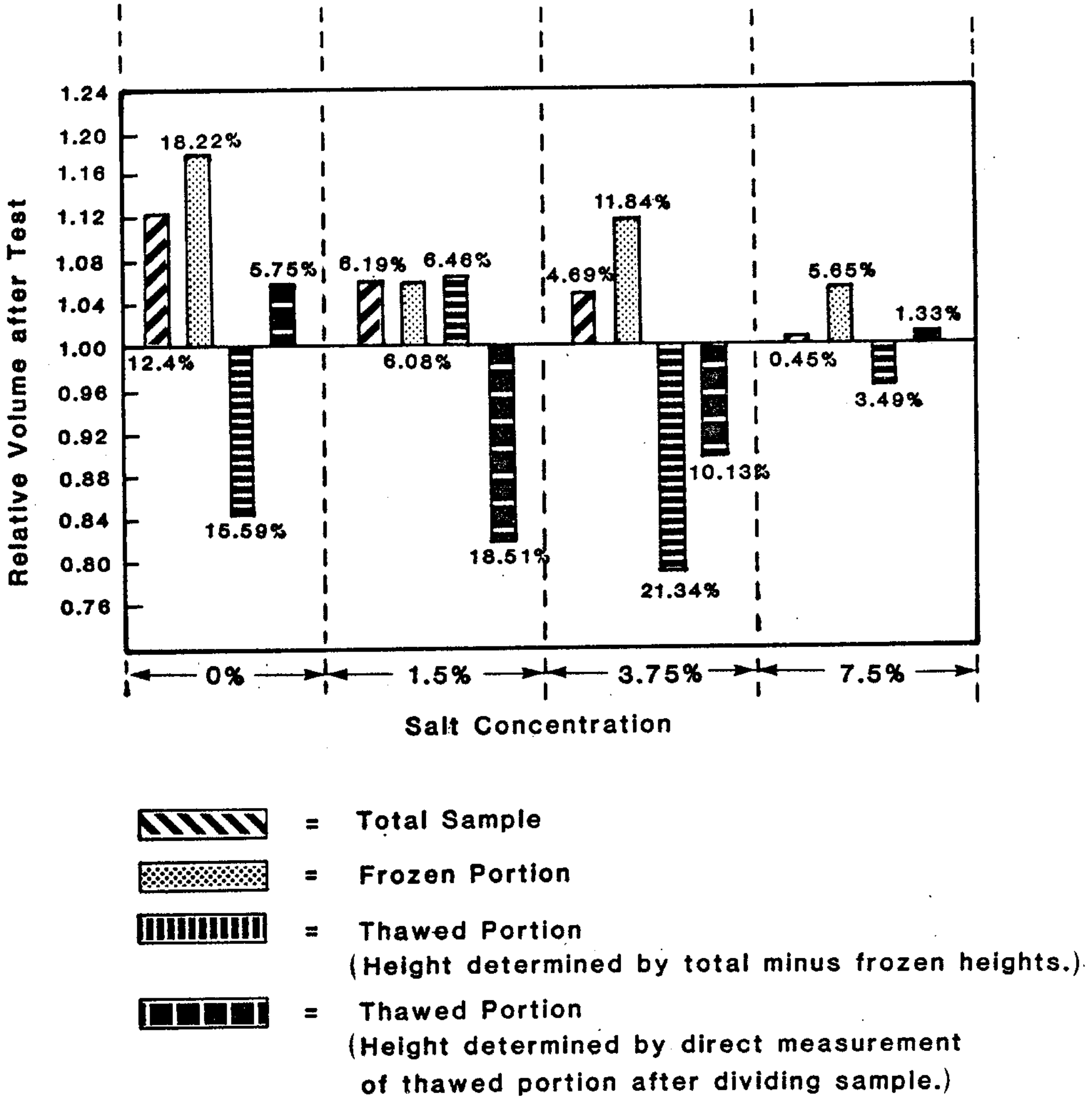
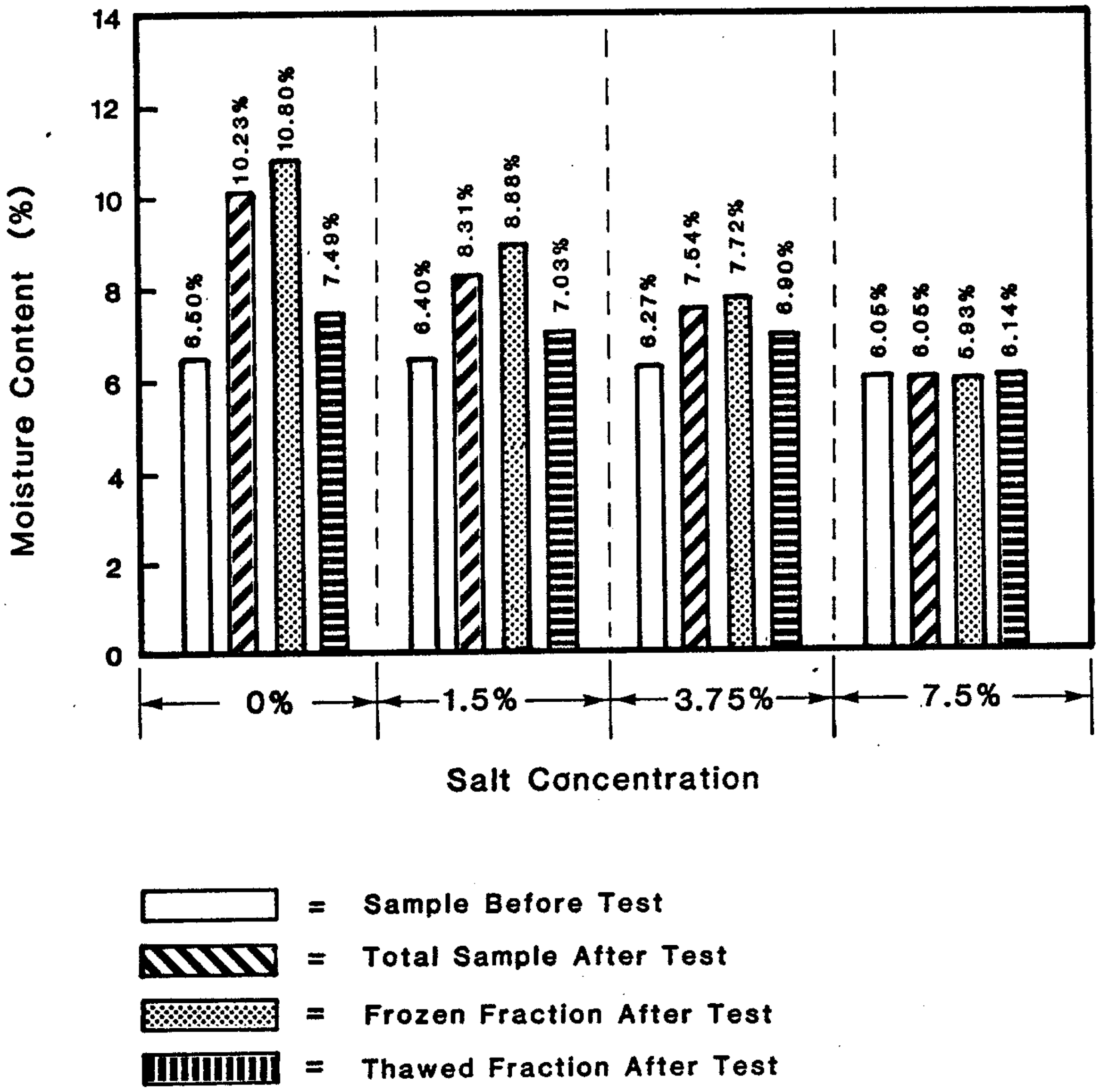


Figure A-3: MOISTURE CONTENT OF TEST SAMPLES



NOTE: All samples were compacted at 6.5% solution content (water plus $CaCl_2$).
"Before" data in this figure refers to water content only.

Figure A-4: Plot of Soil Sample Heave

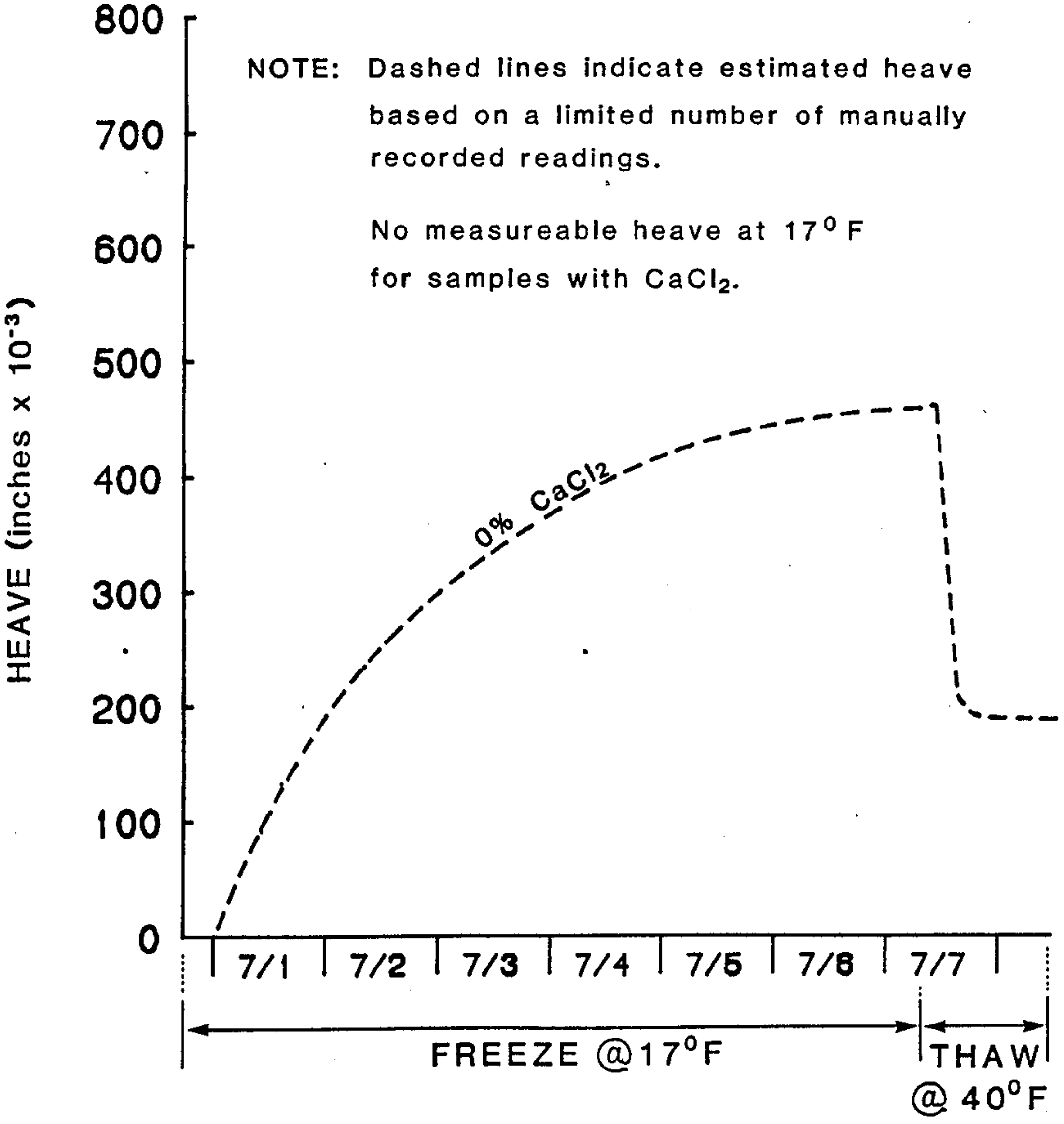
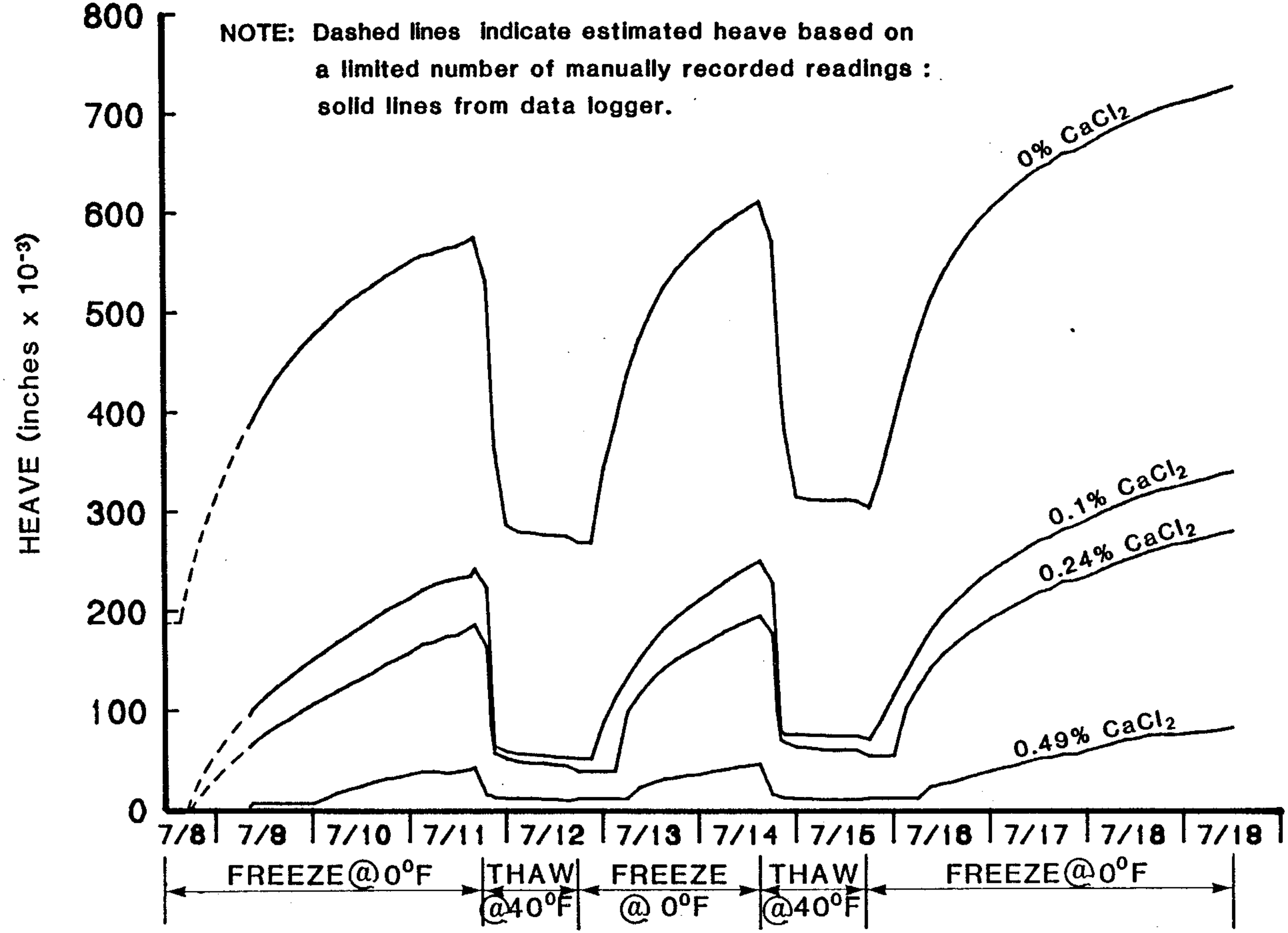


Figure A-4: (Cont.) Plot of Soil Sample Heave



NOTE: Dashed lines indicate estimated heave based on a limited number of manually recorded readings : solid lines from data logger.

Discussion of Results

The most obvious and important results of the heave test are:

- the inverse relationship between heave and calcium chloride content of the samples and
- the inverse relationship between final moisture contents (of both frozen and thawed sample portions) and calcium chloride content

The reasons that these results occurred are not clear. In Figure A-4 it can be seen that there was a greater delay between the time freezing temperatures were initiated and the time heaving began for the samples with greater calcium chloride contents (i.e. #3 and #4) than for those with less (i.e. #1 and #2). This suggests that the freezing point was depressed by the calcium chloride, and that less material was frozen in these samples with higher salt content. With other factors being equal, this would result in less heave.

This effect is not noticeable between samples 1 and 2 (i.e. those with no salt and 0.1% salt by weight of soil). The difference in the amount of heaving of these samples, though, is large. This suggests that there is at least one other mechanism responsible for the reduction in heaving.

It is notable that the difference in the rates of heaving between samples was greater in the first hours of freezing temperatures than during the final hours, although it was not noticeable throughout the test period. What the heave rate differences would be over the long term (weeks or months) is unknown.

Another notable result of this test is the difference in the relative amounts of residual heave (that remaining after the thawing of the samples) compared to the maximum heave observed during the freezing cycle. The maximum residual heave value observed in the third thawing cycle was 49% of the maximum heave observed in the freezing cycle immediately preceding for Sample 1 (the sample with no calcium chloride content). This ratio was 28%, 26% and 22% for samples 2,3 and 4 respectively.

The results of this test indicate that calcium chloride may greatly improve the performance of road aggregate with respect to frost heaving. This improvement is indicated both for the amount of heave itself (during freezing conditions) and for the subsequent thaw weakening. Dramatic results were obtained in this test with as little as 0.1% calcium chloride by weight of soil. This is equivalent to about 40 tons per mile for the top 3' of a road with a 24' surface and 3:1 slopes.

The limitations of this test, however, require that the results be regarded as only a clue to the effect of calcium chloride on frost heaving, rather than a knowledge of it. The test was performed with only one type of soil and under one set of conditions. Different soils, temperatures and length of freeze/thaw periods could all produce different results.

Another important factor limits the amount one can extrapolate from this test to behavior in real road conditions. This factor is the unknown extent to which calcium chloride migrates through an embankment over time. Reference 1 of this report indicates mechanisms by which calcium chloride might move in any direction in an embankment--up, down or sideways. If the calcium chloride migrated out of a treated subbase, any stabilizing effect would be reduced over time. If, on the other hand, calcium chloride migrated down into an embankment over time due to a program of surface application for dust control, an additional benefit of subbase stabilization might be gained. A better knowledge of the efficacy of calcium chloride as a frost stabilization agent could be gained by a thorough program of field and laboratory testing.

APPENDIX B

THAW SETTLEMENT EXAMPLE

The analysis below is less complicated than most real situations. It clearly illustrates, however, the magnitude of thaw settlement problems in areas of warm (30°F) permafrost, even where massive ice is not encountered.

Typical properties of ice-rich silt in Interior Alaska are:
in situ (wet) density: 85-115 pcf
specific gravity of solids: 2.65
maximum lab dry density (Proctor): 110 pcf

The in situ (wet) specific gravity equals $\frac{85}{62.4}$ to $\frac{115}{62.4} = 1.362$ to 1.843.

Assuming all voids are filled with ice (with specific gravity = 0.917) the in situ specific gravity also equals:

$$(f_v)(0.917) + (1-f_v)(2.65)$$

where f_v = volumetric fraction which is voids
$1-f_v = f_s$ = volumetric fraction which is solids

Setting these equal and solving for f_v, we find $f_v = 46.6\%$ to 74.3%.

The void ratio e_o is thus:

$$e_o = {}^{.466}/(1-.466) \text{ to } {}^{.743}/(1-.743) = 87.3\% \text{ to } 289.1\%^{*}$$

If after thawing and consolidation the dry density of the material is 95 pcf (equal to 86.4% of the Proctor value) the voids ratio would be:

$$e = \frac{1 - \frac{95}{(2.65)(62.4)}}{\frac{95}{(2.65)(62.4)}} = 74.1\%$$

The unit settlement under these conditions would thus equal to:

$$\frac{.873 - .741}{1 + .873} \text{ to } \frac{2.891 - .741}{1 + 2.891} = 7.0\% \text{ to } 55.3\%$$

If ten feet of frozen silt were thawed (which can occur in a few years under a thin embankment) this would be 8" to 5'6" of settlement.

*NOTE: This implies a moisture content of 30% to 100%.

APPENDIX C

Maintenance and Reconstruction Costs on Established Roads

Unit Costs (2-lane rural highways)

The following listing (Table C-1) is a set of estimated unit costs for road reconstruction and maintenance activities in Alaska. They are intended to be average costs in current (1982) dollars. Significant variations can, of course, exist in specific cases. The reconstruction related costs were determined by reviewing recent DOTPF contracts for the type of road (2-lane rural) of concern here, and by consultations with DOTPF design personnel. Maintenance related costs were determined by current DOTPF labor and equipment costs, estimates of productivity from DOTPF maintenance supervisors and other sources, and by comparison to similar construction activities.

The prices for base course, surface course and borrow materials are weighted towards their costs in urban areas; in other words, they more nearly reflect their cost from commerical sources than their cost from state-furnished material sources. While the latter is the more likely source of material on the rural roads which are of primary concern in this report, it was felt to be more accurate to use a cost which reflects the loss of resources to the State. This resource cost is approximately \$3-\$4 per cubic yard for the base and surface course materials and about half of this for common borrow materials.

TABLE C-1

Estimated Unit Costs of Highway Reconstruction and Maintenance Activities, Including Incidental Costs

Activity	Unit Cost (1982 dollars)
Reconstruction	
Crushed aggregate base or surface course, in place	\$27.60/c.y.
Crushed aggregate base or surface course, stockpiled	\$16.00/c.y.
2" hot asphalt pavement, in place	\$5.25/s.y.
Bituminous surface treatment ("chips"), in place	\$3.00/s.y.
Recondition roadway (2 lane width)	\$172.50/Station
Borrow, in place	\$10.00/c.y.
Hot Asphalt leveling course	\$1.00/s.y.
Maintenance	
Pavement patching*	\$10.00/s.y.
Recondition roadway (2 lane width)	\$172.50/Station
Crushed aggregate base or surface course (placement of stockpiled material)	\$16.00/c.y.
Road grading	\$95.00/Lane mile
Road grading and calcium chloride application**	\$905.00/Lane mile

* inlcudes gravel as needed to fill dips

** @ 2 1/2 tons $CaCl_2$ per lane mile

It should be noted that the cost of base and surface course materials are equal. This will not always be the case, and differences in specific locations can affect the economics of the choice between paved and unpaved roads. Where clean alluvial gravel sources are used, the production of surface course material with higher fines contents will be more expensive than the production of base course materials as it will require locating, excavating and blending the finer materials. Glacial till sources, on the other hand, often contain significant silt and clay sized particles. Base course materials are likely to more expensive than surface course from these sources. In still other cases, alternating strata of clean gravel and finer material may be found; in this case, the inclusion or exclusion of fines may have little effect on prices.

The costs given here are intended to include incidental costs related to the work. This includes such things as contractor mobilization costs on construction projects, tack or prime coats and lane markings on paving work, standard overhead costs on State personnel, traffic maintenance and surveying related to construction, and the like. The costs of route selection, design and State office and maintenance buildings are not included.

Assumed Levels of Work

Tables C-2 through C-6 list the assumed levels of work required to keep a road in safe condition for high speed travel. These work schedules, combined with the unit costs, are used to determine the annual costs of keeping the road in operation. The original cost of building the road has been neglected in this analysis. This cost will often be about the same for both paved and unpaved roads, except for the cost of the pavement layer itself. Exceptions to this were discussed in the design section of this report; their effect on costs is examined in Chapter 7. The annual costs for both reconstruction and maintenance activities are summarized in Table 4 (Chapter 7).

TABLE C-2

Surfacing Work Schedule - 24' Rural Road
Very Good Foundation

Paved Surface

Reconstruction

2" hot asphalt pavement
Hot asphalt leveling course
Stockpile base course sufficient for maintenance

@ 20 year intervals

Maintenance

Patch 1% of surface annually
Fill potholes & seal cracks @ 50% of cost of patching

Gravel Surface

Reconstruction

3" surface regraveling
Stockpile surface material sufficient for maintenance

@ 5 year intervals

Maintenance

Grade & salt @ twice annually
Recondition 1% of surface annually
Place 4" surface course material in reconditioned areas

TABLE C-3

Surfacing Work Schedule - 24' Rural Road
Good Foundation

Paved Surface

Reconstruction

2" hot asphalt pavement
4" base course material
Recondition roadway
Stockpile base course sufficient for maintenance

@ 20 year intervals

Maintenance

Patch 1.5% of surface annually
Fill potholes & seal cracks @ 50% of cost of patching

Gravel Surface

Reconstruction

3" surface regraveling
Stockpile surface material sufficient for maintenance

@ 5 year intervals

Maintenance

Grade & salt @ twice annually
Recondition 1.5% of surface annually
Place 4" surface course material in reconditioned areas

TABLE C-4

Surfacing Work Schedule - 24' Rural Road
Fair Foundation

Paved Surface

Reconstuction

2" hot asphalt pavement
4" base course material — @ 15 year intervals
Recondition roadway
Stockpile base course sufficient for maintenance

Maintenance

Patch 2.5% of surface annually
Fill potholes & seal cracks @ 50% of cost of patching

Gravel Surface

Reconstruction

3" surface regraveling
Recondition 2.5% of surface — @ 5 year intervals
Stockpile surface material sufficient for maintenance

Maintenance

Grade & salt @ twice annually
Extra grading--average over road once annually
Recondition 2.5% of surface annually
Place 4" surface course in reconditioned areas

TABLE C-5

Surfacing Work Schedule - 24' Rural Road
Poor Foundation

Paved Surface

Reconstruction

2" hot asphalt pavement 4" base course material Recondition roadway Stockpile base course sufficient for maintenance	@ 10 year intervals

Maintenance

Patch 5% of surface annually
Fill potholes & seal cracks @ 50% of cost of patching

Gravel Surface

Reconstruction

3" surface regraveling Recondition 25% of surface Stockpile surface material sufficient for maintenance	@ 5 year intervals

Maintenance

Grade & salt @ twice annually
Extra grading--average over road twice annually*
Recondition 5% of surface annually
Place 4" surface course in reconditioned areas

* "extra grading" may be in conjunction with a grade and salt operation

TABLE C-6

Surfacing Work Schedule - 24' Rural Road
Very Poor Foundation

Paved Surface

Reconstruction

2" hot asphalt pavement	
4" base course material	
Recondition roadway*	@ 8 year intervals
6" borrow material (average)**	
Stockpile base course sufficient for maintenance	

Maintenance

Patch 8% of surface annually
Fill potholes & seal cracks @ 50% of cost of patching

Gravel Surface

Reconstruction

3" surface regraveling	
Recondition 25% of surface	@ 5 year intervals
Stockpile surface material sufficient for maintenance	
6" borrow material (average)**	@ 10 year intervals

Maintenance

Grade & salt @ 2 times annually
Extra grading--average over road three times annually***
Recondition 8% of surface annually
Place 4" of surface course in reconditioned areas

* or "spread roadway" at same cost

** or excavation of high spots in road placed in low spots

*** "extra grading" may be in conjunction with a grade and salt operation

APPENDIX D

Thaw Penetration Calculations

Analytical methods to predict thaw penetration often make use of an "n" factor. The "n" is merely the ratio of the thawing degree-days of surface temperatures to the thawing degree-days in the air at the same location.* Reference 17 lists "n" factors, both measured and computed, from a number of sources. These figures were derived under different conditions and may not all be directly comparable. There are seven figures for gravel surfaces in the Fairbanks area which range from 1.27 to 2.01; the mean value is 1.57. For asphalt surfaces in the Fairbanks area, there are 13 figures ranging from 1.40 to 2.28; the mean value for these is 1.88.

Berg and Aitken[18] measured "n" values for several types of surfaces on adjacent sections of an embankment at the CRREL test site in Fairbanks. Their figures for a gravel surface artificially colored black was 1.40; for their asphalt surface it was 1.96 (they had instrumentation problems with the naturally colored gravel section and so they found no "n" factor for this). Esch[19] measured temperatures in adjacent gravel and paved embankment surfaces in Chitina, Alaska, and found "n" factors of 1.47 and 1.73, respectively.

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*Thawing degree-days are an integral of the amount and the length of time that temperatures exceed 32^{o}F. A temperature of 33^{o}F for one day equals one thawing degree-day; 33_{o}F for one week equals seven thawing degree-days; 42^{o}F for one day equals ten thawing degree-days, etc.

An analysis using the modified Berggren equation was used to predict thaw depths in gravel embankments with both gravel and paved surfaces, using a variety of data for weather conditions and embankment moisture content (see Table 2). The "n" values used were those from references 18 and 19 and the mean values from reference 17. For weather conditions similar to those found in Interior Alaska and in the Nome area, thaw depths were one to two feet greater for paved surfaces than for gravel ones in all cases. For weather conditions similar to those on Alaska's North Slope, the difference was smaller (as was total thaw depth); here the thaw depth beneath paved surfaces was one-half to one foot greater. The variables used and the results found are listed in Table D-1.

TABLE D-1

THAW DEPTHS BENEATH PAVED AND GRAVEL EMBANKMENT SURFACES
Solutions to the Modified Berggren Equation

	CASE NUMBER										
	1	2	3	4	5	6	7	8	9	10	11
Difference in Thaw Depth (ft)	2.0	1.0	1.1	1.0	1.7	1.0	0.9	0.7	1.0	1.0	0.5
Gravel Surface Thaw Depth (ft)	11.9	12.6	12.7	10.6	10.1	12.0	7.9	5.1	4.5	4.7	5.0
Asphalt Surface Thaw Depth (ft)	13.9	13.6	13.8	11.6	11.8	13.0	8.8	5.8	5.5	5.7	5.5
"n" Factor Gravel/Paved	1.4/ 1.96	1.47/ 1.73	1.55/ 1.87	1.55/ 1.87	1.40/ 1.96	1.55/ 1.87	1.55/ 1.87	1.55/ 1.87	1.40/ 1.96	1.40/ 1.96	1.47/ 1.73
Air Thawing Index, °F Days	3500	3500	3000	3000	2500	2500	1500	900	900	900	900
Thaw Season Length, Days	180	180	180	180	145	145	125	90	90	90	90
Average Annual Temperature, °F	27	25	25	25	27	27	18	10	10	10	10
Embankment Moisture Content, %	12	8	6	20	12	6	6	8	20	12	8

NOTE: Properties of the gravel embankment material, other than moisture content, were held constant in all cases.

Design air thawing indexes along the Arctic coast are less than 1000; they increase quickly further south to about 2000 on the south side of the Brooks Range. Air thawing indexes for the interior are generally 2500-3500.

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