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REINFORCEMENT FOR GRAVEL PAVED ROADS

Abstract approved: 

Full scale test roads combined with a theoretical analysis were used to evaluate the benefits of incorporating a fabric as a base course support material for gravel paved roads.

One material, a synthetic, nonwoven, polypropylene fabric was used in this investigation. This fabric was used on top of the subgrade to construct several full scale test road sections which were incorporated into the normal road building operation of a managed forest located in southwestern Washington.

The results of theoretical analysis and the full scale field tests indicate the benefits of incorporating a fabric into the pavement structure are: a) it serves as a filter between the base course and the subgrade, b) it better distributes the loads to the subgrade and c) it facilitates construction over very soft soils.

The situations where the use of a fabric may be economically feasible were examined and preliminary design and construction
procedures were proposed for low volume gravel paved roads incorporating a fabric as a base course support material.
Investigation of a Nonwoven Fabric as a Reinforcement for Gravel Paved Roads

by

Harry Stanley Kelsay

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INVESTIGATION OF A NONWOVEN FABRIC AS A ROADWAY REINFORCEMENT FOR GRAVEL PAVED ROADS

INTRODUCTION

Aggregate paved roads are widely used to provide many miles of low cost roadways suitable for relatively low traffic volumes. Examples of typical applications include temporary haul roads, remote access roads and permanent roads which may be upgraded in stages. While the standards and service requirements of aggregate paved roads vary greatly, the governing factor is usually that the road must be constructed and maintained on a limited budget.

Due to the ever increasing demands of industrialization, the need for better methods of roadway construction, especially on problem soils, is apparent. Where road construction formerly was seasonal due to adverse weather conditions, economic considerations in many instances now dictate that road construction be a year-round operation. In addition to increasing demands for natural resources, the shortages of high quality locally available materials which are normally used in the construction of roads are requiring that new methods of roadway construction be developed.

A possible improvement in the construction of low volume roads is the inclusion of a fabric between the subgrade and the base course material. Through analysis and evaluation of full scale test road
installations this study investigates the benefits of incorporating fabrics into the structures of aggregate paved roads.
STATEMENT OF PURPOSE AND SCOPE

The purposes of this investigation were to identify the factors that control the performance of gravel paved roads and to establish the relationships between these factors and the effects of a fabric layer incorporated into the road structure, to define the situations where the use of a fabric as a roadway component may be economically feasible, and to develop preliminary design and construction procedures for low volume roads incorporating fabric base course support layers.

One material, a synthetic, nonwoven, polypropylene fabric was used in this investigation. This fabric was used on top of the subgrade to construct four full scale test sections, which were incorporated into the normal road building operation of a managed forest, located in southwestern Washington. The forest is owned and operated by Crown Zellerbach Corporation.

With the information obtained from the full scale test sections and a theoretical analysis, a series of preliminary design curves and construction procedures were developed for gravel paved roads incorporating a nonwoven fabric as a roadway element.

Included in this report are: a) a literature review, including a general development of flexible pavement theory and a theory of fabric behavior as it relates to the performance of gravel paved roads,
b) background information concerning the test road investigation, c) the results and a discussion of the results obtained from the full scale test roads, d) a theoretical analysis of the fabric behavior in connection with the pavement structure, e) recommendations for preliminary design and construction procedures using a nonwoven fabric, f) and finally, the conclusions reached from the investigation of a nonwoven fabric as a component for gravel paved roads.
The concept of incorporating a fabric membrane in the pavement structure of low volume gravel paved roads in order to improve performance and efficiency is a relatively new idea. However, several successful applications of this concept have been tried in Europe (3) (4) (7). Various types of fabrics have been used as a filtering and/or a reinforcing material. The results of these studies show that the employment of a fabric between the subgrade and the base course has been greatly beneficial to the performance of access and haul roads.

One series of tests incorporated a fabric of equal numbers of two types of continuous filament. One was wholly polypropylene, the other a heterofilament consisting of a polypropylene core coated with a nylon sheath. The break tensile strength of this fabric was approximately 50 pounds per linear inch with an extension of 50 percent, the thickness was nominally 0.03 inch. This fabric was placed over a variety of soft subgrade soils. At one of the test sites the subgrade soil had recorded values of undrained shear strength as low as 100 psf. The water table was at the ground surface. At this site the fabric was used over approximately 2540 feet of road with a

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Numbers in parenthesis refer to items in the Bibliography.
minimum base course thickness of 16 inches. After several months of use, the riding qualities and general soundness of the roadway surface were reported as satisfactory (7).

In addition to the above, laboratory model studies on the improvement of the bearing capacity of soft ground by laying a low pressure polyethylene net on the subgrade have been performed in Japan (13). The results of the laboratory model experiments indicate the bearing capacity of soft ground can be improved by a polyethylene net for a static load, however the effect is not always as significant for a repeated load. Additional conclusions drawn from the above study indicate the effect of a net varies considerably according to the relationship between the loading width and the depth to which the net is laid. If the net is laid too close to the surface of the soil, the effect of the net is small since the surcharge on the net is too small to mobilize the shearing resistance of the net against the soil. The net appears most effective if it is used at a depth nearly equal to the loaded width.

In another study, by the same author, dynamic repeated loading experiments were performed on model pavements in order to compare a polyethylene net with a sand layer (14). The results of this study show the net was nearly equivalent to a sand layer six and eight inches thick respectively under 68 psi surface load for the unimmersed and immersed conditions. The subgrade soil used in the model study
was volcanic ash, commonly found on the alluvial plains of Japan, having a CBR of 1.3 percent and a water content of 115 percent.

In this country research has been performed on the strength and deformation characteristics of reinforced sand (16). Included in this study were circular plate loading tests which were performed on both reinforced and unreinforced sand. The reinforced sand foundations were prepared by introducing horizontal circular fiberglass nets lying in the sand. The test results show that the ultimate bearing capacity of the reinforced sand foundation can be several times that of the unreinforced sand foundation (16).

A nonwoven polypropylene fabric marketed by an Austrian manufacturer is advertised as reducing the required amount of base course up to 60 percent when rolled directly over poor subgrade soils to provide a base for the gravel. This material does not prevent water penetration, but reportedly stops the movement of soil particles from both above and below the fabric. The fabric weighs about 0.7 pounds per square yard. A team of two people can place this material at the rate of about 3,500 square yards per hour (3).

From the above it has been indicated, that with the inclusion of a material of reasonably high tensile strength the roadway structure will be strengthened. While the direct effects of the fabric have not been fully examined much is known about the behavior of conventional roadways. Therefore, it is helpful to look at the various factors
which control the performance of gravel paved roads and then deduce the effects of including a fabric in the pavement structure.

A flexible pavement is built up of several layers consisting of the wearing surface or surface course, base course, subbase, and subgrade. In some instances a separate surface course and/or subbase are omitted. Ideally the pavement is built up to thickness where the stresses on any given layer will not cause undue rutting, shoving, and other differential movements resulting in an uneven wearing surface.

The surface course must be capable of withstanding the wear and abrasive effects of moving vehicles and must possess sufficient stability to prevent it from rutting under traffic loads. The base course is a layer of high stability. The principal purpose of the base course is to distribute or spread the stresses created by the wheel loads acting on the wearing surface so that the stresses transmitted to the subbase and on to the subgrade soil will not be so great as to result in excessive deformation or displacement of these underlying materials. To accomplish this, a well-graded granular material that derives a high level of stability from grain interlock and intergranular friction is commonly used. Such a base course is most stable when it contains a minimum quantity of fines. However, because of the effects of water the quantity of fines must be limited to insure a high permeability. The plasticity of the fines must be low to prevent weakening
when wet. Typical specifications for such material are given by AASHTO (1). When crushed rock is used for base course materials open-graded (uniform) base courses may be used. The angularity of these materials insures the necessary stability. In all cases the base course materials must be durable to prevent degradation under high stresses. If they are not durable, fines will be produced in the base course during and after construction and may ultimately lead to failure. If frost action may be a problem, special criteria (17) must be adhered to. In this case the open-graded materials have an added advantage. Where the subgrade soil is extremely weak thick layers of granular materials are required for good performance. In these instances a granular subbase between the base course and the subgrade may be used in the interests of economy. Where open-graded base courses are used, the subbase will also serve as a filter to prevent pumping or squeezing of the subgrade up into the base course.

The subgrade is the foundation layer which must eventually support all the loads which come onto the pavement. In some cases this layer will simply be the graded natural earth surface. In other and more usual instances it will be the soil existing in a cut section, which may or may not be compacted, or the upper layer of an embankment section. In the fundamental concept of the action of flexible pavements, the combined thickness of subbase (if used), base course, and surface course (if used) must be great enough to reduce the
stresses occurring in the subgrade to values which are not sufficient to cause excessive distortion and displacement of the subgrade soil layer (17).

Because of the complexities of soils and the fact that the pavements consist of layered systems, the true stresses and strains in the pavement structure can only be estimated. This fact has lead to many variations in the methods of determining the required pavement thickness for a given set of conditions (15). Some of these methods are "rational," some are not; in all cases the final criterion used in the evaluation of pavement design, regardless of the method employed, is performance under actual field conditions.

The primary factors which influence gravel paved road performance are:

1. Stress-strain characteristics of the subbase, base course and surface course;

2. Stress-strain and compressibility characteristics of the subgrade;

3. Thickness of the pavement structure;

4. Type and volume of traffic;

5. Wheel loads and tire pressures;

6. Drainage;

7. Climate;
8. Construction methods;

The actual performance criteria used to evaluate gravel paved roads usually consists of a subjective determination of the roadway serviceability. Surface rutting and roughness constitute the important considerations in the determination of serviceability of roads with gravel or crushed rock surfacing. These factors combined with grades and alignment control user costs.

An aggregate paved road may fail in a number of ways -

1. It may settle due to:
   a) consolidation of the subgrade soil,
   b) plastic flow of the subgrade soil,
   c) shear failure (rupture) of the subgrade soil, or
   d) squeezing or pumping of the subgrade soil up into the base course.

2. There may be shear failures in the subgrade due to heavy wheel loads.

3. Surface rutting may develop due to:
   a) the accumulation of many small inelastic strains in the subgrade under the repeated application of the wheel loads,
   b) local failures in the base course, or
   c) compaction of the base course under traffic.
Failures 1a), b), and c) all relate more to be dead load of the pavement structure itself than to traffic loads. The types of subgrade soils in which these problems are most likely to occur are silty and clayey soils with medium to high plasticity (MH, CH), low strength and high compressibility. If a fabric laid on the subgrade allows for thinner pavements through its reinforcing action, the weight would be reduced and these problems lessened; however, the actual reduction in weight would probably not be highly significant. The usual method of alleviating this problem is removal and replacement of the problem soils with more suitable material.

The problem of squeezing or pumping of the subgrade soils into the base course (Failure 1d on page 11), is the result of a mixture of free water and fine grained soils migrating into the base course material, primarily caused by heavy wheel loads. This is usually only a problem when open-graded bases are used. The effects of pumping can be minimized by placing a graded sand or gravel filter layer between the subgrade and the base course (17), or the base course thickness could be increased to reduce the stresses on the subgrade. The addition of a subbase to serve as the filter would provide a solution to the problem. Another possible solution to this problem would be the inclusion of a fabric with suitable filtering characteristics between the subgrade and base course. Not only would the filtering ability of the fabric all but eliminate the problem
of migration of soil across the boundary between the subgrade and the base course, the inherent tensile strength of the fabric would tend to reduce the deformation in the subgrade.

An example of a punching shear failure in the subgrade (Failure 2) is shown in Figure 1. Experience has shown that flexible pavements more often fail by punching shear, similar to the failures observed under dynamically loaded footings as well as under ordinary footings on soft, loose and layered soils, rather than by the general shear mode illustrated in Figure 2 (11).

![Figure 1. Punching shear failure of a flexible pavement (11).](image-url)
In order to prevent a shear failure in the subgrade, normally the pavement structure is thickened, usually by adding a subbase or increasing the thickness of the base course. Another possible solution is to increase the tensile strength of these layers by a treatment with cement or bitumen. A simpler and possibly more economical method of solving this problem would be the inclusion of a reinforcing fabric between the subgrade and the base course. To be effective, the base course thickness would have to be adequate to provide enough weight to mobilize the shearing resistance between the fabric and the subgrade soil. This would allow the tensile strength of the fabric to develop and thereby reduce the tensile stresses in the base course.
and better distribute the loads to the subgrade soil.

In the case of a relatively weak, compressible subgrade and a strong, well compacted, thin pavement structure, rutting is due primarily to compression and permanent distortion of the subgrade soil (Failure 3a). The primary method of preventing rutting due to subgrade deformations is to limit subgrade stress. This is a major criteria in flexible pavement design. The use of a fabric in the pavement structure may produce benefits relative to failures of this type by the reinforcing action of the fabric which would tend to better distribute the loads and therefore reduce deformations.

In the case of a relatively firm, incompressible subgrade and a poorly compacted or generally weak pavement structure, rutting is caused primarily by distortion or shear deformation of the pavement structure (Failures 3b and c). Quality control of materials and methods used in the construction of all types of roads will prevent rutting due to the case above. It is doubtful that the inclusion of a fabric would prevent surface rutting due to base course failures (Failures 3b and c) unless the inclusion of a fabric would provide better conditions for construction resulting in better initial compaction.

In summary it appears that incorporating a fabric into the pavement structure potentially has three main advantages:
1. It would serve as a filter between the base course and the subgrade.

2. It would better distribute the loads to the subgrade.

3. It would facilitate construction.

Studies should be designed to evaluate these possible benefits.
TEST ROAD INVESTIGATION

In order to determine the feasibility of using a nonwoven fabric as a roadway reinforcement, several full-scale test sections were constructed and subjected to truck traffic. These test road installations were incorporated into the normal road building operation of a managed forest, commonly called a tree farm, owned and operated by Crown Zellerbach Corporation. This tree farm includes about 120,000 acres of land and is located in southwestern Washington near the town of Cathlamet. The climate is wet to very wet, with annual precipitation varying from 50 to 120 inches. Most soils in the tree farm are residual soils developed from basalt and sedimentary bedrock.

The method used to build logging roads in the tree farm simply consists of one or two bulldozers leveling a roadway 20-50 feet wide along a predetermined alignment; followed by the placement of eight to sixteen inches of base course material. The only compaction used in building the fills, preparing the subgrade and placing the base course is the incidental result of the construction traffic.

The general criteria adhered to in selection of the test sites were:

1. The test section should have a fairly uniform subgrade soil.
2. The test section should be constructed over a poor subgrade soil.

The usual pattern followed at the test sites was to divide the test road into treated and untreated sections. The only distinction between the treated sections and the untreated sections was the inclusion of a non-woven fabric between the subgrade and the base course in the treated section. The untreated sections merely functioned as a control section whereby a fair evaluation of fabric treated roadway performance could be made.

The operation of the tree farm did not permit specifications and standards of construction for the test roads different from normal construction practices used at the tree farm. Regular equipment and operators from the tree farm were used for grading and for distribution and compaction of the base course material. Inspection was provided during construction of the test roads insuring uniformity of construction at each test section, so as to minimize this variable as much as possible.

The actual procedure used to construct the test roads was quite simple:

1. The subgrade was prepared by removing sharp objects and major ruts.

2. The fabric was then rolled out over the soil. This was accomplished by two people. When two sections were joined
together, the fabric was simply overlapped approximately three feet.

3. Finally, a layer of base course was spread and compacted over the fabric as shown in Figure 3.

The base course used in the construction of the roads was pit run rock. This material was obtained from nearby sources. Normally, the rock was ripped out with a bulldozer and loaded into 12 cubic yard dump trucks which hauled the material to where the bulldozers were spreading the base course. A typical grain size curve for the base material is shown in Figure 4. Additional properties of the base course which was used on the test roads are:

Durability Index (AASHTO T210) (1)

Course Aggregate = 38%

Fine Aggregate (material passing number 4 sieve) = 24%

Liquid limit ($w_L$) and Plasticity Index ($I_p$) (material passing the number 40 sieve)

$$w_L = 50\%$$

$$I_p = 13\%$$

Typical aggregate base course specifications (1) for the production of plastic fines (AASHTO T210) require a minimum durability index of 35 percent for both course and fine aggregate. In addition to the above, a normally acceptable range for the plasticity index of base course material is two to nine percent. When comparing the
Bulldozer spreading base course to desired thickness

Bulldozer compacting base course

Figure 3. Construction of a test road treated section
Figure 4. Typical grain size curve for base course material.
properties of the base course which was used on the test roads with the typical quality requirements mentioned above, it is apparent that the material used was substandard.

A typical roadway section is shown in Figure 5.

![Typical roadway section diagram](image)

Figure 5. Typical roadway section.

The test sections were built during the summer and fall of 1973, at which time initial performance measurements were made. Provisions were made to measure roadway settlement, surface rutting, and deflections due to heavy wheel loads at each of the test sections. During the wet winter season, the initial series of
measurements were repeated. In addition to the performance measurements the following methods were employed at the test sites to aid in the evaluation of the test road performance:

1. Periodic visual inspections of each of the test sites were made and pictures were taken to record significant findings.

2. During the loading periods, vehicle performance was observed and a survey of driver reactions concerning roadway roughness was recorded.

3. Maintenance as performed by the tree farm personnel was recorded.

The method of applying loads to all of the test roads, except the site located in the log sorting yard, was simply driving loaded dump trucks and log trucks across the various test sites. Normal traffic, as dictated by the tree farm day-to-day operations applied sufficient load applications on all the test sites except one. At that site a loaded dump truck was repeatedly driven over the test section until the desired information was obtained. Typical loads on the tandem-axle units on each of the trucks was in the range of 40,000 to 60,000 pounds, with the majority of loads in the upper range of 50,000 to 60,000 pounds. Figure 6 shows a 12 cubic yard dump truck which is typical of those used to apply the loads to the test sections. The gross weight of this truck and load was 69,580 pounds. The equipment used to apply the loads to the test section located in the log
sorting yard was a log stacker and is shown in Figure 7. This piece of equipment weighs 120,000 pounds without a load and fully loaded with logs it weights over 200,000 pounds.

In conjunction with the field work, laboratory studies were conducted in order to evaluate and analyze the various soil parameters associated with the field studies. The laboratory tests used to characterize the subgrade soils were insitu California Bearing Ratio (CBR), water content, unit weight, Atterberg limits and Munsell color notation.

The fabric used as roadway reinforcement in all tests was a synthetic, nonwoven, continuous filament type web made of isotactic polypropylene. The fabric used was approximately one quarter inch thick and weighed about one pound per square yard. The tensile strength and elongation characteristics were determined using the apparatus illustrated in Figure 8. The results of ten tests indicated the range of load carrying capacity of the nonwoven fabric used in the test roads was from 63 to 78 pounds per lineal inch. The failure strains varied from 146 to 216 percent. The average maximum load carried by the fabric was approximately 70 pounds per lineal inch with a corresponding strain of about 200 percent. An example of the load versus elongation characteristics of the nonwoven fabric used in the test roads is shown in Figure 9. The results of three repeated loading tests indicate that after an initial permanent strain of about
Figure 6. Typical 12 cubic yard dump truck.

Figure 7. Log Stacker.
12 percent the material behaves elastically in the load range of 40 to 45 pounds per lineal inch. The frictional properties of the nonwoven fabric used in the test roads was determined using a device similar to direct shear soil testing apparatus. The coefficient of friction between a medium fine, poorly graded sand having a $\phi$ angle of 38 degrees was about 0.5 and the coefficient of friction between two pieces of the fabric was about 0.4. According to the manufacturer, this material will filter out fine particles to 0.005 mm and this filtration rate is affected little if any when the fabric is elongated (10).

In spite of cooperation from the tree farm personnel numerous problems were encountered in co-ordinating the testing and evaluation of the test sections with the tree farm operations. Due to the tree farm short interval scheduling program, a decision to begin hauling over a test section was sometimes made as little as 14 hours prior to when the actual hauling began. This combined with the fact that there was little control over maintenance operations lead to situations where portions of a test section would fail and be repaired without any monitoring by the researchers.
Figure 8. Fabric testing apparatus.
Figure 9. Load versus elongation characteristics of the nonwoven fabric.
TEST ROAD RESULTS

A general description of the site conditions and the results obtained from each of the test sites are summarized in the following sections.

Kents Bridge Test Site

This test section was constructed on a full bench hillside cut, as shown in Figure 10. The maximum depth of the cut section was approximately ten feet, the depth of the cut with respect to the outside test lane was about one foot. The average roadway grade was 12 percent.

The subgrade soil at this site was a yellowish brown (10YR 5/6) (8) clayey silt (MH) having an in place density and water content of 93 pcf and 65 percent. The liquid limit and plasticity index of this material were 82 percent and 24 percent. The results of two insitu CBR tests and one unconfined compression test were 2.4 and 2.9 percent and 1740 psf.

The roadway was 35 feet wide; therefore, it was possible to construct two similar parallel test lanes at this site. Each test lane consisted of 75 feet of treated roadway bounded on each end by 50 feet of untreated roadway. Scheduling prevented using the normal tree farm traffic to apply the load applications at this site; therefore, a
Figure 10. Kents Bridge Test Site.
loaded dump truck was repeatedly driven over the test section, as shown in Figure 5, until the desired information was obtained.

Only the outside test lane was actually used in the tests. The fabric under the inside test lane was badly damaged by a yarder operated at this location prior to testing.

After 25 load applications the tree farm personnel determined that maintenance was required due to the severe rutting which had developed in the lower untreated test section. Therefore, the testing was stopped and the test section was evaluated. At various locations throughout the test section surface rutting was measured, using a straight edge and a rule. The average rut depth measured in the treated section was five inches and in the untreated sections, without the fabric, the average rut depth was eight inches as shown in Figure 11. The average rut depth shown in Figure 11 was obtained from six measurements made at representative locations in the untreated sections and four measurements made at representative locations in the treated section. After these surface measurements were performed, transverse and longitudinal trenches were hand excavated in order to closely examine the fabric and/or the subgrade and the interface between the layers.

The results of this investigation indicate the majority of the rutting in the treated section was caused by densification, degradation and/or local failures in the base course. This is shown in Figure 11
Figure 11. Comparison of rutting between treated and untreated test sections - Kents Bridge Test Site.
by comparing the depth of rutting in the base course, which was four to six inches, with the corresponding depth of rutting in the subgrade, which was one to two inches. In the untreated sections the base course had penetrated into the subgrade and the subgrade had squeezed into the base course to such a degree that the boundary between the two layers could not be determined.

It was observed in the trenches dug in the treated section at two locations where the base course thickness was less than six inches that the fabric was damaged due to penetration by the base course.

After the loads were applied to the test section a noticeable increase in the amount of fines in the base course was observed in both the treated and the untreated sections. The results of color and Atterberg limits tests determined the fines could not be attributed to the subgrade soil. The subgrade soil was a yellowish brown (10YR 5/6) (8) clayey silt (MH) with a liquid limit of 82 percent and a plastic limit of 60 percent compared to the base course fines (material passing number 40 sieve) which was a brown (7.5YR 5/6) (8) clayey silt (MH/ML) with a liquid limit of 50 percent and a plastic limit of 37 percent.

**Hull Creek No. 1 Test Site**

At this test site a localized area existed which provided the opportunity to investigate the use of the fabric over a subgrade of very
low bearing capacity. Due to ground water seepage, the existing sub-grade was extremely soft. This was demonstrated by a person plunging a 3/4 inch steel pipe approximately three feet into the sub-grade soil, as shown in Figure 12. Since this subgrade condition existed for a short distance only the nonwoven fabric was used over the entire problem area.

The test section was constructed on a full bench hillside cut, as shown in Figure 13. The maximum depth of the cut section was approximately eight feet, the depth of the cut at the outside edge of the test road was about one foot. The average roadway grade was 12 percent and the base course thickness was 18 inches for this test section.

The subgrade soil at this site was a brown (10YR 5/2.5) (8) silty clay (MH) having a natural water content of 52 percent. The liquid limit and plasticity index of this soil were 71 and 23 percent.

The total length of this test section was approximately 135 feet. As mentioned above the fabric was used over the entire test section since the soft subgrade was not extensive enough to yield a fair evaluation of both treated and untreated sections. Prior to construction of the test section it was practically impossible for any piece of equipment to work or even travel over this section of road. After this test section was constructed using the nonwoven fabric as a base course support material, it was estimated by the tree farm personnel that the
Figure 12. Demonstration showing the relative softness of the subgrade at the Hull Creek No. 1 Test Site.
Figure 13. Hull Creek No. 1 Test Site.
amount of time required to build the test road and the amount of base
course used in the actual construction was approximately half what
was anticipated in a problem area of this magnitude. It should be
noted that the blade on the bulldozer which was used to build this test
section was not designed to spread base course, therefore the roadway
width was approximately six feet wider in some locations than origin-
ally planned. The equipment operator who spread and compacted the
base course on this section commented that the center portion of the
roadway i.e. the portion supported by the fabric, was stable compared
to the outside edge of the roadway which had no fabric support. Shortly
after construction of the test section a road grader, which was simply
driving across the test section, almost became stuck when the opera-
tor drove near the edge of the roadway which had no fabric support.
The wheels sunk approximately one to one and a half feet near the
roadway edge where there was no fabric support.

In the original scheme of the test road investigation, deflection
measurements were to be used in the evaluation of the test sections.
These measurements were performed at this site using a self-leveling
surveying level, a two foot section of Philadelphia rod and a fully loaded
12 cubic yard dump truck. The magnitude of the elastic deflections,
which were measured immediately after construction, was approxi-
mately 1/8 of an inch. After the test section had about 25 load
applications of fully loaded log trucks the measurements were repeated. No significant changes in the above figures were noted.

Hull Creek No. 2 Test Site

This test site was constructed on a gently sloping hillside as shown in Figure 14. The actual roadway was constructed on a full bench cut. The depth of the cut section varied from a few feet to a maximum of around six feet. The depth of the cut section at the outside edge of the test road was less than one foot. The average grade was nine percent and base course thickness was eight inches.

The subgrade soil was a yellowish brown (10YR 5/4) (8) silty clay (MH) having an in place density and water content of 91 pcf and 47 percent. The liquid limit and plasticity index of this material were 77 and 32 percent.

The test section consisted of 75 feet of treated roadway bounded on each side by 50 feet of untreated roadway. This test site is approximately one quarter mile from the Hull Creek No. 1 test site; therefore, the same 12 cubic yard dump trucks which were used to apply the loads at the Hull Creek No. 1 test site were also used to apply the loads to the Hull Creek No. 2 test section.

According to the tree farm personnel, after approximately 75 load applications the untreated sections at both ends of the test road had failed and maintenance was required. Before maintenance a fully
Figure 14. Hull Creek No. 2 Test Site.
loaded dump truck practically had to come to a complete stop when approaching the test site and creep through the untreated sections.

Observations made just prior to maintenance operations indicated the general condition of the roadway was poor and in need of repair. The primary problem was severe washboarding of the roadway. The washboarding was obviously more pronounced in the untreated sections of the test road; however, the fabric treated section was affected by a measureable amount of washboarding, as shown in Figures 15 and 16.

Due to construction operations in progress, it was not possible to interrupt traffic and dig down through the base course to examine the underlying fabric and subgrade. Examining the base course just prior to maintenance operations revealed a great deal more fines than existed when the material was originally placed on the roadway. The results of color and Atterberg limits tests determined that the fines could not be attributed to the subgrade soil.

Deflection measurements were also performed at this site. The magnitude of the deflections varied between 1/8 and 1/4 of an inch. The results of these measurements indicated that the presence of the fabric had no significant effect on the amount and extent of the deflections caused by a heavy wheel load.
Figure 15. South end of test road at Hull Creek No. 2 showing untreated section and portion of treated section.

Figure 16. North end of test road at Hull Creek No. 2 showing untreated section and portion of treated section.
Sorting Yard, Bay 1 Test Site

In 1962 a sorting yard was established to facilitate the sorting, grading, and scaling of logs to best utilize the timber resources of the Cathlamet Managed Forest. As the logs arrive at the sorting yard, they are scaled, graded, stored, rebundled, banded, and rafted for delivery to various mills. During this process it is usually necessary to temporarily place the logs in dry storage. It was in one of these storage areas, called Bays, that this test section shown in Figure 17 was constructed.

The test section was constructed on a level fill with a base course thickness averaging six inches. The subgrade soil at this site was a black (7.5 YR 2.5/0) (8), nonplastic organic silt (OL) with large amounts of organic matter and some gravel particles. It should be noted that for over ten years base course has been continuously placed over this section. The continual failures at this site were caused by pumping of the subgrade up into the base and subsequent penetration of the base course into the subgrade soil. The test section consisted of 75 feet of treated roadway adjacent to 75 feet of untreated roadway.

The normal traffic generated by the sorting yard operation was used to apply the load applications to this test section, the typical equipment used was described earlier and is shown in Figure 7. Due
Figure 17. Sorting Yard, Bay 1 Test Site.
to the random distribution of log stacker loads within the sorting yard the number of load applications at this site is unknown.

The magnitude of the deflection measurements of this site was approximately 1/8 of an inch. The results of these measurements indicated the presence of the fabric had no significant effect on the amount and extent of the deflections caused by the heavy wheel load.

Rutting was obviously more pronounced in the untreated portion of the test site when compared to the treated section, as shown in Figures 18 and 19. Within two weeks after the pictures were taken, the untreated portion of the test site shown in Figure 19 had to be repaired while the treated portion of the test road was still providing satisfactory service.
Figure 18. Sorting Yard, Bay 1 - section of roadway which was treated with the nonwoven fabric.

Figure 19. Sorting Yard, Bay 1 - section of roadway which had no treatment.
DISCUSSION OF TEST ROAD RESULTS

The major problems and limitations which were encountered during the field investigation were:

1. Crude construction methods.
2. No quality control over base course materials used on the test sites. The results of tests performed on the aggregate used on the test sites indicate the material did not meet acceptable standards.
3. Limited test road sites. For more significant results, more extensive sites and softer subgrades would have been desirable.
4. Little control over maintenance operations at the test sites. Due to the required continuance of the tree farm operations the test roads were repaired as deemed necessary by the tree farm personnel. In several instances maintenance was performed on the test section before any monitoring or evaluation was performed at the test site.

The combination of the above factors made it difficult if not impossible to obtain quantitative results from the test sites. However, qualitative results obtained from the field studies demonstrated the various effects of incorporating a fabric into the pavement structure.
The ability of the nonwoven fabric used in the field studies to act as a filter between the subgrade and the base course was effectively demonstrated at the Kents Bridge and Sorting Yard, Bay 1 test sites. At the Kents Bridge site one of the mechanisms of failure which caused the deep rutting in the untreated sections was the squeezing of the subgrade up into the base course. The presence of the fabric in the treated section of the test road prevented the subgrade from being squeezed up into the base course. At the Sorting Yard, Bay 1 test site, pumping of the subgrade up into the base course was the primary failure mechanism. The results obtained from this site demonstrated that the fabric performed as an effective filter between the subgrade and the base course. The filter action prevented the failure of the treated portion of the test site whereas the untreated portion of the test site failed and required maintenance.

The deflection measurements performed at the various test sites indicated the inclusion of the nonwoven fabric between the subgrade and the base course had very little if any effect on the deflections of the roadway under heavy loads. However, the reinforcing action of the nonwoven fabric was demonstrated at the Hull Creek No. 1 test site. At this site, the ability of the nonwoven fabric to distribute the heavy wheel loads over a very soft subgrade was demonstrated. The results of the nonwoven fabric performance at Hull Creek No. 1
indicate possible economic benefits when roads are constructed over subgrade soils of very low bearing capacity.

In addition to the above, the results obtained from the Hull Creek No. 1 test road demonstrated the ability of the nonwoven fabric to facilitate construction. The fabric was easy to work with during the actual construction of the test road. It was estimated that the use of the nonwoven fabric reduced the amount of time and materials required to construct the test section by approximately 50 percent.
THEORETICAL ANALYSIS

A set of preliminary design curves was developed by the author using the Forest Service Interim Guide for Thickness Design of Flexible Pavement Structures (5) which was based on the AASHO Interim Guide for Design of Pavement Structures, 1972 (2), and the U. S. Army Engineer Waterway Experiment Station report on the Thickness Requirements for Unsurfaced Roads and Airfields (6). The design curves shown in Figure 20, were developed assuming environmental conditions common to the Pacific Northwest and a base course CBR of approximately 35 percent. That portion of surface course (if used) and/or base course which will be lost during the time the pavement structure is expected to last before resurfacing or replacement is not included in the thickness obtained from Figure 20. In order to convert other axle loads to 18,000 pound single axle load applications equivalency factors are given in Table 1 (5). The base course thickness required for one equivalent 18,000 pound single axle load application was derived by extrapolating the data obtained from the above mentioned design procedure. This was accomplished by projecting an arithmetic plot of the required base course thickness for 100 to 2,000 equivalent 18,000 pound single axle load applications for different subgrade conditions.
Figure 20. Design curves for gravel paved roads located in the Pacific Northwest having a base course CBR of 35 percent.
Table 1. Eighteen thousand pound single axle equivalency factors (5).

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18,000 pound single axle
Tire Pressure = 70 psi

Curve A (without fabric)

Curve B (with fabric, tensile load = 40 lbs/in)

Vertical pressure on top of subgrade (psf)

Insitu subgrade CBR (%)

Figure 21. Base course thickness versus vertical pressure on subgrade and subgrade CBR for fabric treated and untreated roadway.
The analysis of the behavior of pavement structures and subgrades under a large number of load applications is very complex. Therefore, the effects of one load application was investigated. A relationship was developed between the base course thickness and one equivalent single wheel load whereby the vertical pressure at the top of the subgrade soil was calculated, as shown by Curve A in Figure 21. This was accomplished assuming a static circular load was applied to an elastic material which distributed the load as shown in Figure 22.

![Diagram](image)

Figure 22. Idealized load distribution without fabric.

The equation used to calculate the vertical pressure on top of the subgrade was

\[ \sigma_z = \frac{P}{\pi/4 \ (B + t)^2} \]
If a fabric was included between the soft layer and the firm layer in the model shown in Figure 22 and the system failed in punching shear, similar to the mechanism shown in Figure 1, the idealized model would appear as shown in Figure 23. In this model the tensile strength developed in the fabric would reduce the vertical pressure at the top of the subgrade for a given load.

![Idealized failure model with fabric](image)

Figure 23. Idealized failure model with fabric.

The amount of the reduction would be a function of the tensile strength developed in the fabric, the diameter of the circular load applied to the firm layer and the thickness of the firm layer, as shown by the following equation,

\[
\sigma_z = \frac{P - T \pi (B + t)}{\pi/4 (B + t)^2}
\]
If an allowable working load of 40 pounds per inch is assumed for the fabric (T), the resulting vertical pressure at the top of the subgrade is shown by Curve B in Figure 21. It should be noted that the horizontal distance, represented by x in Figure 23, required to develop 40 pounds per lineal inch in the fabric through friction between the fabric and the base is about three feet. This assumes 100 pounds per square foot (surcharge) acting on the fabric.

Figure 21 also relates base course thickness to subgrade CBR according to the Forest Service method of roadway design (5). This information was obtained from Figure 20 using the base course thickness required for one load application. From the relationships shown in Figure 21, the fabric-equivalent base course thickness versus subgrade CBR was established as shown in Figure 24. To use this curve it is necessary to assume this relationship is independent of the number of load applications.

The insitu CBR test was used to evaluate the subgrade since it is easily performed in the field and is the basis for the most widely used and understood pavement design methods. Included in the Forest Service design guide (5) are various correlations for CBR and other methods of evaluating the subgrade strength. In addition to the above there have been studies comparing the insitu subgrade CBR with the insitu subgrade shear strength (9) (12).
It should be realized that the curve shown in Figure 24 was based on several significant assumptions and is not intended for conventional design purposes. These relationships were developed as a guide to further research and to provide a general understanding of the beneficial aspects of the reinforcing action of the fabric.

The curve in Figure 24 shows that the relative significance of the fabric increases as the strength of the subgrade decreases. When the subgrade CBR is less than two percent the inclusion of a fabric in the pavement structure begins to have a significant effect. This infers that when a fabric is used over subgrade soils of very low bearing capacity the reduced base course thickness, due to the fabric reinforcing action, may be significant from an economical standpoint.

It should be realized that the filtering benefits of the fabric are not limited to soils of low bearing capacity. Benefits from the fabric filtering ability relate to the probability of subgrade intrusion into the pavement structure. When open graded base courses are used over saturated fine grained soils in which clay and silt fractions predominate, there is a high possibility of subgrade intrusion (17). In the above circumstances, the inclusion of a fabric between the subgrade and the open graded base course which would prevent the migration of fines may be significant from an economical standpoint regardless of the CBR of the subgrade.
Figure 24. Fabric-equivalent base course thickness for punching shear failure.
RECOMMENDED DESIGN AND CONSTRUCTION PROCEDURES

The primary considerations in designing aggregate paved roads are the bearing capacity of the subgrade and the stability of the material in the pavement structure required to support a specific type and number of axle load repetitions. The usual practice is to convert all the estimated axle loads based on traffic data for the design period to the equivalent number of some standard axle load such as the 18,000 pound single-axle load. Climatic conditions which relate to the specific location of the road are also considered.

With the above information, the pavement thickness requirements can be determined using one of the conventional methods such as the one used to develop the design curves shown in Figure 20. These curves were developed for average environmental conditions common to the coastal Pacific Northwest and a base course with a CBR of approximately 35 percent. No allowance has been made for surface loss due to traffic during the design period. The minimum base course thickness recommended is seven inches or twice the maximum particle size, whichever is greater.

Once the functional depth of the pavement structure has been determined the thickness may be reduced with the inclusion of a fabric between the subgrade and the base course as indicated by Figure 24. In order to use Figure 24 the roadway width must be wide
enough to provide the three feet embedment length required to develop the fabric allowable working load as shown by x in Figure 23. In addition to the above, it is recommended that a fabric be included under all open graded base courses regardless of the thickness required where pumping may be a problem. A lighter weight, less expensive, fabric could be used over stronger subgrades where filtering was the main purpose.

The recommended construction technique for incorporating a fabric into the pavement structure is:

1. Compact the subgrade to the required standard. In situations where it is not practical to compact the subgrade, simply prepare the subgrade by removing sharp objects and major ruts.

2. Roll the fabric out over the subgrade soil. When two portions of the fabric are joined together the fabric should be overlapped approximately three feet.

3. A layer of base course is then spread and compacted over the fabric. A minimum base course depth of six inches or twice the maximum particle size, whichever is greater, should be maintained during construction operations in order to prevent damage to the fabric.

In order to insure quality materials and workmanship it is recommended that the AASHTO specifications (1), or equivalent, be used as a
guide for the construction of gravel paved roads incorporating a fabric in the pavement structure. The important elements in aggregate paved roads which should be emphasized are: a) compaction of the subgrade and all the materials used in the pavement structure, b) gradation, percent fines and plasticity of the fines of the materials used in the pavement structure, c) and finally, the ability of the surface course (if used) or the base course to withstand the abrasive action of traffic. It should be realized that good gravel paved roads require quality materials combined with good construction methods. Incorporating a fabric into the pavement structure is not a substitute for either of these requirements. Finally, it must be emphasized that these recommended design and construction procedures were developed as a guide for further research and are not intended for conventional design purposes.
CONCLUSIONS

1. The fabric used in this investigation was easy to work with and was not easily damaged.

2. Incorporating a fabric into the pavement structure will provide three possible benefits:
   a. Reinforcement
   b. Filtering
   c. Facilitate construction on soft ground.

3. The fabric-equivalent base course thickness due to reinforcement may only be significant when the subgrade is very soft i.e. CBR is less than 1.5 to 2 percent.

4. The fabric is very effective where pumping and/or subgrade intrusions are problems. When the fabric is used over firm subgrades to control pumping, thinner fabrics may be used.

5. Use of the fabric over very soft foundation soils may facilitate construction.


