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GRAVEL ROADWAY MAINTENANCE IN COLD REGIONS

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Abstract

Many surface treatments are available for the treatment of gravel roadways in cold regions. Primary concerns are the control of dust, stabilization of the surface to avoid rutting and potholes, and prevention of adverse effects of spring breakup. Calcium chloride has been the primary product added to Alaska's gravel roadway surfaces for this purpose. Several treatments are reviewed, including calcium chloride, lignosulfonate, asphalt emulsion, Earth Material Catalyst Squared™, Road Oyl™, sodium montmorillonite, and no additive. From a cost standpoint, the least expensive surface appears to be the "no treatment" option, although calcium chloride and EMC Squared™ are also cost competitive and may provide a superior surface. When other factors such as re-graveling, road user costs, safety and environmental effects are included, it is unlikely that "no treatment" will be the preferred option. A spreadsheet for comparing alternative costs has been developed and is available for analyzing cost, effort, application frequency and application density data for any particular situation. The design of a field demonstration program for applying several treatment alternatives and monitoring their long-term cost and performance completes the report.
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information and photographs in the Coldfoot area. Finally, appreciation is expressed to Dr. Lutfi Raad, Director of the University’s Transportation Research Center, for both his administrative expertise and his personal interest in the outcome of this project.
1.0 Introduction

This report finalizes the findings and recommendations for the project, Gravel Roadway Maintenance in Cold Regions (SPR-UAF-92-14), sponsored by the Alaska Department of Transportation and Public Facilities under its Alaska Cooperative Transportation and Public Facilities Research Program (ACRP). The project was proposed in April 1992 and commenced in the fall of 1992 while the author was on sabbatical leave at Luleå University of Technology in Luleå, Sweden.

As stated in the proposal, the project's objectives were threefold, as follows:

1. Investigate and summarize current practice and recent research results that may improve the surface characteristics of Alaska's gravel roadways

2. Provide cost and benefit data on potentially economically viable alternatives

3. Design a research program that will test identified alternatives on a future roadway project.

The study is restricted to surface treatments and performance and does not involve embankment, subgrade or geometric design.
Interest in the surface characteristics and performance of gravel roadways in Alaska is a result primarily of the state’s special environmental conditions combined with relatively low traffic volumes in rural areas, which cannot justify higher class roadway surfaces. In Interior Alaska in particular, the extreme dry conditions in the summertime cause major dust control problems which lead to surface deterioration, environmental degradation and visibility problems. In the springtime, roadway thawing can lead to rutting, potholes and other surface effects, which impact vehicle performance and safety as well as maintenance costs. Furthermore, some areas of Alaska have relatively limited and expensive gravel sources, thus providing another incentive for improving the operational characteristics of this limited resource.

On a lane mile basis, 41% of Interior Alaska’s roadway surfaces are untreated gravel, with another 4% being gravel with some type of surface treatment. Examples range from the 414 mile Dalton Highway, from the Elliott Highway to Prudhoe Bay, some of which has received various types of surface treatment; and the 118 mile unpaved portion of the Steese Highway, to such short lengths as the Ester Dome Road, which is also maintained by the Department of Transportation and Public Facilities.

The report begins with a description of the current practice utilized by the Department of Transportation and Public Facilities for gravel roadway design, construction and maintenance. It then presents a summary of Scandinavian gravel roadway practice, as complied by the author during an investigation in fall 1992. Further information from the literature, including various surface
treatments and various methods for evaluating and classifying surface conditions, is summarized.

A major section describes the eight alternatives identified in the study, with as much cost data as could be obtained, together with information on application methodology and possible limitations. We then note three parties within the State of Alaska, outside DOTPF, who expressed interest in the investigation during the time it was underway. Finally, we present the design for a proposed field demonstration program that would apply and monitor seven different surface treatments over a period of two years, with an emphasis on application and maintenance methods, costs, performance, environmental effects and safety considerations.

2.0 Alaska Department of Transportation and Public Facilities Practice

In this section, we discuss both 1) the official design documents for gravel roadway construction in Alaska, using two recent projects as examples, and 2) the use of various surface treatments for dust control and surface stabilization, both standard practice as developed by various maintenance crews and some one-time experimental projects.

2.1 Design and Construction Documents

The 1992 project, "Dalton Highway Mile 111 South Resurfacing F-065-3(2)/65387," (1992) provided either a reconditioned gravel surface or a raised embankment plus new gravel surface (depending on the location) to a portion of
the already gravel surfaced Dalton Highway. A portion of the project utilized calcium chloride as a dust palliative. Figure 1 is taken from the design documents for that project. Note that the surface has a 0.03 ft per foot cross slope and that the surface course consists of a 6 inch thick layer of subbase with grading C, with a maximum aggregate size of 1" and a fines (<#200 sieve) content of between 15 and 18%. Where used, the calcium chloride content was to be 10 tons per mile.

Alaska Department of Transportation and Public Facilities Standard Specifications for Highway Construction (1988) applied to this project, as modified by the Standard Modifications and Special Provisions to the contract. The following are selected portions of the relevant sections:

203-3.02 Embankment Construction "...All embankments shall be constructed with moisture and density control unless the Engineer determines that such controls are not feasible, in accordance with approved methods."

303-2.01 Reconditioning Construction Requirements "...The existing surface shall be scarified to a depth of 0.5 feet. Material shall be pulled from existing foreslopes and combined with the scarified material so as to conform reasonably with the typical sections. The combined material shall then be spread uniformly to the line and grade approved by the Engineer and compacted as specified in Subsection 203-3.03 [which requires that embankment material be compacted to not less than 95% of the maximum density]."
Figure 1. Gravel Roadway Cross Sections, Dalton Highway Mile 111 South Resurfacing F-065-3(2)/65387 Project, 1992
304-3.01  Subbase Construction Requirements  "...When subbase material is utilized as the finished wearing course, placement in the roadway shall conform to the requirements of Subsection 301-3.01. After each layer of subbase material has been placed, the materials shall be uniformly mixed while at the approximate optimum moisture content, by means of a motor grader or other approved equipment, until the mixture is uniform throughout. Compaction of each layer shall be in accordance with Subsection 203-3.03."

624-3.01  Calcium Chloride for Dust Control Construction Requirements  "The equipment used for applying the calcium chloride shall be any spreader capable of uniform application.

Subgrade Grading "C" shall be spread and shaped to the required cross section prior to treatment. No calcium chloride shall be applied when rain is falling or is probable in the 48-hour period following application or when moisture conditions of the Subbase Grading "C" or roadway exceed that required for proper application of dust palliatives, as determined by the Engineer.

Immediately after application of the dust palliative the roadway shall be bladed into final shape and compacted with a rubber tired roller. The treated roadway shall be maintained in final grade and line by additional grading and compaction for a minimum of 2 days after placement or as directed by the Engineer.
Calcium chloride shall be applied uniformly across the roadway but no
closer than one foot from the shoulder of the prepared surface. The
calcium chloride shall be thoroughly mixed into the surface of the
Subbase Grading "C" by alternately winrowing and spreading to the
satisfaction of the Engineer.

It is the intent of this specification that the calcium chloride is mixed with
the upper two inches of the subbase at a rate of 10 tons per mile.

Sufficient water shall be added during the mixing operation to provide
approximately the optimum moisture content of the subbase as
determined by AASHTO T 80-D. All water necessary to maintain the
optimum moisture content of the subbase shall be incidental to pay item
no. 624(1) Calcium Chloride."

The 1983 project, "Steese Highway Perhaps Creek to Sourdough Creek Grading
and Drainage S-0670(23)," (1983) also provided a highway with a gravel
surface. In contrast to the Dalton Highway project described above, this project
did not specify the use of calcium chloride or other dust palliatives. Figure 2
shows a typical section of improvement, providing for 0.03 ft per foot cross
slopes and a 6" subbase of Grading "C" as the surface layer, placed on top of
Type "A" borrow.

The 1981 version of the Alaska Department of Transportation and Public
Facilities Standard Specifications for Highway Construction applied to this
project. The relevant section with respect to subbase utilized as the wearing
surface is similar to that quoted above for the Dalton Highway project. We quote
Hand Clearing
10°
See Note 3

Existing Ground
(See Slope Table)

4:1
40'
12'

12' flat bottom will be used left at Stations 1434.00
to 1439.00 with a 100' transition on each end.

Unclassified excavation and/or borrow
Borrow Type 'A' (See Plan & Profile sheets for minimum depth)
6' subbase, Grading 'C'

Profile Grade
0.03' / ft

Varies (See Slope Table)

TYPICAL SECTION OF IMPROVEMENT

---

Figure 2. Gravel Roadway Cross Section, Steese Highway Perhaps Creek to Sourdough Creek Grading and Drainage
S-0670(23), 1983
the paragraph here, to indicate the relaxed compaction requirement for this project, as follows:

304-3.01 Subbase Construction Requirements "...When subbase material is utilized as the finished wearing course, placement in the roadway shall conform to the requirements of Section 301-3.01. After each layer of subbase material has been placed, the materials shall be uniformly mixed while at a moisture content approximately equal to the optimum moisture content, by means of a motor grader or other approved equipment, until the mixture is uniform throughout. Compaction of each layer shall continue until a density of not less than 90 percent [a change from the standard 95 percent] of the maximum density, determined in accordance with AASHTO T 180, Method D, or Alaska T-12, has been achieved."

The requirements of Section 301-3.01, cited above, are written for aggregate base courses. They apply by reference to substrates used as wearing surfaces and specify the placement method, as follows:

301-3.01 Placing "The maximum compacted thickness of any one layer shall not exceed 6 inches, unless special compacting equipment is utilized. When vibratory or other approved types of special compacting equipment are used, the compacting depth of a single layer of the base course may be increased to 8 inches upon written approval.

During placement of the base material on the roadway, the roadway surface shall be adequately drained at all times."
Like the 1988 edition, the 1981 edition of the Standard Specifications for Highway Construction contained a section (Section 624) on Calcium Chloride for Dust Control, but the calcium chloride was not specified for use on this Steese Highway project. Section 624 of the Standard Specifications provides for scarifying to a minimum depth of 1 1/2 inches prior to the first application, with water applied prior application of the calcium chloride. The initial application of calcium chloride is at a rate of one pound per square yard (approximately 8 tons per mile for a 28 foot wide roadway surface), whereas additional applications are at a rate of one-half pound per yard (approximately 4 tons per mile).

2.2 Past and Current Surface Treatment Practice

Several surface treatments have been used by Department of Transportation and Public Facilities Maintenance and Operations personnel in their routine maintenance of gravel roadways and in experimental roadway sections. We describe here a sampling of those activities.

Calcium chloride is used frequently by Alaska’s DOTPF for dust control and surface stabilization. Reckard (1983a) reported that the most common method at the time of his study was to spray the material onto the roadway in a brine form. Application rates are on the order of five to ten tons of dry material per mile.

On the Dalton Highway, calcium chloride has been used since 1984. The methods of application, frequency and quantity vary somewhat, based on experience of different maintenance crews, specific site conditions and
availability of funds. The following describes a typical procedure, as observed
during a visit to an operation being performed north of Coldfoot by the crew from
the Coldfoot Maintenance Camp:

The road surface is watered with a water truck. Four passes with a
grader equipped with carbide teeth loosen the top four inches of gravel
surface over the 28 foot width. Another pass of the water truck applies
additional water.

Two passes of a sanding truck equipped with a spinner distribution
system spread a total of ten tons per mile of granular calcium chloride.
Three passes of a grader with a plain blade mix the calcium chloride and
gravel and place it on one side of the roadway. Four passes of the same
grader further mix the materials and move them into a windrow on the
other side of the roadway.

Water is added to the entire bare portion of the roadway. The grader with
the plain blade spreads the materials across the roadway to an average
depth of four inches, with a six inch thickness at the center and a two inch
thickness at the shoulder. Together with the crown in the existing
subbase, the total crown is approximately 6%.

The final cross section is compacted, either with a vibratory roller or a
fully loaded water truck, with additional compacting by the passing traffic.

Appendix A contains a trip report prepared by Lei Chen that includes a more
detailed description of the procedure outlined above. Cost and effort data
collected on that trip form the basis for cost estimates for calcium chloride surface treatments in Section 5.0.

**Road Oyl™** is a product of the Road Products Corporation, distributed by Soil Stabilization Products Company, Inc. (Road Oyl™ 1992) It is a resin modified emulsion that can be used to bond pavement surfaces and base courses. The Alaska Department of Transportation and Public Facilities has used the product on an experimental basis for two years, 1992 and 1993, for streets in Eagle. A total of 0.87 mile was treated in 1993. The procedure consists of the following steps:

The road is graded as part of the normal grading operation and shaped to final cross section.

A tank truck with spray nozzles applies the Road Oyl™ at a rate of 0.25 gallons per square yard (3520 gallons per mile for a 24 foot wide roadway).

Traffic remains off the roadway for at least twenty-four hours, to allow an initial "set."

No compaction is used, except for that of normal traffic.

Maintenance personnel judge its performance by saying "if it is applied the right way it does work fairly well." (Brinkman 1993) A limitation is the need to keep all traffic off the roadway for at least 24 hours to allow the material to soak in and
set up. Also, applying the Road Oyl in wet weather proved unsatisfactory. Cost and effort data cited in Section 5.0 are based on the Alaska DOTPF's experience in the Eagle area.

An alternative approach is to apply the material in smaller quantities over a longer period, say four days, during which traffic is allowed to use the roadway immediately after use (Gates 1994).

**Earth Materials Catalyst Squared (EMC²)** is a liquid product of the Soil Stabilization Products Company, Inc. (EMC² 1990 and 1993). Its composition is based on biocatalytic proteins which produce an organic reaction to bind the soil particles and resist moisture infiltration. The material was used on a 2.5 mile section of the Elliott Highway during a reconstruction project in 1991. The plan application rate was one gallon of EMC² for every 324 cubic feet of compacted subbase. On the 2.5 mile length, a total of 770 gallons were used, or about one gallon per 635 square feet. Two sections of 1.25 miles each were placed. In the first, the EMC² was mixed with subbase material in a pugmill, hauled in trucks to the site, spread with graders and compacted. In the other section, a roadmix method was used, wherein the diluted liquid is sprayed onto the surface, mixed into the top layer and compacted. Both sections were given a top surface treatment with dilute EMC². Alaska DOTPF personnel found that the road mix method was more satisfactory, with a final product that was equal to that obtained by the pugmill method and that was obtained more easily and less expensively. Moisture content was critical for placement, workability and finishing. (Herning 1991)
In summer 1992, the test section was scarified, regraded and recompacted but no new EMC Squared material was added. (McHattie 1993)

Laboratory tests of aggregate from a stockpile at 47.5 mile Elliott Highway, stabilized with EMC Squared were performed for Soil Stabilization Products Company by Arctic Alaska Testing Laboratories. Compression tests of cylindrical samples resulted in an approximately 60% increase in compressive strength of the treated mixture, compared to the untreated mixture. Compactive effort decreased approximately 15% and density increased slightly over two percent for the treated samples. Two other samples were treated with the same quantity of EMC Squared and cured under the same conditions. One was compacted with full Modified Proctor effort, while the other received 57% of that compactive effort. Compressive strengths of the two samples were in the ratio of 100 to 60. ("Material Property Tests on Aggregate Stabilized with EMC Squared" 1993)

McHattie (1993) reported on the performance of the experimental EMC Squared section on the Elliott Highway, based on observations in July and August 1992. Dust samples were collected in "dust cups," which are open topped containers 2" in diameter and 4" deep, placed about two feet above the ground surface approximately 25 feet either side of the roadway centerline. In addition, photographs and visual observations were made of a standard Chevrolet sedan traveling at 50 mph. The conclusion was that dust palliative action was excellent one year after construction. Furthermore, required maintenance operations were normal, and there were no problems with severe potholing or other severe kinds of surface roughness.
Sodium Montmorillonite is a clay binder distributed by the Soil Stabilization Products Company, Inc., under the trade name Stabilite™. It was used on a 2.5 mile section of the Elliott Highway during the same 1991 reconstruction project that utilized EMC Squared™ described above. The material was mixed with subbase in a stationary pugmill at a rate of 2% of the dry aggregate weight, hauled 17 miles to the site, spread with graders and compacted. DOTPF personnel observed that moisture content was an important factor affecting the product's placement, workability and finishing, and that the 17 mile haul length made control of moisture content difficult. The relatively high percentage of fines in the subbase at this location led to the conclusion that the percentage of sodium montmorillonite should have been about one instead of two percent. The resulting road surface did not bind together well and was more expensive than the EMC Squared surface. An important conclusion was that the sodium montmorillonite is more appropriate for subbases with low percentages of fines. (Herning 1991)

McHattie's report (1993) also discussed the performance of the experimental Sodium Montmorillonite section on the Elliott Highway. The methods for observing dust palliative action were similar to those for the EMC Squared section, and the conclusions were similar. In short, after one year of operation, including standard scarifying, regrading and recom pacting but no additional Montmorillonite, the surface performance remained satisfactory. When compared to a control section utilizing calcium chloride as a dust preventative, the experimental sections performed equally effectively.

Stabilite™ was used recently at the Fort Yukon airport. It is important to understand that it was originally developed for use with completely "clean"
aggregate which has a plasticity index of essentially zero (Randolph 1994a).
Because of the more permanent nature of the final product, the initial cost is high
compared to other alternatives.

**Lignosulfonates** are by-products of the papermaking process. They are sold
under such trade names as Lignosite® Road Binder, as produced by the
Georgia-Pacific Corporation, which is an aqueous form of its Lignosite® Calcium
Lignosulfonate. (Georgia Pacific 1988; Polley 1993) The aqueous solution is
sprayed onto the surface, mixed into the subbase and compacted. This product
was used in the Anchorage area in the 1970's with mixed results. "The results
ranged from very good to very poor performance with the variability blamed
primarily on existing road conditions and surface materials." (Reckard 1983a)
The presence of sufficient fines seems to be an important requirement, as is the
need for a stable base.

On the Dalton Highway, lignosulfonates were applied on two mile sections in
each of two different years (mile 138 to 140 in 1990 and mile 136 to 138 in
1992). The 1990 application was in liquid form, while the 1992 application was
in powder form. Short term results were mixed and tended to confirm the report
by Reckard cited in the paragraph just above. In particular, the process for
applying the powdered form was rather unwieldy and considerably more
expensive than that for the liquid form, even though the shipping cost for the
powdered form was much less. (Milne 1994) On the other hand, it was
necessary to heat the liquid material before application, which made its use less
convenient than, say, calcium chloride.
3.0 Scandinavian Practice

The author spent the fall 1992 semester at Sweden's Luleå University of Technology while on sabbatical leave from the University of Alaska Fairbanks. During that time, he was able to obtain considerable information about roadway construction and maintenance in Scandinavia. In particular, a report has been prepared in connection with the study of gravel roadway maintenance. Appendix B contains the complete report from that portion of the study.

A summary of the findings reported in Appendix B is as follows:

- Compared with Interior Alaska, Scandinavia's gravel roadways contain a significantly higher proportion of surface treatments, whereas a larger proportion of Alaska's gravel roads are untreated.

- Swedish practice evaluates gravel road conditions on the basis of "evenness" and "cohesiveness," with three classes defined for each -- 1) Good; 2) Sufficient, and 3) Low. The average daily traffic defines which condition classification a particular roadway must meet.

- An detailed procedure is specified in Sweden for the aggregate gradation for gravel roadway surfaces, based on an "ideal gravel curve" which combines the needs for bearing material and binding material.
- Swedish gravel road maintenance practice emphasizes both recycling gravel from the shoulders and the use of "fraction graveling," wherein only the fraction above 4 mm is added as new material.

- Gravel road surface treatments in use in Scandinavia include the following:

  Oil gravel -- a very low grade plant-mixed "asphalt" (Finland and Sweden)

  Surface dressing with asphalt binder -- a surface dressing whose binder and aggregate are spread separately (Finland, Norway and Sweden). Bitumen emulsions have been used experimentally, some with Portland cement added.

  Calcium chloride and other salts -- (Finland, Norway and Sweden)

  Lignosulfonates -- (Norway and Sweden, on an experimental basis)

- An extensive testing program in Sweden evaluated a number of gravel wearing surfaces. Among many findings, the results show that surfaces with high plasticity indices gave better durability but needed some sort of dust binding material to prevent drying, dusting and blowing away of the fine material. Wearing courses with low plasticity
indices and silt as a binder showed surprisingly good resistance to such deterioration even without the addition of dust binding agents.

- The Scandinavian countries are concerned about the possible environmentally detrimental effects of some surface treatments, especially salts. Lignosulfonates, bitumen emulsions and cements may provide cost- and performance-effective treatments without undesirable environmental effects.

4.0 Other Reports of Research and Practice

In addition to current Alaska Department of Transportation and Public Facilities practice, and the methods used in gravel roadway maintenance in Scandinavia, we report in this section some other background information as reported in the literature. We consider both technologies for surface treatments and methods for evaluating surface conditions.

4.1 Surface Treatment Methodology

In Appendix C, we include abstracts of thirty-one selected papers, articles and reports related to the subject of gravel roadway maintenance. Two of these publications are described in greater detail in the Digests section of that Appendix. (Eaton, Gerard and Cate 1987; Reckard 1983a). Additional references are included in the reference list in Section 9.0. We summarize in the next five paragraphs some of the significant findings from that literature.
Because of the potential for large amounts of dust production from gravel roads, and the increasing national attention being focused on air pollution, considerable research has been oriented toward "fugitive dust control methods." In particular, the ambient air quality standard for particulate matter less than or equal to 10 microns (PM$_{10}$) has led to the development of software packages that assist in developing emissions inventories. (Barnard and Gschwandtner 1989) Studies have looked at both the effects on workers in such industries as coal mining and the impacts on residents and others located adjacent to such unpaved surfaces as coal haul roads. (Hughes 1989) Watson and others (1989) state, "Fugitive dust sources are major contributors to PM 10 in many airsheds and will have to be controlled in order for federal PM 10 standards to be attained. Paved and unpaved road dust and construction and demolition categories comprise about 90% of the total emitted fugitive dust in most urban areas."

Reckard (1988a and 1988b) conducted two parallel studies of dust control methods in Eagle River and the Mendenhall Valley, Alaska. In each case he considered four options for improving unpaved streets -- 1) paving with hot asphalt, 2) paving with bituminous surface treatment, 3) oiling, and 4) calcium chloride application -- and three means for reducing dust in areas of already paved streets -- 1) paving driveways, 2) using cleaner sand, and 3) reduced sanding and better cleanup. His study estimated the annual cost of each option and the benefits in terms of the reduction in PM$_{10}$ emissions.

Several studies have reviewed the use of geotextiles in unpaved road construction. The importance of careful and proper construction is noted by both Hausmann (1987), who states, "...careful management of construction activities
is vital for successful use of fabrics in unpaved roads, and by Bonaparte and others (1988), who report on a long-term test of buried geotextile strength from which it was concluded that nearly all of the strength loss was due to mechanical damage that occurred during construction. A study of the durability of a polypropylene geotextile material in an unpaved road structure found some polymer degradation probably caused by oxidation. (Peggs, Tisinger and Bonaparte 1989) Design charts for determining required aggregate thickness for geotextile-reinforced roads have been used successfully for unpaved roads. (Holtz and Sivakugan 1987)

The potential for using scrap tires in road construction is a subject of considerable recent interest. While there does not appear to be an emphasis on such applications in the surface course of unpaved roads, their use as fill material does appear to be satisfactory. One study (Eidin and Senouci 1992) identified no major handling or placement problems. The test sections were monitored under service loads that included freeze-thaw conditions. Acceptable performance with moderate maintenance requirements and low impact on ground water quality were noted. Disadvantages included high compressibility and a tendency to shift laterally under compaction equipment.

In the so-called "developing" countries, unpaved road technologies are of critical importance to economic and social development. The literature contains many reports of studies in these countries (although no such reports are from cold regions). Material investigations are a consideration, such as a project in Ethiopia to utilize crushed or screened weathered basaltic gravels. (Beaven, Robinson and Aklilu 1988) Paige-Green (1990) describes an investigation into the performance of wearing course materials for unpaved roads in southern
Africa which led to the development of models for prediction of roughness and gravel loss. The importance of the maximum use of local labor and materials is the subject of a paper by Partridge, Williams and Brink (1989), who suggest the need for "fundamental changes in design philosophy and contractual procedures, as well as a re-evaluation of appropriate technology." Robinson (1988) urges the use of condition measurement surveys utilizing rapid assessment methods and suggests that maintenance management systems utilize maintenance frequencies determined on a economic basis using "whole-life" costs.

In his 1983 report for the Alaska Department of Transportation and Public Facilities and the Federal Highway Administration, Reckard (1983a) identified several needed areas for further study. Included were the effect of dust palliatives on the frost susceptibility of road embankment materials, the extent to which surface-applied palliatives leach or migrate into embankments, and the potential economic advantage of using "dirty" subbase materials for unpaved roads, with little adverse impact on performance. These studies are part of the proposed field demonstration program presented in section 7.0. One study that resulted from the Reckard suggestions was completed in 1986. Kinney and Reckard (1986) investigated the impacts of salts on road embankment stability under freezing and thawing conditions and concluded that salt greatly affects the mechanisms involved in frost heaving; it may make soil easier to compact, increase its permeability and decrease its strength when frozen; and little if any salt remains in the road section several years after construction.

In addition to the information summarized above from the literature review in Appendix C, a recent publication by the American Society of Civil Engineers
(Local Low Volume Roads and Streets 1992) contains much valuable information about roadway management that is applicable to Alaska. Several sections are devoted to unpaved roads. Dust on unpaved surfaces causes three primary problems -- 1) nuisance, 2) safety hazard and 3) loss of materials. The annual loss of materials averages about 45 cubic yards per mile for an 18 foot wide surface with a traffic volume of 100 vehicles per day. Dust palliatives can reduce this loss by as much as 50%.

The ASCE publication emphasizes the importance of well shaped crowns and adequate ditches for proper surface drainage. A crown slope of 1/2 inch per foot is recommended, which, at about 4%, is somewhat less than the 6% that crews on the Dalton Highway try to maintain.

Dust palliatives include calcium and other chlorides, which act by absorbing moisture from the air and retaining it from rainfall; bituminous materials, fly-ash and lignin derivatives which act as adhesives; and synthetic fibers. Application of such materials is best done before the formation of dust begins and when the roadbed is slightly damp. The moisture absorbing additives and the adhesives must be replaced periodically, with calcium chloride replaced as much a three times per year and bituminous materials and lignins replaced at least once per year. Dust problems can be minimized when there are just enough fines in the surface to fill the voids in the aggregate mass of a soil-aggregate mixture. (Local Low Volume Roads and Streets 1992).
4.2 Methods for Evaluating Surface Conditions

Riverson and others (1987) report on a method for the subjective rating of unpaved county roads in Indiana which uses a rating scale between 0 and 5, which was then correlated with such quantitative measures as road roughness number and average rater speed, plus visually rated corrugation, potholes, rutting and gravel looseness. The condition rating formed a portion of the basis for selecting maintenance activities.

Eaton and others (Eaton, Gerard and Cate 1987; Eaton 1988; Eaton, Gerard and Dattilo 1989; Eaton and Beaucham 1992) have developed a detailed procedure for evaluating the conditions of gravel road surfaces. The approach is considerably more comprehensive and time-consuming than the two category-three class method used in Sweden and described in section 3.0.

The Eaton method identifies seven distress types -- 1) improper cross section; 2) inadequate roadside drainage; 3) corrugations; 4) dust; 5) potholes; 6) ruts; and 7) loose aggregate. Based on a visual inspection, a section of roadway is assigned "deduct values" for these categories. The total deduct values are used to determine the road's unsurfaced road condition index (URCI), a value between 0 ("failed") and 100 ("excellent"). Maintenance priorities and remedial actions can then be assigned based on each road's category and its URCI value. A sample inspection sheet is reproduced here as Figure 3. This method will be used to evaluate road surface conditions during the field demonstration program described in section 7.0.
Figure 3. Inspection Sheet for Determining Unsurfaced Road Condition Index (URCI) (from Eaton and Beaucham 1992)
In the report on Scandinavian gravel roadway maintenance practices reproduced in Appendix B, we describe a rating system used in Sweden for classifying both the "evenness" and "cohesiveness" of such roadways, where visual inspections rate the roads as good; sufficient, or low for each of the two criteria. This approach is obviously considerably less complicated than the Eaton system described above. In the experimental program outlined in section 7.0, we propose to utilize both systems to evaluate the conditions of the experimental sections.

5.0 Surface Alternatives

This study has identified several alternative gravel roadway surface treatments which may be of interest to the Alaska Department of Transportation and Public Facilities. An analysis of the costs of utilizing these alternatives was prepared, to determine an estimate of the material, personnel equipment and total costs. These costs were calculated on a per-mile and per-square-foot basis, both for each application and for one year. We describe the alternatives in the paragraphs that follow, and we summarize the findings in tabular form in Table 1.

Cost data for materials are from current supplier quotes or recent Department of Transportation and Public Facilities purchase experience, with the cost of shipping to Fairbanks included. Personnel costs are based on an average straight time hourly wage for three Interior Alaska locations (Jim River, Sag River and Montana Creek) of $25.05, plus 64% for benefits. For a 7.5 hour workday, the daily wage plus benefits cost is $308.62. Except for the
| Table 1. Gravel Roadway Maintenance Project – Surface Treatment Alternatives – Cost Comparisons |
|----------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| **Material Quantity Measured in** | **Unit Cost per day** | **No treatment** | **Calcium Chloride** | **Lignosulfonate** | **Asphalt Emulsion** | **EMC Squared** | **Road Oyl** | **Montmorillonite** | **EMC Sq/Road Oyl** |
| Application Rate per mile | Tons | Tons | Pounds | Gallons | Gallons | Tons | Gallons |
| Application Frequency, times per year | 0 | 7.5 | 25 | 62832 | 270 | 3520 | 127 |
| Application Duration, days per year | 11 | 1 | 1 | 5 | 1 | 2 | 0.33 |
| Roadway width, feet | 34 | 34 | 16 | 34 | 35 | 24 | 34 |
| Material Unit Cost | $0.00 | $459.00 | $210.00 | $0.13 | $19.93 | $3.06 | $235.00 | $3.91 |
| Crew Size | $308.62 | 2 | 4 | 2 | 3 | 3 | 5 |
| **Equipment:** | | | | | | | |
| Grader | $231.25 | 2 | 3 | 2 | 2 | 2 | 1 | 2 | 2 |
| Sander/Spreader | $20.50 | 1 | | | | | |
| Tanker Truck | $31.50 | 1 | 1 | 2 | 1 | 1 | 1 |
| Pickup | $30.75 | 1 | 1 | 1 | 1 | 1 | 1 |
| Pump | $2.50 | 1 | 1 | 1 | 1 | 1 | 1 |
| Roller/Compactor | $250.00 | 1 | 1 | 1 | 1 | 1 | 1 |
| Front Loader | $93.50 | 1 | | | | | |
| Pug Mill | $480.00 | 1 | | | | | |
| Bottom Dump Truck | $110.25 | | | | | | |
| Material cost/mile/application | $0.00 | $3,442.50 | $5,250.00 | $8,168.16 | $5,381.10 | $10,771.20 | $29,845.00 | $20,535.32 |
| Material cost/mile/year | $0.00 | $3,442.50 | $5,250.00 | $12,252.24 | $5,381.10 | $21,542.40 | $9,848.85 | $20,535.32 |
| Material cost/sf/application | $0.00 | $0.0192 | $0.0621 | $0.0455 | $0.0291 | $0.0850 | $0.1662 | $0.1144 |
| Material cost/sf/year | $0.00 | $0.0192 | $0.0621 | $0.0683 | $0.0291 | $0.1700 | $0.0549 | $0.1144 |
| Personnel cost/mile/application | $123.45 | $271.59 | $203.69 | $462.93 | $1,388.79 | $4,629.30 | $3,086.20 | $8,641.36 |
| Personnel cost/mile/year | $1,357.93 | $271.59 | $203.69 | $694.40 | $1,388.79 | $9,258.60 | $1,018.45 | $8,641.36 |
| Personnel cost/sf/application | $0.00 | $0.0015 | $0.0024 | $0.0026 | $0.0075 | $0.0365 | $0.0172 | $0.0481 |
| Personnel cost/sf/year | $0.00 | $0.0015 | $0.0024 | $0.0039 | $0.0075 | $0.0731 | $0.0057 | $0.0481 |
| Equipment cost/mile/application | $105.45 | $189.75 | $266.89 | $388.63 | $1,165.88 | $1,480.00 | $2,834.00 | $5,661.25 |
| Equipment cost/mile/year | $1,159.95 | $189.75 | $266.89 | $582.94 | $1,165.88 | $2,960.00 | $935.22 | $5,661.25 |
| Equipment cost/sf/application | $0.0006 | $0.0011 | $0.0032 | $0.0022 | $0.0063 | $0.0117 | $0.0158 | $0.0315 |
| Equipment cost/sf/year | $0.0006 | $0.0011 | $0.0032 | $0.0032 | $0.0063 | $0.0234 | $0.0052 | $0.0315 |
| Total cost/mile/application | $228.90 | $3,903.84 | $5,720.58 | $9,019.72 | $7,935.77 | $16,880.50 | $35,765.20 | $34,837.93 |
| Total cost/mile/year | $2,517.88 | $3,903.84 | $5,720.58 | $13,529.57 | $7,935.77 | $33,761.00 | $11,802.52 | $34,837.93 |
| Total cost/sf/application | $0.0013 | $0.0217 | $0.0677 | $0.0502 | $0.0429 | $0.1332 | $0.1992 | $0.1941 |
| Total cost/sf/year | $0.0140 | $0.0217 | $0.0677 | $0.0754 | $0.0429 | $0.2664 | $0.0657 | $0.1941 |
roller/compactor and pug mill, daily costs for equipment are standard charge rates as used by Northern Region DOTPF Maintenance and Operations, based on monthly rates divided by twenty days per month. Cost data for the roller/compactor and pug mill were furnished by A.K. Johansen and W.B. Fuller of H & H Contractors (Johansen 1994; Fuller 1994).

Although the approach used in the cost analysis has its limitations, we have attempted to provide consistency by determining an estimate of the costs necessary to maintain all the alternative surfaces in a very good to excellent condition. It is assumed that the roadway in question has a relatively high traffic volume (200 to 500 vehicles per day), with a significant proportion of heavy vehicles that demand a good surface, such as the Dalton and Elliott Highways.

The interested reader, of course, can modify the assumptions shown in Table 1 with respect to application rates, frequencies and durations; crew sizes; equipment spreads; and costs, in order to calculate more realistic unit costs for any particular situation.

5.1 No Treatment

The most common method for maintaining gravel roadways is to shape, level and smooth the surface using a road grader, with no special materials added except water. The frequency of such an operation depends primarily on the traffic volume and also on the type of surface and weather conditions. Low volume gravel roads are often graded on an a-periodic basis, with the grading planned to follow rainy weather. For higher volume roadways where regular grading is necessary, water is applied prior to, and sometimes during, the
grading process. Several passes are made with the grader to provide the proper shaping. As noted in the description of Scandinavian practice, the coarser fractions must be pulled from the shoulder portions to provide adequate gradation.

On heavily traveled gravel roadways, grading frequencies greater than once per week may be needed. Reckard (1983a) reports frequencies as high as three times per week in the Haines, Alaska, area. Our cost analysis assumes a frequency of once every two weeks for five months per year, or eleven times per year. We have assumed that a crew of two will operate two graders and a water tanker truck, plus a pump to fill the tanker, with one pickup truck also assigned to the crew. The analysis assumes that five miles per day can be completed with this crew and equipment spread.

The total annual cost per mile is $2518, of which fifty-four percent is in personnel costs. For a 34 foot wide roadway, the annual cost per square foot is $0.014.

5.2 Calcium Chloride

The most common surface treatment additive used on Alaska's gravel roads is calcium chloride. Although it can be applied in a brine form, it is more commonly mixed into the surface as granules during construction and/or maintenance. For 1994, the Alaska Department of Transportation and Public Facilities purchased 656.5 tons of the material, most of which was for dust control and surface stabilization, with 491 tons in one-ton bladders and 155.5 tons in 80 pound bags. Delivered prices ranged from $323.66 per ton at Juneau to $594.84 per ton at Nome for the 80 pound bags and from $323.66 per ton at Juneau to $575.00 per
ton at Valdez for one-ton bladders (the last price being for additional quantities beyond the 656.5 tons upon which the supply contract was based). The state's commitment to the basic supply contract totaled $242,671.11. ("Invitation to Bid 52136" 1994) The cost analysis uses a delivered cost per ton of $459.00 per ton, which is the supply contract price for Fairbanks for 1994. A typical product is called Peladow®, a granular pelletized produced by the Dow Chemical Company.

Calcium chloride attracts moisture from the atmosphere, thus retarding the drying of the fine materials. This reduction of the loss of fines tends to bind the coarse materials together and improve surface stabilization, as well as reduce dust formation.

Required quantities of calcium chloride vary with the surface gradation, with larger quantities required when the aggregate has fewer fines. In wetter climates, the calcium chloride tends to leach into the embankment, and the required frequency of application increases. (Reckard 1983a) Limitations on the use of calcium chloride on roadway surfaces include 1) a tendency to become slippery when wet, 2) corrosive effects on vehicles, 3) potential adverse impacts on the surrounding environment, and 4) the need for protection of personnel during the application process. The product label for Peladow® includes the following warning: "Causes irritation. Harmful if swallowed. Avoid contact with eyes, skin or clothing. Do not take internally. Wash thoroughly after handling." (Dow Chemical Company 1990) Note the protective mask worn by the water truck operator in Figure 9.
Appendix A describes in detail the process used on a section of the Dalton Highway to apply calcium chloride during summer maintenance operations. A grader with carbide teeth scarifies the top four to six inches, a spreader/sander truck applies calcium chloride, graders are used to mix the material with the surface course, and the resulting cross section is compacted, either with a roller or with traffic. Throughout the process, water is applied in liberal quantities. The pictures in Figures 4 through 12 indicate some highlights of the procedure.

Based on DOTPF practice in the Coldfoot area of the Dalton Highway, our cost analysis assumes that a crew of four applies ten tons of calcium chloride per mile to 4.6 miles per day in the first two years and five tons per mile thereafter. Thus, we use an average application rate of 7.5 tons per mile. Equipment includes three graders (two with plain blades and one with carbide teeth), a sander/spreader truck, a front loader for loading the truck, a water truck, a water pump and a pickup truck. With a material cost of $459 per ton, the total cost per application is estimated at $3904 per mile; for a 34 foot wide roadway, this cost per square foot is $0.022. If the application is made once per year, the annual costs are these same $3904 per mile or $0.022 per square foot. The delivered cost of the calcium chloride represents about 88% of the total estimated cost, with personnel costing about seven percent and equipment five percent. If a fifth crew member and a roller/compactor are added, and the productivity remains unchanged, the annual cost estimate increases to $4026 per mile or $0.022 per square foot.

In addition to applying calcium chloride once per year, it will be necessary to grade the surface at other times. If we assume that this extra grading is accomplished twice per year at the same rates and costs as the "no treatment"
Figure 4. Applying Water Prior to Initial Grading for Calcium Chloride Application at Mile 182 Dalton Highway, June 24, 1993.

Figure 5. Initial Grading with Carbide Tipped Grader; Calcium Chloride Application at Mile 182 Dalton Highway, June 24, 1993.
Figure 6. Carbide Tipped Grader Blade; Calcium Chloride Application at Mile 182 Dalton Highway, June 24, 1993.

Figure 7. Loading Calcium Chloride Pellets into Sanding Truck for Application at Mile 180 to 184 Dalton Highway, June 24, 1993.
Figure 8. Applying Calcium Chloride at Mile 182 Dalton Highway, June 24, 1993.

Figure 9. Protective Gear Worn by Operator; Calcium Chloride Application at Mile 180 to 184 Dalton Highway, June 24, 1993.
Figure 12. Final Grading after Calcium Chloride Application at Mile 182: Dalton Highway, June 24, 1993.
option, we must add $572 per mile per year, or $0.003 per square foot. The total annual costs then become $4476 per mile and $0.025 per square foot for the case in which no roller/compactor is used and $4598 per mile and $0.026 per square foot if it is used.

5.3 Lignosulfonate

Calcium lignosulfonate is a by-product of the papermaking process. This organic material is derived from the lignin that binds cellulose fibers into the woody structures of trees and higher plants. It is "tacky" when moist and performs as an adhesive to bind solid particles, including animal feeds and packaging products. In a roadbed, it serves to bind the aggregate particles and thus stabilize the surface and control dust.

One product form of calcium lignosulfonate is produced by Georgia-Pacific Corporation under the name Lignosite® Road Binder (Georgia-Pacific Corporation 1988). It is available in liquid or dried form, although the most prevalent is the liquid form. Despite the extra cost of shipping the water in the liquor to Alaska, Georgia-Pacific officials believe this product is less expensive overall than the dried form, because of the excessive expense required to dry the product (Quinn 1994).

The recommended application procedure is to scarify the roadway to depth of several inches, saturate the surface with water and apply the liquid lignosulfonate, diluted with water, with a tank truck equipped with spray nozzles. The aggregate and liquid are then mixed with a grader blade, moving the mixture several times across the cross section. After the cross section is shaped, it is
compacted with a roller. Under normal conditions, one application per year is sufficient to stabilize the surface and prevent the formation of dust.

One potential disadvantage of liquid lignosulfonate for use in Alaska, compared to dry materials, is the freezing of unused product. Georgia-Pacific states that, when re-thawed, the lignins will return to the liquid state with no adverse impact on quality (Quinn 1994). Because the solutions are biodegradable, contamination by naturally occurring airborne organisms can cause pressure to develop if the fermenting material is placed in a sealed container. Excessive heating during storage can result in decomposition and the release of toxic sulfur dioxide fumes. "The use of appropriate protective clothing, e.g., goggles, rubber gloves, and/or suitable respirator, is recommended when handling LIGNOSITE products. In case of skin contact, wash the affected area thoroughly with water. Accidental spills should be hosed down and diluted with water." (Georgia-Pacific 1990)

An advantage of the use of lignosulfonates is that there appear to be no adverse environmental impacts when used in quantities recommended for road binding. Studies in the United States and Scandinavia have reached essentially the same conclusion (Adams 1988; DUSTEX 1992; Hörke 1992).

As indicated in section 2.2, Alaska has had varying degrees of success with lignosulfonates as road binders. A stable base and a high proportion of fines are believed to be important to good performance. The four mile experimental section on the Dalton Highway was judged to be only partly successful.
Our cost analysis of the use of lignosulfonates assumes a single treatment per year. The recommended application rate of 1/2 gallon per square yard, a density of 10.4 pounds per gallon, and the common practice of using twenty-five tons per mile for Forest Service roads (Quinn 1994) leads to the conclusion that these roads are about sixteen feet in width. The material price is about $50 per ton at the production point, Bellingham, Washington (Quinn 1994), to which we have added $160 per ton for shipping to Fairbanks. A productivity of three miles of roadway per day is assumed. For an equipment spread, we use two graders, two tanker trucks (one for water and one for the diluted mixture), one pump, one pickup truck and one roller/compactor. A versatile crew totaling two is assumed (Quinn 1994) to operate the equipment.

The yearly cost is estimated at $5721 per mile or $0.068 per square foot, of which about 92% is for materials, 3.5% is for personnel and 4.5% is for equipment.

5.4 Asphalt Emulsion

Various petroleum-based products are available for gravel road dust control and surface stabilization. As noted in Appendix B, Scandinavian practice includes oil gravel, which is actually a low grade, plant-mixed "asphalt pavement;" cutback asphalt; and asphalt ("bitumen") emulsion. On an experimental basis, Sweden has used a top layer consisting of emulsion plus sand.

We confine this discussion to the use of asphalt emulsions. Reckard (1983a) cautions that good penetration and a stable base are important conditions for petroleum-based products to work well. The emulsion must be diluted with large
amounts of water (five or more parts of water per volume) to achieve good penetration. Such treatments have yielded mix results. "In some cases, they have yielded good results through the 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." (Reckard 1983a) One probable cause of these problems is the presence of large amounts of fines, especially clays, in the roadway, which can absorb the petroleum product and reduce its effectiveness as a binder.

Although the Scandinavian practice is to apply the emulsion with a simple sprayer operation and no mixing, "better results are likely if the emulsion is road mixed with at least the top inch or two of the road surface material." (Reckard 1983a) Our analysis assumes the latter procedure, in which the road is scarified with a grader and covered with the emulsion from the spray bar of a tanker truck. We assume that the dilution ratio is adjusted to achieve proper moisture content in the roadway surface without having to add water from a second tanker truck. A grader mixes the materials several times across the cross section and then shapes the final cross section, which is then compacted with a roller/compactor. We assume a productivity of two miles per day for a 34 foot wide roadway and, because of the mixed reports about performance, an application frequency averaging one and one-half times per year. Sections of a roadway not requiring a second treatment (assumed to be one-half of the total) would be left until the next year. The analysis uses an application rate of 0.35 pounds per square foot, based on the Swedish surface dressing specification that results in 1.8 kilograms per square meter for bitumen emulsions on heavily trafficked roadways (see
Appendix B). This rate is about 0.4 gallons per square yard, which falls within
the range of 0.2 to 0.5 suggested by Reckard (1983a).

A unit material cost of $260 per ton delivered to Fairbanks is equivalent to $0.13
per pound. This relatively low price is the result of its being produced at the
MAPCO refinery at North Pole; the Anchorage price would be about $310 per
ton (Emulsion Products of Alaska, Inc. 1994). A crew of three will utilize two
graders, a water truck, an emulsion spray truck, a pump, a roller/compactor and
a pickup truck.

The results of the analysis show an annual total cost of $13,530 per mile, or
$0.075 per square foot. Slightly over ninety percent of the cost is in material,
while about five percent is for personnel and about four percent is for equipment.

After several years of asphalt emulsion application, there is some likelihood that
the resulting surface may assume a condition similar to "recycled asphalt." After
that, there is potential for eliminating any further need for dust control additives
or at least reducing their use significantly. Thus, the $13,530 cost per mile
derived in this analysis may apply for only a few years, after which the annual
maintenance costs may be zero or nearly so. This prospect, and the prospect of
much reduced road user costs due to the improved roadway surface, when
compared to other alternatives considered here, make asphalt emulsion
treatment a likely candidate for further investigation. The field demonstration
proposed in section 7.0 includes a long term study of such a treatment.
5.5 EMC Squared®

Earth Materials Catalyst™, or EMC Squared™, is manufactured by the Soil Stabilization Products Company, Inc. It is a product that consists of biocatalytic proteins that activate water and react with the soil particles to increase density, strength and resistance to moisture infiltration. In the densification process, pore and void space are reduced and closer proximity of soil particles and agglomerates is achieved. This increase in proximity strengthens interparticle forces and internal cohesion. (Soil Stabilization Products Company, Inc. 1990a)

The material is supplied as a liquid concentrate in 55 gallon plastic drums. It is diluted in ratios ranging from 30:1 to 600:1 of water to product depending on the moisture content of the road surface. The recommended procedure begins by using a scarifier or disk to loosen the top six inches of the surface. The material in dilute form is sprayed onto the surface from a tanker truck and is then mixed into the aggregate using a standard road grader, with a process similar to that described above for other materials. Compaction is essential to the effectiveness of the treatment, using the "best available compactive equipment." (Soil Stabilization Products Company, Inc. 1993) Vibratory compactors are recommended to achieve the highest possible density.

As noted in section 2.2, experimentation with EMC Squared™ on the Elliott Highway used both the method described above and a plant mix method. The preferred method was the road mix method, which achieved an equal quality at lower cost. It was found that proper moisture content was critical for satisfactory placement, workability and finishing.
One disadvantage for Alaska may be the recommended daytime temperature of at least +10° C (+50° F) during application. "When necessary" it can be applied at colder temperatures, and freezing after compaction is not considered a problem. The material is non-flammable, non-hazardous and non-corrosive, is acceptable for environmentally sensitive areas, requires no special cleanup measures for personnel or equipment and does not leave deposits on equipment. It requires no special safety precautions in handling or storage. (Soil Stabilization Products Company, Inc. 1993)

Precautionary labeling includes the following statement: "Caution! Avoid prolonged or repeated contact. If splashed in eyes, flush with running water. Wash thoroughly after handling." (Soil Stabilization Products Company, Inc. 1990b)

Our cost analysis uses a cost per gallon of the concentrate of $19.93, based on a quotation of $19.08 per gallon FOB Anchorage (Randolph 1994b), plus $0.10 per pound (or about $0.85 per gallon) for shipping to Fairbanks. For comparison, the actual material cost for the Elliott Highway experiment in 1991 was $21.18 per gallon. The application rate is assumed to be 270 gallons per mile for a 35 foot wide roadway, based on an average of experience on the Elliott Highway experiment and a manufacturer’s recommendation of one gallon per fifteen square yards. Experience in California and Wyoming suggests that a one mile application can be completed in between six hours and two days. (Gates 1994) We use 1.5 days per mile in this analysis. It is assumed that one treatment will be sufficient each year.
The manufacturer recommends a crew of three, with one plain grader, one scarifier, one water truck and one vibratory roller. We add one pickup truck and one water pump. The result of our cost analysis is an estimated total annual cost per mile of $7936, or $0.043 per square foot. Because of the somewhat slower production rate, the material cost is nearly 68% of the total, with personnel representing 17.5% and equipment nearly 15%.

5.6 Road Oyl™

Road Oyl™ is a patented resin modified emulsion manufactured by Road Products Corporation and supplied by Soil Stabilization Products Company, Inc. It is used as a natural flexible pavement "cement" and for such applications as dust control, erosion control and soil stabilization (Soil Stabilization Products Company, Inc. 1992). It is supplied in liquid form and is diluted with water in a ratio of about ten to one before application. It is normally applied as part of a grading operation, in which the surface is graded to final shape and a distributor truck with spray nozzles then applies the Road Oyl™. After the surface attains some degree of "set," traffic is used to compact the surface. An alternative method is to apply a "blotter" course of sand on top of the emulsion, followed by compaction by pneumatic and smooth steel wheel rollers.

On the project at Eagle, Alaska, in 1992 and 1993, described in section 2.2, it was determined that it is essential keep traffic off the finished roadway for at least one day, so as not to disturb the surface while the material sets. This application utilized a single coat of Road Oyl™ of about 0.25 gallons per square yard. Another approach is to apply this total during a span of four days, with
about 0.06 gallon per square yard per day. Gates (1994) reports that this method allows traffic onto the surface each day immediately after application without damaging the surface. In our cost analysis, we shall assume a total five day preparation and application period for a crew of three, based on the experience at Eagle, where approximately 100 person-hours were devoted to the 0.87 mile project.

Figures 13 and 14 are pictures taken at Eagle, Alaska, in May 1993 during experimental application of Road Oyl™. Note the dark areas where the product has been applied.

Special handling precautions for Road Oyl™ include "Wash thoroughly after handling; Do not get in eyes, on skin or clothing; Do not breath dust, vapor, mist, gas; Keep container closed; Empty container may contain hazardous residues." (Road Products Corporation 1990) Since the material is an emulsion, it must be protected from freezing during storage (Soil Stabilization Products Company, Inc. 1992).

A total application rate of 0.25 gallons per square yard is equivalent to 3520 gallons per mile for a 24 foot wide roadway. As stated above, we assume the process takes five days per mile based on experience on the Eagle project. Further, it is assumed that two applications per year will be sufficient, based, again, on DOTPF's experience at Eagle. The per-gallon material cost of $3.06 is based on a quotation of $2.92 per gallon delivered to Anchorage (Randolph 1994b), plus shipping to Fairbanks. (The delivered cost at Eagle in 1992 and 1993 ranged between $5.08 and $5.95 per gallon depending on the quantity ordered.)
Figure 13. Road Oyl™ Application at Eagle, Alaska, May 24, 1993. Photo courtesy of C.R. Milne.

Figure 14. Road Oyl™ Application at Eagle, Alaska, May 24, 1993. Photo courtesy of C.R. Milne.
We assume a crew size of two, operating one each grader, tanker, pickup truck and pump. The analysis results in an estimated annual cost of $33,761 per mile, or $0.226 per square foot. Here, the material cost is about 64% of the total, while personnel and equipment are about 27% and 9%, respectively.

5.7 EMC Squared™ and Road Oyl™ in Combination

We include an estimate of the cost of providing a treated roadway that uses EMC Squared™ to stabilize the lower portion of the subbase and Road Oyl™ to treat the top surface. It is likely that the final surface will be of higher quality than those assumed to be produced by the other methods discussed above. However, we also assume that such a treatment will have a life of one year, whereas the Road Oyl™ treatment is assumed to require two applications per year. The $3.91 used for the unit price of the material is the weighted average price for each gallon of the two materials, and the quantity per mile is the total of the two if used separately; both values are normalized to the assumed 34 foot wide roadway. The application duration is assumed to be seven days per mile, based on the 1.5 days per mile for EMC Squared™ alone on a 35 foot wide roadway and the Eagle Road Oyl™ experience of 13.3 crew days for a 24 foot wide section that was 0.87 miles long. We assume that a four person crew will operate the same equipment as for the EMC Squared™, with the addition of one tanker truck.

The resulting cost estimate for the combination of the two surface treatments is $34,838 per mile per year, or $0.194 per square foot per year for a 34 foot wide
roadway. Fifty-nine percent of these costs is for materials, twenty-five percent is for personnel, and sixteen percent is for equipment. Note that, on an annual per-square-foot basis, this estimate is lower than that for Road Oyl™ alone, since it is assumed that this combination treatment will be required only once per year.

5.8 Sodium Montmorillonite

Sodium montmorillonite, sold by Soil Stabilization Products Company, Inc. under the name Stabilite™, is a natural mineral product whose colloidal form produces a gel that acts as a "glue" for binding the aggregate in a road surface. It is intended for aggregates with very little or no fines and is mixed at a low concentration of between one and two percent by weight of aggregate. Section 2.2 describes its use on the Elliott Highway in 1991, where success was limited, due primarily to the presence of fines in the aggregate and the long haul distance from the plant to the jobsite.

The production method involves the use of a pug mill to mix the aggregate with the additive, bottom dump trucks for hauling and placing, motor graders for spreading and shaping, and rollers for compacting. Thus, the final product can be considered a low grade pavement. In fact, the manufacturer suggests that the surface produced in this manner is "permanent." (Randolph 1994b)

Sodium montmorillonite is a natural mineral product that is mined, milled, dried and packaged. No adverse environmental effects have been noted.
As with other products, a major element of montmorillonite's cost is that for shipping to Alaska. Whereas the current price at the production facility is about $70.00 per ton (Randolph 1994b), the cost as supplied to the Elliott Highway jobsite in 1991 totaled $235.00 per ton (Herning 1991a); we use this price for our cost estimate analysis. We also use the application rate of 127 tons per mile, as applied on the Elliott Highway, where 318.57 tons were used for 2.5 miles. On that project, five days were required to finish the 2.5 mile section; thus, we use an application duration of two days per mile.

Although the manufacturer suggests that the resulting surface is permanent, we assume an application frequency of once every three years, to maintain the same quality road surface produced by the other methods. A crew assumed to number five will operate one pug mill, one bottom dump truck, two graders, one roller/compactor and one pickup truck. On the basis of these assumptions, the cost per mile per year is estimated at $11,803, or $0.066 per square foot per year for a 34 foot wide roadway. Material, personnel and equipment are 83%, 9% and 8% of the total, respectively.

5.9 A Further Comment on Costs

It is important to emphasize that the costs developed in this section are only those borne by the public agency in applying surface stabilization materials and maintaining the roadway surface. Other important costs include 1) re-graveling, which will be required of the agency more frequently when the surface is less stable (such as "no treatment" instead of asphalt emulsion) and 2) road user costs, which are also higher when the surface is less stable. Both of these costs are very real but difficult to quantify. Reckard (1994) suggests that re-graveling
may cost thousands of dollars per mile per year, while annual differences in road
user costs from one alternative to another may be as high as several tens of
thousands of dollars per mile.

Consider one simplified example. Suppose we accept the figures determined
herein for "no treatment" and calcium chloride. Our annual costs per mile for
these two alternatives were $2518 and $4598, respectively, assuming 1) grading
of the untreated surface eleven times per year and 2) one application of calcium
chloride, the use of roller/compactor and two additional gradings per year. If we
neglect re-graveling costs, the difference in annual per-mile road user costs
would have to be less than $4598 - $2518 = $2080 in order to justify the "no-
treatment" option. This annual $2080 is equivalent to $5.70 per day. At an
average traffic volume of 100 vehicles per day, the per-mile difference in road
user costs would have to be less than $0.06 per vehicle. When all such road
user costs are considered -- fuel efficiency, wear and tear on vehicles and tires,
reduced productivity due to slower speeds, possible additional damage to
contents -- it seems likely that the more expensive calcium chloride treatment
can be easily justified, even without including the extra cost of the re-graveling
that is likely to be more frequent with no surface treatment.

Other aspects of cost that are even more difficult to quantify include those
related to safety and to environmental impacts. Poorer surfaces lead to more
dangerous conditions, due to 1) difficulty in controlling vehicles on rough
surfaces, 2) limited visibility due to dust, 3) flying particles caused by other
vehicles, and 4) the more frequent presence of roadway maintenance machinery
on untreated roadways. The impact of dust on surrounding persons, wildlife,
structures and vegetation, the noise pollution resulting from rough surfaces, and
the environmental effects of the more frequent need for new gravel are examples
of impacts due to untreated roadway surfaces whose costs are real but difficult
to ascertain. On the other hand, there can also be adverse impacts of some
surface treatments, such as calcium chloride.

6.0 Expressed Interest in the State of Alaska

During the time this investigation was being conducted, the author received
inquiries from two parties within the State of Alaska, not related to the
Department of Transportation and Public Facilities, that indicated interest in
information about improving gravel roadway surface characteristics. Although
not directly related to the project, the contact information given below may
warrant follow-up after this investigation is concluded.

A telephone call was received in October 1993 from June Wardle, newly elected
Nome City Council member. Ms. Wardle was elected in part because of her
interest in improving Nome's gravel streets. Suggestions were given for various
surface treatments, and the possibility of a demonstration project was discussed.
She has also been in contact with Alaska Department of Transportation and
Public Facilities personnel in both Nome and Fairbanks. Ms. Wardle's
telephone numbers are 443-5640 and 443-5984. A follow-up telephone
conversation with Ms. Wardle in January 1994 revealed considerable interest in
pursuing the possibility of a demonstration project, wherein several surface
alternatives would be placed and their performance monitored on a regular,
long-term basis (say, for two years).
John Harris, Chief of Construction Engineering, United States Fish and Wildlife Service in Anchorage called in November 1993 seeking information and recommendations with respect to a low cost roadway his agency was designing on the Kenai Peninsula. Since the research project was in its early phases, no definitive response could be given. As a result of the conversation, however, contact was made with Soil Stabilization Products Company, Inc., for data on its Road Oyl® and Earth Materials Catalyst Squared (EMC2®) products. Mr. Harris’ telephone number is 786-3344, and his FAX number is 786-3370. His address is 1011 East Tudor Road, Anchorage, AK 99503. A subsequent telephone call to Mr. Harris in January 1994 confirmed his continuing interest in the topic of this research. No decision has been made on the type of material his agency will be using for its roadway project. His information indicates that the cost of shipment of surface treatment materials is a significant portion of the total project cost.

In January 1994, at Ms. Wardle’s suggestion, the author called William Hunter, City Manager in Bethel, Alaska, to inquire about gravel street surface treatments. Although some experimentation has been conducted by the City of Bethel into the use of lignosulfonates, Mr. Hunter indicated that his city continues to have a major mud and dust problem with its gravel roadways.

The conversations reported above lead to the conclusion that several agencies besides the Department of Transportation and Public Facilities have an interest in the outcome of this investigation and may be interested in cooperative demonstration programs to determine cost effective solutions for their particular conditions.
7.0 Proposed Field Demonstration Program

In this section we outline a field experiment to test several of the alternative surface treatments identified during this investigation. This experimental program evolved from a review of the literature and product information, observation and study of Alaska Department of Transportation and Public Facilities practices and a summary of the currently available knowledge about gravel road surface treatments in cold regions. Clark R. Milne, P.E., DOTPF's Northern Region Director of Operations and Maintenance, provided especially helpful suggestions for and critique of the proposed testing program. (Milne 1993) Details of the proposed program can be changed as other alternative products become available or the needs of DOTPF change. The program will fulfill many of the objectives suggested by Reckard (1983a) with respect to the effects of various surface treatments on frost heave and leaching and the potential for using "dirty" surface aggregate without loss of performance, as described in our section 4.1.

The objectives of the experimental program will be to compare several alternative gravel roadway surface treatments under actual field use conditions, with special consideration to the effects of such cold regions conditions as freezing/thawing, spring breakup, low humidity and limited gravel availability. These comparisons will be based on 1) performance with respect to both dust control and surface stability, 2) environmental effects, 3) safety and 4) cost. Cost effectiveness will be an essential objective, within the constraints of performance, environmental compatibility and safety. The intended result of the study will be to provide recommendations for use by Alaska's DOTPF and other
cold regions road management organizations that will meet these criteria for various subbase material types and roadway geometries.

The selected site should be an existing gravel roadway that meets all of the following stipulations: 1) It should be easily accessible by the project investigators. 2) It should provide sufficient variability of slope and curvature. 3) It should provide a sufficiently typical mix of vehicle types. 4) It should have relatively uniform surface material characteristics that are representative of the predominant gravel roadways in Interior and Northern Alaska.

Based on the above stipulations, the suggested site is a portion of the Elliott Highway. Twenty-one one-third mile sections will be selected; if possible, the sections will be contiguous, so that a continuous seven mile stretch will be utilized. Each of the seven treatments listed below will be placed in three sections -- 1) a relatively level, straight section, 2) a sloping section, and 3) a curved section. Initial surface conditions will be as close to uniform as possible.

The following surface treatments will be investigated:

- Asphalt Emulsion
- Calcium Chloride
- Control section with no treatment
- EMC Squared®
- Lignosulfonate
- Montmorillonite
- A new, seventh alternative suggested by the Alaska Department of Transportation and Public Facilities
In each case, the treatment application will follow the producer/supplier's recommended placement procedure with respect to equipment, procedure, moisture content, and the like. The data listed below will be recorded during the application process.

Date
Location
Weather conditions
Type of treatment
Application method
Material quantities and costs
Crew sizes and costs
Equipment types and costs
Surface condition prior to treatment, using
   Eaton rating method
   Swedish rating method
   Profilometer technique

Surface condition immediately after treatment, using same three methods
Photographic and video documentation of prior condition, application methods and condition after treatment

After the surface is treated, an extensive monitoring program will be undertaken. Surface conditions will be recorded monthly during the late spring, summer and early fall for two years following the initial treatment. The Eaton and Swedish rating methods will be used each time, with the Profilometer used less frequently. Records of all maintenance activities will be developed, including the
dates of occurrence, the type of activity (grading, addition of surface treatment material, application of water, and the like) and the costs. Traffic volumes will be obtained from the Alaska Department of Transportation and Public Facilities Northern Region Planning and Administrative Services. Interviews will be conducted with road users, to ascertain such information as rider comfort, ease of vehicle handling, visibility and perceived environmental effects; the proposed method for obtaining such information is to ride with the drivers and obtain their comments firsthand. Roadside soil, water and plant conditions will be investigated for possible adverse effects. To monitor dust production, "dust cups" such as those used on previous trials on the Elliott Highway and described in section 2.2 will be used. Extensive photographic and video documentation will be developed.

This experimentation is intended to investigate materials and methods not already well understood and is not intended to repeat tests already conducted by the Alaska Department of Transportation and Public Facilities. Thus, new application materials, methods, rates and frequencies will be tried, and the suggestions of DOTPF design, construction and operations personnel will be sought. Of particular interest is the prospect of several annual applications of asphalt emulsion (three years, in the case of this proposed program). If the resulting surface resembles "recycled asphalt," such a surface might be a likely candidate for use in Alaska, with little or no need for additional dust control. (Reckard 1994)

Assuming approval in spring 1995, the project schedule will proceed as follows:

Site selection and section identification -- June 1, 1995
Surface treatments completed -- July 1, 1995

1995 monitoring program -- monthly, July 1 to October 15, 1995

Additional applications of surface treatments, especially asphalt emulsion
-- June 15 to July 1, 1996

1996 monitoring program -- monthly, April 15 to October 15, 1996

Interim report -- July 1, 1996

Additional applications of surface treatments, especially asphalt emulsion
-- June 15 to July 1, 1997

1997 monitoring program -- monthly, April 15 to July 31, 1997

Final report -- September 30, 1997

A bar chart depicting this proposed schedule is shown in the following figure:

![Bar chart](chart.png)

Figure 15. Schedule for Proposed Field Investigation
Only a rough estimate can be developed for the project budget at this time. Including an allowance of $60,000 for surface treatment materials, an estimated budget for such a project is approximately $140,000, plus overhead if applicable. This estimate is based on project personnel providing overall project management, design, oversight, monitoring, analysis and technology transfer, and DOTPF personnel providing treatment application and surface maintenance. The project budget would support acquisition of surface treatment materials, except for calcium chloride, which it is assumed would be acquired by DOTPF.

It should be noted that a demonstration program may be appropriate in another location, such as Nome, instead of or in addition to the program outlined above. Local conditions and needs would be considered as a vital aspect of such a community-based demonstration project.

8.0 Conclusions and Recommendations

Cost and performance characteristics of gravel roadway surface treatment alternatives vary widely. Based on 1) past experience with application procedures and schedules, 2) assumptions about required frequency of application, and 3) current material, shipping, personnel and equipment cost data, the study developed the estimated annual costs per square foot for the alternatives shown in Table 2.
<table>
<thead>
<tr>
<th>Surface Treatment</th>
<th>Estimated Annual Cost per Square Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Treatment</td>
<td>$0.014</td>
</tr>
<tr>
<td>Calcium Chloride</td>
<td>$0.022</td>
</tr>
<tr>
<td>Calcium Chloride + 2 gradings per year</td>
<td>$0.026</td>
</tr>
<tr>
<td>EMC Squared™</td>
<td>$0.043</td>
</tr>
<tr>
<td>Sodium Montmorillonite</td>
<td>$0.066</td>
</tr>
<tr>
<td>Lignosulfonate</td>
<td>$0.068</td>
</tr>
<tr>
<td>Asphalt Emulsion</td>
<td>$0.075</td>
</tr>
<tr>
<td>EMC Squared™ and Road Oyl™</td>
<td>$0.194</td>
</tr>
<tr>
<td>Road Oyl™</td>
<td>$0.266</td>
</tr>
</tbody>
</table>

Table 2. Estimated Annual Cost Per Square Foot for Alternatives Studied

Thus it appears that the most economically feasible alternative treatments are 1) no treatment, 2) calcium chloride, 3) EMC Squared™, 4) montmorillonite, 5) lignosulfonate and 6) asphalt emulsion. However, this ranking is based solely on the costs of applying surface stabilization materials and maintaining the roadway surface. It does not include the costs of re-graveling and the costs to the road user and his or her vehicle. When such considerations are added, it is likely that the ranking will no longer show "no treatment" as the least costly.

Furthermore, since the "no treatment" option was based on a grading frequency of once every two weeks, the actual cost may be considerably higher for heavily trafficked roadways, especially when heavy vehicles predominate.

Calcium chloride will no doubt continue to be used in large quantities. Its cost is less than that of both lignosulfonate and EMC Squared™. It produces roadways that achieve the desired characteristics of stability and dust control. Its disadvantages, including potential corrosion, damage to plants, and personnel protection, could preclude its use sometime in the future.
EMC Squared™ emerged as a likely candidate for consideration, based on the cost analysis and reports of its successful use. Even with only one application per year, its cost is about 65% greater than that of calcium chloride, on an annual per-square-foot basis.

The use of lignosulfonate appears to competitive economically, if the assumption of one application per year is correct. Its apparently benign effect on the environment makes it attractive relative to salts such as calcium chloride. Further testing will contribute to knowledge about proper application quantities and procedures and appropriate uses for the special conditions in Alaska.

Varying road surface conditions make it impossible to specify one product for all of Alaska's gravel roadways. For example, if a surface has a very low proportion of fines, montmorillonite may be the preferred choice, especially if it can be reapplied only every three years, as was assumed in our cost analysis.

Because several annual asphalt emulsion treatments may result in an extremely stable surface, requiring little or no additional treatment, it is considered a viable alternative even though its tabulated cost numbers do not appear competitive.

The study made it quite clear that Road Oyl™ and Road Oyl™ in combination with EMC Squared™ are not economically viable alternatives for the assumed application rates and frequencies. However, further study may be warranted to determine the performance characteristics of these materials under actual service conditions.
The study affirmed the predominance of material costs and the major proportion that shipping costs represent in total material costs. Material costs ranged from fifty-nine percent of the total for the EMC Squared™/Road Oyl™ combination to ninety-two percent of the total for lignosulfonates.

Because little actual long term cold regions performance and cost information has been collected and summarized for the alternatives considered in this study, because Alaskan entities outside DOTPF continue to express concern with the performance of their gravel roads and streets, and especially because of the potential environmental concerns with the use of calcium chloride, the field demonstration program suggested in section 7 may be particularly timely. The results of that program should provide a clear basis for the selection of effective and economical surface treatments for a variety of conditions common in Alaska and other cold regions.

9.0 References


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Summary of Investigation of
Dalton Highway Calcium Chloride Application

Brief Description of Dalton Highway

The 414-mile (666.3km) Dalton Highway (still referred to as the "Haul Road") begins at Milepost F 73.1 on the Elliott Highway and ends at Prudhoe Bay on the Arctic coast. The Dalton Highway was built as a haul road between the Yukon River and Prudhoe Bay during construction of the Trans-Alaska Pipeline, and was originally called the North Slope Haul Road. Construction of the road began April 29, 1974, and was completed 5 months later. The road is 28 feet (9m) wide with 3 to 6 feet (1 to 2m) of gravel surfacing. Some sections of road are underlain with plastic foam insulation to prevent thawing of the permafrost. There are several steep (10-12 percent) grades.

Purpose of The Investigation

The investigation was conducted on June 23 and 24, 1993. It covered one half of the Dalton highway beginning from Junction 0 at Livengood to J211 at Disaster Creek, the DOT/PF turnaround point. The main purpose of this research trip was to investigate the current application of calcium chloride in gravel road dust control and surface stabilization by the Alaska Department of Transportation and Public Facilities (DOT/PF). Subjects of interest included 1)maintenance operation procedures with calcium chloride; 2)the amount of calcium chloride applied per one mile of road; 3)effectiveness of calcium chloride application for both dust control and road surface stabilization; 4)the effect of calcium chloride application on the environment; 5)users' reactions to the calcium chloride treated roads.

Windshield Inspection

Starting from the junction of the Elliott and Dalton Highways approximately 10 miles beyond Livengood, we observed the road surface condition and dust severity as we drove all the way to the J211 at Disaster Creek. The general condition of this section of the Dalton Highway was good; however, typical gravel road problems appeared at some locations, such as potholes, ruts, loose aggregate, dust, and corrugations.
On Site Investigation

The DOT/PF Coldfoot Maintenance Camp is responsible for the maintenance of the section of the Dalton Highway from J159 to J209. On the day we were conducting investigation, a crew of maintenance personnel was grading and applying calcium chloride on the road between J180.2 and J184.8. The road maintenance procedures were as follows:

1. Apply water to the road to soften the surface for later grading.

2. Make four passes with a grader equipped with carbide teeth, to cover the full width of the road. The road's 4" top surface of D1 was scarified.

3. Apply water to the top of scarified D1.

4. Using a sanding truck with a spinner blade, make two passes to spread a total of about 10 tons of calcium chloride per mile.

5. Make three passes with a grader equipped with a plain blade, mixing the D1 and calcium chloride and placing the mixture in a winrow on one side of the road.

6. Make four additional passes with the plain grader to mix the D1 and calcium chloride further and place the mixture in a winrow on the other side of the road.

7. Apply water to the now uncovered top of the road surface.

8. Make several passes with the plain grader to level and crown the calcium chloride and D1 mixture on the road with the center thickness of 6" and a shoulder thickness of 2". Together with the existing crown in the underlying material, the total crown is about 6%.
9. Compact the road surface with full load water tank truck; also rely on other traffic on the road to complete the compacting. (If available, a vibrating compacting roller is used; it was not used on the days of the investigation.)

The 4 person crew worked 10 hours for the day, and completed the application and finishing of the 4.6 mile section. The 4 person crew included a foreman (who also operated the plain grader), a carbide tooth grader operator, a sand spreading truck (for spreading calcium chloride) operator and a water truck operator. The equipment used for the maintenance operations included:

1. 1 carbide tooth grader.
2. 2 plain graders.
3. 1 sand spreading truck.
4. 1 water tank truck (10,500 gal).
5. 1 front loader (for loading calcium chloride).
6. 1 6" pump.
7. 1 pickup truck for moving the pump.

The distance between the location where calcium chloride was stored and the working site averaged about 3.5 mile. Water was pumped from ponds near the site.

Interviews with Maintenance Personnel

We talked with crew members during break times and while waiting for precedent procedures to be completed. A summary of comments is given below.

Bill Bunch (Foreman and plain grader operator):

"We work 10 hours a day, 4 days a week. Usually we do 3-4 miles a day. We will do 4.6 miles today, because we have a bigger crew."

"Why do we apply 10 tons per mile? We want to apply 20 tons per mile, the more the better if possible. But DOT only buys this much. In Yukon Canada, they apply 15-16 tons per mile."

3
"I think the minimum amount of calcium chloride used for dust control is 5 tons per mile. Last year, Wilder, a contractor, contracted certain maintenance work on this road. They graded 2" of the road surface and applied 5 tons calcium chloride per mile. Their work was for dust control only. We now grade 4" depth and apply 10 tons calcium chloride per mile. The calcium chloride applied not only can control the dust, but also can stabilize the road surface."

"When it is real dry, we can water the road, and the surface will be maintained in good shape for a couple of weeks."

"We have not seen any bad effects on the environment and vegetation when using calcium chloride on the gravel road. The calcium chloride seems to bind tightly with the top surface. We have not heard of any complaints about calcium chloride either."

**Bob** (Water tank truck operator):

"Calcium chloride works very well. The road condition is good after using calcium chloride. People like it."

"When we do a calcium chloride job, we need ponds of water. Water plays a important role in the calcium chloride maintenance operation."

"The last procedure in this operation is compacting. The job is supposed to be done by roller. Since the roller is not available, we just use the fully loaded water tank truck to compact the road. We also rely on other traffic to compact the road surface."

**Chuck** (sand truck and front loader operator):

"The calcium chloride is supposed to be loaded by forks rather than front loader."
A Sampling of Statistics of the Traffic on the Dalton Highway

On Thursday, June 24, 1993, the traffic encountered during a 5 hour trip on the Dalton Highway from the Wiseman turnoff to the Maley Springs Junction is recorded as following:

<table>
<thead>
<tr>
<th>Type of Vehicle</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy truck</td>
<td>29</td>
<td>48.3%</td>
</tr>
<tr>
<td>Light truck</td>
<td>15</td>
<td>25.0%</td>
</tr>
<tr>
<td>Light van</td>
<td>12</td>
<td>10.0%</td>
</tr>
<tr>
<td>Medium duty truck</td>
<td>3</td>
<td>5.0%</td>
</tr>
<tr>
<td>Heavy duty van</td>
<td>3</td>
<td>5.0%</td>
</tr>
<tr>
<td>Motor home</td>
<td>2</td>
<td>3.3%</td>
</tr>
<tr>
<td>Tour bus</td>
<td>1</td>
<td>1.7%</td>
</tr>
<tr>
<td>Station wagon</td>
<td>1</td>
<td>1.7%</td>
</tr>
</tbody>
</table>

Total       60    100%

Gravel Roadway Maintenance in Cold Regions: A Review of Scandinavian Experience

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June 1993

An Interim Report for the Project
Gravel Roadway Maintenance in Cold Regions
(SPR-UAF-92-14)

David Esch, P.E., Project Manager
Bruce R. Freitag, P.E., Technical Research Advisor
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Gravel Roadway Maintenance in Cold Regions:
A Review of Scandinavian Experience

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June 1993

1.0 Introduction

As part of an investigation of cold regions gravel roadway maintenance being conducted for the Alaska Department of Transportation and Public Facilities, the author sought information on this topic among roadway agencies in Finland, Norway and Sweden while on sabbatical leave in fall 1992. The information obtained will contribute to the project's objective of improving the surface characteristics of Alaska's gravel roadways. Other activities included in the investigation include 1) a literature review of research results and current practice, 2) a summary of current DOTPF practice and 3) the design of a research program to test several identified surface alternatives on a future roadway project.

In this report we present some statistics on various roadway surfaces in Scandinavia and compare them with Alaska. Then, we report experience with the following surface treatments: oil gravel, surface dressing with asphalt binder, calcium chloride and other salts, lignosulfonates, and other treatments. We conclude with some general observations, a list of references and appendices containing copies of appropriate technical information.

2.0 Roadway Statistics

The following table provides a breakdown of pavement types for public roads in Finland, Norway and Sweden for the years indicated (Finnish National Road Administration 1991; Berg 1993; Axelson 1993), and a comparison with Alaska:

<table>
<thead>
<tr>
<th>Pavement type</th>
<th>Finland*</th>
<th>Norway</th>
<th>Sweden</th>
<th>Interior Alaska**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt concrete</td>
<td>16,078 km (21%)</td>
<td>29,800 km (56%)</td>
<td>46,091 km (47%)</td>
<td>5314 km (55%)</td>
</tr>
<tr>
<td>Oil gravel + surface treatment of gravel</td>
<td>30,877 km (40%)</td>
<td>13,000 km (24%)</td>
<td>24,341 km (25%)</td>
<td>406 km (4%)</td>
</tr>
<tr>
<td>Gravel surface</td>
<td>29,676 km (39%)</td>
<td>10,400 km (20%)</td>
<td>27,295 km (26%)</td>
<td>3942 km (41%)</td>
</tr>
<tr>
<td>Total</td>
<td>76,761 km (100%)</td>
<td>53,200 km (100%)</td>
<td>97,727 km (100%)</td>
<td>9662 km (100%)</td>
</tr>
</tbody>
</table>

* Includes 35,707 km of local roads
** Northern Region, Interior District, Alaska DOTPF, in lane kilometers
At least three observations are apparent from these statistics. First, even though Interior Alaska's road lengths are reported on a lane kilometer basis, they are significantly smaller than those of each of the three Scandinavian countries. On a road kilometer basis, the total from Interior Alaska will equal less than one-tenth the total for any of the other three. Explanations are well known -- Alaska's smaller population, centuries of habitation in Scandinavia, and its concerted resource development and manufacturing effort.

The second comment is that Interior Alaska's asphalt pavements represent a higher percentage of the total than the Scandinavian countries, whose percentage is 40% compared to Interior Alaska's 55%. However, that 55% is roughly the same as the 56% and 47% in Norway and Sweden, respectively.

Third, Interior Alaska's gravel roads have very little surface treatment, compared to the Scandinavian countries studied. Whereas approximately one-half of the gravel roads in each of those three countries is treated or is built of oil gravel, just under ten percent of Interior Alaska's gravel roads are so constructed, with the remaining 90% untreated gravel surfaces.

3.0 Some Swedish Practice

The material in this section is taken from two sources, both of which are published in Swedish by Vägverket, the Swedish National Road Administration. The first, Vägunderhåll: Barmark (1992) [Road Maintenance: Except Snow Control], contains an extensive section on gravel road maintenance, including both maintenance of untreated roads and dust control using a variety of treatments. The other, Regler för Underhåll och Drift (1990) [Regulations for Maintenance and Operations], includes maintenance standards for various classes of roadways, including gravel roads. This information has been translated to English for use in this report.

3.1 Roadway Condition Classifications and Standard Maintenance Classes

Gravel road conditions are described by both evenness and cohesiveness. For evenness, the three classifications are as follows:
- Class 1 -- Good -- The surface of the road has a necessary cross slope and is level and firm. A few pits can occur.

- Class 2 -- Sufficient -- The surface of the road has largely a necessary cross slope and is mostly level and firm. Pits and uneven parts occur on parts of the road.

- Class 3 -- Low -- The surface of the road has a bad cross slope or is deformed in cross section. Large parts of the surface are unleveled due to pits and corrugations.
For cohesiveness, the three classifications are as follows:

- Class 1 -- Good -- Loose gravel does not exist on the roadway or is present in very small amounts, perhaps on the shoulders. There is almost no dust.

- Class 2 -- Sufficient -- There is loose gravel in small amounts on the roadway and in small embankments at the shoulders. Small dust clouds often appear.
- Class 3 -- Low -- Loose gravel is present in large heaps over the entire road and in pronounced embankments along the shoulders. Large dust clouds appear over nearly the entire road.

Gravel roads are classified according to average daily traffic, as follows:

<table>
<thead>
<tr>
<th>Average daily traffic</th>
<th>Standard class</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50</td>
<td>C</td>
</tr>
<tr>
<td>50 to 124</td>
<td>B</td>
</tr>
<tr>
<td>&gt; or = 125</td>
<td>A</td>
</tr>
</tbody>
</table>

When no special restrictions are given, the road should be accessible to vehicles that are normally allowed on the specific road system. The road should be driveable during the entire year by vehicles with at least four tons gross weight.

The road should be so leveled, strong and cohesive that permitted vehicles can travel the road safely. Surroundings must not be affected by dust to a great degree. Along a road with no nearby buildings, dust clouds are allowed. Cross slopes should be no less than 2.0%. The traveled way should meet at least class 2, as given above, which means

- Sufficient cross slope
- No pits or unevenness except on short distances
- Even and strong, with loose gravel permitted on shorter distances
- Only small dust clouds when the road is trafficked.
The above requirements do not apply during the time when ground frost is thawing.

For the standard classes, which are based on average daily traffic, as shown in the table above, the following requirements apply:

- **Standard Class A** -- Evenness and cohesiveness should at least meet condition classification 2. Class 3 conditions may occur, but for no more than three days in a row.

- **Standard Class B** -- Evenness and cohesiveness should at least meet condition classification 2. Class 3 conditions may occur, but for no more than seven days in a row.

- **Standard Class C** -- Evenness and cohesiveness should at least meet condition classification 2. Class 3 conditions with respect to dust may occur in sections where there are no nearby buildings, but otherwise class 3 conditions may occur for no more than seven days in a row.

3.2 **Material Composition**

In the 1930's Gunnar Beskow developed the "ideal gravel curve" for the wearing surface of gravel roads. As shown below, the ideal gravel zone is the common zone between the upper limit for bearing material and the lower limit for binding material.
Experience has shown that the ideal gravel curve is valid only for gravel from naturally occurring gravel pits, where the material is mostly rounded. Higher resistance against softening in spring and autumn is obtainable by using gravel with a larger maximum size. Sharp edged material is recommended. If the finer material has enough cohesion, a coarser grading (than the ideal curve) should be able to be used, which would be expected to give an improved bearing capacity, especially during spring breakup. A comparison of the ideal curve with a curve with a larger proportion of large fractions is shown below.

With today's crushing technology, a fraction of gravel is obtained with a higher amount of crushed surfaces. It is believed that such crushing gives a higher resistance to surface softening and that it also results in less messy vehicles during rainy weather.

In the maintenance of gravel road surfaces, much emphasis is placed on the combination of 1) recycling gravel from the shoulders and 2) "fraction graveling," in which only the fraction above 4 mm is added as new material. Both traffic and leveling operations tend to break down the gravel fractions into finer material. This finer material tends to disappear as dust or be thrown to the roadway edge. Thus, the wearing layer is transformed as shown in the figure on the following page, which has too much sand.
A correctly balanced reuse cycle is used to 1) maintain reasonable surface water drainage and 2) compose the wearing layer correctly. A thickness of 4 to 5 cm is most suitable for the wearing surface, to provide for a surface that has sufficient cross slope and evenness at reasonable cost. The maintenance process proceeds by first spreading the supplementary material (4 to 18 mm) at a rate of about 20 to 30 cubic meters per kilometer. Then, a grader is used to pull old material from the shoulder; one side of the roadway typically yields 40 to 70 cubic meters per kilometer. The materials are mixed and watered, and the proper cross slope is created. The surface is rolled, and dust control, if any, begins. If one to two centimeters of old wearing material was on the surface at the beginning of the operation, sufficient material will be present, at the quantities stated above, to provide a 4 to 5 centimeter thick wearing surface with proper cross slope.

Because crushed gravel typically contains about 40% of the fraction less than 4 mm, by separating at the 4 mm point and using only the larger fraction, nearly half of the material does not have to be transported. If all the gravel roadways in Sweden would use the reuse method with fractional graveling, the effect in one year would be to reduce the amount of gravel used by 200,000 cubic meters and the amount of truck transportation of the material by 100,000 kilometers. "Only by all contributing in the small can we together reach the big goals for a better environment. Environmental concern is very important today and will be in the future. It is a duty for both companies as well as for each of us to contribute to that. The Road Administration should of course do its part. There is no obvious reason, today or in the future, for using 500,000 m$^3$ of gravel if 300,000 m$^3$ is enough to do the task. Gravel is a scarce resource and should be treated as
such. The choice of working methods that use less truck transportation is also an obligation of the Road Administration."

3.3 Dust Control in General

The Vågunderhåll: Barmark (1992) book contains the following introductory information about dust control, prior to discussing various methods, which we shall incorporate into the appropriate respective sections:

"Previously this publication has discussed how best to get a properly composed wearing gravel surface. Now dust control will be discussed and how it can keep the composition of the wearing layer.

Dusty roads are irritating for those who live by them as well as those traveling on them. If the very smallest particles disappear, the roadway will be susceptible to corrugation and less cohesive. This means that leveling has to be performed quite frequently. Grading or leveling is expensive and also has a negative impact on the wearing surface since the larger particles are crushed by the grader. This crushing leads to a larger need for supplementary gravel. Through dust control, a proper composition of the wearing surface can be maintained for a longer time.

This approach means lower costs. The Road Administration's costs for dust control in 1990 were 50,000,000 skr (approx $10,000,000 US). A road with a strong wearing surface, good friction and a level surface is also safer for traffic. The dominating material is calcium chloride. Recently, some regions have used emulsions, and there has been some laboratory research on evaporated sulfate lye (lignosulfonate). Some other industrial by-products have been tried but are not considered as interest to the Road Administration, partly because of environmental reasons."

4.0 Surface Treatments

4.1 Oil Gravel

Although the use of oil gravel in Alaska is probably impractical because of its excessive cost, we include some information here because it is being used in Scandinavia and because it represents one option for improving the stability and dust control characteristics of Alaska's low volume roads. Compared with asphalt concrete pavements, oil gravel is inexpensive. The mixture consists of mineral aggregate, a road oil and, usually, an adhesion improving additive. It is mixed cold in a plant, applied either with a normal asphalt paver or with a truck
and grader and compacted with a roller. Use is confined to roadway sections where average daily traffic is less than 1000 to 1500 vehicles.

The road linking Kiruna, Sweden, and Narvik, Norway, utilized an oil gravel surface. The road, which lies mainly in Sweden (132 kilometers), was completed in 1982 and provides an alternate to the railway that was built in the early 1900's to carry iron ore from Kiruna to Narvik. The road construction project manager (Feldin 1992) described the road surface as soft and flexible, allowing the ground to "move" slightly without major pavement damage; low cost; and easy to recondition. He indicated no adverse effects of oil damaging the surrounding vegetation or groundwater.

We include as Appendix A copies of pertinent sections of the Finnish and Swedish specifications for oil gravel. ("Oil Gravel, Finland" no date; Krigsman 1991) Finland provides for three possible road oils, with different viscosities, and makes the use of adhesion improving additives ("dope") permissible but not mandatory. The Swedish specification, on the other hand, states, "An approved amine shall be used as the adhesion agent." Quantities of these additives specified in Finland vary between 0.5 and 1.2% of binder weight for a mono-amine/diamine mixture, depending on whether the aggregate has been dried. A less common "dope" is straight diamine, which is added at between 0.5 and 0.8% of binder weight. In Sweden, the specified percentage varies between 1.0 and 1.5%, depending upon the product.

The binder content in Sweden varies between 3.4% by weight for OG 25 (25 mm maximum aggregate size) and 3.6% for OG 12. In Finland, binder contents of 3.2 to 3.6% by weight are used. (Proceedings of ASTQ Conference 1991) Temperature of the binder when added to the mix must be between 80° and 90°C (Sweden) or between 85° and 115°C (Finland). Moisture content of the aggregate must be between 0.7 and 1.5% in Finland and between 1.0 and 3.0% in Sweden. Sweden requires the aggregate to be no warmer than 40°C.

Both specifications emphasize the importance of adequate mixing before placement -- "Mixing time must be long enough to achieve homogeneity." (Finland) "The amine shall be mixed very carefully with the binder. Normally circulation pumping or stirring is required for about 30 minutes." (Sweden)

Often oil gravel is stored after it is produced. In fact, the Finnish guidelines suggest that, "The quality of a cold mixed oil gravel can be improved by stock ing it." In such a case, the binder content is to be increased by 0.2%. Sweden places a maximum of five years on the storage time and requires that the storage be covered.

The five year Asphalt Pavement Research Program just completed in Finland (Saarela 1991) focused some attention on oil gravel. If Alaska develops an
interest in such pavements, the research results may be of interest. The proceedings from an interim conference (Proceedings of ASTO Conference 1991) reported on road oil properties, water sensitivity and manufacturing and installation methods.

It should be noted that a test program in Sweden utilized oil gravel as a pavement surface. The primary purpose of the program was to test stabilized base courses built with a ground, lime activated blast furnace slag placed on a subbase of well drained sand. Test results were generally good. The project location was near Umeå in northern Sweden. (Höbeda 1987)

Some Finnish cost information indicates that, for 1991, the cost of installing oil gravel was eight Finnish marks per square meter ($0.14/sf), a figure that was two-thirds of the cost of asphalt concrete.

4.2 Surface Dressing with Asphalt Binder

The term "surface dressing" refers to "flexible pavement where the binder and the aggregate are each spread separately." (Krigsman 1991) Finland's paving policy confines the use of surface dressed gravel roads to average daily traffic volumes of less than 300. Between this volume and 1000 vpd, oil gravel is generally used in Finland, consistent with the data given at the beginning of section 4.1.

In Sweden, bituminous pavement specifications provide for four types of such surfaces, as follows:

Y1B -- a one layer surface placed on a bituminous base course
Y2B -- a two layer surface placed on a bituminous base course
Y1G -- a one layer surface placed on a gravel base course
Y2G -- a two layer surface placed on a gravel base course

We confine this report on Swedish practice to the Y1G type, in which a single layer is placed on a gravel base. Swedish specifications for the "chippings" (the layer placed over the binder) require that the aggregate gradation lie under the upper limit for aggregate for OG 12 oil gravel. Binder is to be road oil, cutback bitumen or bitumen emulsion, with an adhesion agent added to road oil and cutback bitumen but not to bitumen emulsion. The amount of binder varies between 1.2 and 2.0 kilograms per square meter (0.25 to 0.40 pounds per square foot), depending on the binder type and the average daily traffic. We include as Appendix B the Swedish specifications for surface dressing.

Construction proceeds by first reshaping and compacting the road surface to obtained an even, firm surface. The binder is heated and spread on the surface with a spray bar. The surface temperature must be at least +5°C, and the
surface must be damp but without water accumulation. No work is to be done in the rain. Chippings are then placed and rolled "to the extent that the aggregate attains good contact with the underlying road surface." If the binder is a bitumen emulsion, the chippings must be damp.

In Sweden, three studies have investigated the impact of Y1G surface treatments on driver behavior and fuel consumption. In a controlled experiment (Arnberg 1976), eighteen drivers drove on several gravel road sections, before and after treatment. The results showed that the drivers drove about two kph faster after the surface treatment but that the "safety margin" was improved, despite the increased speed, because of considerably increased friction. Drivers reported that the treated surface was "safer, quicker, more comfortable and less harmful to the car."

In the late 1970's the Swedish Road Administration coated some 100 km with Y1G and observed driver behavior and accident occurrences. Surface dressing resulted in an increase in the coefficient of friction by 0.1 to 0.3, an increase in the median speed between 1.5 and 3.5 kph, and an estimated reduction in the median stopping distance of 0 to 6 meters, which corresponds to 0 to 15% of the untreated gravel road stopping distance. The study concluded that the surface dressing "may have had" favorable effects on traffic safety. (Carlsson and Öberg 1977)

A study to compare fuel consumption on asphalt pavements and surface treated roads concluded that, if both surfaces are new, the surface treated road required an excess fuel consumption of 5% compared to the asphalt pavement. However, since the aggregate in the Y1G type surface is gradually polished by traffic, while asphalt pavements tend to become rougher with time, the excess fuel required by surface treated roads is reduced to 1 or 2% after one or two years. (Sävenhed 1983)

Some alternate methods that utilize bitumen binders have been tried with some success, although the tentative conclusion is that they are excessively expensive. Experimentation is continuing. The Norwegian Public Roads Administration reports the use of bitumen emulsion for dust control of gravel roadways. The binder is applied from a truck at a rate of two to three percent by weight of gravel (compared with five percent for asphalt concrete). The binder mixes with the gravel with no mechanical mixing or compaction. This approach, currently in the test stage, relies on road traffic for compaction. Road authorities label the method as expensive in comparison with calcium chloride or lignosulfonate treatments.

In Sweden, both field and laboratory experiments of the use of bitumens to modify or stabilize gravel surfaces have indicated the positive potential for the method. Here, as in Norway, bitumen binder is added to the existing gravel on
the roadway surface; in this case, however, it is mixed in place. A recent report ("Low Traffic Roads Stabilized with Bitumen Binders." 1992) states, in part,

"One way of strengthening an older road is to stabilize or modify the upper unbound layer, the roadbase, with a binder such as bitumen emulsion or foamed bitumen. Cement or similar materials may also be used unless the subgrade is excessively susceptible to frost. The binder may be mixed in place or using a simple stationary mixing plant.

"Modification entails mixing a small quantity of binder to inactivate parts of the fine material so that water susceptibility is reduced. Thus, only a small proportion of the material is really bound. Stabilization entails mixing in a relatively large quantity of binder, whereby the properties of the material are altered considerably since the aggregate is then bound. This type of strengthening reduces water susceptibility but also increases the load distributing properties and stability of the material, improving bearing capacity to a large extent. By using existing aggregate in the road, major cost savings are possible compared with conventional paving methods.

"The binder used in this type of strengthening in Sweden at present is usually bitumen emulsion, which means that the material is mixed cold. Also foamed bitumen and road oil are sometimes used. A combination of bitumen emulsion and a low content of cement offers certain advantages in regard to improved water susceptibility during laying, as well as long-term durability."

Five test roads were used to study 1) the capacity of the machinery to distribute and mix the binder homogeneously, 2) the influence of the binder quality, 3) the addition of cement with the bitumen emulsion, and 4) the mixing-in of additional aggregate.

The use of a bitumen emulsion plus sand has been tried in Sweden. (Vägunderhåll: Barmark 1992) It is less expensive than Y1G, currently costing about seven Swedish crowns per linear meter for a 4 to 4.5 meter width ($.30 per linear foot for a 13 to 15 foot width). Tests were conducted in the Blekinge region over a three year period. As a result, all gravel roads in that region will have such a surface after 1993. This decision was based on a consideration of costs and benefits. The extra annual cost of 650,000 skr is expected to result in a benefit to road users of 3,500,000 skr per year. Also, the Road Administration will be able to lower its routine maintenance effort.

The basic emulsion-plus-sand method proceeds as follows:

The year before dust control --
• Cleaning of the ditch

• Disposing of large rocks

• Graveling with fractional material so the amount of fines in the top two cm is less than 10% (for the 0.074 mm fraction)

The year of dust control --

• Leveling and watering the road so that the correct shape is obtained

• Rolling the road after leveling

• Moistening the road just before application of emulsion

• Spreading 1.5 liters BE 50 MY emulsion and 10 liters sand (0 to 8 mm) per square meter

• Sweeping the road after several days

Some variations have been tried, such as eliminating rolling and/or sweeping. The importance of the underlying material having less than 10% fines, and the surface having proper 3 to 4 percent cross slope, are stressed.

The positive effects of this emulsion-plus-sand method are stated as follows:

1. A clean, level, dust free road that is resistant to rainfall

2. Use of excess 0 - 8 mm material

3. High bitumen concentration, which improves long term performance

4. Fewer worries during spring breakup, compared with Y1G

5. Less corrosion due to salt

6. Benefits for the road user

7. Improved environment in the area surrounding the road

Another emulsion method has also been tried in Sweden, the so-called "soft" method. This approach mixes crushed gravel with a BE 60/65 emulsion at 3.5% by weight. It can be produced in an oil gravel mill or in a mobile slurry machine. It can be stored until used and then spread with a truck and adjusted with a
grader. The thickness is 4 to 5 cm, and the surface is rolled with a rubber tire compactor. This method appears to be quite similar to the conventional oil gravel.

Finally, we quote from the summary of a Swedish literature survey (Lindh 1981) of dust binding on gravel roads. Although it predates the work reported just above and the current concern with salts in the environment, the comment with respect to economics may still be valid.

"Dust-binding with bitumen products has also been tested with the aim of obtaining better long-term effects and good results have been achieved in some cases. However, this method is not regarded as being a realistically economical alternative for dust-biding on Swedish gravel roads if dust-binding alone is the objective." (emphasis added)

4.3 Calcium Chloride and Other Salts

Calcium chloride seems to be the most common surface treatment in Scandinavia for controlling dust on gravel roads. It absorbs water and forms a solution with a larger surface tension than only water. The surface tension binds the gravel, and a bound roadway is obtained. In Finland, especially in northern areas, standard construction incorporates one ton (1000 kg) per kilometer (about 3500 pounds per mile) of calcium chloride mixed into the surface layer. Such roads are upgraded once per year, in the spring, with the addition of up to one ton of calcium chloride, mixed into the surface with graders.

In Norway, the most common means for dust control is also calcium chloride, applied once per year at a rate of 700 kilograms per kilometer (about 2500 pounds per mile). Environmental problems for such use have caused the Norwegian Public Roads Administration to investigate other methods, including bitumen emulsion, as discussed above, and lignosulfonates, to be discussed below.

Likewise, calcium chloride is the most prevalent method for dust control in Sweden. (Vägunderhåll: Barmark 1992) The most common timing is to apply the material after spring breakup but while the roadway is still moist. 0.5 to 1.5 kg per meter (1800 to 5200 pounds per mile) is spread in connection with leveling the roadway. If natural moisture is lacking, watering must be performed. A maintenance leveling during the summer, using 0.2 to 0.5 kg per meter (700 to 1800 pounds per mile), is required.

Swedish authorities disagree as to the proper timing of the calcium chloride application. Early in the spring, the moisture in the roadway is advantageous. However, if another leveling is required after the breakup is fully complete, the early application will have been partially wasted.
Two types of equipment are used in Sweden. A sand spreader is often used for spring salting when large amounts are spread. Spreading should be done in two steps so that the entire width is covered. During the summer in connection with routine leveling, a salt spreader is more suitable; finer control of the amounts spread can be achieved.

Guidelines for accomplishing quality and economy in Sweden include the following:

- Let the road settle down in the spring before starting dust control.
- Grade the road carefully.
- Never level without enough moisture in the roadway.
- Spread the salt on a sufficiently moist, newly leveled surface.
- Adjust the amount of salt to the need of the particular road.
- Use dust control on the entire width of the roadway.
- Do not apply salt during heavy or continuous rain.
- Store the material so that no lumps form.

Three types of environmental concerns are discussed in the Swedish literature. (Vägunderhåll: Barmark 1992) With respect to the work environment, workers should wear protective clothes, goggles and gloves. Spilled material makes floors and ladder slippery; thus such surfaces should be made as non-slip as possible. In the road environment, calcium chloride has both positive and negative effects. A well bound road is safer for traffic and a better environment for those living nearby. But, corrosion of vehicles is also a result. Calcium chloride in the summer has a more detrimental effect on metals than sodium chloride in the winter.

In the natural environment, calcium chloride dissolves in water. Its long term effects are not well known. What is known is that exposure to strong concentrations kills trees and other vegetation. Also, drinking water wells located near the roadway can be adversely affected. Thus, it is important not to use excessive amounts of salt.

The Swedish literature survey noted above (Lindh 1981) also indicated a preference for calcium chloride -- "In the small number of comparative field experiments described here where calcium chloride was used for dust-binding,
this agent was found to give the best overall results in terms of cost, availability, simple application, efficiency and durability." Note that this 1981 survey is silent about possible detrimental environmental effects.

The Lindh survey also reports on the use of sodium chloride, which was termed "unsatisfactory."

4.4 Lignosulfonates

Lignosulfonates have been used on an experimental basis in both Norway and Sweden as dust control and stabilization agents. The Scandinavian product is called "DUSTEX," produced by LignoTech, a member of the Borregaard Group. It is a lignin product from the sulfite pulping process in papermaking. Lignin is a natural organic material found in all woods, where it binds the fibers together. This by-product has been used for more than thirty years in such diverse applications as water treatment chemicals, animal feed pellet binders, textile dye dispersants and oil well drilling mud additives, as well as road surface binding.

In a roadway, a lignosulfonate acts as a binder by gluing the fine aggregates together. The surface layer becomes stiff, and individual particle movement is reduced or eliminated. Wear resistance is improved, and dust control is achieved.

DUSTEX is available in both liquid and powder form. The suggested method of application is by means of a water solution (20% DUSTEX/80% water by weight) applied by spray nozzles. Gravity application of the solution is also possible. Normal application rate is 1.5 liters per square meter.

The liquid binder is spread on a loose, moist road surface and compacted while still damp. A loose surface allows greater penetration, and moist aggregate permits more even application and better compaction.

In Norway, some experimentation used DUSTEX in dry powder form. The material was dropped onto the road surface, bladed to mix and then left for traffic to compact. The top three to four centimeters were bound successfully by this method.

Rather extensive investigation indicates no adverse environmental effects from the use of lignosulfonates. There are no dioxins, toxic trace minerals are below EPA limits, toxicity to fish and plants is low, and no human health problems have resulted. Furthermore, metal corrosion is much less than that from calcium chloride. A Swedish study concluded that, in a controlled experiment, metal loss in a lignosulfonate environment was 45% of that occurring in a calcium chloride environment. (Adams 1988; DUSTEX 1992; Hörke 1992)
Finally, we note the Lindh (1981) literature survey again. One reference in that survey is a study conducted for the Saskatchewan Department of Highways, which concluded, for lignosulfonates as dust control agents in gravel roads, that applications should be rated "good" and that the surface "held up under traffic loads."

4.5 Other Treatments

The use of cement and blast furnace slag for stabilization has been reported in several sources. While the primary uses appear to be for base courses (Judycki 1991; Höbeda and Thorén 1989), some pavement surfaces has been so treated, according to Judycki (1991). An early study in Sweden (Örbom and Ydrevik 1976) utilized an existing gravel road and strengthened the top layer with cement prior to paving with oil gravel and asphalt concrete. The cement was applied at 5% per weight of gravel, with a 6.0% water content (although there were variations around these percentages in the actual field installations), and the materials were mixed in place. After three years, bearing capacity was satisfactory, with better results for sections not treated with sheepsfoot rollers. The indicated design life was between about five and six years. Observed transverse cracking was minimal, which seemed to surprise the researchers. Although this study was focused on upgrading gravel roads for eventual paving, the method also holds promise for those gravel roads that will not be paved.

As noted earlier, cements have also been used recently in Sweden on an experimental basis, both on several test roads and in the laboratory. ("Low Traffic Roads Stabilized with Bitumen Binders" 1992) In these tests, cement was added in combination with bitumen emulsion, and the materials were mixed in place into the existing gravel surface. General findings are that such in-place stabilization performs satisfactorily if the road has a sufficiently strong subgrade and the drainage is adequate.

The Lindh literature survey (1981) includes a table of brief summary results from another literature survey performed in Arizona (Sultan 1974) of over one hundred additives evaluated for their dust control and soil erosion reducing properties.

5.0 Summary of a Swedish Gravel Road Test

A test road was constructed at Linköping in 1980 to try to answer several questions about the performance of gravel roadway surfaces. Although the results are now several years old, they are still of some interest (Lindh 1983). We present below an English language abstract of the study, followed by a recent translation of a section that summarizes the principal questions and answers.
"The report summarizes the results from a test road with gravel wearing courses constructed at Linköping in 1980. Eleven test stretches were built. The wearing course was studied during one year of use, the first period without a dust binding agent and the second period using dust binding with calcium chloride.

The purpose of the test road was primarily to study the significance of plasticity characteristics of the wearing course with regard to durability, possibilities of using crushed rock aggregate with a coarser particle size distribution than prescribed by current norms for wearing courses and a number of substitute materials for clay as binder components.

Test stretches with both low and high plasticity index (PI) were constructed both with norm-compliant composition of the wearing course and also with material which has an excess of sand. (sand interference).

The substitute materials for clay which were tested comprise residual kaolinite, residual gypsum and limestone filler.

The results indicate that a gravel wearing course with a high plasticity index gives a better durability but requires a dust binding agent since the surface desiccates rapidly during dry periods, after which dust formation and traffic abrasion of the binder begins. However, a wearing course with low plasticity index and silt as binder showed surprisingly good resistance to desiccation of the surface even without the adding of a dust binding agent. Rain after a long dry period caused pot hole formation on stretches with low PI but not on those with high PI. This may result from the fact that desiccation occurred to a greater depth in the wearing course on the former test stretches where the wearing course had a more open structure and consequently a lower internal stability. This was on the contrary to those test stretches with higher PI and greater internal cohesion.

After a time of traffic the wearing courses of crushed rock aggregate demonstrated a coarse surface structure with hole formation.

A good result was obtained when using residual kaolinite as a substitute material for clay as binder. The worst result was obtained with residual gypsum. Wearing courses with a binder of limestone filler showed mainly a fairly good result but the abrasion resistance was partly poor."

In a section called "Generalization of Results," the report presents seven questions, followed a cautionary statement and then the seven answers. We
change the order slightly by quoting the statement first and then giving each question followed immediately by its answer.

"The conclusions that can be reached from the test road results are somewhat uncertain because the different test distances could not be made identical. The results are based on subjective judgment, and the differences among the different test distances are so small that it is questionable whether it is enough to cause a difference in judgment. Consideration must also be given to the fact that the results are based on a test road with only 50 meters length on each test distance and that the wearing layer materials are mixed in a plant."

"a. Would a gravel layer with high plasticity give better durability then one with low plasticity?"

"A gravel wearing layer with a high $I_p$ gives a better durability during a long period of dry weather provided the road surface is prepared to maintain the dense surface and thus prevent dust clouds"

"b. How does sand overabundance affect durability if the wearing material has high or low plasticity?"

"A gravel wearing layer with sand overabundance (so-called sand bump) could have durability closely comparable with ideal gravel if the soil binder percentage is sufficiently high."

"c. Will a gravel wearing layer with a high plasticity index (approx 10) become slippery with rain?"

"A gravel wearing layer with a high $I_p \ (= 10)$, where the clay is well mixed in, has a slightly lower friction than one with silt as a binder but is, after being compacted, not slippery in rain."

"d. Would a wearing layer of crushed rock material with a larger grading curve than ideal gravel (so-called Illinois curve) give a durability as good as, or better than, a wearing layer of ideal gravel?"

"A wearing layer of crushed rock material with a larger grading curve than ideal gravel will, especially with high $I_p$ but also with low $I_p$, give a rough surface structure, and pits appear early. The wearing layer's grading composition is more easily changed than one with naturally graded gravel."

"e. Would a wearing layer of crushed rock as in d) give a better durability with a high $I_p$ than with a low $I_p$?"
"A crushed rock material as in d) will not give better durability with a high $I_p (= 10)$ than with a low $I_p (= 1)$.

"f. Could residual kaolinite, residual gypsum or limestone flour be used as a soil binder?"

"Residual gypsum is not an effective soil binder material. Limestone flour is slightly better than residual gypsum as a soil binder but has relatively bad abrasion resistance. Residual kaolinite has, on the test road, showed to be an effective soil binder but should probably be used in a lesser percentage than the 5% by weight used in the test road. It should probably be mixed in successively so that the road surface will not become slippery during the mixing. A lower water proportion should possibly be used with the residual kaolinite, which should help in the mixing."

"g. What effect does the dust binding material have on durability?"

"The dust binding on the test road generally had the effect that the test stretches with high $I_p$ had better durability because they do not get so dusty. Without dust binding material the surfaces of these stretches dried up earlier than the ones with silt as the soil binder. The surface then became rough because the fine material blew away."

6.0 General Observations

With respect to fuel consumption as a function of gravel road surface characteristics (which was noted in section 4.2 in our discussion of surface dressings), a study in Sweden on a gravel road gave some interesting results. The type of surface was not stated in the summary report, but an important conclusion was that it is more important that the road be free from loose gravel or sand than that it be even. Also, "the fuel consumption is higher on a soft road surface than on a hard one. For a short time, while the gravel road is smooth, hard and free from loose gravel or sand, about a week after the reshaping with grader, fuel consumption is almost the same as the fuel consumption on paved roads." (Sävenhed 1988)

We conclude the following from this brief review of potential applications in Alaska as a result of Scandinavian experience with gravel road surface maintenance:

- The use of oil gravel is probably not cost effective in Alaska for the kinds of dust control and stabilization envisioned here. Such a treatment with
what is essentially a low-grade asphalt is not warranted for the low volume roads being considered in this project.

- Likewise, the use of surface dressings that include binder plus aggregate "chips" is probably not warranted from a cost standpoint for Alaska's low volume gravel roads.

- Calcium chloride is currently the most popular surface treatment in Scandinavia, as it is in Alaska, for reasons of cost, ease of application and effectiveness. Concerns with environmental impacts are causing road officials to consider other alternatives.

- One alternative for consideration is lignosulfonates. The technique is effective and has been used experimentally in Alaska as well. A major question involves the cost of the material and its application. It appears to have very minor negative environmental effects.

- Another alternative is bitumen emulsions, mixed in place. Again, cost considerations may make this treatment prohibitive.

- The use of cements in combination with bitumen emulsion, and perhaps other treatments as well, may also have potential application in Alaska.

- Solely on the basis of this review of Scandinavian practice, without benefit of other aspects of this research investigation that will be completed later, it appears that some benefit could be derived from a several-year study of the treatments listed below, where careful documentation is kept of costs, service life, surface conditions, driver comfort and environmental effects. These treatments would be applied to a gravel road section or sections having common aggregate characteristics. Surfaces could include

  1. No treatment
  2. Calcium chloride
  3. Lignosulfonate
  4. Bitumen emulsion
  5. Bitumen emulsion and cement.

Final recommendations for such a study, if any, will be made following the completion of other parts of this research project.
7.0 Acknowledgments

I am grateful to Ms. Elisabeth Kvarnstrom and Mr. Jerry Blomberg, University of Alaska Fairbanks engineering exchange students from Luleå University of Technology in Luleå, Sweden, for assistance in translating several documents for use in this report. Also, I acknowledge the contributions of numerous colleagues at Luleå and elsewhere throughout Scandinavia. Clark R. Milne, P.E., DOTPF's Northern Region Director of Maintenance and Operations, aided in furnishing statistical data.

8.0 Reference List


Axelson, L. 1993. Personal communication, Swedish National Road Administration.


"Oil Gravel, Finland." no date. from Finnish National Road Administration

Örbom, B. and K. Ydrevik. 1976. Full-scale Experiment on a Gravel Road at Vadstena to Study the Effect of In-place Stabilization with Cement on Bearing Capacity and Transverse Crack Formation. Swedish Road and Traffic Research Institute, VTI Report 104.


Appendix A

Oil Gravel Specifications from Finland and Sweden
OIL GRAVEL

Oil gravel is mainly used on roads where the average diurnal traffic flow is not more than 1000 vehicles/day. It is also used as a patching mix and as a surface treatment for old oil gravel roads.

Crude materials

Crushed gravel and macadam are used as a mineral aggregates. Mixing can be improved if the mineral aggregate is divided into grading classes.

Road oil (BÖ-2) or road oil with adhesion improving additive [dope] (BÖ-2T) is used as a binder. Binder should contain enough dope to accomplish active adhesion. Adhesion improving additives are diamine or mixtures of mono- and diamine.

Recommended contents are following: percent of road oil weight

<table>
<thead>
<tr>
<th>DOPE</th>
<th>MINERAL AGGREGATE NOT DRIED</th>
<th>MINERAL AGGREGATE DRIED</th>
</tr>
</thead>
<tbody>
<tr>
<td>mono- and diamine mixture</td>
<td>1,2</td>
<td>0,5</td>
</tr>
<tr>
<td>diamine</td>
<td>0,8</td>
<td>0,5</td>
</tr>
</tbody>
</table>

If adhesion improving additive is added already in the refinery, values of the table are 0,1 % bigger. If the adhesion between road oil and gravel is weak dope can be added 0,1...0,3 %.

In sites dope is melted in smelteries or by mixing it with binder. When dope is completely mixed with binder the mixing must go on until the whole binder has gone through the pump one more time. The quantity and the effect of the dope decrease little by little because of the oxidation. The oxidation increases when the
temperature rises. To diminish the oxidation, the circulation in the mixture/binder tank must happen below the mixture level.

The quality and the amount of the dope and the allowed using period of the binder (with dope) are determined by the client.

Adhesion tests are made everytime dope is added and continuously after every 500 tons of mixture.

**Manufacturing**

Oil gravel is usually made of mineral aggregates that has not been dried. Drying is necessary if:

1. 0.074 mm passing is over 5 % and moisture over 2.5 %
2. Moisture is over 4 %
3. Air temperature is less than +5 C during laying or less than 0 C during stocking
4. 0.074 mm passing is over 6 %

Moisture of dried mineral aggregates should be 0,7...1,5 %. Spraying temperature of the road oil should be 100 ± 15 C before it is added to the mineral aggregate.

The mineral aggregate and binder should be feeded to the mixer same time in cold mixing. Mixing time must be long enough to achieve homogeneity.

If grading classes are used binder must be mixed with the coarse aggregate first (batch-mixer).

Oil gravel manufacturing (mixing) on the road is not allowed.

The quality of a cold mixed oil gravel can be improved by stocking it. Normal amount for maintenance is 30 tons/km. Binder content of the stocked oil gravel is 0,2 % bigger than normally.

It is not allowed to manufacture oil gravel during rain if the moisture is rising so high that the quality goes down.
A normal asphalt paver is used for oil gravel laying. Laying is also possible to do with a drag if that is agreed beforehand. The quantity of layed oil gravel and the area are verified after every work shift. The average consumption should be at least the same as ordered. If thin spots appears those must be fixed during the work.

Oil gravel course is rolled soon after laying. Man must pay enough attention to the compaction of the margins of the surface.
<table>
<thead>
<tr>
<th>ROAD OIL SPECIFICATIONS 1990</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>UNIT</th>
<th>DEMAND</th>
<th>Viscosity, 60°C</th>
<th>Fractional distillation</th>
<th>Water</th>
<th>Flash point</th>
<th>Inflammable fluid category</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm²/s</td>
<td>min-max</td>
<td>up to 225°C</td>
<td>max</td>
<td>max</td>
<td>max</td>
<td>max</td>
</tr>
<tr>
<td>vol-%</td>
<td>0</td>
<td>0</td>
<td>1.0</td>
<td>8.0</td>
<td>12</td>
<td>0.5</td>
</tr>
<tr>
<td>mm²/s</td>
<td>350...650</td>
<td>1000...2000</td>
<td>45000...90000</td>
<td>ASTM D 1770</td>
<td>ASTM D 402</td>
<td>ASTM D 2170</td>
</tr>
<tr>
<td>weight-%</td>
<td>0</td>
<td>0.3</td>
<td>4.0</td>
<td>8.0</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>°C</td>
<td>56</td>
<td>56</td>
<td>70</td>
<td>III</td>
<td>III</td>
<td>III</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<th>ROAD OIL</th>
<th>ROAD OIL</th>
</tr>
</thead>
<tbody>
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<td>BI06 T</td>
<td>BI04 T</td>
<td>BI02 T</td>
<td>BI01 T</td>
</tr>
<tr>
<td>45000...90000</td>
<td>1000...2000</td>
<td>350...650</td>
<td>2000...4000</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>METHOD</th>
<th>ASTM D 2170</th>
<th>ASTM D 402</th>
<th>ASTM D 95</th>
<th>ASTM D 93</th>
</tr>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Demand</th>
<th>Briquette</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Maximum</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm²/s</td>
<td>350...650</td>
<td>1000...2000</td>
<td>45000...90000</td>
<td>ASTM D 1770</td>
<td>ASTM D 402</td>
<td>ASTM D 2170</td>
<td>ASTM D 95</td>
</tr>
<tr>
<td>vol-%</td>
<td>0</td>
<td>0.3</td>
<td>4.0</td>
<td>8.0</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>°C</td>
<td>56</td>
<td>56</td>
<td>70</td>
<td>III</td>
<td>III</td>
<td>III</td>
<td>III</td>
</tr>
</tbody>
</table>
OG

Oil Gravel
Specification for Road Oil in Sweden

The official specification for road oil states:

Viscosity 60 °C 350-700 mm²/s

Distillation
ASTM D402
-260 °C max 1 vol%
-315 °C max 7 vol%
-360 °C max 12 vol%

Residue
Viscosity
at 50 °C
min 2000 mm²/s
max 5000 mm²/s

Solubility in toluene
min 99.5 wt-%

Water content
max 0.4 wt-%

Flash point
min 60 °C

In addition to these specification the following should be considered to make a good product.

Water content: It is of course important from a safety point of view that no free water is present, and normally we try to keep it under 0.2 wt-%

Pour Point: It is recommended in Sweden to have a pour point of max +5 °C.

Raw material: If the components are material from a cracking process, some polymerisation "gumming", can take place in storage tanks, apart from the fact that it does not serve as a proper binder.
.04 Bituminous Pavements of Oil Gravel, OG

.04.01 Mix Formula

The contractor shall submit a written mix formula proposal to the client at least 5 days before commencing oil gravel production. The mix formula shall include:
- the grading curve for the mineral aggregate with a special specification of the Content (0.074/tot) (filler content)
- the specific gravity of the mineral aggregate
- the binder content
- the adhesion agent, amount and type

Proportioning

The oil gravel shall be proportioned so that it meets the requirements on binder content and grading curve for each pavement type.

Changing the Mix Formula

If the binder content or grading curve has to be changed during the course of the work, a new mix formula shall be drawn up and submitted to the client in writing.

.04.02 Production

The water content should be 1-3%. The mineral aggregate for OG 25 shall be divided into at least two particle size fractions.

The temperature of the mineral aggregate may be a maximum of 40°C.

The grading curve shall fall within the curve limits specified for each pavement type. See the standard sheets.

An approved amine shall be used as the adhesion agent. The amine shall be mixed very carefully with the binder.

Normally circulation pumping or stirring is required for about 30 minutes.

See ch 7:01 for the requirements on the type and amount of adhesion agent.

The binder content in an individual sample may not deviate from the mix formula by more than 0.3% of the weight.

The binder temperature shall be between 80°C and 90°C.

Oil gravel should not be stored longer than 5 years. The storage should be covered.
.04.03 Placement

A gravel underlying surface shall be well re-shaped and compacted. A bituminous underlying surface shall be well cleaned. Oil gravel may not be placed on a surface where there are water pools nor on a surface which has been softened by water.

Work shall cease in the event of rain.

Each side of the road shall be left unpaved 0.1 m wide.

The aim is preferably to pave the entire roadway width during one day.

.04.04 Compaction

Compaction shall be done with a 10-14 ton three-wheel roller or a vibrating two-wheel roller weighing at least 4 tons. If a vibrating roller is used the first roller crossing shall be done without vibration. There shall be at least three crossings.

Should there be an excess of binder during compaction work so that shiny parts are formed on the surface, these parts shall be sanded using aggregate 0-4 or 0-8 mm.

If shiny parts are formed notwithstanding, they shall be taken care of by rolling in BCS 4-8 mm.

.04.05 Evenness

The pavement may not show more unevenness relative to a 5 m long straight edge laid along the longitudinal direction of the road than that which is specified in table 7:02-18.

| OG pavement on an underlying surface re-shaped the same year | 9 mm |
| OG pavement on other underlying surfaces | 12 mm |

Table 7:02-18 Evenness Requirements on OG

.04.06 Inspection

General

Inspection of the oil gravel mix and pavement shall be carried out through production control and quality control.
Production Control

Oil Gravel Mix

The contractor/mix producer shall carry out production control primarily with reference to the binder content and the grading curve so that unacceptable deviations from the mix formula are avoided.

The extent of the testing is decided by the contractor/mix producer and is adapted to the material and equipment used.

Pavement

The contractor shall carry out production control so that separated parts (bleeding and open) are avoided.

Quality Control

The specified testing and sampling shall be done in a way approved by the SVRA and in accordance with their method descriptions for control and testing, Ao 110:II 4.2.1. (A similar method description, MBB, is published by FBB, The Association for Bituminous Pavements.)

Mix samples shall be taken in the presence of representatives for both the contractor/mix producer and the client. At least one sample shall be taken for every 1,200 tons of mix produced.

Every sample is divided into three sub-samples marked A, B and C.

Sub-sample A shall be analysed by the contractor/mix producer as to the binder content and grading curve.

The analysis result made by the mix producer shall be submitted to the client within a month of taking the sample.

The analysis result made by the contractor shall be submitted to the client at least two weeks prior to the final inspection.

Sub-sample B is analysed by the client to the extent he deems necessary.

Sub-sample C is retained by the client until after the final inspection as is sent in to a test institute for analysis in the event of a dispute.

Judging the Samples Taken

A deviation in the binder content and grading curve from the specifications shall be judged for every project and type of mix.
OG 12 (Oil Gravel)

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Binder</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sort</td>
<td>Content 1)</td>
</tr>
<tr>
<td></td>
<td>weight-</td>
<td>lowest</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>OG 12</td>
<td>B 180</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>BL 500 S</td>
<td>3.6</td>
</tr>
</tbody>
</table>

1) The amount binder is based on the specific gravity of 2.66 for the mineral aggregate.
2) Determination on fraction 8.0-11.3 mm
OG 16 (Oil Gravel)

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Binder</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sort</td>
</tr>
<tr>
<td></td>
<td></td>
<td>weight-%</td>
</tr>
<tr>
<td>OG 16</td>
<td>B 180</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>BL 500</td>
<td>3.5</td>
</tr>
</tbody>
</table>

1) The amount binder is based on the specific gravity of 2.66 for the mineral aggregate.
2) Determination on fraction 1.18-16 mm

Particle size (mm)
OG 25 (Oil Gravel)

| Concrete | Binder | Content \(^{1}\) weight-% | Crumb surface \(^{2}\) | Flaxiness index | Impact value \(^{\text{highest}}\) |
|----------|--------|---------------------------|------------------------|-----------------|----------------|----------------|
| OG 16    | B 180  | 3.4                       | 0/50                   | 1.55            | 60             |
|          | BL 500 S | 3.4                       | 0/50                   | 1.55            | 60             |

1) The amount binder is based on the specific gravity of 2.66 for the mineral aggregate.
2) Determination on fraction 11.3-16 mm
Appendix B

Surface Dressing Specifications from Sweden
SURFACE DRESSING

00 General
  01 Surface dressing, types Y1B and Y2B
  02 Surface dressing, types Y1G and Y2G

00 GENERAL

The term surface dressing is intended to refer to flexible pavement where the binder and the aggregate are each spread separately. This includes Y1B, Y2B, Y1G and Y2G surfacing.

Before surface dressing is carried out, the underlying road surface should be levelled so that

- the required evenness is obtained
- good drainage is obtained
- a homogeneous structure is obtained on the underlying road surface

The mix used when levelling the underlying road surface prior to surface dressing is to be so composed that the chippings can only be pressed down into it to a limited extent.

If the levelling is carried out the same year as a surface dressing with cutback as the binder, the binder content in the levelling mix should be up to 0.5% lower than the binder content in the corresponding mix used as a wearing course.

Different requirements ought to be placed on the aggregate for surface dressing depending on the amount of traffic. This is discussed in chapter 7:01.

Before Y1B and Y2B surfacings are performed, the levelled underlying road surface should be open for traffic for at least a month if the surface dressing is to be carried out with cutback, and for at least two weeks if a bitumen emulsion is to be used for the surface dressing.

The first layer in a Y2G surfacing should be open to traffic at least 4 weeks before the second layer is spread out.

The following directives should be prescribed when performing a Y1B surfacing on roads where the AADT is greater than 2,500

- at least 2 rollers are to be used
- the work is to be carried out on weekdays Monday to Thursday
- the first removal of loose aggregate is to be done the day after the work has been done
Piloting of traffic should be prescribed on all work projects with:

- a bitum emulsion when the AADT exceeds 1,000
- a cutback bitumen when the AADT exceeds 2,500

for an hour after the surface dressing has been carried out.

The pilot vehicle, equipped with a sign "TRAFFIC PILOT, FOLLOW ME", should keep traffic at a 30 km/h speed limit. See Swedish National Road Administration (SNRA) publication DD 137.

Furthermore, when the AADT exceeds 2,500, traffic should be channelled through the use of cones so that it is shifted laterally across the newly surfaced area at suitable intervals.

The speed limit on work projects where surface dressing has been performed should be limited to 50 km/h as long as there is loose aggregate on the carriageway. This should, however, apply for at least 48 hours.

.01 SURFACE DRESSING, TYPES Y1B AND Y2B

.01.01 Surface dressing specification

The contractor must present a written proposal containing his surface dressing specification to the orderer at least two weeks prior to the surfacing work.

The surface dressing specification is to be comprised of:

- a grading curve for the chippings specifically indicating the Content (0.074/total)
- the amount of chippings
- the type of binder
- a list of the variations in the amount of binder within the road project
- the amount and type of adhesion agent

Proportions

The surface dressing specification must be balanced in order to avoid stripping or bleeding.

Chippings

The amount of chippings must be determined after a test-spreading.
Guideline values for determining the amount of chippings for single surface dressing on a flakiness index of 1.45 are given in table 7:07-1 and for double surface dressing on a flakiness index of 1.35 in table 7:07-2. The amount of chippings should be decreased for a higher flakiness index and increased for a lower index.

<table>
<thead>
<tr>
<th>Particle size, mm</th>
<th>litres/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 - 8</td>
<td>6</td>
</tr>
<tr>
<td>8 - 12</td>
<td>9</td>
</tr>
<tr>
<td>12 - 16</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 7:07-1, Guideline values for determining the amount of chippings when the flakiness index is 1.45.

<table>
<thead>
<tr>
<th>Particle size, mm</th>
<th>litres/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 - 16</td>
<td>8 - 9</td>
</tr>
<tr>
<td>4 - 8</td>
<td>6 - 8</td>
</tr>
</tbody>
</table>

Table 7:07-2, Guideline values for determining the amount of chippings when the flakiness index is 1.35.

The chippings particle size distribution must comply with the requirements given in table 7:07-3.

<table>
<thead>
<tr>
<th>Width of the mesh 1)</th>
<th>Quantity sieved as a percent of the weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4-8 mm</td>
</tr>
<tr>
<td>The size immediately above the upper size limit</td>
<td>100</td>
</tr>
<tr>
<td>Minimum upper size limit</td>
<td>95</td>
</tr>
<tr>
<td>Maximum lower size limit</td>
<td>20</td>
</tr>
<tr>
<td>The size immediately below the lower size limit</td>
<td>5</td>
</tr>
<tr>
<td>Maximum 1 mm</td>
<td>-</td>
</tr>
<tr>
<td>Maximum 0.5 mm</td>
<td>1</td>
</tr>
</tbody>
</table>

1) The particle size is checked with the sieve series given in method Ao 110:11 4.2.1.29 (MBB 21). E.g., particle size 12 mm is checked with sieve 11.2 (11.3).

Table 7:07-3 Requirements for chippings particle size distribution for Y1B and Y2B surfacing.
Binder

The binder for YLB surfacing must be E 1500 R, E 4500 R, E 65 R or E 60 R.

The binder for YEB surfacing must be E 65 R.

An adhesion agent must be added to a cutback bitumen. See chapter 7:01-03.

N.B. Adhesion agent is not to be added to a bitumen emulsion.

Table 7:07-4 gives the basis for determining the amount of binder in the surface dressing specifications for YLB surfacing. The amount of binder indicated is intended for cutback bitumen. The amount is increased by approximately 30% when a bitumen emulsion is used. The amount should be increased by 0.2 kg/m² on shady road sections. The amount should be decreased by 0.1-0.3 kg/m² on ascents. On roads trafficked by heavy vehicles always using one specific track, it can be advisable to increase the amount of binder by 0.2-0.4 kg/m² on surfaces between and outside the wheel tracks.

Table 7:07-5 gives the basis for determining the amount of binder for YEB surfacing. In the case of motorways, the extent of traffic on the various traffic lanes ought to be taken into consideration when determining the amount of binder.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variation kg/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic AADT</td>
<td></td>
</tr>
<tr>
<td>0-500</td>
<td>0</td>
</tr>
<tr>
<td>500-1500</td>
<td></td>
</tr>
<tr>
<td>1500-2000</td>
<td></td>
</tr>
<tr>
<td>2000-3000</td>
<td></td>
</tr>
<tr>
<td>3000-5000</td>
<td></td>
</tr>
<tr>
<td>5000-8000</td>
<td></td>
</tr>
<tr>
<td>Road width in meters</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.1</td>
</tr>
<tr>
<td>5</td>
<td>0.1</td>
</tr>
<tr>
<td>7</td>
<td>0.2</td>
</tr>
<tr>
<td>8</td>
<td>0.3</td>
</tr>
<tr>
<td>9</td>
<td>0.4</td>
</tr>
<tr>
<td>Underskirt</td>
<td></td>
</tr>
<tr>
<td>Soft/fresh one or a few years</td>
<td>AG25</td>
</tr>
<tr>
<td>Old levelling course</td>
<td>188</td>
</tr>
<tr>
<td>188</td>
<td>0.1</td>
</tr>
<tr>
<td>1812</td>
<td>0.2</td>
</tr>
<tr>
<td>1816</td>
<td>0.3</td>
</tr>
<tr>
<td>Particle size in millimetres</td>
<td></td>
</tr>
<tr>
<td>3.8</td>
<td>0.1</td>
</tr>
<tr>
<td>8.12</td>
<td>0.2</td>
</tr>
<tr>
<td>12.16</td>
<td>0.3</td>
</tr>
<tr>
<td>Climatic zone (Sweden)</td>
<td></td>
</tr>
<tr>
<td>Southern</td>
<td>0.1</td>
</tr>
<tr>
<td>Central</td>
<td>0.2</td>
</tr>
<tr>
<td>Northern</td>
<td>0.3</td>
</tr>
<tr>
<td>Season</td>
<td></td>
</tr>
<tr>
<td>May-June</td>
<td>0.1</td>
</tr>
<tr>
<td>July-August</td>
<td>0.2</td>
</tr>
<tr>
<td>September</td>
<td>0.3</td>
</tr>
<tr>
<td>Extent of traffic confined to one track</td>
<td></td>
</tr>
<tr>
<td>Non-existent</td>
<td>0.1</td>
</tr>
<tr>
<td>Normal</td>
<td>0.2</td>
</tr>
<tr>
<td>Accentuated</td>
<td>0.3</td>
</tr>
<tr>
<td>Degree of unpolished surfaces on crushed aggregate</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0.3</td>
</tr>
<tr>
<td>Amount of binder, initial value</td>
<td></td>
</tr>
</tbody>
</table>

Table 7:07-4 Single surface dressing YLB. Binder amount in wheel tracks. Intended for cutback bitumen.
A change in the surface dressing specification

If the amount of binder, or the chippings grading curve has to be changed during the course of the work, the surface dressing specification must be changed immediately and the orderer must be informed.

.01.02 Work procedure

The underlying bituminous road surface must be clean before work on surface dressing can be started.

The surface temperature of the underlying road surface must be at least 50°C for Y1B surfacing and at least 100°C for Y2B surfacing.

The air temperature in the shade may not exceed 250°C. Normally surface dressing should be carried out across the entire width of the road during the same day.

Spreading of the binder

The underlying road surface may be damp but there must be no water accumulation. Work is to cease in the event of rain.

The binder must be spread with a spray bar which must have been tested according to the SNRA Ac 110:11 4.2.1.27 method. An approved test certificate updated for the season at hand must be presented before the commencement of the work.

The temperature of the binder when being spread must fulfill the requirements given in table 7:07-5.

If the bitumen emulsion is warmed in the binder distributor, this should be done by means of careful pump circulation.

<table>
<thead>
<tr>
<th>Cutback bitumen</th>
<th>Bitumen emulsion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200 - 1300°C</td>
<td>60°C - 80°C</td>
</tr>
</tbody>
</table>

Table 7:07-5 The temperature of the binder when being spread.
The amount of binder spread has to comply with the surface dressing specification. Table 7:07-7 gives the maximum acceptable deviation, 4.2 and 4.3 respectively, when taking samples in accordance with the sampling method specified in method Ao 110:II 4.2.1.47.

<table>
<thead>
<tr>
<th>Test according to</th>
<th>Single value deviation</th>
<th>Mean deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2</td>
<td>0.15 kg/m²</td>
<td>0.05 kg/m²</td>
</tr>
<tr>
<td>4.3</td>
<td>25 % of the weight</td>
<td>5 % of the weight</td>
</tr>
</tbody>
</table>

Table 7:07-7 Maximum acceptable deviation from the surface dressing specification in the amount of binder

Longitudinal joints in the second layer of Y2B surfacing are to be shifted 0.2 m laterally.

**Spreading of the chippings**

When the binder is a bitumen emulsion, the chippings must be damp.

The chippings should be spread within a minute after the spreading of the binder.

The chippings should cover the surface totally for a Y1B surfacing.

In the case of Y2B surfacing, the first layer of chippings should not cover the surface totally. The aggregate particles should be separated from one another and be in direct contact with the binder.

No vehicle is to travel on the Y2B surfacing until the second layer has been spread.

Any parts of the surface which have been missed are to be taken care of by manual spreading and brushing. Thinly spread parts are also to be supplemented.

**01.03 Rolling**

Rolling must be carried out immediately after the chippings have been spread either by a tyred roller weighing at least 10 tons or by a vibrating roller weighing at least 6 tons and equipped with rubbercovered cylinders.

Y1B surfacings must be rolled to the extent that the aggregate attains good contact with the underlying road surface. This must, however be done at least three times. The roller speed must not exceed 10 km/h.

In connection with Y2B surfacings, the first chippings layer is to be rolled once. The roller speed is not to
exceed 5 km/h. The second chippings layer must be rolled at least twice with a roller speed not exceeding 10 km/h.

At least two additional rollings should be carried out on the surface dressing both between and outside wheel tracks.

Sand dressing must be carried out immediately in the event of rain on a surface dressing with a bitumen emulsion.

Sand dressing through the use of material with a particle size of 0-4 up to 8 mm, 1-3 1/m² must be carried out immediately after rolling for YLB surfacing with a bitumen emulsion when the upper particle size fraction exceeds 8 mm.

Sand dressing must be done with a sand spreader. The sanded surface is to be rolled with a tyred roller or a vibrating roller with rubbercovered cylinders.

If bleeding causing low friction arises during the guarantee period, the surface must be spread and rolled with so much BCS 2-4 or 4-8 mm that satisfactory friction is obtained.

Loose aggregate must be removed from the carriageway as soon as the chippings have adhered into position. This must however be done within a week at the latest. The air temperature in the shade may not exceed +25°C when this is carried out.

.01.04 Inspection

Both production and quality control are aspects which are to be included in the inspection of the surface dressing.

Production control

The chippings grading curve, the binder quality, as well as the spreading of the chippings and binder are aspects of the production control which the contractor must carry out in order to avoid any impermissible deviations from the surface dressing specifications. The extent of the samplings is determined by the contractor and these samplings are to be adapted to the materials and equipment used.

Quality control

Samples for checking the chippings and the binder are to be taken when representatives for both the contractor and the orderer are present.
The chippings particle size distribution

The chippings particle size distribution is to be checked once for every 25,000 m² of surface laid, although at least once on every road project. Samples are to be taken according to the Ao 110:II 4.2.1.31 method. Every sample taken is to be divided into three parts marked A, B and C.

Part A is analysed by the contractor to the extent he deems necessary.

Part B is analysed by the orderer according to the method in Ao 110:II 4.2.1.29.

Part C is retained by the orderer until the final inspection has been made and is sent in for laboratory analysis in the event of any controversy or dispute.

Amount of binder

The amount of binder is checked by the orderer according to the method in Ao 110:II 4.2.1.47. This check is first made when the project is set underway as well as to the extent indicated in table 7:07-8.

<table>
<thead>
<tr>
<th>Traffic, AADT</th>
<th>Test according to</th>
<th>Minimum extent</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 000</td>
<td>4.2</td>
<td>Once a day</td>
</tr>
<tr>
<td>≥ 1 000</td>
<td>4.2</td>
<td>Once per 25,000 m²</td>
</tr>
<tr>
<td></td>
<td>4.3</td>
<td>Once per 100,000 m²</td>
</tr>
</tbody>
</table>

Table 7:07-8 Check on the amount of binder.

Quality of the binder

Samples to determine the quality of the binder are to be taken according to the method in Ao 110:II 4.2.1.50 every third working day, although at least once on every road project.

When testing cutback bitumen, every sample taken is to be divided into three parts marked A, B and C.

Part A is analysed by the contractor to the extent he deems necessary.

Part B is analysed by the orderer.
Part C is retained by the orderer until the final inspection has been made and is sent in for laboratory analysis in the event of any controversy or dispute.

The viscosity is determined on cutback bitumen samples according to the method in Ao 110:114.2.1.52.

When testing bitumen emulsions, the sample is to be divided into two parts marked A and B.

Part A is analysed by the contractor to the extent he deems necessary.

Part B is analysed by the orderer.

The viscosity and the strainings are determined on bitumen emulsion samples according to methods Ao 110:II 4.2.1.53 and 4.2.1.56 respectively.

Judgements made on the samples taken

Chippings

The chippings grading curve must comply with the requirements given in table 7:07-3. Every sample is judged individually.

Amount of binder

The amount of binder is to comply with the requirements given in table 7:07-7.

Quality of the binder

The binder must comply with the specifications given in chapter 7:01.02.
02 SURFACE DRESSING TYPES Y1G AND Y2G

02.01 Surface dressing specification

The contractor must present a written proposal containing his surface dressing specification to the orderer within a good time margin, although no later than 5 days before surfacing is to be carried out.

The surface dressing specification is to contain:
- a grading curve for the shippings specifically indicating the Content (0.074/total)
- the type of binder
- a list of the variations in the amount of binder within the road project
- the amount and type of adhesion agent

Proportions

The surface dressing specification must be balanced in order to avoid stripping or bleeding.

Chippings

The chippings grading curve is to lie under the upper limit for the aggregate for OG 12 for Y1G surfacing. See standard sheet chapter 7:02.04. The largest particle size may not exceed 25 mm.

The chippings grading curve has to comply with the requirements given in table 7:07-9 for Y2G surfacing.

<table>
<thead>
<tr>
<th>Width of the mesh</th>
<th>Quantity sieved as a percent of the weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>First layer</td>
<td>Second layer</td>
</tr>
<tr>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>at least 95</td>
</tr>
<tr>
<td></td>
<td>a maximum of 20</td>
</tr>
<tr>
<td></td>
<td>a maximum of 5</td>
</tr>
</tbody>
</table>

Table 7:07-9 Requirements for the chippings particle size distribution for Y2G surfacing.

Binder

Road oil VO 500, cutback bitumen BL 1500S or bitumen emulsion BE 60 MY are to constitute the binder for Y1G surfacing.
For Y2G surfacing, cutback bitumen BL 4500 R or bitumen emulsion BE 65 R or BE 65 M are to constitute the binder. However, when the underlying road surface temperature is less than 10°C, cutback bitumen BL 1500 R is to be used.

Adhesion agent is to be added to road oil and cutback bitumen. See chapter 7:01.03.

N.B. Adhesion agent is NOT to be added to bitumen emulsion.

Tables 7:07-10 and 7:07-11 give the basis for determining the amount of binder.

The following should be set in application for Y1G surfacing

* the amount of binder is to be decreased by 0.1 kg/m² on road sections exposed to strong sun, e.g. roads through open country

* the amount is to be increased on exceptionally shady road sections

<table>
<thead>
<tr>
<th>Traffic AADT</th>
<th>Binder kg/m²</th>
<th>VO 500</th>
<th>BL 1500 S</th>
<th>BE 60 MY</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-200</td>
<td>1.4</td>
<td>1.5</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>200-400</td>
<td>1.3-1.4</td>
<td>1.4-1.5</td>
<td>1.8-2.0</td>
<td></td>
</tr>
<tr>
<td>400-800</td>
<td>1.2-1.3</td>
<td>1.3-1.4</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>800-1000</td>
<td>1.2</td>
<td>1.3</td>
<td>1.8</td>
<td></td>
</tr>
</tbody>
</table>

Table 7:07-10 Amount of binder for Y1G surfacing.

<table>
<thead>
<tr>
<th>Binder</th>
<th>Traffic, AADT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 200</td>
</tr>
<tr>
<td>First layer</td>
<td></td>
</tr>
<tr>
<td>BL 4500 R</td>
<td>1.9</td>
</tr>
<tr>
<td>BL 1500 R</td>
<td></td>
</tr>
<tr>
<td>BE 65 M</td>
<td>2.4</td>
</tr>
<tr>
<td>Second layer</td>
<td></td>
</tr>
<tr>
<td>BL 4500 R</td>
<td>1.9</td>
</tr>
<tr>
<td>BL 1500 R</td>
<td></td>
</tr>
<tr>
<td>BE 65 R</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Table 7:07-22 Amount of binder for Y2G surfacing in kg/m².
A change in the surface dressing specification

If the amount of binder, or the chippings grading curve has to be changed during the course of the work, the surface dressing specification must be changed immediately and the orderer must be informed.

02.02 Work procedure

Before Y1G or X2G surfacing is set underway, the underlying road surface is to be reshaped and compacted so that an even, firm surface is obtained.

The surface structure of the underlying road surface should be uniform.

The surface temperature of the underlying road surface must be at least +50°C.

The underlying road surface must be damp, but without any water accumulation. Work is to cease in the event of rain.

Spreading of the binder

The binder must be spread with a spray bar which must have been tested according to the SNRA Ao 110:II 4.2.1.27 method. An approved test certificate updated for the season at hand must be presented before commencement of the work.

The temperature of the binder when being spread must fulfil the requirements given in table 7:07-12.

If the bitumen emulsion is warmed in the binder distributor, this should be done by means of careful pump circulation.

<table>
<thead>
<tr>
<th>V0 500</th>
<th>BL 1500</th>
<th>BL 4500</th>
<th>EE 60</th>
<th>EE 65</th>
</tr>
</thead>
<tbody>
<tr>
<td>80-90°C</td>
<td>110-120°C</td>
<td>120-130°C</td>
<td>50-70°C</td>
<td>60-80°C</td>
</tr>
</tbody>
</table>

Table 7:07-12 The temperature of the binder when being spread

Spreading of the chippings

When the binder is a bitumen emulsion, the chippings must be damp.

Supplementary treatment must be given to parts either missed or where the spreading was done insufficiently.
02.03 Rolling

Rolling must be performed immediately after the spreading of the chippings to the extent that the aggregate attains good contact with the underlying road surface.

Special rolling is to be done between and outside of wheel tracks.

If there is a binder surplus, sufficient 4-8 mm aggregate is to be rolled in so that acceptable friction is obtained.

Loose aggregate is to be removed from the carriageway as soon as this is possible without tearing loose any stone particles in the surfacing. This must, however, be done within a week.

02.04 Inspection

Both production and quality control are aspects which are to be included in the inspection of the surface dressing.

Production control

The contractor must carry out production control in such a manner that any unauthorized deviations from the surface dressing specification are avoided.

Quality control

Samples for checking the chippings and the binder are to be taken when representatives for both the contractor and the orderer are present.

Samples are analysed by the orderer.
OG 12 (Oil Gravel)

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Binder</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sort</td>
<td>Content 1)</td>
</tr>
<tr>
<td></td>
<td>weight-%</td>
<td>lowest</td>
</tr>
<tr>
<td>OG 12</td>
<td>B 180</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>BL 500 S</td>
<td>3.6</td>
</tr>
</tbody>
</table>

1) The amount binder is based on the specific gravity of 2.66 for the mineral aggregate.
2) Determination on fraction 8.0-11.3 mm

Particle size (mm)
.03 Additives

.03.01 Adhesion Agents

Amine

The adhesion agents specified in table 7:01-13 are approved by the ANRA and shall be added to the pavement types requiring adhesion agents in amounts specified respectively.

<table>
<thead>
<tr>
<th>Type of Pavement</th>
<th>Adhesion Agent</th>
<th>Amount as a % of the binder weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>HABD (open graded)</td>
<td>Lilamine VP 75</td>
<td>0.4</td>
</tr>
<tr>
<td>Others</td>
<td>Lilamine EDO</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Amine HBG-</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Diamine HBG</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Diamine BG</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>Amine DHBG</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>Noram S</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Dinoram S</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>Noram TVH</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Noram SH</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Dinoram SH</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Noram TVSH</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>Amine PL 665</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 7:01-13 Approved Adhesion Agents

An adhesion agent may not contain water. An adhesion agent shall be stored dry.

When working with adhesion agents, the SNRA Protection Specification for work with Bituminous Products, 1983, shall be observed.

Lime

The lime shall be Ca(oh)₂ (slaked lime) of technical quality. The lime shall adhere to the requirements in table 7:01-14 as far as particle size distribution is concerned.

100 % lime shall pass through a sieve, mesh size 0.5 mm at least 95 % shall pass through a sieve, mesh size 0.125 mm at least 90 % shall pass through a sieve, mesh size 0.074.

Table 7:01-14 Lime Particle Size Distribution requirements

.03.02 Cement

Cement shall be standard quality, eg. Portland Cement.
2 PLANT MIX.

.00 General

.01 Bituminous Pavement of Plant Mix Types MAB, HAB, TOP and AG

.02 Bituminous Pavements of Plant Mix Type HABD

.03 Bituminous Pavement of Cold Mix Type AEBO

.04 Bituminous Pavement of Oil Gravel

.00 General.

Plant mixes are mixed placed and compacted mineral aggregate and bituminous binder mixes. Included are, for instance, MAB, HAB, HABD, TOP, OG and AEBO.

See ch 1 concerning the choice of pavement type and pavement thickness.

When calculating the thickness of plant mixes, one can count on approximately 10 kg/m² of asphalt concrete being 4 mm thick (1 cm = approximately 23 kg/m²) for MAB, HAB, TOP, AG and OG and 5mm thick 1 cm = approximately 20 kg/m² for HABD and AEBO.

When planning pavement projects, the following shall be taken into consideration:

When planing a wearing course on a surface with wheel track formations, an asphalt paver finisher with a 4-part screed should be used.

In order that a HABD type pavement shall function in the manner intended, it is important that the underlying surface is tight and has the crossfall intended.

An AG roadbase may be open to traffic during a shorter period, 8 months maximum. When such is the case, AG 15 or AG 25 are constructed with a binder content exceeding the proportion value and guideline value respectively by 0.3 percent of the weight.

An AG roadbase on a previously wearing course as a strengthening measure for example, is constructed as AG 16 or AG 25. Again in this case the binder content in the AG is 0.3 percent of the weight higher than the proportion value and the guide value respectively.
Gravel Roadway Maintenance in Cold Regions

APPENDIX C

LITERATURE REVIEW

Digests


Abstract: About two-thirds of all highways in the United States are unsurfaced or lightly surfaced low-volume roads. To help local highway agencies manage the maintenance of these roads, a system for rating each section of road has been developed to indicate how badly that section needs repair and to identify problem areas. An unsurfaced road is any road that does not have portland cement concrete, asphalt concrete, or other surface treatment. Some agencies consider gravel to be a surfacing material; for the purposes of this article a gravel road is an unsurfaced road. The method for rating the condition of unsurfaced roads has three steps: 1) dividing the road network into sections; 2) inspecting the sections and identifying problems; and 3) calculating ratings that indicate the condition for each section.

An unsurfaced road is any road that does not have portland cement concrete, asphalt concrete or any other surface treatment.

Unsurfaced roads are managed much differently from paved roads. Maintenance is needed much more often on unsurfaced roads. Long-term planning for a paved road would be for 5-20 years; for an unsurfaced road it would be for 1-2 years. Normally you maintain an unsurfaced road by blading it with a road grader three or four times a year. The road conditions may change quite a bit between gradings because of traffic and weather. Planning or scheduling of maintenance is done once a year.

How the method works The method for rating the condition of unsurfaced roads has three steps: 1. Dividing the road network into sections; 2. Inspecting the sections and identifying problems; 3. Calculating ratings that indicate the condition for each section. Each step is very important and must be done carefully. (Unsurfaced Road Inspection Sheet is given and rating standard is defined; also calculation methods are introduced). You will need to be able to recognize certain kinds of problems, which we call distresses. Seven distress types include: 1. Improper Cross Section--An unsurfaced road should have crown with enough slope from the centerline to the shoulder to drain all water from the road's surface. No crown is used on curves, because they are usually banked. The
Gravel Roadway Maintenance in Cold Regions

cross section is improper when the road surface is not shaped or maintained to carry water to the ditches. 2. Inadequate Roadside Drainage--Poor drainage causes water to pond. Drainage becomes a problem when ditches and culverts are not in good enough condition to direct and carry runoff water because of improper shape or maintenance. 3. Corrugations--Corrugations (also known as washboarding) are closely spaced ridges and valleys (ripples) at fairly regular intervals. The ridges are perpendicular to the traffic direction. This type of distress is usually caused by traffic and loose aggregate. These ridges usually form on hills, on curves, in areas of acceleration or deceleration, or in areas where the road is soft or potholed. 4. Dust--The wear and tear of traffic on unsurfaced roads will eventually loosen the larger particles from the soil binder. As traffic passes, dust clouds create a danger to trailing or passing vehicles and cause significant environmental problems. 5. Potholes--Potholes are bowl-shaped depressions in the road surface. They are usually less than 3 feet in diameter. Potholes are produced when traffic wears away small pieces of the road surface. They grow faster when water collects inside the hole. The road then continues to disintegrate because of loosening surface material or weak spots in the underlying soils. 6. Ruts--A rut is a surface depression in the wheel path that is parallel to the road centerline. Ruts are caused by a permanent deformation in any of the road layers or subgrade. They result from repeated vehicle passes, especially when the road is soft. Significant rutting can destroy a road. 7. Loose Aggregate--The wear and tear of traffic on unsurfaced roads will eventually loosen the larger aggregate particles from the soil binder. This leads to loose aggregate particles on the road surface or shoulder. Traffic moves loose aggregate particles away from the normal road wheel path and forms berms in the center or along the shoulder (the less-traveled areas).


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 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.

**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 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.

**Recommendations:** 1) 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 agent. American Association of State Highway and Transportation officials (AASHTO) Specification M-147 as it applies to surface courses could be adopted verbatim as standard Alaskan specification. 2) 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. 3) DOT&PF 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 as trial section.
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. 2) The effect of such paliatives on the frost susceptibility of road embankment material needs to be studied in greater depth. There are indications that calcium chloride and lignin 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 paliatives 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 be very useful.

Calcium Chloride: 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 later method is the most frequently used in the Yukon; brine application is the usual method used by DOT&PF Maintenance forces. 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. 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,
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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. 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.

Petroleum-based Products: There include waste oil, cutback asphalt and asphalt emulsions. 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." 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. 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.

Lignin: Another material which has been widely used as a dust palliative/cementing agent is lignin, usually obtained as 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 sultanates and sugars in the spent liquor act to cement road aggregate achieving results similar to other palliatives. Recommended application rates for sulfite liquor are about 1/2 gallon per square yard for surface treatment. 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 operation existed in Alaska, this treatment might be a practical alternative.

General Comments on Sureface Additives: 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 applied by the number of inches treated, i.e. a 6" layer treatment would require about six times the quantity as 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.

**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. There costs are summarized in Table (page 38).

**User costs**: The study of highway user cost 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 and 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 (increase 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.)
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Abstracts

Author: Alenowicz, Jacek; Dembicki, Eugeniusz
Title: Recent laboratory research on unpaved road behaviour.
Source: Geotextiles and Geomembranes v10 n1 1991 p21-34
Abstract: A two-dimensional model of geotextile-reinforced unpaved road was constructed and used to evaluate the strengthening effect of the geotextile on the system. The paper presents a brief description of the laboratory model and discusses results of the tests. Conclusions concerning the influence of geotextile and sand layer thickness on measured pressures and deformation as well as presence of a second geotextile inclusion within the granular layer are presented. 15 Refs.

Author: Alfeler, Roemer M.; McNeil, Sue
Title: Method for determining optimal blading frequency of unpaved roads.
Source: Transportation Research Record n1252 1989 p21-32
Publication Year: 1989
Abstract: Management systems for unpaved roads are often viewed as unwarranted because of the low levels of traffic normally found on these roads. However, unpaved roads in many developed and developing countries represent the larger portion of mileage in the network. Even at the low cost of maintenance per mile of unpaved roads, the total cost resulting from multiplying this value by the overall road mileage corresponds to a large financial outlay. Therefore, the efficient management of these roads is justified. Recognizing the need to optimize the blading and regaveling frequencies of unpaved roads, some agencies tried to develop methodologies for determining the appropriate maintenance strategies. This paper presents a dynamic optimization approach for determining the optimum blading frequency for an unpaved road using the principles of optimal control. A sensitivity analysis is performed to evaluate the parameters in the model. 15 Refs.

Author: Anon
Title: Gravel road maintenance innovations.
Publication Year: 1988
Abstract: The Roads and Waterways Administration of Finland has carried out extensive research to develop efficient gravel road maintenance operations. The most common gravel road surface defects - potholes and puddles, rutting, dust, surface softening, and corrugation - stem from the quality of surface material and the level of maintenance activities. Use of economical and durable material is the best protection against gravel road damage, studies find. Finnish research shows that the best material should have sufficient
amount of fine material that will pass through a 200-mesh sieve (i.e. silt and clay components). Improvements to the surface material of gravel roads is a rainy season task. Correct proportioning of the ideal gravel road surface materials will reduce the amount of dust produced. To ensure dust binding, the Finnish roads authority applies about 60,000 t. of calcium chloride yearly.

**Author:** Barnard, William R.; Gschwandtner, Gerhard  
**Title:** Development of a microcomputer-based system for determining PM10 emission several fugitive dust sources.  
**Source:** Proceedings - A&WMA Annual Meeting v 1. Publ by Air & Waste Management Assoc, Pittsburgh, PA, USA. 13p  
**Publication Year:** 1989  
**Abstract:** On July 1, 1987 the U.S. Environmental Protection Agency (EPA) published a final rule establishing an ambient air quality standard for particulate matter less than or equal to 10 microns (PM10/10). This new standard replaced the old Total Suspended Particulate (TSP) standard. The U.S. EPA has identified areas of the country where there is a probability of non-attainment of the new standard. These areas have been designated as either Group I or Group II areas based on whether the area will not meet the new standard (Group I) or whether there is a significant probability of not meeting the standard (Group II). This paper details the development of a microcomputer-based system designed to automate the calculation of TSP and PM10 fugitive emissions from aggregate storage pile, unpaved road and paved industrial road fugitive sources for Group I and II sources in Ohio. The calculation program developed is based on JAVELIN PLUS, a commercially available spreadsheet, information base and and modeling software package. The information presented shows that commercially available software packages are capable of performing calculations needed to develop emissions inventories for the development of State Implementation Plans. 1 Ref.

**Author:** Beaven, P. J.; Robinson, R.; Akilu, Kassaye  
**Title:** Performance of experimental weathered basalt gravel roads in Ethiopia.  
**Source:** Research Report - Transport and Road Research Laboratory n 147 1988 29p, Publication Year: 1988  
**Abstract:** A joint study by the Ethiopian Transport Construction Authority and the Transport and Road Research Laboratory from the United Kingdom has constructed two experimental roads in Ethiopia to examine the possibility of using weathered basalt gravels as surfacing material for unpaved roads. These experiments studied gravels from several different sources under a range of traffic levels ranging from 30 to 175 vehicles per day. The results of the experiments have led to proposals for the use of weathered basalt gravels and have shown that crushing or screening is likely to be cost-effective to reduce oversize material when used on roads with traffic levels in excess of about 50 vehicles per day. 1 Ref.
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Author: Bonaparte, R.; Ah-Line, C.; Charron, R.; Tisinger, L.
Title: Survivability and durability of a nonwoven geotextile.
Source: Geotechnical Special Publication n 18. Publ by ASCE, New York, NY, USA p 68-91, Publication Year: 1988
Abstract: This paper presents the results of a field investigation and laboratory testing program to evaluate the properties of two different polypropylene, thermally-bonded nonwoven geotextiles exhumed from seven existing unpaved road structures. The results of the field investigation and test program are used to assess the construction survivability and long-term durability characteristics of the two materials. Measured geotextile strengths after one to twelve years of burial range from 50 to 90% of their initial values. The conclusion is reached that almost all of the strength loss experienced by the geotextiles is due to mechanical damage that occurred during construction. 16 refs.

Author: Bourdeau, P. L.; Chapuis, J.; Holtz, R. D.
Title: Effect of anchorage and modulus in geotextile-reinforced unpaved roads.
Source: Geotextiles and Geomembranes v 7 n 3 1988 p 221-230
Publication Year: 1988
Abstract: In order to consider the influence of geotextile anchorage and modulus on the soil-geotextile interaction and interface response, a critical examination was made of some large-scale model tests of geotextile-reinforced unpaved roads on peat. It was found that soil-geotextile interaction is strongly nonlinear and full anchorage of the geotextile is not a necessary condition of the reinforcement mechanism. 11 Refs.

Author: Davis, D. W.
Title: Seasonal trends among PM10 crustal elements in California.
Abstract: This paper focuses on trends in levels of fine- and coarse-fraction iron; in addition, silicon, manganese, titanium, and calcium are also discussed. Data are presented from two dissimilar locations which represent extremes in data trends found for 'crustal' elements in California. The first site to be considered, Yuba City, is an urban area of moderate size located in the Sacramento Valley, which is typical of the agricultural areas of California. The second location, Long Beach, represents the highly urban areas near the Pacific Coast. At both sites, the climate has a rainy season from about mid-November until the end of April, and a dry season for the remainder of the year. However, considerably more precipitation falls during the rainy season at Yuba City than at Long Beach. 3 Refs.

Author: Douglas, Robert A.
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Title: Anchorage and modulus in geotextile-reinforced unpaved roads.
Source: Geotextiles and Geomembranes v 9 n 3 1990 p 261-267
Publication Year: 1990
Abstract: In the light of recent comments, a programme of research into geotextile-built model unpaved roads is summarized, and the question of reinforcement by the provision of a geotextile in the road cross-section is discussed. It is found that the improvement in the road section response to loading, compared with the performance of the subgrade itself, is not dramatic and reasons for this are given, referring to experiment and theory. 6 Refs.

Author: Eaton, R.A.
Title: Development of the unsurfaced roads rating methodology
Abstract: A method for rating the surface drainage and conditions of unpaved roads has been developed, and a field manual has been prepared to assist county, municipal, military and township highway agencies in managing the maintenance of such roads. The types of distress found in unpaved roads are categorized and listed in the manual. For each type of distress listed, there is a description of the distress and the levels of severity, an illustration, and a measurement method. The manual also includes instructions on how to inspect unsurfaced road conditions, a field inspection work sheet, and a family of "deduct value" curves for the distress types and associated severity levels. The curves were validated using data gathered during 6 field surveys throughout the United States. This report describes the development of the deduct value curves for the seven distresses identified in unsurfaced road maintenance. The development of the original curves and the adjustments after each field trip are described. The surface and drainage rating method and maintenance management strategies can be used alone, or they can be adapted for use with any existing computerized pavement management system (PMS). The rating method and strategies are compatible with the PAVER PMS developed by the U.S. Army Corps of Engineers and the American Public Works Association. With appropriate software modifications, an unsurfaced roads component of the PAVER PMS will be available for use, giving local highway agencies a more comprehensive roadway management system.

Author: Eaton, R.A., Gerard, S., and Cate, D.W.
Title: Rating Unsurfaced Roads--A field manual for measuring maintenance problems.
Source: Special Report 87-15, August 1987, CRREL.
Abstract: About two-thirds of all highways in the United States are unsurfaced or lightly surfaced low-volume roads. To help local highway agencies manage the maintenance of these roads, a system for rating each section of road has been developed to indicate how badly that section needs repair and to identify problem areas. An unsurfaced road is any road that does not have portland cement concrete, asphalt concrete, or other surface treatment. Some agencies consider gravel to be a surfacing material; for the purposes of this article a gravel road is an unsurfaced road. The method for rating the condition of unsurfaced roads has three steps: 1) dividing the road network
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into sections; 2) inspecting the sections and identifying problems; and 3) calculating ratings that indicate the condition for each section.

Author: Eaton, R. A.; Gerard, S.; Dattilo, R. S.
Title: Method for rating unsurfaced roads.
Source: Northern Engineer v 21 n 1-2 Spring-Summer 1989 p 30-40
Publication Year: 1989
Abstract: A method for rating the surface condition and drainage of unpaved roads has been developed, and a field manual has been prepared to assist county, municipal, military, and township highway agencies in managing the maintenance of such roads. Types of distress found in unpaved roads are categorized and listed. For each type of distress listed, there is a description of the type and level of severity, an illustration, and a measurement method. The manual also includes instructions on how to inspect unsurfaced road conditions, a field inspection worksheet, and a family of deduct-value curves for the distress types and associated severity levels.

Author: Eldin, Neil N. and Senouci, Ahmed B.
Title: Use of Scrap Tires in Road Construction
Abstract: Growing piles of discarded tires create fire and health hazards. Current disposal methods are wasteful and costly. This paper presents the results of an investigation into the potential of shredded tires as fill material in road construction. A test road was built to study the constructability, durability, and performance of tire chips as a new construction material. The road was made up of six sections to examine the effects of (1) Tire-chip size; (2) method of placement; and (3) soil-cap thickness on road performance. The field operation proved that use of shredded tires in road construction poses no major handling or placement problems. However, the high compressibility of tire chips and their tendency to shift laterally under compaction equipment need to be noted. The performance of the test road was monitored under freeze-thaw conditions and under service loads. The road showed acceptable performance with moderate maintenance requirements and minimum undesirable effects on ground water quality under the tested conditions.

Author: Giroud, J. P.
Title: Tomorrow's designs for geotextile applications.
Source: ASTM Special Technical Publication 952. Publ by ASTM, Philadelphia, PA, USA p 145-158
Publication Year: 1987
Abstract: This paper presents a review of existing design methods for selected geotextile applications such as filtration, drainage, and unpaved roads. The discussion shows that geotextile applications can be designed using rational methods and that most of these methods are similar to classical soil mechanics design methods. This paper is also an attempt at predicting the evolution of design concepts and design methods. The following topics are
addressed: new materials, new construction methods, progress in the evaluation of geotextile properties, and expected results from research. The discussion shows how important it is for geotechnical engineers to keep abreast of new developments. 14 refs.

Author: Hausmann, M. R.  
Title: Geotextiles for unpaved roads-A review of design procedures.  
Source: Geotextiles and Geomembranes v 5 n 3 1987 p 201-233  
Publication Year: 1987

Abstract: Fabrics have been successfully used for unpaved roads on very soft subgrade for some time, usually fulfilling one or more of the basic functions of separation, filtration, drainage and reinforcement. A number of structural design procedures have recently been developed which mostly rely on the fabric controlling subgrade failure model, improving surface load distribution and providing membrane support. The results of some of these procedures are compared for particular soil and fabric properties and traffic conditions; and design charts based on Apple computer programs are presented. Several of the design methods appear to give equally reasonable results; but it is pointed out that fabrics should also be selected based on expected construction survivability and workability and that careful management of construction activities is vital for successful use of fabrics in unpaved roads. 24 refs.

Author: Holtz, R. D.; Sivakugan, N.  
Title: Design charts for roads with geotextiles.  
Source: Geotextiles and Geomembranes v 5 n 3 1987 p 191-199  
Publication Year: 1987

Abstract: Design charts have been developed to determine the required aggregate thickness for geotextile-reinforced roads using the Giroud and Noiray procedure. The charts are for rut depths of 75, 100, 150, 200, and 300 mm, with tire pressures of 480 and 620 kPa for a standard design axle load of 80 kN. The charts can be used for the design of geotextile-reinforced unpaved roads, roadway stabilization aggregate, and for the first construction lift for embankments on very soft foundations. 7 refs.

Author: Hughes, J. Martin  
Title: Respirable dust exposure to residents near unpaved coal haul roads.  
Publication Year: 1989

Abstract: The coal mining industry provides an essential ingredient to the economic base of Southwestern Virginia. The dust exposure to workers in the coal industry falls under the close scrutiny of both state and federal regulators since state and federal regulations specify the limits on respirable dust exposure to workers in coal mining and processing activities. For others, however, who live or work in areas impacted by dust generated by the coal
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industry the dust exposure standards are given. This study was carried to
determine dust levels that exist adjacent to unpaved coal haul roads. 5 Refs.

Author: Lees, G.; Zakaria, M.
Title: Degradation-unbound aggregates.
Source: Highways and Transportation v 34 n 7 Jul 1987 p 32-36
Publication Year: 1987
Abstract: Aggregate degradation has been reported by many investigators to
occur, in unbound layers of pavements, during construction and also during
service life. The phenomenon of degradation has been recognised as one of the
important factors affecting the performances of unbound aggregate in base, sub-
base or in unpaved roads. Degradation is defined in this paper as the
reduction in size of particles which occur during the process of laying and
compaction and as a consequence of traffic action in association with
weathering processes during pavement life. The work reported in this paper
refers to a degradation study carried out in the laboratory in which different
types of compaction, initial grading, material and size of compacting moulds
were involved. 10 Refs.

Author: Meyer, Wolfgang E. (Ed.)
Title: First International Symposium on Surface Characteristics.
Source: ASTM Special Technical Publication v STP n 1031 Jun 1990. Publ by
ASTM, Customer Service Department, Philadelphia, PA, USA. 541p
Publication Year: 1990
Abstract: The volume contains 40 symposium papers. The papers are grouped
under general topics that include skid resistance and texture, pavement
roughness, and pavement distress and management, and rolling resistance, fuel
economy, noise, and other related subjects. Specific subjects covered include
the use of fuzzy sets mathematics for analysis of pavement skid resistance,
aircraft/ground vehicle friction measurement, surface smoothness evaluation and
specifications for flexible pavements, some surface roughness, loss and
slipperiness characteristics of unpaved roads, surface deterioration resistance
of concrete pavement materials, road conditions and accidents in winter, and
others.

Author: Muleski, G. E.; Englehart, P. J.
Title: Compilation of estimation methods for the control of PM-10 from roads.
Management Assoc, Pittsburgh, PA, USA. 11p
Publication Year: 1989
Abstract: The recent years have witnessed numerous field tests of paved and
unpaved road dust control measures. Because these controls are 'periodic' in
the sense that the controls must be periodically reapplied, each test series
can produce only one measure of the average decay rate. Consequently, a data
base of 100 field tests may produce only, say, 10 values of average control
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performance, and only very limited information is available for many controls. Because of the lack of available information, simple field measurements are recommended in this paper to assess performance. These measurements provide both industry and regulatory personnel with a valuable tool in assessing dust control programs and determining compliance with any applicable rules. 8 Refs.

Author: Paige-Green, Philip
Title: Some surface roughness, loss, and slipperiness characteristics of unpaved roads.
Publication Year: 1990
Abstract: An extensive investigation into the performance of materials used in wearing courses for unpaved roads in southern Africa has recently been completed. This involved the routine monitoring of 110 sections of selected gravel roads covering a range of material types, climatic regimes, traffic volumes, and road geometrics. Monitoring involved the routine measurement of road roughness, gravel loss, corrugation and rut development, and a routine description of the surface condition. This paper briefly describes the results of the roughness, gravel loss, and slipperiness investigations. Models for the prediction of roughness and gravel loss are described and compared with models developed in other countries. Significant differences between the models are noted. The investigation into the slipperiness of unpaved roads is described, and the slipperiness when dry is shown to be directly related to the grading and plasticity of the material. 14 Refs.

Author: Partridge, T. C.; Williams, A. B.; Brink, A. B. A.
Title: Appropriate technology for the design and construction of low-cost unsurfaced roads in developing countries.
Publication Year: 1989
Abstract: Roads continue to play a fundamental role in the development of most Third World countries, but the establishment of road networks using imported First World design philosophies and construction methods has led to an undue emphasis on high-cost, surfaced roads built using mechanised methods. Such an approach results in unjustifiable costs, both of initial construction and of maintenance, and is seldom appropriate either to local traffic requirements or to the widespread need for labour-intensive construction projects in underemployed communities. Under these circumstances the emphasis should be placed on unsurfaced roads built to standards which enable the maximum use to be made of local resources of labour and materials. Experience has shown that such a shift in emphasis must necessarily involve fundamental changes in design philosophy and contractual procedures, as well as a re-evaluation of appropriate vehicle technology. Four categories of unsurfaced
rural road are proposed for use in the planning of infrastructure in developing countries. Design standards appropriate to the use of labour-intensive construction methods are suggested for each, and simple, cost-effective methods are proposed as an aid to route location and the evaluation of in situ soils and construction materials.

Author: Peggs, I. D.; Tisinger, L. G.; Bonaparte, R.
Title: Durability of a polypropylene geotextile in an unpaved road structure.
Source: Transportation Research Record n 1248 1989 p 1-12
Publication Year: 1989
Abstract: This paper addresses select durability characteristics of a continuous-filament, nonwoven geotextile commonly used in transportation-related applications. Two samples of the geotextile were exhumed from the base of an unpaved road structure located at an industrial site in East Texas. The two samples had been in service for 12 and 13 years, respectively. The samples, together with an unused reference sample manufactured at the same time as the exhumed samples, were subjected to a series of destructive mechanical tests, structural analyses, and examinations via scanning electron microscopy. The mechanical tests included measurements of grabtensile strength and elongation, burst strength, puncture strength, trapezoid-tearing strength, as well as individual fiber strength and elongation. The results of these tests indicated that some polymer degradation had occurred such as might be caused by oxidation. 13 Refs.

Author: Rada, Gonzalo R.; Schwartz, Charles W.; Witczak, Matthew W.; Jafroudi, Siamak
Title: Analysis of climate effects on performance of unpaved roads.
Source: Journal of Transportation Engineering v 115 n 4 Jul 1989 p 389-410
Publication Year: 1989
Abstract: The performance of unpaved roads is strongly dependent upon the moisture content within the roadway profile. Unfortunately, there are no analytical models currently available for quantitatively predicting the influence of depth and time-dependent moisture distribution upon this performance. Existing procedures rely on laboratory or field tests, or indirect empirical correlations, to define the strength characteristics of each roadway layer in terms of a single, generally conservative value intended to reflect worst-case climatic conditions. This paper presents rational methodology for analyzing the effects of site-specific rainfall and evaporation history upon the performance of unpaved roads. The methodology consists of a predictive model for weather-induced soil-moisture changes over time; relationships between soil moisture, compaction level, and strength for a variety of typical roadway soils; and a damage analysis model tailored to low-volume unpaved roads. The capabilities of the proposed methodology are demonstrated through a numerical example. Performance predictions from the proposed methodology are comparable to those from more conventional approaches.
Gravel Roadway Maintenance in Cold Regions

Author: Reckard, M.K.
Title: Economic Aspects of High Speed Gravel Roads--Final Report
Source: State of Alaska Department of Transportation and Public Facilities. (1983)
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 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.

Author: Reckard, Matthew K.
Title: Multi-Year Maintenance Costs of Selected Alaskan Highways
Source: State of Alaska Department of Transportation and Public Facilities. (1983)
Abstract: This report contains multi-year maintenance cost information for most of the major rural highways in Alaska. All figures are derived from data maintained by the Alaska Department of Transportation and Public facilities (DOTPF). This data base is compiled from employee time and equipment reports (timesheets). Maintenance costs are recorded in four separate categories.

Author: Reckard, M.K.
Title: Cost-effectiveness of geotextiles--Review of performance in Alaskan Roads.
Abstract: Much of DOT&P's geotextile use in the mid-1980's was intended to improve road performance in areas with bad foundation conditions. Geotextiles were specified for new roads and road reconstruction areas where problem soils were present or suspected. They were placed as separators between soils containing fines and cleaner fill materials. They were also used where pavement structures were known to be inadequate, or where problems such as frost heaving or surface settlement from permafrost thawing were contributing to road roughness. Geotextiles placed in road embankments in the Northern Region have had no noticeable effect on the amount of cracking in the overlying pavement. The widespread use of geotextiles without specific design objectives and methods is unlikely to be cost effective. It appears from this study, however, that site specific geotextile designs may be cost effective in many situations in the Northern Region, especially in addressing slope instability and longitudinal cracking problems.
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Most of the geotextile installations in the Northern Region were less than five years old, which limited the study in some ways. 5 Refs.

Author: Riverson, John, D. N.; Sinha, Kumares, C.; Scholer, Charles, F.; Anderson, Virgil, L.
Title: Evaluation of subjective rating of unpaved county roads in Indiana.
Source: Transportation Research Record n 1128 1987 p 53-61, Publication Year: 1987
Abstract: Counties and other local highway agencies continually use visual or subjective rating systems for routine and periodic road inspections. In a study of unpaved roads in Indiana, a subjective rating of unpaved roads was evaluated. Using a rating scale ranging from 0 to 5 for worsening road conditions, regression relationships were determined among a panel condition rating and measured road roughness number, average rater speed and visually rated corrugation, potholes, rutting and gravel looseness. As expected, the panel condition rating worsened with increasing roughness, and average rater speed decreased with increasing panel condition rating. However, because most of the roads studied were in reasonable condition, considerable reduction in average speed was not experienced. The results were used to suggest a basis for selecting maintenance activity based on the panel condition rating, present serviceability rating, roughness, and average speed. 15 Refs.

Author: Robinson, R.
Title: View of Road maintenance economics, policy and management in developing countries.
Abstract: Work that has been carried out at the Transport and Road Research Laboratory of the United Kingdom in the field of road maintenance in developing countries is reviewed under the headings of economics and policy, project implementation, and management. Numerical examples are given to illustrate the economic benefits of road maintenance, and some of the reasons for the poor conditions of road networks in developing countries are discussed. Different approaches to carrying out maintenance are described, including a discussion of equipment and labor-based methods, and of using contractors. Recommendations are made on priorities for budgeting. Maintenance management systems are described in terms of their objectives and their component steps, and the recommendation is made that maintenance frequencies should be determined on an economic basis using whole-life costs. Examples of the use of such methodology in the management of unpaved roads are given. The need for condition measurement surveys to determine maintenance needs for paved roads is described and different methods of rapid assessment are discussed. 62 Refs.

Author: Watson, John; Frazier, Clifton; Chow, Judith; Farber, Robert J.
Title: Survey of fugitive dust control methods for PM10.
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Abstract: Many urban areas in the United States have been classified as being in nonattainment, or are expected to be in non-attainment, of the annual average or twenty-four hour PM 10 standard. These areas are currently developing State Implementation Plans (SIPs) which identify the control measures, and the emissions reductions anticipated from those measures, which will bring these areas into attainment. Fugitive dust sources are major contributors to PM 10 in many airsheds and will have to be controlled in order for federal PM 10 standards to be attained. Paved and unpaved road dust and construction and demolition categories comprise about 90% of the total emitted fugitive dust in most urban areas. 43 Refs.

Author: Williams, Allen L.; Stensland, Gary J.
Title: Uncertainties in emission factor estimates of dust from unpaved roads.
Source: Proceedings - A&WMA Annual Meeting v 2. Publ by Air & Waste Management Assoc, Pittsburgh, PA, USA. 11p
Publication Year: 1989
Abstract: Road dust emission experiments were carried out on four different occasions during the summer of 1988. In each case dichotomous aerosol samplers were placed on a tower in the downwind direction of graveled roads while the prevailing wind was nearly perpendicular to the road. The vehicles for each experiment were light automobiles, which were driven past the sampling site one-hundred times at each speed of 25, 35, 45, and 55 miles per hour. The data discussed here includes the PM-10 emission factor, defined as the mass of dust aerosol less than 10 microns in diameter (PM10) emitted per length of road during one vehicle pass. Before and after each set of 100 vehicle passes samples of the road surface material were collected for particle size analysis. Study methods and results are discussed. 9 Refs.