Long-Term Performance Evaluation of Wood Fibre Fills

Final Report
August 1992

WA-RD 239.1

Washington State Department of Transportation
Transit, Research, and Intermodal Planning (TRIP) Division
and in cooperation with
U.S. Department of Transportation
Federal Highway Administration

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO
WA-RD-239.1

2. GOVERNMENT ACCESSION NO.

3. RECIPIENT'S CATALOG NO.

4. TITLE AND SUBTITLE
LONG-TERM PERFORMANCE EVALUATION OF WOOD FIBRE

5. REPORT DATE
August 1992

6. PERFORMING ORGANIZATION CODE
WA75-04 & 05

7. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NO

9. PERFORMING ORGANIZATION NAME AND ADDRESS
WASHINGTON STATE DEPARTMENT OF TRANSPORTATION
OLYMPIA, WA 98507

10. WORK UNIT NO.

11. CONTRACT OR GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
WASHINGTON STATE DEPARTMENT OF TRANSPORTATION
OLYMPIA, WA 98507

13. TYPE OF REPORT AN PERIOD COVERED
FINAL REPORT

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. ABSTRACT
This paper presents the results of a research project to determine the long-term performance of wood fibre embankments, that were constructed by the Washington State Department of Transportation (WSDOT) beginning in 1972. At the time of their construction, concern existed that wood fibre fills would only provide a 15 to 20 year service life.

Performance of existing wood fibre fills was evaluated based on the quality of the wood fibre material, quality of the effluent, and condition of the pavement. A visual classification system rating the wood fibre from fresh to completely decomposed was developed and used in order to establish a criteria from which all wood fibre material could be rated. Visual examination in conjunction with laboratory tests were used as determining aspects for the effluent quality. The WSDOT Pavement Management System was used to evaluate relative pavement performance. Site descriptions are presented giving specific characteristics and properties of the fills inventoried. An analysis of this information was done to determine the effectiveness of the fills.

Over half the wood fibre samples were found to be nearly fresh or fresh and none were found to be completely decomposed. In all but one case, the pavement quality over the wood fibre fills surpassed the comparative highway segment rating indicating the wood fill's performance exceeded that of the surrounding area. Generally, the surface water in the vicinity of the wood fibre was found to be clean and pure indicating no adverse impact of effluent. Given the above findings, embankments constructed of wood fibre were found to perform well over almost a 20 year period. Service life in excess of 50 years can be expected of wood fibre fills.

17. KEY WORDS
Wood fibre
Leachate
Embankments
Pavements

18. DISTRIBUTION STATEMENT

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	82	

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TABLE OF CONTENTS

Section

Page

LIST OF APPENDICES

LIST OF FIGURES

ABSTRACT

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Performance of existing wood fibre fills was evaluated based on the quality of the wood fibre material, quality of the effluent, and condition of the pavement. A visual classification system rating the wood fibre from fresh to completely decomposed was developed and used in order to establish a criteria from which all wood fibre material could be rated. Visual examination in conjunction with laboratory tests were used as determining aspects for the effluent quality. The WSDOT Pavement Management System was used to evaluate relative pavement performance. Site descriptions are presented giving specific characteristics and properties of the fills inventoried. An analysis of this information was done to determine the effectiveness of the fills.

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INTRODUCTION

In 1972, the first wood fibre fill was constructed on the Washington State highway system as an emergency repair on SR-101 to repair a landslide that had destroyed a section of roadway. Wood fibre was selected for two primary reasons for the repair of the roadway. First had to do with constructability as an all-weather material. Rain does not effect the placement and compaction of the embankment. Secondly, a lightweight fill was used to lessen the driving forces of the unstable ground causing instability. (19) Additionally, wood fibre material was readily available and could be obtained on short notice from local saw mills. Historically, timber areas like the cities of Raymond, Aberdeen and Hoquiam along the Washington coast have used wood fibre material to construct non-engineered fills over very weak marine sediments.

To use wood fibre as embankment material for permanent roadways two critical concerns faced the Department of Transportation. First, will wood fibre resist decay and rotting sufficiently so as to have an embankment life in excess of 75 years? Some estimates speculated wood fibre to have a design life of 15 to 30 years. Results from investigations by WSDOT of old sawdust piles reportedly in the order of 70 years old found a decomposed outer zone of 2 to 3 ft thick with an inner core where no decomposition had occurred.

The second critical issue is the risk of spontaneous combustion which could result in the wood fibre fill catching fire. Biological oxidation increases temperature to approximately 167 F followed by a chemical reaction that increases temperature up to ignition. Controlling the fill temperature and reducing the availability of oxygen are methods of preventing a fire of this sort.(14)

A number of terms are used to describe the wood fill material. Throughout this report wood fibre is used as a generic term. The actual fill material may be hog fuel, sawdust, planer chips or woodwaste. Hog fuel is defined as ground wood and bark. This material is commonly used to create steam by burning in a boiler. The small particles of wood generated when logs are cut into lumber are classified as sawdust. Planer chips are the excess material removed when a log is cut to final dimensions. Woodwaste, the last category, encompasses sawdust, hog fuel, bark chips, or a combination of the three. This material is generated from handling the logs at the saw mill.

Since the first fill, twenty additional fills were constructed between 1973 and 1986. The location of these fills are shown on Figure 1 and are referenced in Appendix I. They were all built in high to moderate rainfall areas of Western Washington. The average age of these fills is about 15 years.

The goal of this research was to evaluate the general long-term performance of wood fibre fills. To evaluate the performance of the fills the investigation focused on the quality of the wood fibre material, the quality of the leachate, and performance of the pavement section.

An evaluation of the quality of the wood fibre fills was accomplished by classifying the fill material primarily by observation because no testing method is available to measure the degree of rotting. No existing classification system was identified in the literature. A system was developed using five classifications to rate the amount of decomposition. The classes range from fresh to completely decomposed. Appendix II presents the determining criteria for the five classes. The classification ratings for the samples taken at the individual sites are included in Appendix III. Temperature readings taken as a possible indicator of decomposition are also presented in Appendix III. Since no previous classification system existed prior to this research, there is no information stating the freshness of the wood fibre at time of construction. With this in mind the given ratings can only indicate the quality of wood fibre at the time of this field work.

The second performance measure is a determination of the quality of leachate. When water interacts with the wood fibre an extraction of the wood occurs and a toxic solution is formed. This solution is known as leachate or effluent and is an environmental concern when near streams or surface water. Characteristics of this aqueous solution composed of extractions of cellulose and lignin include a high oxygen demand, low pH, dark color and foul odor. Methods of controlling leachate involve reducing water flow in the fill, treatment of the effluent from the fill, and controlling the type of material placed in fill.(21) To ensure the leachate is not harmful to the existing wildlife dependant on the receiving water, laboratory tests are run to determine the biological oxygen demand (BOD).

Pavement performance was evaluated by comparing the existing condition of the pavement with previous year's conditions. Adjacent areas without wood fibre fills were compared to evaluate relative performance. The pavement rating provided in this research is a representation of the pavement directly above the lightweight fill. Generally, this is a small percentage of the highway segment that receives a WSDOT Pavement Management System rating. All roadways are rated by the Transportation Data Office in conjunction with the Pavement Management Section of the Headquarters Material Laboratory every year. The categories evaluated for asphalt pavements are alligator, longitudinal and transverse cracking, patching, raveling and flushing. Appendix III lists the research rating for the fill section followed by the comparative WSDOT rating for the highway segment in parentheses. It should be noted that maintenance patch areas can cause local variances from the average roadway rating.

Research for this project was primarily conducted during the summer of 1991 when nearly all field testing was completed, with the exception of wood fibre samples at SR-16 Burley Olalla Road and three in-situ densities which were collected in the summer of 1992.

This report provides information on the performance of wood fibre fills over a 5 to 20 year period of time, and an interpretation of how they will be expected to behave over the long term.

LITERATURE REVIEW

To evaluate the current state of knowledge regarding the use of wood fibre as an embankment material a comprehensive literature review was conducted. The review consisted of library computerized and manual searches of published literature and file reports. Selected references are reviewed below and noted by reference number.

1. A Study of Woodwaste Leachate (1976)

Since no literature previously existed on the effects of leachate, from woodwaste, on the environment, a study was performed to determine these effects. For informational purposes the authors included brief definitions of woodwaste and leachate. The term woodwaste encompasses a wide assortment of materials including sawdust and hog fuel to a mixture of wood, bark, dirt, and rock. The authors note a potential water quality problem arises when woodwaste fills are used. An increase in BOD and a depression in the dissolved oxygen (DO) of the receiving water may be harmful to the wildlife. Laboratory experiments of cedar, fir and hemlock monitored the chemical properties of leachate. Experiments indicated increasing toxicity with increasing concentrations of leachate. Toxicity reports ordered the species starting with fir as the highest, followed by cedar and hemlock. This did not follow previous reported data for the order of toxicity. The research showed a need to be aware of the species of wood and the type of fibre (i.e. bark, sapwood, or heartwood) since they are varying factors in fish toxicity.

When the leachate concentration was high the soil could no longer treat the leachate, but the groundwater was able to reduce the concentrations.

2. A Summary of the Use of Sawdust for Highway Fills (1979)

Initial information is included in this report on the climate and geology of southwest Washington to provide a background explaining the reasons and benefits of using "sawdust" as a lightweight fill. In a timber-oriented area where landslides have occurred and the possibility exists for new landslides, using sawdust as a lightweight fill is not out of reason. In 1979 when this paper was written "sawdust" projects constructed in Washington State in 1972 and 1973 had corrected two landslides. Settlement of 6 to 8 inches occurred relative to the guard rail alignment. The guard rail was placed at a later date and experienced little movement.

Tests were performed on the in-place sawdust placed over soft peat and organic silts. Internal temperature was monitored for a year after construction. Two problems the author cautions to anyone considering the use of woodwaste products are the risk of spontaneous combustion and leachate. A conservative life span of the wood fibre of 15 years is the popular prediction. The author expects in time remedial construction may be needed.

Recommendations were made to reduce post-construction settlement within the sawdust fill by placing a small surcharge or cambering the grade to compensate for expected settlement.

3. Bark Spoil Disposal Consultation (1972)

Environmental effects of mixing bark with fill on the east side of the Port Peninsula in Olympia, Washington are summarized in this document. Bark deposits potentially causing pollution problems from leachate were addressed. Introduction of water either by rainfall or surface and subsurface water flow were identified as means that can pollute receiving water with a high oxygen demand. Dumping bark into an embayment that will produce harmful pollutants was a concern. Using the technique of controlled sanitary landfills was identified as one of the most effective methods available to dispose of leachate-producing material. Enclosing the bark in an impervious soil minimizes inflow and outflow. This leachate is essentially sealed off from groundwater avoiding any possible harm. Near tidal areas, confining and covering the bark with an impervious seal was considered necessary. Bark's high compressibility and long term bark deterioration were considered potential future problems for land development where buildings may be located over the area.

4. Effects of Log Dumping and Rafting on the Marine Environment of Southeast Alaska (1974)

Through experiments and tests, observations were made to determine the environmental impact of log dumping and rafting. From these observations it was concluded that the biological and chemical demand for oxygen were the most serious impacts. Sites were studied and the results from these tests are included in the report. The author predicts that in areas with leachate it is likely fish would detect the leachate and low DO (Dissolved Oxygen) and swim away. Investigations of relative leaching rates of hemlock, spruce, red cedar, and yellow cedar were conducted. Increasing age of bark deposits results in a decreased BOD level. Tests indicated that the leaching rate in descending order was red cedar, yellow cedar, hemlock and spruce.

5. Embankment Failure on Organic Clay (1969)

A failure of an embankment consisting of shells, sand lenses and wood chips was analyzed by the author. Background information was provided by lab tests, construction history and a description of the failure. Together with shells and sand lenses the wood chips contributed to the greater measured strength, but no information was included as to the wood chips individual contribution. No recommendations were suggested relating to the use of wood chips.

6. Fill Slope Repair Using Soil Bioengineering Systems (1989)

Testing and construction techniques of using live plant parts were included in this report. This process is known as soil bioengineering. Wood, stone, or synthetic materials may be added as structural support. The article addressed the engineering qualities of live plants in detail, but the use of wood, stone or synthetic materials was not discussed.

7. Highway Design and Construction Over Peat Deposits in Lower British Columbia (1966)

This report describes the methods used to construct roadways over peat deposits. Due to residential and industrial development the need to expand transportation facilities arose. Peat areas were previously undeveloped due to the soft soils, but growth demanded the use of these areas. Different methods were tried. Examples included excavating the peat and replacing with soil and gravel or sand, placement of corduroy which consists of logs laid down crosswise with gravel on top, and installation of vertical sand drains to increase the rate of primary settlement. Most of these projects experienced problems. "Sawdust" was used on a project to provide fill volume without extra weight. Precautions in using sawdust entailed placing fill below water level, placing enough fill to reduce the load, but not adding too much. Enough room must remain for the specified amount of granular material so a stability problem is avoided. The author noted that the soft clays underneath the peat proved to be the troublemaker rather than the peat and that the sawdust performed very well as a construction material. This all-weather material had no difficulties with compaction or moisture content. During construction passenger cars had no problems driving over it. Pavement thickness was required to be at least 1 ft less over the sawdust than over peat. The physical properties of peat are discussed in length.

8. Lightweight Fill (1977)

A soils investigation for an area located between Raymond and South Bend in regards to a foundation of a new alignment was summarized. Tests indicated its inability to support a fill height of 20 ft. Using a lightweight fill was a possible solution since hogged fuel was available. Before a design criteria could be developed a standard Benkleman Beam test was performed. An existing computer program, Chev 5L processed the data and calculated stresses and strains. Results from test data predicted failure would occur before the normal life of the pavement was reached.

9. Lightweight Fill Using 100% Wood Fibre

Research on the characteristics of wood fibre and the reasons for its use were described. Geological formations south of Aberdeen were described as being prone to landslides. A lightweight fill such as wood fibre, use of underdrains, and minor alignment revisions were methods described to provide stability. Advantages of wood fibre noted include a lower cost, an all-weather material, that weak foundations will subside 75% less if wood fibre is used, and that an excess from local industries exists. Compactibility and leachate were noted as two disadvantages. The Highway Maintenance division constructed a hog fuel fill on SR-101 to correct effects of a landslide in March of 1972. Another landslide area was re-constructed with wood fibre in 1973 near the 1972 landslide. A hand mixture of liquid asphalt and wood fibre provided a semi-impervious protective layer. Using top soil was mentioned as another method of sealing the slope. Old sawdust piles that were investigated reportedly had a top layer of 2 to 3 ft resembling soil but inside no decay had occurred.

10. Sawdust as Lightweight Fill Material (1974)

This article summarizes "sawdust" as a replacement for existing high density fills. The Cosmopolis, Washington area on SR-101 was described as a vicinity where landslides have resulted in continual maintenance. Combining improved draining patterns with sawdust embankments were designed to improve stability. The author notes the City of Aberdeen, Washington, British Columbia and Norway have all used sawdust. Sawdust was used to correct a landslide in 1972 on SR-101 south of Cosmopolis due to its all-weather properties. No deterioration occurred for one year. As a consequence sawdust was used in another project just south of the previous slide. The three varieties of wood fibre used were hog fuel, planer chips, and bark chips. Deflection under the front-end loader remained constant at 2 to 3 inches during compaction. A somewhat permeable seal of asphalt emulsion covered the 1:1 sideslope. This seal was designed to act as a crust with the intent to prevent deterioration. Given the 125 inches of annual rainfall the fills were predicted to last at least 14 to 15 years. An impermeable seal was suggested to prevent pollution in receiving waters. A reduction in weight of 71% in the fill area was experienced with the use of sawdust. Lab tests had an optimum density of 21.3 pcf and a moisture content of 175%.

11. Sawdust Embankment (1976)

This article described the process involving the construction of a highway over a "sawdust" embankment. The U.S. Department of Transportation had no previous experience using sawdust, but a favorable report done by D.S. Nelson and W.L. Allen Jr. titled "Sawdust as Lightweight Fill Material," describing work in Washington State and a reduced cost were two positive reasons to try constructing a sawdust fill on U.S. 65. The described highway crosses a slide prone area that had needed continual maintenance. Reconstruction began after heavy rains in the winter of 1974. Embankment was placed on a 2:1 slope covered with asphalt emulsion. It was reported that during construction the outer edge of the fill appeared softer and looser than the rest, but the dozer had no problems. One cubic foot sample of sawdust that had been placed in three lifts and rodded had a weight of 31.7 pounds. A loose weight density was cited as 20 pcf. These values were determined from sawdust at the stockpile after construction. Using the sawdust resulted in a 75.6% reduction in weight. After eight months there was no noticeable settlement.

12. Spontaneous Combustion in Wood Waste Landfills--IDC (1977)

This correspondence outlined current articles written about spontaneous combustion. Three individuals were contacted about this issue. Mr. Schermer, of Grays Harbor College reported that the department's fills were not expected to have problems with spontaneous combustion due to the lack of air oxidation. Jim Fisher of Weyerhauser suggested the following two general rules to avoid the problem of spontaneous combustion. First, to place lifts that are a maximum of 3 to 6 ft, and provide adequate compaction. Secondly, there must be a sufficient amount of drainage. Dr. Kendal of ITT Rayonier reported the above ground "sawdust" fills at ITT Rayonier have never had any problems if compaction and moist material were used.

13. Spontaneous Combustion of Forest Fuels: A Review (1973)

The process leading up to a spontaneous combustion fire was discussed in this article. As an example, it was described that two weeks after construction a wood chip pile has a center temperature of approximately 140°F. A gradual increase in temperature will happen over several months and then ignition may occur from a rapid temperature increase. Observers tend to believe spontaneous combustion occurs due to a combination of mechanisms. Biological reactions are the initial process that raises the temperature up to the physiochemical process. From this point the temperature continues to increase until ignition occurs through physiochemical reactions.

Peat, and dead and rotting wood, or grass are examples of where spontaneous combustion is most likely to occur. The first heating phase is from the heat generated by bacteria. If bacteria has produced enough heat to reduce moisture content to a certain point, then the second phase begins with chemical reactions. With enough oxygen present the internal temperature will increase until ignition.

The conditions necessary for the oxidation to occur were being researched by the Forest Fire Research Institute.

14. Spontaneous Heating and Ignition in Sawdust Heaps (1956)

Known conditions of spontaneous combustion were discussed and some precautions were included in this article. Three examples from Swedish pulp mills of spontaneous combustion were described by H. Bergström. He stated that the warm, rainy weather and the large size of the heaps were the reasons behind the spontaneous ignition. Bergström also predicted a tropical, damp climate had a higher probability of spontaneous ignition occurring and it may happen in smaller heaps.

Maintaining a pile that is under 20 ft in height may eliminate the chance of a fire since all spontaneous ignition fires have been over 20 ft. Heaps with temperatures near 180°F are likely to ignite, but 135°F heaps showed no signs of fire developing during a three year monitoring period.

Determining whether a fire is due to accidental ignition or spontaneous combustion is difficult. Studies indicated a sawdust heap may smoulder for weeks before detection.

Precautions included initially restricting height of heap to 15 ft and installing thermometers. A heap temperature near 180°F should be allowed more time for cooling. Once the initial 15 ft is safe the height can gradually be increased. Reducing the ventilation is another method to reduce the risk of ignition.

The heaps should be constructed in layers and compacted with a road roller or bulldozer. Sawdust and sawmill waste should be mixed to avoid air contacting the layers. The writer advised being aware of sparks, hot ashes, and cigarette ends that may ignite the sawdust. A layer of earthen covering can provide protection against an accidental ignition and may reduce the ventilation if it is well compacted and remains intact.

15. The Application of Limestone and Lime Dust in the Abatement of Acidic Drainage in Centre County, Pennsylvania (1980)

In hopes of improving the water quality near Snow Shoe, Centre County, Pennsylvania a mixture of limestone fragments, lime flue dust, aged sawdust and vegetation was applied to the embankment surface. This report explains the project, but sawdust's contribution was not discussed.

16. The Engineering Properties of Wood Fiber Fills (1985)

The objective of this paper was to conduct tests to determine moisture and weight-volume relationships, strength and behavior under load, compressibility, and creep behavior of wood fiber fills. Triaxial strength and isotropic creep tests were performed to examine the properties mentioned above. Different types of wood products were cited as being used in the fills. Some types include sawdust, hogfuel, wood chips and planer chips. Tables presented density and strength data. A complete explanation of how the tests were run and the preparation needed to begin the testing is included in the report.

17. The Use of Wood Chips in Low-Volume Road Construction in the Great Lake States (1987)

Information in regard to the properties of wood chips and the construction procedures used in placing a wood chip fill were discussed in the paper. Wood chips were cited as providing a cost effective method to construct embankments over swamps. Not only is it lightweight, but maintenance cost and environmental damage are reduced. Supply of wood chips near the project is necessary for costs to be lower. Observations of some old logging railroads built over logs indicated if wood chips maintained water contact, and minimal air contact was allowed through a soil cover, then the fill might last 30 years. The moisture content percentage varied depending on the weather, a dry spell produced 41% compared to 61.8% from a summer shower. Even with 100% moisture content the wood chips were one-fourth the weight of the original soil fill.

The author noted that wood chips performed well under the complications of the road being used during construction. As the trucks crossed the road, the tires would sink about 4 to 6 in into the fill, but the chips would return to their original position once the truck passed. Current research has developed larger particles termed, wood chunks. Anticipation that wood chunks may be a good choice for road construction spurs from the various shapes and sizes and its low production costs.

18. Use of Lightweight Sawmill Residue in Highway Embankments (1980)

A possibility for a lightweight fill using sawmill residue was described. Provided the decomposition is controlled, the sawmill residue can provide a lightweight and inexpensive fill material. A polyethylene sheeting restricts the air contact and prevents rainwater from producing leachate. Due to the restricted oxygen, the aerobic substrate was made anaerobic. The author noted that the anaerobic breakdown of carbohydrates produced less heat than an aerobic breakdown, therefore the risk of spontaneous combustion was reduced. Tests were performed to determine the amount of compression given the proposed pavement loading. Density of fill depends on the wood species and initial wetness. Actual construction methods are provided in this paper. Temperature and gas sensing devices indicated a change from aerobic to anaerobic microbiological activity.

19. Use of Sawdust in Landslide Correction and Settlement Control (1984)

Properties of "sawdust" are discussed in this article. Advantages to using sawdust as a fill material were cited. Four of these advantages include a reduced driving force, a less dense material which reduces fill settlement, its durability as an all-weather material, and cost. Leachate and short term settlement once fill reaches full height are two disadvantages. Leachate characteristics include a high oxygen demand, low pH, brown color, and foul odor. Internal fill settlement was noted as ranging from 5 to 10% of the fill height. A soil cover over the sawdust fill minimizes the amount of oxygen reaching the sawdust to prevent a spontaneous combustion fire. Another method to prevent combustion and decomposition is applying an emulsified asphalt seal on the slope.

Different types of sawdust varied in their strengths. Planer chips and bark have high strengths, but wood chips from log chippers had low strengths.

Recommendations were given to control leachate such as reducing the water flow, controlling the materials selected for the fill, and containing the leachate. However, if the structure fails this last choice may be too risky.

20. Use of Sawdust on Forest Roads (1984)

Some specific locations where the U.S. Forest Service has constructed "sawdust" fills were described in this paper. Since 1976 the Mt. Baker-Snoqualmie National Forest used sawdust or woodwaste as solutions to stability and settlement problems. Roads in the Forest may be located over silts and clays that are subject to sliding. Case histories were given where slumping in the roadway was the result of sliding. Sulattle Road had incurred maintenance problems so the use of a lightweight sawdust embankment was suggested by FHWA. Monitoring of water quality at three sites for the leachate was performed. Test results showed that there was a gradual improvement in the water quality over time. Pavement deflections still continued to be greater than acceptable values. Since the completion in 1976 to the date of the paper there had been no slumping. A second study area, Bolt Creek Road had three changes made to the sawdust design. First, the fill slope was designed as 1-1/2:1. Secondly, asphalt emulsion was not used. Thirdly, no cutoff trench or underdrain was designed. It was noted that there has been no maintenance problems since completion in 1979. On Eldred Creek Road the landslide was so massive that the fill had no significant effect. Thus, it was concluded that reducing the weight of the fill by using sawdust had no effect. Design and construction for Ridgerunner Road included placing fill on the existing road.

North Fork Stilly Road was also reconstructed with sawdust. Laboratory tests indicated a maximum dry unit weight of 12 pcf and 45 pcf for a sample saturated 48 hours. Permeability tests indicated a permeable drainage layer behind and under sawdust fills should be included in the project. The author noted that overall, sawdust has worked well with little required maintenance. Low-cost and all-weather material characteristics were found as advantages in using sawdust.

21. Use of Wood Fiber in Lightweight Embankments for Northern Applications (1987)

The author addressed roadway construction over ice rich permafrost using wood fibre in an attempt to solve differential settlement. Characteristics of the wood are listed in the article. Site settlement was from the thermal degradation of ice rich permafrost. Difficulties arose when trying to analyze different fills that also have a variety of wood species present. Laboratory data was provided indicating a dry density of 20 pcf, and wet density of 40 to 60 pcf. Compression was found to strengthen the wood fibre. Pavement sections built on wood fibre fills were cited as commonly compressing 15% to 20% of the original volume.

Advantages of wood fibre were its relatively low density, more thermally resistive, available near construction sites, and cost. Disadvantages included leachate, spontaneous combustion and short term settlement.

A recommendation for controlling the compressibility involves surcharging with an asphalt treated base and to wait 2 to 8 months for it to stabilize. Then the wearing course can be applied. Methods to reduce the amount of air reaching the wood fibre were noted as installing polyethylene barriers and chemically treating the wood. Paving the wood fibre embankments out to the shoulder, treating the side slopes with asphalt and careful selection of the wood are suggested methods to reduce the leachate problem.

22. Water Quality Impacts Associated with Leachates from Highway Woodwastes Embankments (1980)

The leaching process that occurs to wood produces leachate that differs in its extractive composition depending on species and if it is wood or bark. Tests were performed on wood and recommendations were made from the results. The author noted that the pollutant concentrations rapidly increased to a peak value and then a low residual concentration was reached in an almost exponential manner. Measurements of organic pollutant concentrations are given in terms of BOD, Chemical Oxygen Demand (COD) and Total Organic Carbon (TOC). Reported ranges of peak values were 36 to 6640 mg/l BOD, 290 to 12,500 mg/l COD, and 850 to 8500 mg/l TOC. Acidity was another area of interest. Low pH values were caused by a high concentration of dissolved carbon dioxide and from soluble organic acids. Flow reduction, leachate treatment, and material control were three methods to avoid the danger of leachate. The experiments had three objectives. Finding the BOD, COD, and TOC, comparing peak and residual concentrations of BOD, COD, and TOC, and assessing if microbial activity was present. Site location for the laboratory data was a WSDOT project on SR-302 at Case Inlet. Leachate was routed through pipes and discharged on the beach. The underdrain system could not remove all the groundwater, so leachate built up in the fill, and eventually seeped out onto the beach face. Two different discolorations occurred a few months after leachate began to flow. From observations the author suggested that the dense growth of fungi, algae and bacteria was the cause for one type of discoloration. The remaining type was a predominately biological or chemical film. In experimental results the pH never returned to the original uncontaminated value. Two different leachating processes occurred for the project at Case Inlet. Taking into consideration the concentrations of pollutants and leachate volumes it is likely that they caused only minor changes in the water quality at Case Inlet.

Recommendations made from the above data included reducing the water inflow into the embankment, providing an adequate buffer zone between site and receiving water, using a different seal for the side slope rather than asphalt emulsion and soaking the woodwaste material, and treating the collected leachate.

23. Wick Drains, Membrane Reinforcement, and Lightweight Fill for Embankment Construction at Dumbarton (1982)

The construction of a lightweight fill over soft bay mud in California was presented in this paper. Sawdust was one feature used to build an embankment over soft bay mud to increase stability and reduce the weight. Placing the fill below the water level prevented problems with deterioration. An earth cover protected the fill from wind blown losses and also it added support. Trucks transported and D-6 dozers placed the sawdust.

The construction practices and specifications here are similar to those exercised by WSDOT. This specific project was successful over mud bays in California, but no recommendations were provided for upkeep or maintenance.

FIELD STUDIES

Each existing site having wood fibre fill was reviewed in the field to evaluate the long-term performance of the wood fibre. A brief description is provided below of each site reviewed. Figures containing a cross-section and sample profile are included for each project where wood fibre samples were obtained. Also described below are the year the wood fibre fill was constructed, a visual description of the wood fibre, the area surrounding the fill and the water quality. The side slope was used as a reference from which sample depths were measured.

Pavement ratings are cited in the text and also included in Appendix III for an overall evaluation of the subgrade performance. There are four major areas that were considered when rating the pavement. These were alligator cracking, longitudinal cracking, transverse cracking, and patching. Within alligator cracking three categories existed to describe the pavement which were hairline, spalling, and spalling and pumping. Depending on the width of a crack and/or the length of a patch points were subtracted from 100 to give an overall score of the roadway section.

Temperature readings, taken as a possible indication of decomposition, can be found in the text as well as Appendix III.

The BOD values measured for the site are useful as a site specific reference to adjacent non-impacted water. Due to the summer season, when samples were taken, difficulties were encountered when trying to locate water for the samples. Therefore some sites were not tested. However, there are some limitations due to the fact that a National Standard does not exist since each body of water must be evaluated individually to determine its allowable BOD level. Therefore the actual BOD values for the sites tested are not used for the purpose of analysis, but are useful for further reference and comparative site specific studies.

DECEPTION CREEK SR-2, MP 51.5 to MP 51.6

The site is located in a rural area in northwestern Washington. The highway directly crosses a peat bog. In 1980 an existing 11 ft high highway fill built over the peat bog was widened for a truck climbing lane. The foundation conditions consisted of 17 ft of peat underlain by dense sand and gravel as depicted on Figure 2. The purpose of this wood fibre fill was to achieve a stable fill and reduce settlement over the soft foundations. The fill experienced 3 ft of settlement during and after construction. Vegetation was plentiful with trees and flowers. The existence of phreatophytes predicted the presence of water in the fill area, and standing water is present during the winter.

Sampling was done in the toe area of the fill. A plastic sheath that separated the wood fibre from soft soil underneath had no free standing water during the field investigation, but the sample of wood fibre was wet. A sample taken at a depth of 1.7 ft, under a foot of topsoil, was almost fresh. A classification rating of 2 was given to the wood fibre which was in excellent condition with the exception that applied finger force could bend the material. The wood fibre temperature was measured to be 15°F lower than the soil temperature. Due to difficulties in locating water during the unusually dry summer, a water quality sample was not taken. A pavement rating of 80 was given for this research section compared to a 68 for the highway segment. However, a pavement patch covered over half the fill length affecting the section rating.

FRONTAGE ROAD IN KELSO I-5, MP 39.79 to MP 39.82

This project is located within the City of Kelso at the Allen Street Interchange. This frontage road was constructed over soft soils in 1977 as part of a larger project involving the adjacent highway, Interstate 5. The wood fibre was used to reduce settlement of an embankment placed on about 15 ft of medium dense sand underlain by 60 ft of soft organic silt. Trees, flowers and wild berries covered the side slope where the wood fibre was located under a very compacted 2.7 ft cover of soil.

The first wood fibre sample taken 2.7 ft below the ground surface, had decomposed a great amount, but a sample taken approximately 3.5 ft deeper or 6.5 ft below the surface was completely fresh. In the classification criteria these samples received ratings of 4 and 1, respectively. The temperature of a sample at a depth of 2.7 ft was about 5°F higher than the soil, but in contrast the 6.5 ft sample was lower than the soil's temperature by approximately 3 degrees. No water could be located in the vicinity of the fill for a sample. Roadway pavement inside and outside the fill area appeared excellent excluding a couple of cracks, therefore the research section rating was a 99. A comparison could not be made with recorded highway segment rating since the WSDOT rating was unavailable for this frontage road.

BAILA DIP SR-12, MP 2.48

This site is located in coastal western Washington near the City of Aberdeen. In 1974 a landslide in a fill area was repaired by constructing a lightweight wood fibre fill and the placement of horizontal drains. In July 1991 the old wood fibre fill was partially replaced and then widened with fresh wood fibre. Trees grew around the fill area but since reconstruction had begun the existing side slope had been removed.

Two samples of the 1974 wood fibre were obtained from the side slope before reconstruction at depths of 1.5 and 3.0 ft. Their classification ratings were 3 and 2 respectively. Visual observation of the 1.5 ft sample was that decomposition had begun, but the 3.5 ft sample appeared fresh and in good condition. At the time of reconstruction a wood fibre sample from the original project was taken 2.7 ft directly underneath the pavement. This sample was nearly fresh, receiving a classification rating of 2. A sample of the new wood fibre was also taken from the side slope that had been placed only 1 or 2 days previous that was completely fresh. Temperatures were not taken for the first two samples taken before reconstruction, but the old wood fibre under the roadway was 63°F and the exposed wood fibre was 71°F. Water draining from horizontal drains was clean and clear. Since reconstruction was in progress at the time field work was performed, the pavement was not rated.

BURLEY OLALLA ROAD SR-16, MP 25.15 to MP 25.32

Wood fibre fill was used as embankment material for up to a 20 ft high fill placed over peat and soft silts. The site is located in a rural area between the cities of Tacoma and Bremerton. Lightweight fill was placed over soft soil on SR-16 in 1976 to reduce settlement, from 4.5 ft for an earth fill to 1.5 ft for the wood fibre fill.

Above the wood fibre fill vegetation was plentiful with blackberries, dried grass, and small trees. Samples were taken approximately 25 ft from the fog line and approximately 15 ft below the top height of the berm shown on Figure 5. The berm reached a height of 3 feet above the pavement and in some places dropped off exposing over 3 ft of the compacted earth cover. Samples were taken under a 2 ft compacted earth cover at depths of 2.5 ft and 4.4 ft. Both samples were fresh and received ratings of 1. Ground above the hole where samples were obtained was 60°F compared to 71°F for the first wood fibre sample at 2.5 ft. Water was not available to be tested.

The pavement over the fill area was given a rating of 94 compared to an 89 for the highway segment.

PORT DOCK TO FOWLER SR-101, MP 57.6 to MP 57.8

This site is located within the City of Raymond. The wood fibre was used to construct an embankment over soft silty clays that extended to depths of 30 ft. To solve the difficulties of constructing a four lane roadway over soft soils in Raymond in 1976, the wood fibre was used to reduce settlement and achieve stability. A design section is shown in Figure 6. To monitor the possibility of a spontaneous combustion fire, thermistors were placed during construction. One of the three monitored thermistors quit functioning soon after monitoring began. The remaining two experienced an initial temperature increase, but within a year a safe temperature was reached.

The earth cover over the wood fibre was found to be a depth of 2.5 ft. Vegetation was plentiful including phreatophytes in the fill area indicating the presence of water. Of the two samples collected at depths of 2.7 and 3.9 ft beneath the fill slope, both were classified as a 2. Temperatures of the collected samples were 62.1°F and 63.4°F, respectively and the soil was 61.9°F. Flowing water at the base of the fill looked clean and pure.

Pavement patching was found to cover an area where settlement had occurred. Research ratings for the section were 80 for both the right and left lanes compared to the highway segment ratings of a 46 for the right lanes and 65 for the left lanes.

Overall the four lane roadway through the city rides and has performed well. The sixteen year old wood fibre is in excellent condition.

ROCK CRUSHER HILL SR-101, MP 72.7

The wood fibre fill located at Rock Crusher Hill was constructed as an earth replacement embankment to stabilize a landslide in 1978. The highway is located at the head of a major ancient landslide. Relatively local instability had occurred for years. The wood fibre fill was used to reduce the driving forces at the head of the landslide. The average depth of fill is 25 ft. Geo-drains were placed at the base of the lightweight fill to control seepage into the wood fibre and reduce the water level in the slide mass. A two foot earth cover was placed over the wood fibre and was found still to be in good condition. Flowers, small trees, and wild berries grew in the vicinity.

A wood fibre sample, near the soil cover, at a depth of 2.4 ft had decomposed more than a sample taken less than a foot deeper. Samples received a classification of 3 and 2 respectively. Temperatures for the wood fibre sample depths of 2.4 ft and 3.2 ft were 64.0°F and 62.0°F, respectively and the soil temperature was 61.0°F. A difference in temperature between the soil and samples was a maximum of 3°F. To collect water for a leachate sample, a hole was dug at the base of the fill. The location was typical having many trees and decomposing vegetation. A roadway patch covered the pavement in the section where the wood fibre was located, but there was little cracking in the patch. Pavement ratings were a 92 for the research section over the wood fibre and a 65 for the highway segment. Visual observations noted that soil was pulling away from the guard rail posts.

COSMOPOLIS HILL SR-101

Intending to stabilize landslide areas along SR-101 and SR-12, seven wood fibre fills were constructed in 1976. The following six fills, identified by state milepost location, are part of a large project on SR-101: MP 71.77, 71.9, 77.27, 77.35, 77.61, 77.97. This portion of SR-101 is located generally along the mid-Washington coast between the cities of Raymond and Aberdeen. The remaining fill is located on Aberdeen Bluffs on SR-12 at MP 1.39. Field study descriptions for the individual sites are provided below.

MP 71.77

This site is the location of a shallow slump in a fill section caused by saturation of the slope. The landslide debris was removed and the slope rebuilt with wood fibre. During this field review vegetation was found to encompass the most southern fill with phreatophytes, trees and flowers.

Over 2.5 ft of asphalt covered the 8.35 ft fill. Wood fibre revealed by a backhoe was warm to the touch and some steam could be seen coming off the wood fibre. Actual temperature for the wood fibre was 84.1°F compared to 77.9°F for the nearby rocks. The wood fibre was still in good condition, although decomposition had begun in the collected sample therefore a rating of 3 was given. No cracking existed in the overlay above this wood fibre fill giving a research section rating of 100 compared to the highway segment rating of 46. There was no effluent at this site to be tested.

MP 71.9

This landslide involves the entire roadway section consisting of a 30 ft to 40 ft high fill. Wood fibre was used to reconstruct the fill to a depth of 8 ft and reduce the driving forces of the slide mass. Samples were taken from the sideslope under an asphalt emulsion cover of 0.8 ft and topsoil of 0.2 ft. Trees, plants, and grass covered the slope area where the samples were taken.

The first sample taken at a depth of 1.8 ft was in advanced stages of decomposition and received a classification rating of 4. A sample taken at 4 ft was almost fresh with a rating of 2. Recorded temperatures were 65.0°F for the soil, 74.3°F for wood fibre at a depth of 1.8 ft, and 73.8°F for wood fibre at a depth of 4.0 ft. A water sample was taken from a small stream below the fill area where organic material was present, but water appeared clean. Above this area a patch covered the roadway, but outside this area the pavement appeared to be in good condition. Scores for the pavement were an 84 for the research section and a 46 for the pavement section. Visual observations noted that the side slope looked to be breaking apart in "steps".

MP 77.27

This area was the location of a mudflow-like landslide caused primarily by a cross culvert draining onto a partially unstable fill. The culvert was relocated and the fill reconstructed using wood fibre.

The wood fibre at this location had experienced more decomposition than MP 71.77 and 71.9. No vegetation grew over the asphalt emulsion seal that covered the 18.35 ft depth of wood fibre. A classification of 4 was given for samples taken at depths of 1.3 and 3.3 ft. Little difference existed between the small amount of soil located above the samples and the sample temperatures. The wood fibre samples taken at depths of 1.3 and 3.3 ft had temperatures of 75.3°F and 76.4°F, compared to a temperature of 72.1°F for the soil. No standing water was in the fill, but the wood fibre was wet. A pavement rating of 84 was given for the research section over wood fibre where a patch with no cracks covered the section. Comparatively, the highway segment received a rating of 46. Even though the samples mentioned above were no longer fresh, the side slope still has maintained its original shape without sloughing.

MP 77.35

This location is the site of a large but local fill failure on the upper reaches of an ancient landslide. The landslide was unloaded and a portion of the fill rebuilt with wood fibre. The 13.3 ft of wood fibre was protected with an asphalt/topsoil sealed slope.

Samples of wood fibre taken at depths of 0.5 and 2.5 ft were classified as 3 and 2. Samples taken at the same time but approximately 5 feet away at depths of 0.5 and 3.2 ft also received ratings of 3 and 2, respectively. Temperatures were not taken when samples were obtained, but the wood fibre appeared in good condition. Water from drainage pipes approximately 25 ft from the fill area was clean and pure. A patch covered the pavement in the right lane where the 13.3 ft of lightweight fill was located. The pavement research section over the wood fibre fill was intact and had no cracking, therefore receiving an 88 for a score. In contrast the highway segment was given a 46. The guard rail was bent and cracked where the soil was pulling away from the pavement.

MP 77.61

This landslide is similar to others above, where the highway transverses across the upper area of a very large ancient landslide. The great majority of the slide lies below the roadway and is massive making stability of the whole area virtually impossible. To correct the local slide the fill was rebuilt with wood fibre. Vegetation scantly covered the side slope where the wood fibre was located for this individual site. During construction the side slope was treated with asphalt emulsion to provide a protective cover.

A sample under the protective cover and soil at a 3 ft depth was classified as a 3. Temperature readings were not taken at the time field work was performed. The pavement ratings for this wood fibre fill were the same as MP 77.35 which were 88 for the wood fibre research section and 46 for the highway segment. Soil appeared to be pulling away from the guard rail.

MP 77.97

This area is again similar to the above with a fill placed across the upper reaches of a landslide. Wood fibre was used to reduce the driving forces of the slide. The side slope of the this wood fibre fill had a large quantity of asphalt, base coarse, gravel base and wood fibre exposed. Trees and grass grew outside the exposed face on the side slope.

A sample of wood fibre taken at a depth of 3.2 ft was completely fresh. A classification of 1 was given. This sample had a temperature of 66.8°F and the surrounding soil had a temperature of 68.8°F. No water could be located for a leachate sample. A pavement patch in the inner right lane experienced some cracking, while the far right lane and guard rail had failed again as part of the larger landslide movement. A research section rating for the inner right lane received a 90 compared to a 46 for the entire highway segment.

ABERDEEN BLUFFS SR-12, MP 1.39

This site was the location of a washout necessitating rebuilding of the fill slope. A 6 ft high gabion wall was placed at the toe of fill and approximately 20 ft of wood fibre fill placed above. The slope was sealed with a 1 ft asphalt emulsion and soil cover. No vegetation grew on the asphalt emulsion cover, but phreatophytes, flowers, and bushes grew outside the fill area.

The fill consisted of large chips mixed with small wood fibre material that remained almost fresh. A classification of 2 was given for a sample at a depth of 2.2 ft. Temperature readings were 69.9°F for the wood fibre sample and 71.6°F for the soil. Water was collected below the gabion wall from a small pool of collected water. The water sample had a lot of silt and duck weed present, but still had a relatively low BOD. Resurfacing done recently resulted in the roadway being in excellent condition. Consequently the research section over the wood fibre had a pavement rating value of 100 and the highway section also had rating of 100.

EMERGENCY REPAIR SR-101, MP 78.02

This location is where the first wood fibre fill was constructed in 1972 to fix an emergency slide. The area is a cut/fill section on the head portion of a large ancient landslide. A shoulder drop off due to shallow slumping in the 1:1 wood fibre fill slope left wood fibre exposed. Even though exposed, the wood fibre remained intact and was in excellent condition with a classification of 2 for both samples taken at depths of 2.1 and 3.0 ft. Temperatures here were much higher than other site locations. The samples taken at 2.1 and 3 ft depths were 83.1°F and 85.3°F, respectively. These temperatures were almost 13°F higher than the surrounding soil which was 72.4°F. Steam came out as the hole was dug. Similar to most of the fills on SR-101, no water could be located. A patch covered the remaining right lane giving a section pavement rating of 92, but in comparison the pavement segment for the entire pavement had a rating of 60.

COSMOPOLIS TO SR-107 SR-101, MP 78.1

At a location of only one-tenth of a mile north of the emergency repair a second wood fibre fill was constructed in 1973. The site conditions are a similar cut/fill section as at MP 78.02. The outside truck climbing lane has had recent movement due to the large ancient slide moving. Several layers of patching were exposed on the side slope as repairs to the slide movement.

A sample taken at a depth of 2.5 ft had remained intact, yielding a classification of 3 for this vicinity. Only a small amount of decomposition was present when visually observed. A minimal temperature difference of

1.4°F separated the soil and wood fibre, that had temperatures of 65.6°F and 67.0°F, respectively. No water could be found for a water quality sample. The pavement research section was in good condition with a rating of 90, but the highway segment had a rating of 60. As logging trucks travelled southward, vibrations could be felt under foot when standing on outer right lane which was blocked off.

SR-107 TO COSMOPOLIS SR-101, MP 79.2

Wood fibre was used at this site as part of realignment and reconstruction of the highway across a landslide area. Wood fibre was used to minimize applied loads to existing marginally stable slopes.

Under an earth cover of one foot samples taken at depths of 3 and 4 ft looked completely fresh with a classification rating of 1 for both depths. Temperatures were not taken at the time samples were obtained. Water for the water quality tests could not be located. A pavement patch with a few visible cracks received a research section rating of 92 compared to a highway segment rating of 44.

WEST HOQUIAM SR-109, MP 2.12 to MP 2.27

This lightweight fill was constructed in 1986 over very soft organic silt utilizing five layers of geosynthetics for reinforcement, Figure 12. Total fill height is 44 ft, crossing a valley floor of swampland. Foundation soils consist of about 40 ft of very soft to soft organic sandy silt. This was the most recent wood fibre fill studied. The sample site consisted of a very compacted, two foot topsoil layer covering the wood fibre. The 2:1 sideslope was covered with vegetation, dandelions, small trees and grass.

Samples taken at depths of 2.7, 3.5 and 4.5 ft were all classified as Class 2. Visual examination showed no signs of decomposition. The sample nearest the surface was 7.5 degrees above the soil's temperature of 65.8°F. The wood fibre samples were 73.3°F, 72.5°F and 69.9°F, respectively. At the base of the fill where vegetation was plentiful pools of water existed both in the upstream and downstream areas. Two water quality samples were taken. The first was taken below the fill area from one of the pools and the second water sample was taken above the fill area. The quality of water from the downstream area was better than the water upstream of the fill. The pavement appeared in excellent condition. Both the section and segment ratings were 100.

BOB WAIN HILL SR-109, MP 33.06 to MP 33.18

The fill at Bob Wain Hill, constructed in 1979, was unique from the other fills. Rather than a continuous fill of wood fibre, Bob Wain Hill has granular soil placed intermittently in layers in the wood fibre as shown in

Figure 13. The fill was placed to reconstruct a failed fill slope. The wood fibre was used to achieve a stable fill by reducing the load placed on the downslope area. The site has heavy vegetation consisting of trees and brush. Water in a near stagnant condition was located downslope of the fill area. A water sample appeared relatively clean compared to the overall appearance of the water, and was tested and had a low BOD. The pavement was in excellent condition. The pavement research section rating was a 99 due to one small crack compared to a 100 for the highway segment.

PT GRENVILLE SR-109, MP 36.58 to MP 36.75

Roadway problems at Pt. Grenville were landslide based. To provide stability and reduce the driving force a wood fibre fill was used in 1976 near the head area of the slide to improve local stability problems as shown in Figure 14. Large scale landslide correction was not attempted. Only 4 ft of wood fibre was used as a lightweight fill material which is less than all the other projects. A 0.5 ft cover of asphalt emulsion was placed to protect the surface of the wood fill from decay. Heavy uphill seepage flowed through the wood fibre keeping it wet.

Sample of wood fibre at 1.3 ft was completely fresh. Soil and sample temperatures were within a tenth of each other. A small amount of standing water was found amongst the trees and vegetation, but no water samples were taken due to outside factors impacting the water. A pavement rating was not made for this section due to recent large landslide movement.

VICTOR CUTOFF ROAD SR-302, MP 5.38 to MP 5.46

In 1978 wood fibre was used in order to establish stability in a vicinity where frequent landslide activity has previously occurred on SR-302. Wood fibre was used in a low fill section built just above high tide level of the Puget Sound. Currently, this area located on Case Inlet, has experienced continued landslide movement related to static liquefaction. As a consequence on the beach side of the fill the soil was pulling away which revealed about 1.5 ft of asphalt. Samples taken at two locations by a drill crew using hollow stem augers were semi-decomposed, but it appeared to get fresher as the depth of the sampling increased. At a depth of 1.5 ft the classification rating was a 4 and at 3.0 ft the rating was a 3. Temperature readings were not taken during the sampling. Water draining out of the fill was clear. No samples were obtained for water quality testing, but test results from lab work performed ten years previous (Vause, 21) noted only a minor degradation of the water quality occurred. Cracks extended through a pavement patch above the fill. A pavement rating was not given for this site due to landslide activity.

CEDAR CREEK SR-505, MP 14.2 to MP 14.3

Wood fibre was used at this site to correct local instability. The highway crosses the "head" of a long landslide extending downslope some 500 ft that was intermittently active. A typical cross section is shown in Figure 16. This project was unique in that common mill wood fibre was not available. For this project wood chips from a chipping machine were primarily used as the fill material.

Samples were taken under a 1.5 ft soil cover. Samples taken at 1.5 and 3.5 ft were both classified with a rating of 2. This site is where the greatest difference in temperature between the soil and the underlying wood fibre samples existed. The samples were 8 and 16 degrees, respectively, above the soil's temperature of 64.0°F. A water sample taken from a mixture of culvert water and its receiving pool of water looked clean and pure. Due to continued landslide activity of the larger massive slide a direct correlation between the pavement rating and the quality of the wood fibre cannot be made, so a rating was not given when field work was performed.

Performance of the wood fibre during construction was marginal with the chips. Construction equipment could not be driven through the chips, i.e. stability of the very uniform sized and shaped chips was poor. Interlock between the wood fibre was hard to achieve so specifications were later developed concerning the size and shape of the wood fibre material to avoid the problems encountered on this project.

CONCLUSION

The research conducted during this study verified the generally excellent life of wood fibre used in engineered fills for up to the twenty year period of emplacement. It was found that some sites had significant degradation of the wood fibre. Questions arose as to the quality of the wood fibre initially placed. Though not formally documented it is known within WSDOT that, particularly during the 1970's, the use of "aged" wood fibre was encouraged to lesson the danger of fire.

To evaluate the long-term performance of wood fibre, the site locations were separated into three categories ranging from greater than 15, 10-15, and 5-10 years old. The first range, or oldest, included three areas that remained nearly fresh. Even though the wood fibre at Baila Dip was replaced with fresh wood fibre material, the old wood fibre remained intact with only some degradation. Although the remaining two sites had wood fibre exposed on the side slope face, the material had performed well with minimal amount of decomposition in one area and a little more in the other.

The middle category, 10-15 years, ranged from fresh to almost decomposed. The classification scores varied between site locations and the depth of the fill from where samples were taken. Most samples taken deeper in the fill were fresher than those from the surface. Soil/earth, asphalt, and asphalt emulsion seals, placed on the wood fibre for protection varied in their performance. In general, sites with soil covers had better ratings indicating quasi-isolation protected the wood fibre and enhanced durability. Even though wood fibre at SR-109 Pt. Grenville was wet the collected wood fibre sample remained completely fresh. Yet, at SR-101 MP 77.27 the samples were also wet but in the process of decomposition. At Kelso, under a very compacted soil cover, the immediate wood fibre was highly decomposed but material underneath was completely fresh.

Recent fills, those built in the past 5 to 10 years, have remained intact and nearly fresh. One location was completely fresh while the remaining two locations were almost fresh. At Cedar Creek difficulties arose when interlock between the wood chips was not achieved. To avoid similar problems in the future specifications required the wood fibre material to be in various sizes with a maximum dimension of 6 inches and be interlocking.

Of the twenty-one sites tested for water quality twelve were not able to be tested for BOD levels due to the absence of water. Two sites appeared to have water flowing through the wood fibre. They had low BOD levels. Seven other sites had standing or flowing water nearby. Two of the twenty one sites had relatively higher BOD counts. At the SR-109 West Hoquiam site the adjacent downstream water tested better than the comparative reference sample taken upstream. There was an oily film in some stagnant pools. Yet the BOD count indicated no adverse impact. The other site that had a comparatively higher BOD level was the SR-101 Rock Crusher Hill site. Standing or flowing water was not present. A pit was dug, allowed to fill with groundwater, sampled, and tested. The BOD count was higher but inconclusive as to impact. A definite conclusion in regards to the water quality of these areas was not possible since enough data was not gathered as part of this durability study.

Pavement condition proved to be a good indication of the wood fibre's performance. Overall, stable roadway subgrades were evident in the wood fibre areas. Of the six fills over soft soils, three have pavement scores of 99 and above. Roadways over the landslide fills have patching or resurfacing, but most scores are in the high eighties and above.

During field sampling, eight in-situ densities were taken. Material for determining the in-situ densities under the protective covering were taken near the sideslope surface. These values ranged from approximately 29 to 62 pcf for moist, wet unit weights. Classification of these wood fibre samples varied from 1 to 4 but no relationship could be made to relate these scores to the density. Generally, the drier samples had lower densities compared to a higher density for the wetter material. This generalization applied to all but one sample that was wet but its in-place density was only 39 pcf. Care should be taken in using these densities for other purposes as higher densities would be expected deeper in the fill due to the relatively large compressibility of the material.

Research should be done in another 15-20 years to evaluate the rate of degradation of the wood. At that time the wood fibre may resemble the "old sawdust piles" previously studied (9) that have an outer seal of decomposed material protecting a fresh core. If the fills follow this pattern then a possible prediction would be that significant decomposition will not occur. On the other hand if more decomposition is occurring then research could be done on the quality and types of seals being used.

Settlement is a factor taken into account when designing a lightweight fill. Installing settlement devices in controlled fills in both the soil and fill during construction is needed to better define settlement characteristics of the wood and would provide data for future designs. Individual data for the soil and fill enables a more precise value of the fill's contribution to the overall settlement to be determined.

Further research should be done on the effects of water on wood strength. Since some of the fills had a large amount of water it would be valuable to know if any strength is lost when the wood soaks in the enclosed water.

RECOMMENDATIONS

The up to twenty year history of successful usage of wood fibre on Washington State Department of Transportation projects as engineered fills implies that its usage should continue for lightweight fills. Degradation of some fills documented in this research indicates wood fibre may have a finite lifespan as an engineered material in some situations. Usage on high volume "lifeline" roadways, where repairs are prohibitive, should be considered carefully. Usage on major roadways of moderate volume, or less critical roadways, should be considered as acceptable. The typical 2 ft pavement section was found to perform generally better over the wood fibre sections than adjacent earth fill areas, and its continued use is recommended.

The following technical guidelines are suggested for continued usage of engineered wood fibre fills:

1. For areas of similar climate to western Washington only fresh wood fibre should be used to build the fill. This will prolong the lifespan of the fill.

2. To mitigate the effects of wood leachate the volume of water entering the wood should be controlled so that a minimum of water flow occurs.

3. Fill slopes of 1.5H:1V or flatter with a two foot soil cover are recommended to reduce the decay of the wood and lesson fire danger.

4. A minimum two foot pavement section should be used.

5. Wood fibre should be specified to be irregular in shape and size to facilitate good interlock and result in stability.

IMPLEMENTATION

The research investigation performed documents the excellent long-term performance of wood fibre fills. Wood fibre should continue to be considered as a viable option where lightweight engineered fills are warranted.

Continued monitoring of all wood fibre fills should be undertaken to verify their structural quality over their full design life. The following fills showing greatest level of decay warrant further review approximately every four years:

A. SR-101, MP 71.9

B. SR-101, MP 77.27

C. SR-302, Victor Cutoff Road

ACKNOWLEDGEMENTS

The authors wish to thank John Hart, WSDOT Project Engineer, for long standing contributions in the development of wood fibre usage, and assistance on this project. Also appreciated for their assistance during this project are fellow WSDOT employees David Jenkins, Keith Anderson, and LeRoy Wilson.

REFERENCES

1. Schermer, E.D. and Phipps, J.B., "A Study of Woodwaste Leachate," Choker Research, Grays Harbor College, 1976.

2. Jackson, N.C., "A Summary of the Use of Sawdust for Highway Fills," Washington State Department of Transportation Report No. 157, 1979.

3. Tuttle, J.K., "Bark Spoil Disposal Consultation," Dames and Moore, 1972, unpublished.

4. Pease, B.C., "Effects of Log Dumping and Rafting on the Marine Environment of Southeast Alaska," General Technical Report PNW-22, 1974.

5. Ladd, C.C., Aldrich, H.P. Jr. and Johnson, E.G., "Embankment Failure on Organic Clay," Soil Mechanics and Foundation Engineering Conference Proceedings, pp 627-634, 1969.

6. Sotir, R.B. and Gray, D.H. Ph.D., "Fill Slope Repair Using Soil Bioengineering Systems," Public Works, pp 37-40 & 77, 1989.

7. Lea, N.D. and Brawner, C.O., "Highway Design and Construction Over Peat Deposits in Lower British Columbia," 42nd Annual Meeting of the Highway Research Board, 1966.

8. Wilson, L.D., "Lightweight Fill," 1977, unpublished.

9. Hart, J.L., "Lightweight Fill Using 100% Wood Fibre," Washington Department of Highways, unpublished.

10. Nelson, D.S. and Allen, W.L. Jr., "Sawdust as Lightweight Fill Material," Highway Focus, Vol. 6, No. 3, pp 53-66, 1974.

11. Robinson, J.R., "Sawdust Embankment," Highway Focus, Vol. 8, No. 3, 1976, pp 106-112.

12. Carras, J.M., "Spontaneous Combustion in Wood Waste Landfills," Intra-Departmental Communication, 1977, unpublished.

13. Armstrong, J., "Spontaneous Combustion of Forest Fuels: A Review," Forest Fire Research Institute, Ottawa, Ontario, Information Report FF-X-42, 1973.

14. Bowes, P.C., Spontaneous Heating and Ignition in Sawdust Heaps, "Wood", 1956.

15. Waddell, R.K. Jr., Parizek, R.R., Buss, D.R., "The Application of Limestone and Lime Dust in the Abatement of Acidic Drainage in Centre County, Pennsylvania," The Pennsylvania State University, Research Project 73-9, 1980.

16. Cox, P.B., "The Engineering Properties of Wood Fiber Fills," University of Idaho Graduate School Master Thesis, 1985.

17. Bowman, J.K., Lidell, R.B. and Schulze, G.B., "The Use of Wood Chips in Low-Volume Road Construction in the Great Lake States," Transportation Research Record 1106, pp 47-58, 1987.

18. Smith, R.S. and Coulter, T.S., "Use of Lightweight Sawmill Residue in Highway Embankments," RTAC Forum, Vol. 3, No. 1, pp 84-89, 1980.

19. Kilian, A.P., "Use of Sawdust in Landslide Correction and Settlement Control," 35th Annual Road Builders' Clinic Proceedings, 1984.

20. Buss, K.G., "Use of Sawdust on Forest Roads," 35th Annual Road Builders' Clinic Proceedings, 1984.

21. McMahon, R.J., "Use of Wood Fiber in Lightweight Embankments for Northern Applications," The Northern Engineer, Vol. 19, No. 3 and 4, pp 35-39, 1987.

22. Vause, K.H., "Water Quality Impacts Associated with Leachates from Highway Woodwastes Embankments," A Washington State Department of Transportation Research Report WA-RD-39.1, 1980.

23. Hannon, J.B. and Walsh, T.J., "Wick Drains, Membrane Reinforcement, and Lightweight Fill for Embankment Construction at Dumbarton," Transportation Research Record 897, pp 37-42, 1982.

APPENDIX I

WOOD FIBRE PROJECT INVENTORY

APPENDIX I

WOOD FIBRE PROJECT INVENTORY

SR	PROJECT	DATE	APPLICATION	WOOD DEPTH	FIBRE LENGTH
002	SKYKOMISH WYE	1980	Soft soils	11′	800′
005	KELSO FRONTAGE ROAD	1977	Soft soils	30′	1285′
012	WASHOUT AT ABERDEEN	1976	Landslide correction	20′	100′
012	BAILA DIP	1974	Landslide correction	15′	310′
016	BURLEY OLALLA RD.	1976	Soft soils	20′	900′
101	PORT DOCK TO FOWLER	1976	Soft soils	20′	950′
101	COSMOPOLIS HILL MP 71.77	1976	Landslide correction	8.35′	90′
101	COSMOPOLIS HILL MP 71.90	1976	Landslide correction	8.35′	132′
101	ROCK CRUSHER HILL	1978	Landslide correction	25′	360′
101	COSMOPOLIS HILL MP 77.27	1976	Landslide correction	18.35′	120′
101	COSMOPOLIS HILL MP 77.35	1976	Landslide correction	13.35′	272′
101	COSMOPOLIS HILL MP 77.61	1976	Landslide correction	8.35′	178′
101	COSMOPOLIS HILL MP 77.97	1976	Landslide correction	8.35′	260′
101	COSMOPOLIS EMERGENCY REPAIR	1972	Landslide correction		
101	COSMOPOLIS TO SR 107	1973	Landslide correction	10′	250′
101	SR 107 TO COSMOPOLIS	1982	Landslide correction	10′	70′
109	WEST HOQUIAM	1986	Soft soils	35′	810′
109	BOB WAIN HILL	1979	Soft soils	10′	625′
109	PT. GRENVILLE	1976	Landslide correction	4′	900′
302	VICTOR CUTOFF RD.	1978	Landslide correction	10′	450′
505	CEDAR CREEK SLIDE	1982	Landslide correction	15′	500′

APPENDIX II

WOOD FIBRE CLASSIFICATION CRITERIA

APPENDIX II

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION WOOD FIBRE CLASSIFICATION CRITERIA

CLASS	GENERAL APPEARANCE	APPEARANCE OF DECAY[a,b]	PARTICLE STRENGTH (BREAKING)[c,d]	PARTICLE STIFFNESS (BENDING CAPACITY)[d]
1	WOODLIKE, SHARPLY DEFINED GRAININESS	FRESH: SHARP COLOR, FRESH WOODY SMELL, NO DISINTEGRATION	CANNOT BE BROKEN WITH FINGERS	RETAINS ITS SHAPE WITH FORCE
2	3/4 MATERIAL IS WOODLIKE, WELL DEFINED GRAININESS	INITIAL SIGNS OF DECOMPOSITION: DISTINCT COLOR, DEFINITE WOOD SMELL, VERY LITTLE DISINTEGRATION OF WOOD FIBRES	VERY DIFFICULT TO BREAK WITH FINGERS	EASILY RETURNS TO ORIGINAL SHAPE WITH RELEASE OF FORCE
3	1/2 MATERIAL IS WOODLIKE, COMPLETE, BUT POORLY, DEFINED GRAININESS	MIDDLE STAGE OF DECOMPOSITION: FADING COLOR, WEAK WOOD SMELL, SOME DISINTEGRATION OF WOOD FIBRES	BREAKS WITH FIRM FINGER FORCE	SHAPE IS PERMANENTLY, BUT SLIGHTLY DISTORTED WITH FORCE
4	1/4 MATERIAL IS WOODLIKE, ONLY PARTIAL GRAININESS REMAINS	ADVANCED STAGE OF DECOMPOSITION: FADED COLOR, ORGANIC SMELL, MOSTLY DISINTEGRATED	BREAKS EASILY WITH FINGERS	SHAPE IS PERMANENTLY DISTORTED WITH FORCE
5	NO LONGER WOODLIKE, NO GRAININESS	COMPLETELY DECOMPOSED: DULL COLOR, FOUL SMELL, COMPLETELY DISINTEGRATED	SQUEEZES BETWEEN FINGERS	NO LONGER RETURNS TO ORIGINAL SHAPE, SPONGY

a primary emphasis is on disintegration
b all discriptors may not apply
c standard testing size is 2" x 1/2" x 3/8"
d moisture content for tested sample is "wet to touch"

CLASSIFICATION CRITERIA

The classification criteria developed to rate the wood fibre's current condition was based on four categories. These categories followed a progressive description from fresh to completely decomposed. General Appearance was used to describe the wood fibre on a macro scale, compared to the Appearance of Decay that considered the micro scale.

Visual observations of the wood fibre's grain quality was the basis for determining the General Appearance rating. Appearance of Decay used discriptors indicating the amount of decomposition ranging from fresh to completely decomposed, followed by in-depth visual observations such as the color, smell, and amount of disintegration. Of these four discriptors, the primary emphasis was on the amount of disintegration. However, not all of the discriptors may apply to a specific sample of wood fibre. If this situation arose then the remaining discriptors determine the quality of the wood fibre.

Wood fibre's material properties were determined by its strength and stiffness. Selected pieces of wood fibre that were not saturated, or dry, but were "wet to touch", and approximately fit the dimensions of 2" x 1/2" x 3/8" were used to test material properties by applying finger force. Some samples may not have pieces fulfilling the moisture content and dimension requirements and if this situation occurred then the remaining criteria was used to determine the wood fibre's quality.

APPENDIX III

WOOD FIBRE PROJECT SUMMARY

APPENDIX III

WOOD FIBRE PROJECT SUMMARY

SR	PROJECT	DEPTH	CLASS	TEMP F	DENSITY pcf *	PAVEMENT RATING SECTION(SEGMENT)
2	Skykomish Wye	1.7'	2	58.6	51	80 (68)
		soil		74.1		
5	Kelso Frontage Rd	2.7'	4	71.5		99 (NA)
		6.5'	1	63.3		
		soil		66.0		
12	Washout at Aberdeen	2.2'	2	69.9		100 (100)
		soil		71.6		
12	Baila Dip	2.7'	2	63.0		none
	site 1	new	1	71.0		
		1.5'	3			
	site 2	3.0'	2			
		air		62.0		
16	Burley Olalla Rd.	2.5'	1	71	29	94 (89)
		4.4'	1	--		
		soil		60.0		
101	Port Dock to Fowler	2.7'	2	62.1	35	RT 80 (46)
		3.9'	2	63.4		LT 80 (65)
		soil		61.9		
101	Rock Crusher Hill	2.4'	3	64.0		92 (65)
		3.2'	2	62.0		
		soil		61.0		
101	Cosmopolis Hill					
	MP 71.77	4.8'	3	84.1	62	100 (46)
		rocks		77.9		
	MP 71.9	1.8'	4	74.3	33	84 (46)
		4.0'	2	73.8		
		soil		65.0		
	MP 77.27	1.3'	4	75.3	38	84 (46)
		3.3'	4	76.4		
		soil		72.1		
	MP 77.35	#1 0.5'	3	none		88 (46)
		2.5'	2			
		#2 0.5'	3			
		3.2'	2			
	MP 77.61	3.0'	3	none		88 (46)
	MP 77.97	3.2'	1	66.8		90 (46)
		soil		68.8		

* In-place, moist densities

APPENDIX III

WOOD FIBRE PROJECT SUMMARY

SR	PROJECT	DEPTH	CLASS	TEMP F	DENSITY pcf *	PAVEMENT RATING SECTION(SEGMENT)
101	Emergency Repair	2.1′	2	83.1		92 (60)
		3.0′	2	85.3		
		soil		72.4		
101	Cosmopolis to SR 107	2.5′	3	67.0		90 (60)
		soil		65.6		
101	SR 107 to Cosmopolis	3.0′	1	none		92 (44)
		4.0′	1			
109	West Hoquiam	2.7′	2	73.3	38	100 (100)
		3.5′	2	72.5		
		4.5′	2	69.9		
		soil		65.8		
109	Bob Wain Hill	none				99 (100)
109	Pt. Grenville	1.3′	1	60.5	21	none
		soil		60.6		
302	Victor Cutoff Rd.	1.5′	4	none		none
		3.0′	3			
505	Cedar Creek Slide	1.5′	2	72.0		none
		3.5′	2	80.0		
		soil		64.0		

* In-place, moist densities

APPENDIX IV

FIGURES

WOOD FIBRE FILL SAMPLE SITES

SR-2	Skykomish Wye to Deception Creek
I-5	Kelso Frontage Road
SR-12	Baila Dip
SR-16	Burley Olalla Road
SR-101	Port Dock to Fowler
SR-101	Rock Crusher Hill
SR-101	Cosmopolis Hill & Washout at Aberdeen
SR-101	Emergency Repair at MP 78.02
SR-101	Cosmopolis to SR 107
SR-101	SR 107 to Cosmopolis
SR-109	West Hoquiam
SR-109	Bob Wain Hill
SR-109	Pt. Grenville
SR-302	Victor Cutoff Road
SR-505	Cedar Creek Slide

SR 2

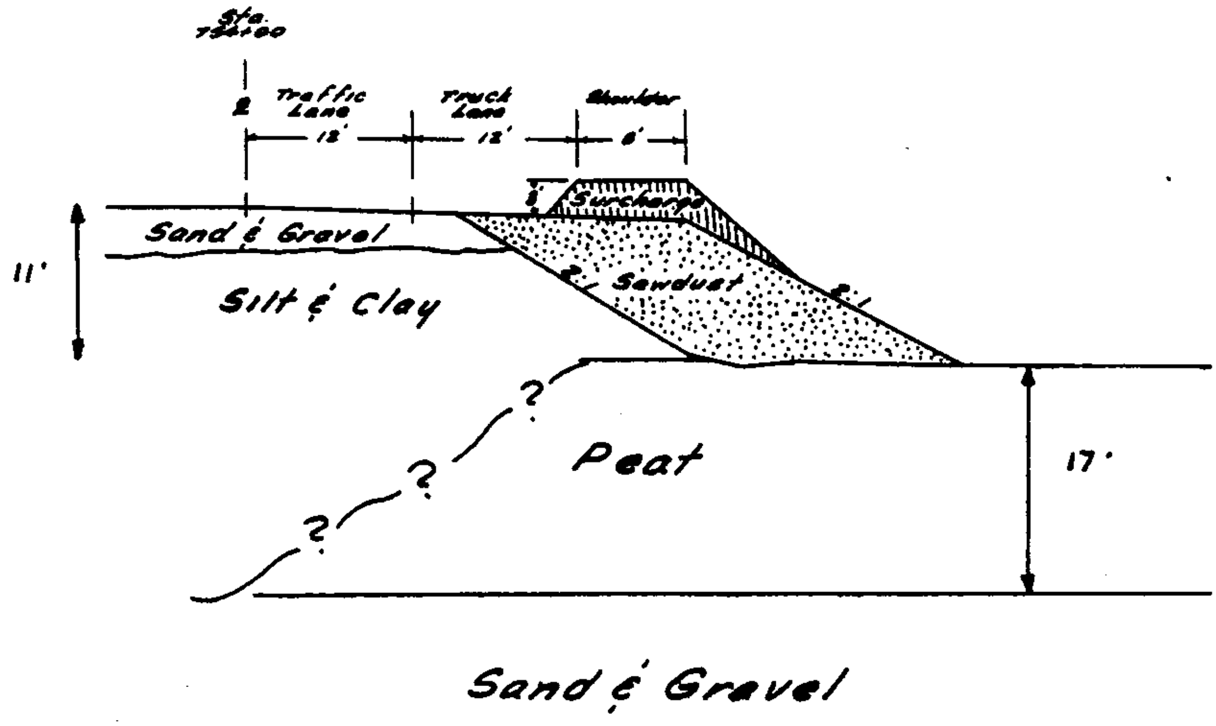
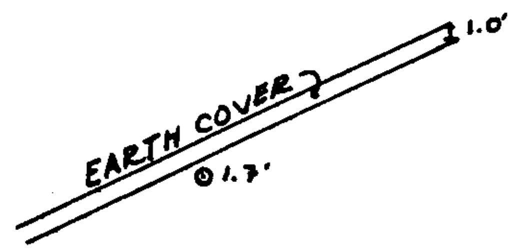


FIGURE 2

Skykomish Wye to Deception Creek

MP 51.5 to MP 51.6



I-5

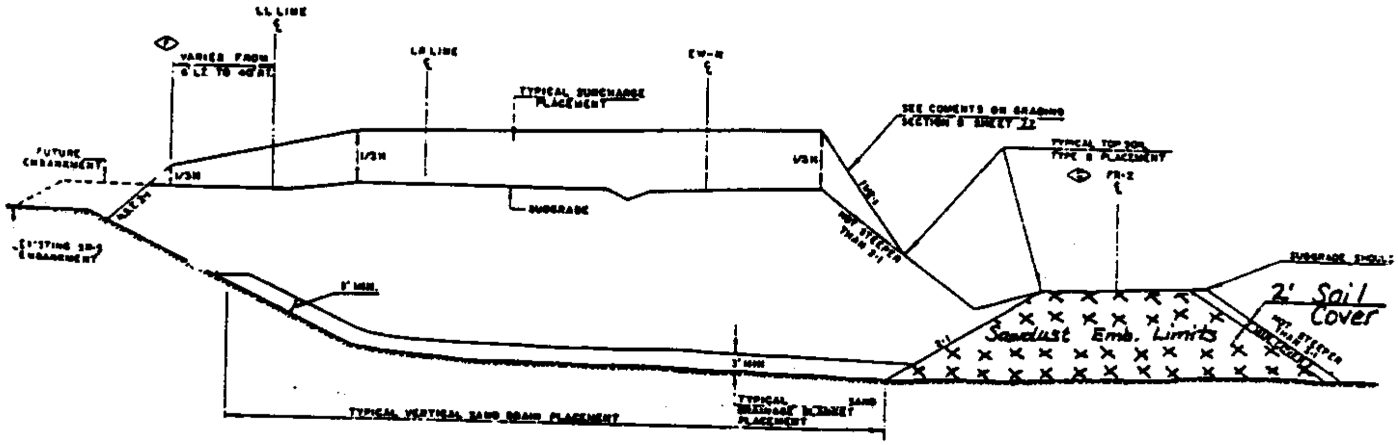
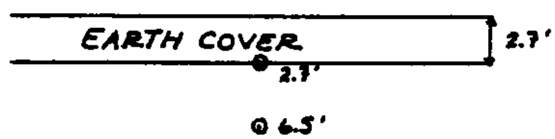


FIGURE 3
Kelso Frontage Road
MP 39.79 to MP 39.82



SR 12

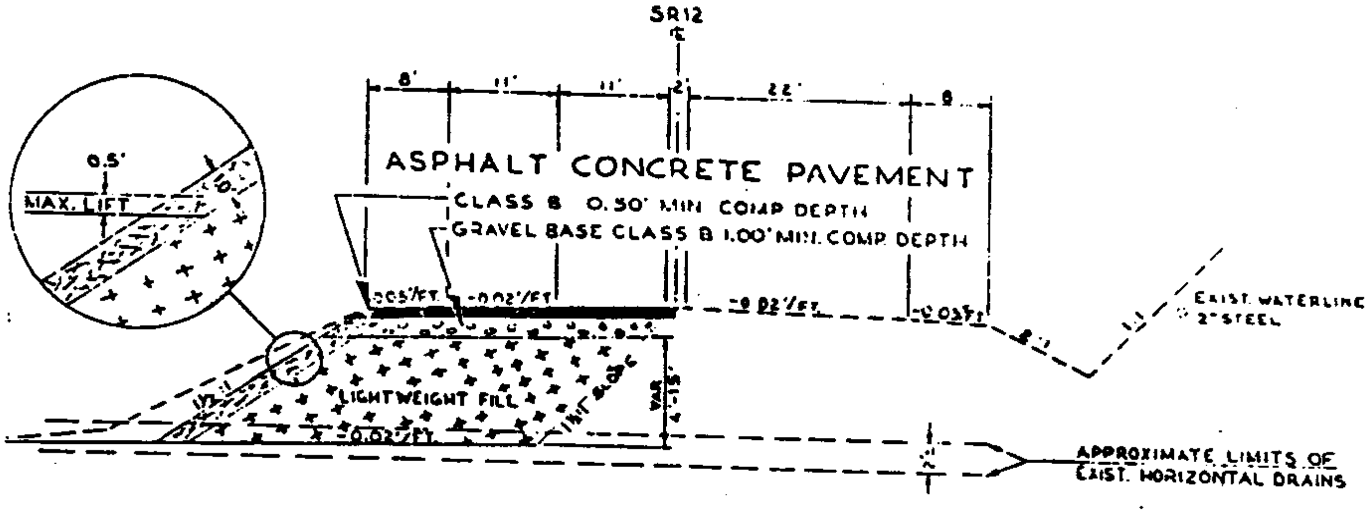
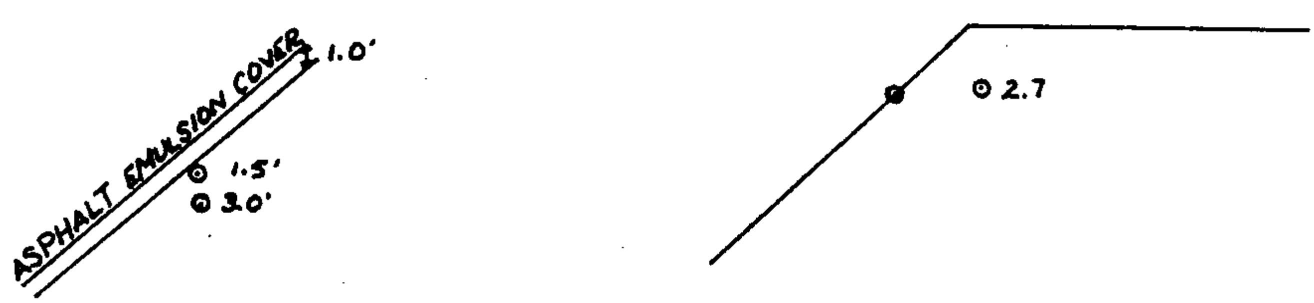


FIGURE 4
Baila Dip
MP 2.4B



site 2 site 1

SR 16

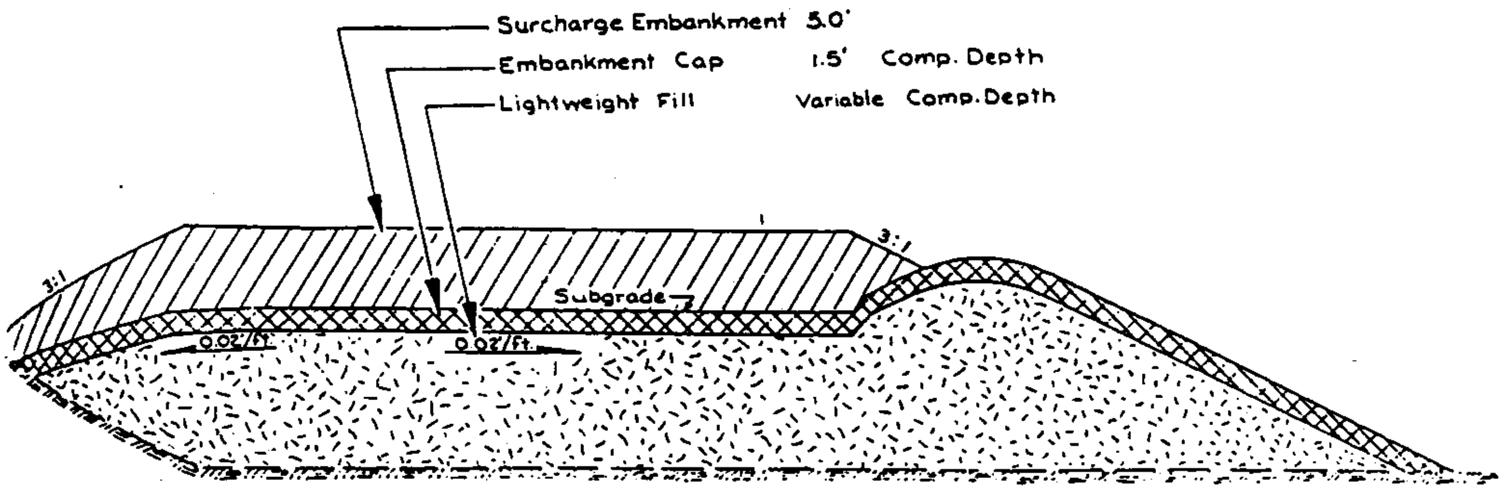
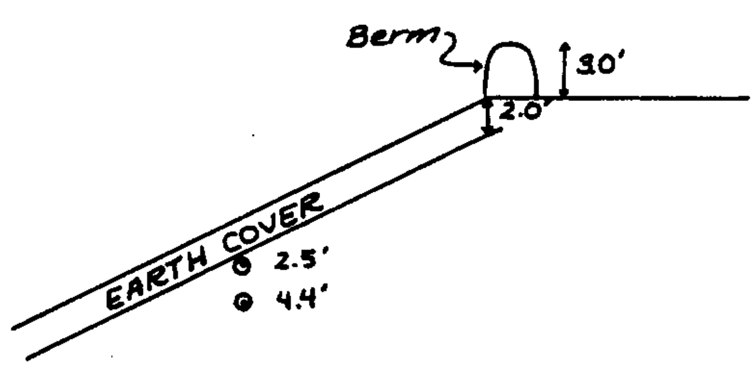
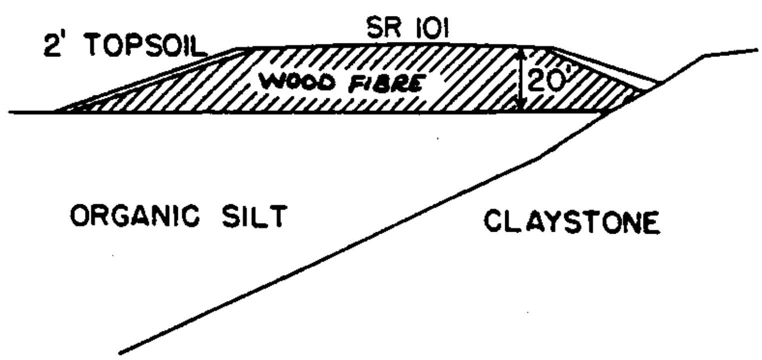


FIGURE 5
Burley Olalla Road
MP 25.45 to MP 25.60



SR 101



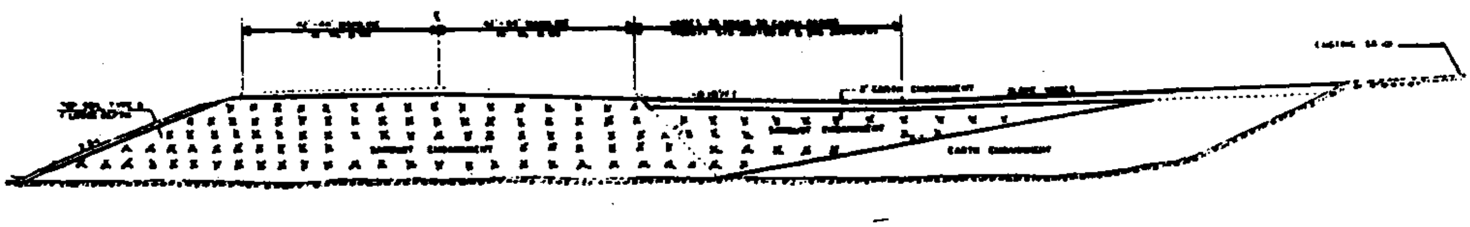
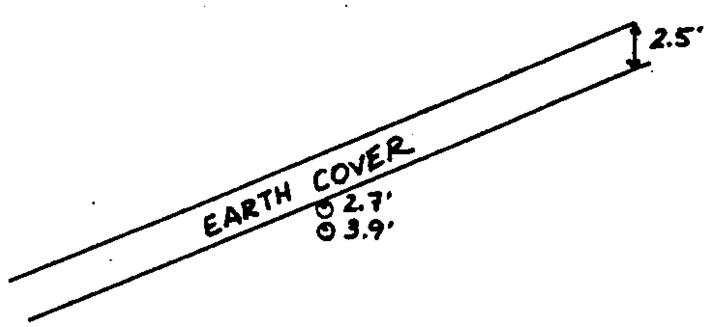
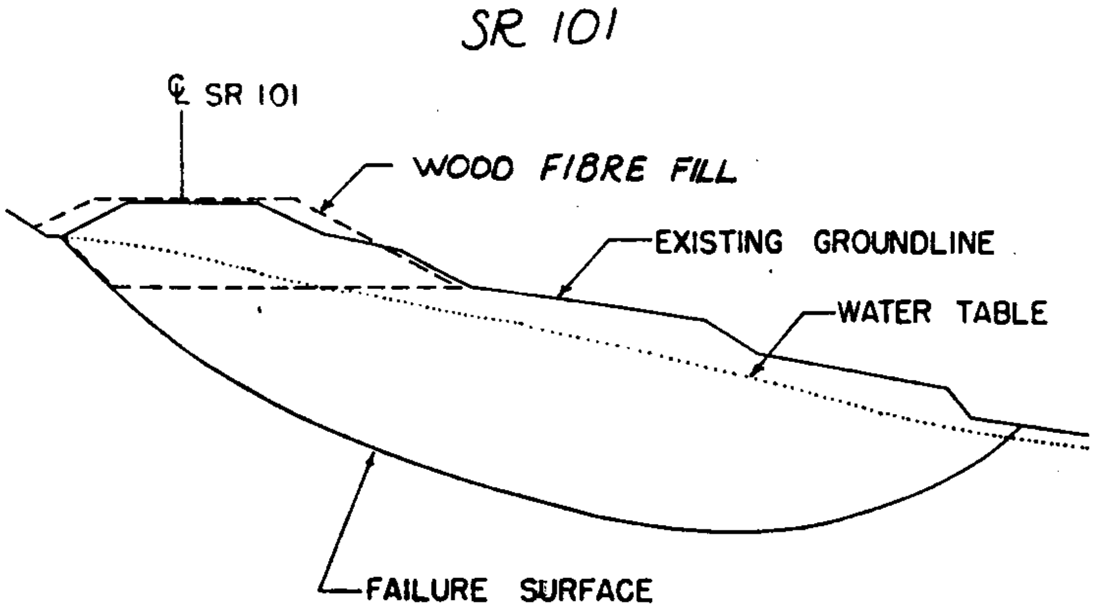


FIGURE 6

Port Dock to Fowler.

MP 57.6 to MP 57.8





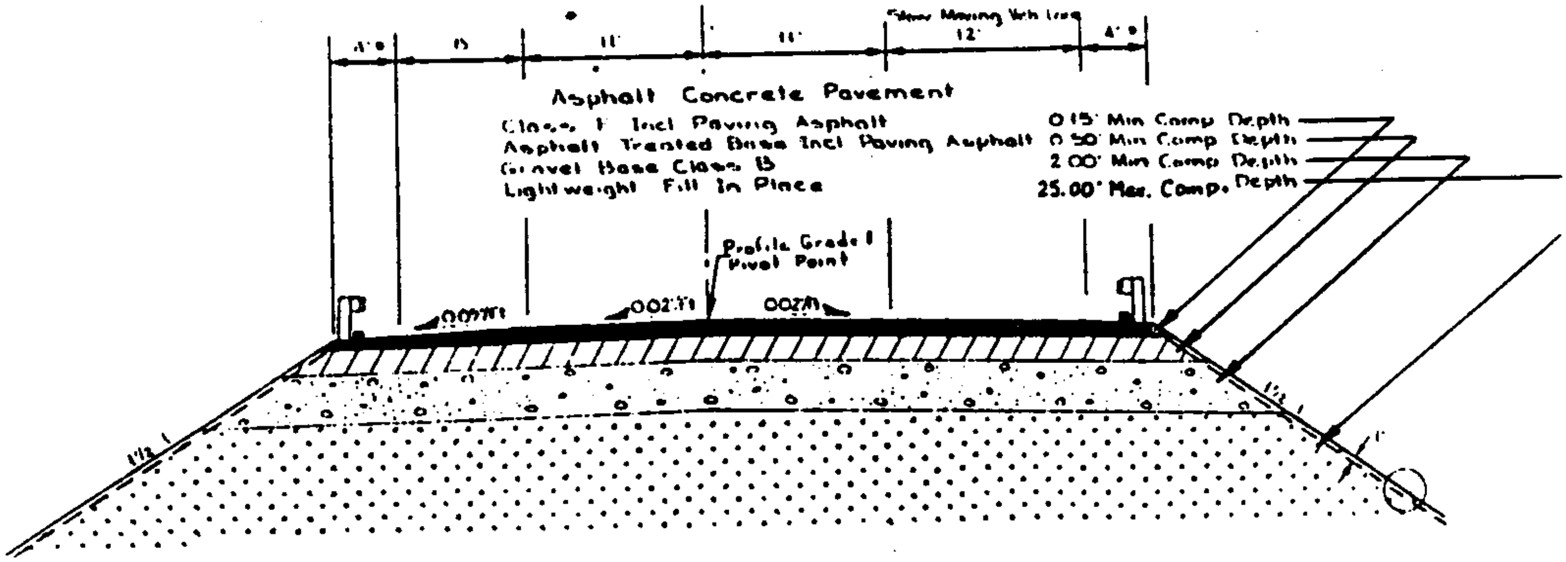
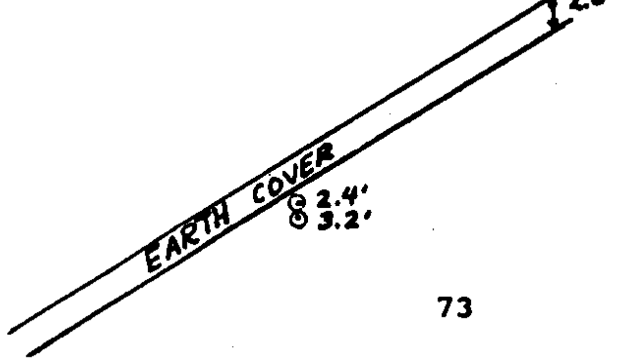


FIGURE 7

Rock Crusher Hill

MP 72.7



SR 12 & SR101

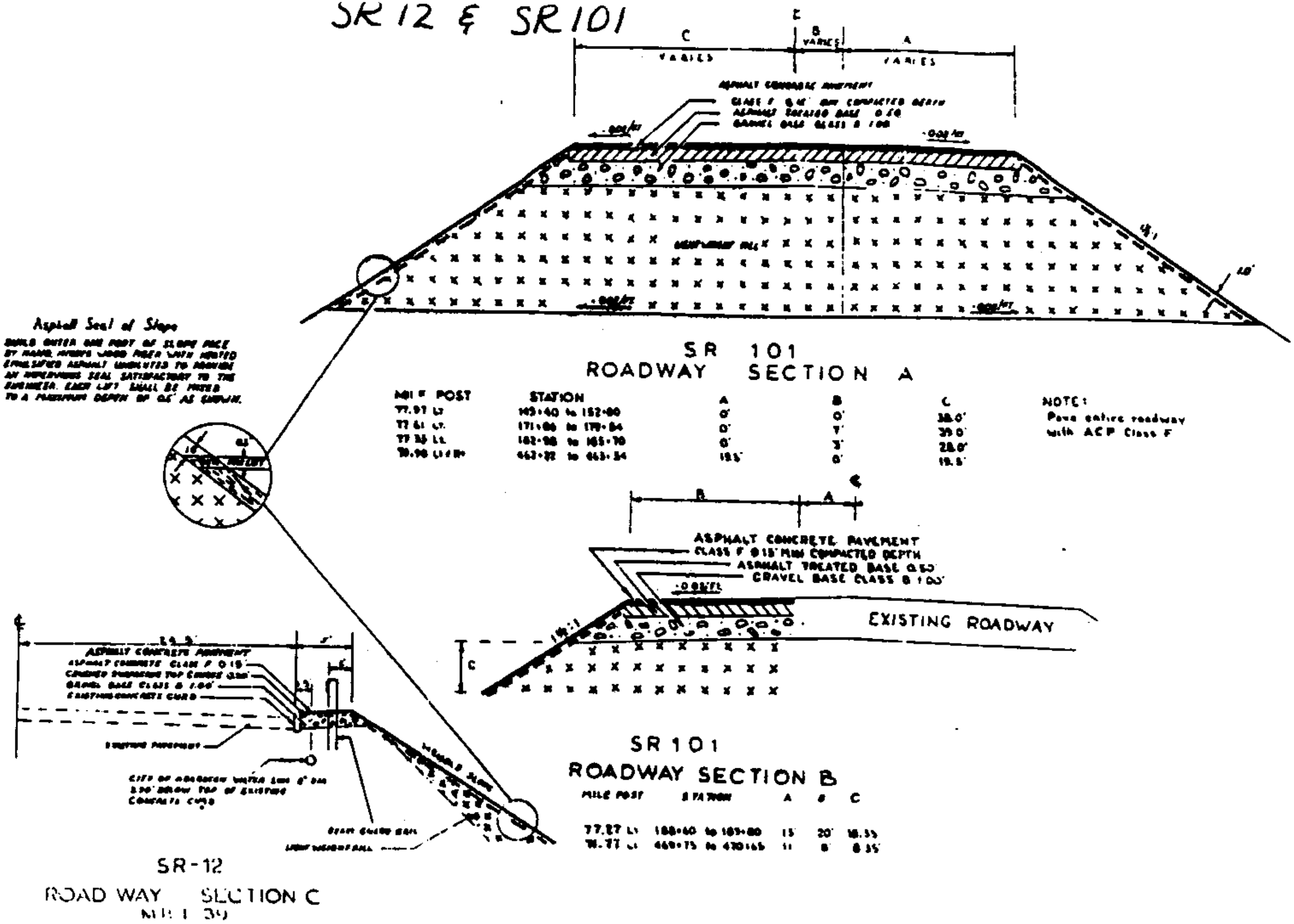
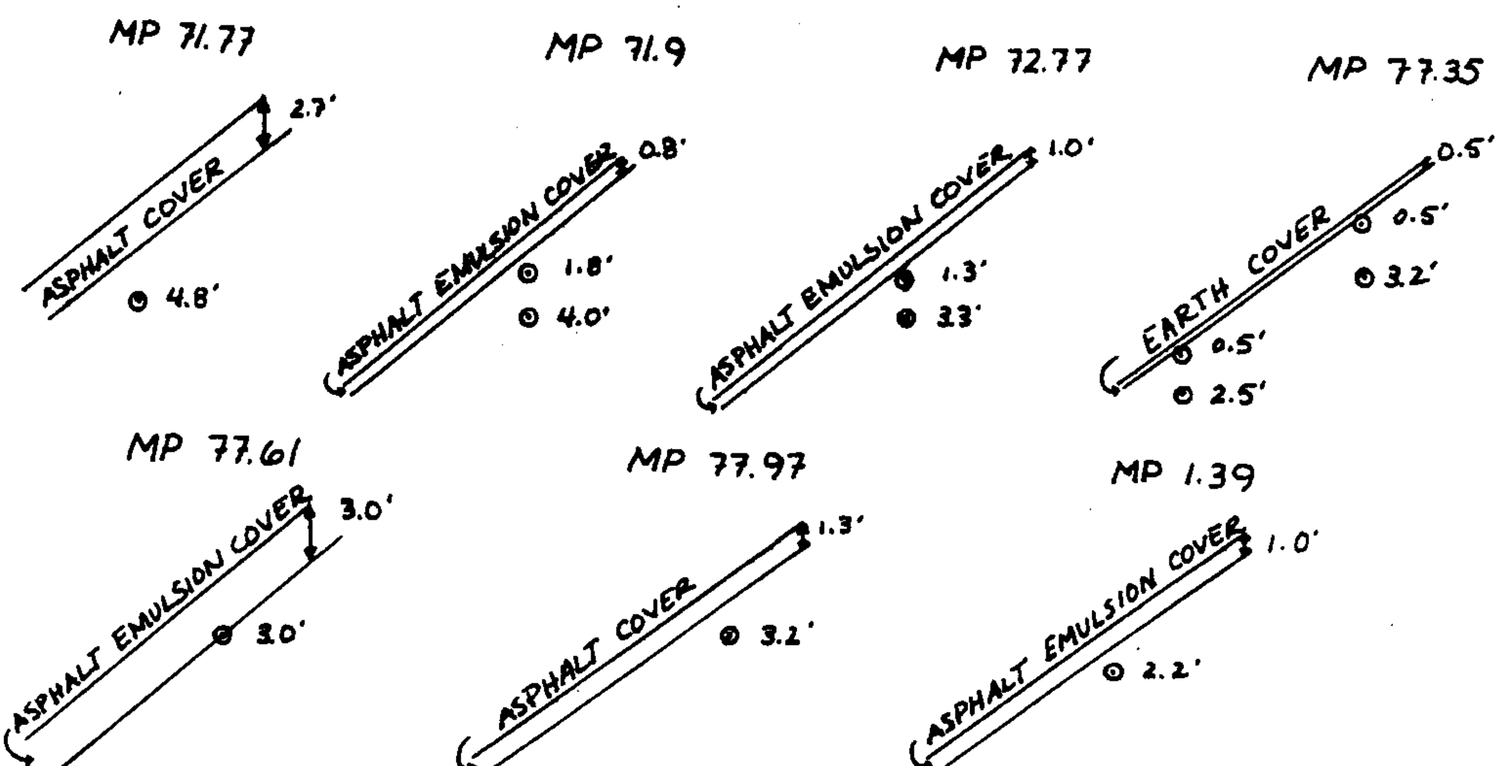


FIGURE 8
COSMOPOLIS HILL &
WASHOUT AT ABERDEEN



SR 101

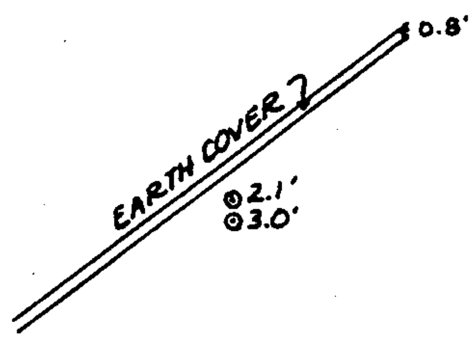
(No Cross Section or

Pavement Section Available)

FIGURE 9

Emergency Repair

MP 78.02



SR 101

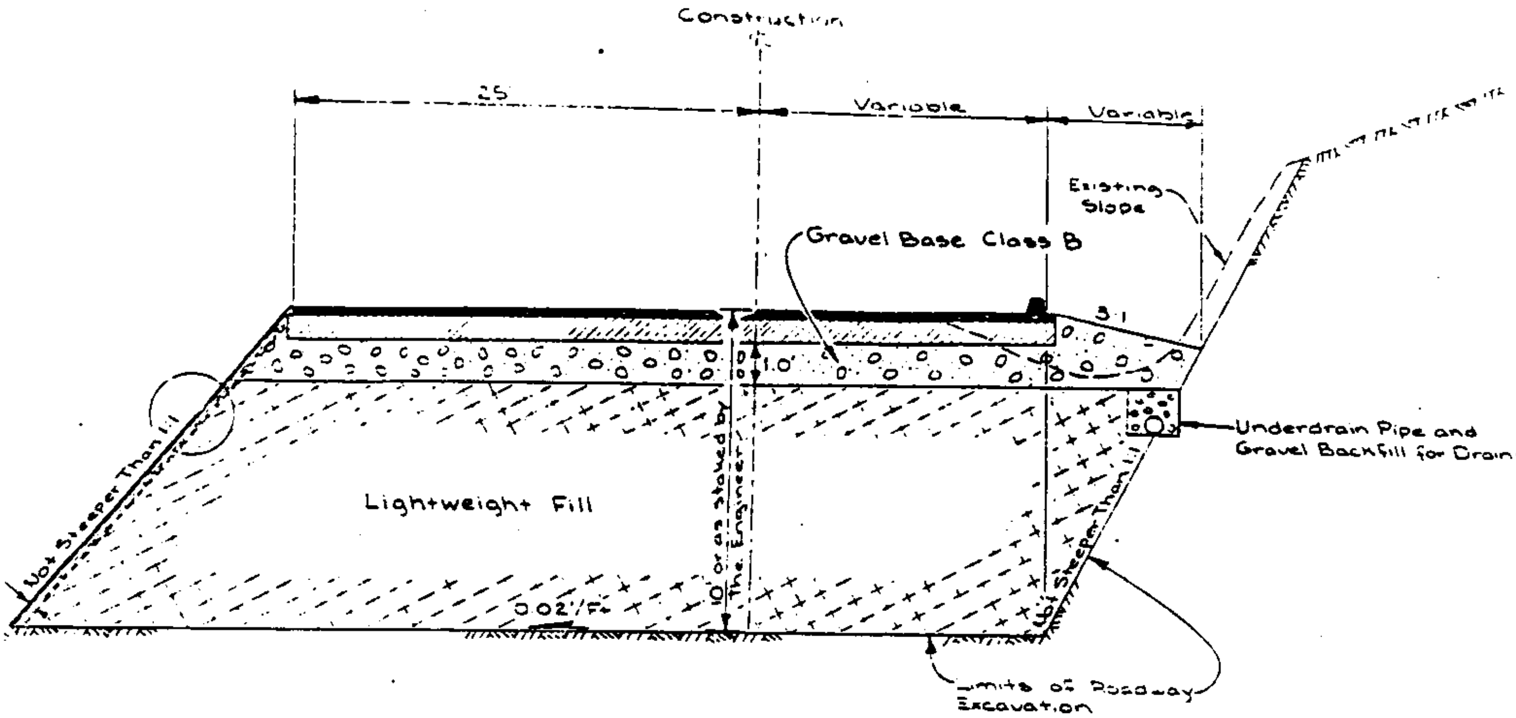
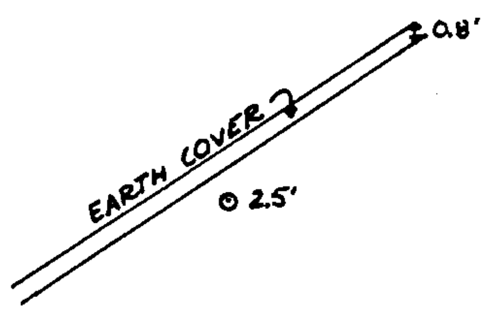


FIGURE 10
Cosmopolis to SR 107
MP 78.1



SR 101

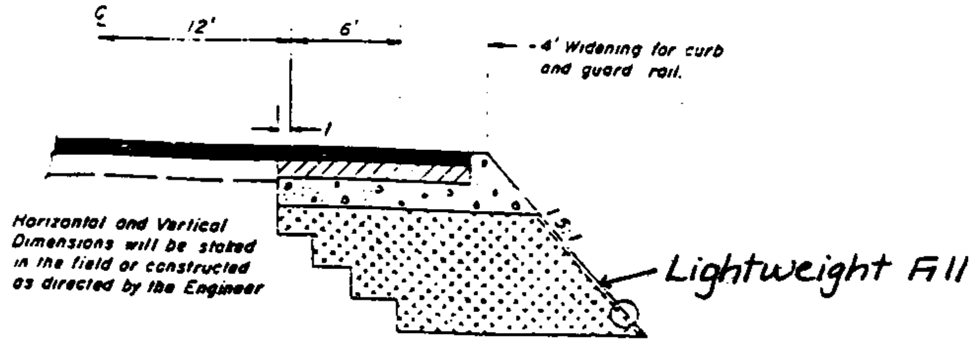
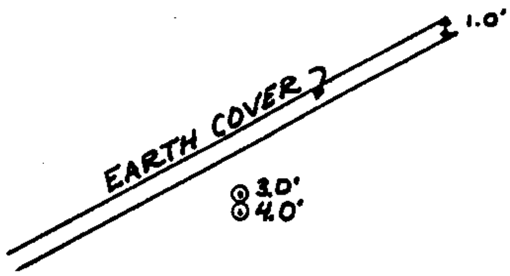


FIGURE 11
SR 107 to Cosmopolis
MP 79.2



SR 109

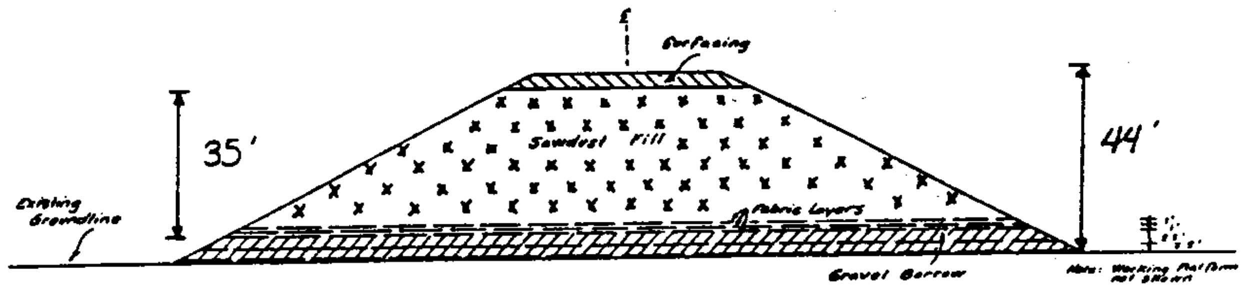
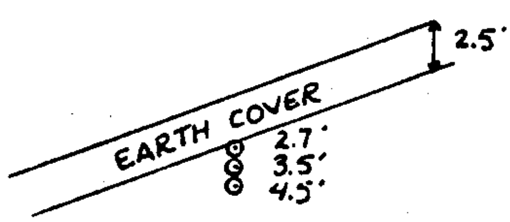


FIGURE 12
West Hoquiam
MP 2.12 to MP 2.27



SR 109

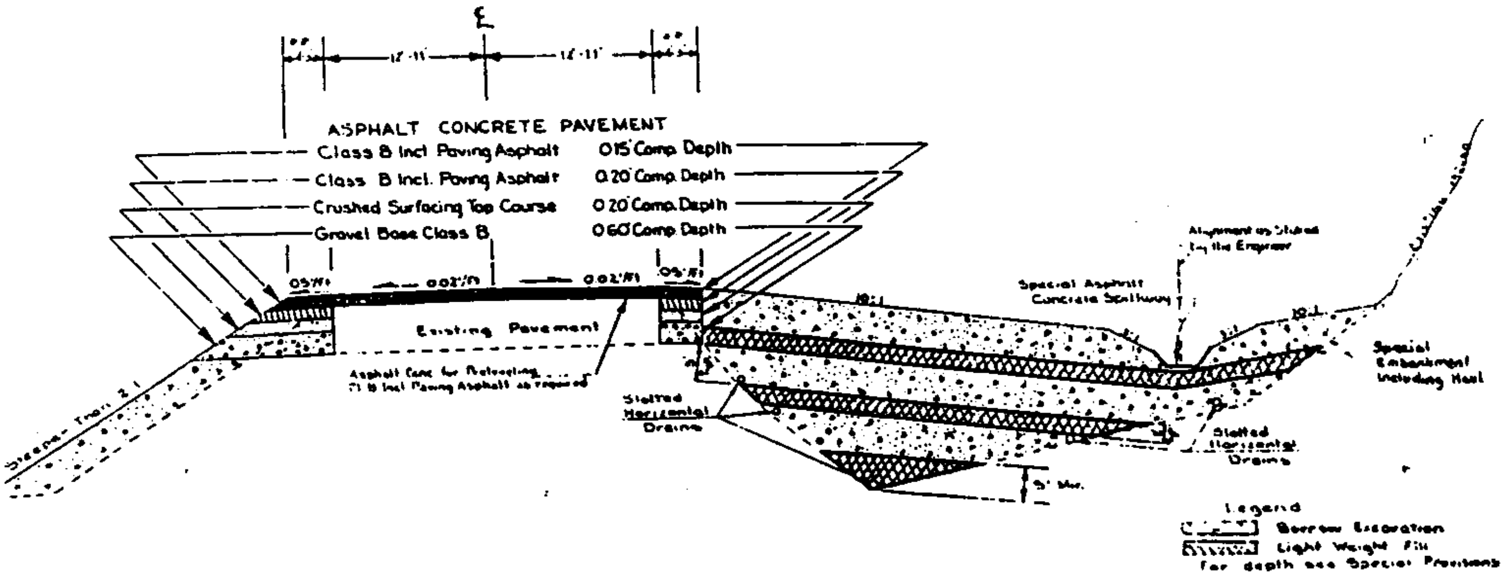


FIGURE 13
Bob Wain Hill
MP 33.06 to MP 33.18

SR 109

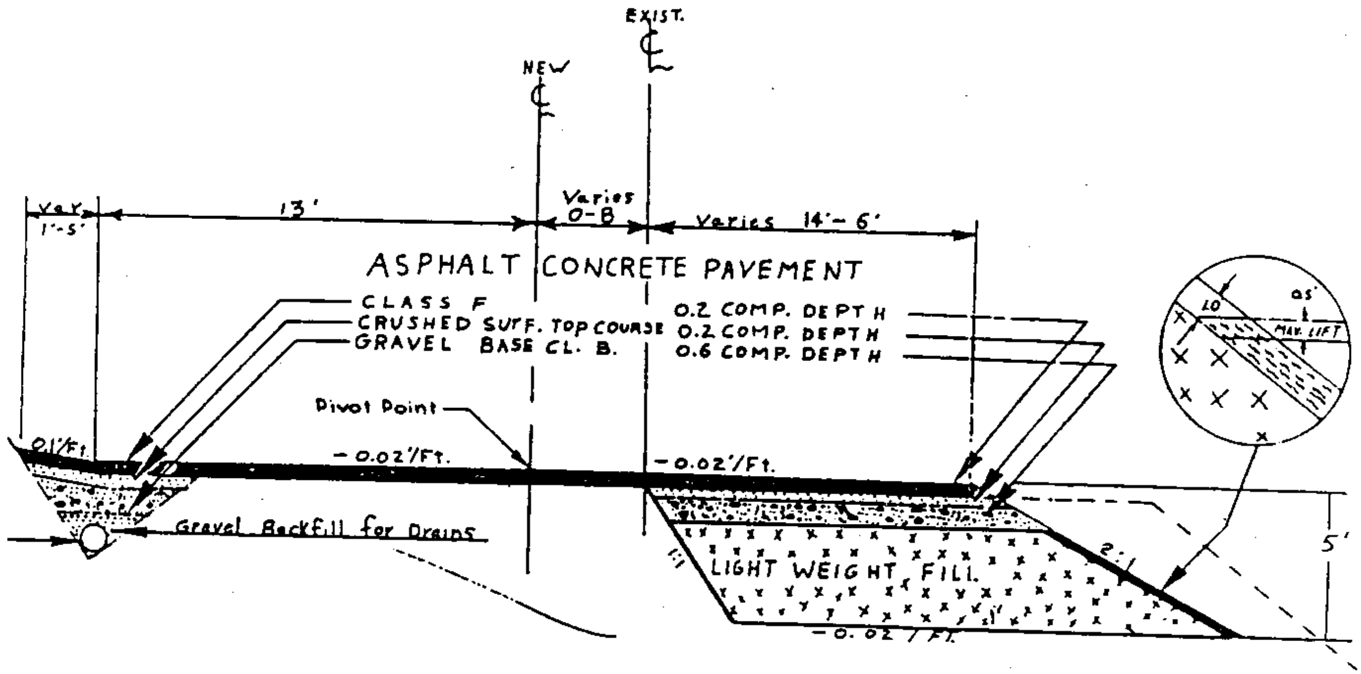
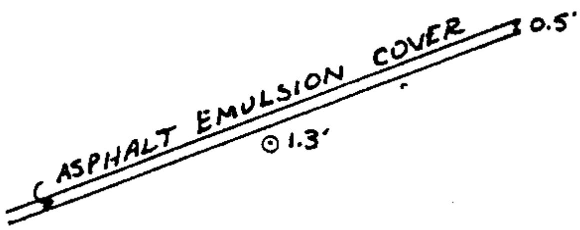


FIGURE 14
Pt. Grenville
MP 36.58 to MP 36.75



SR 302

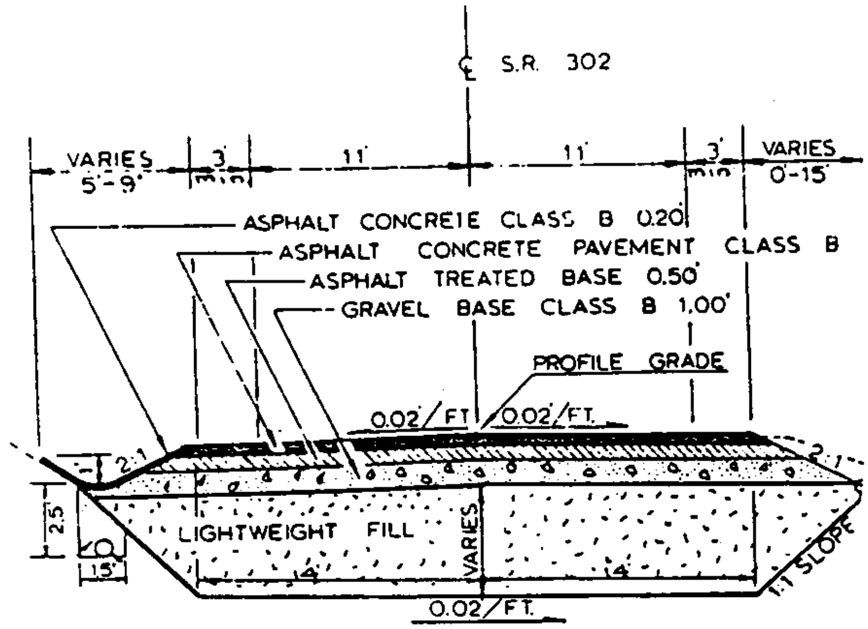
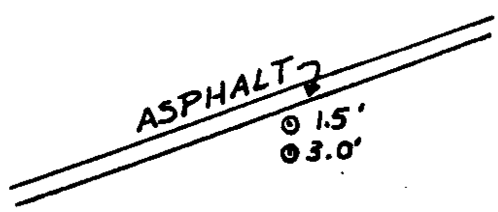
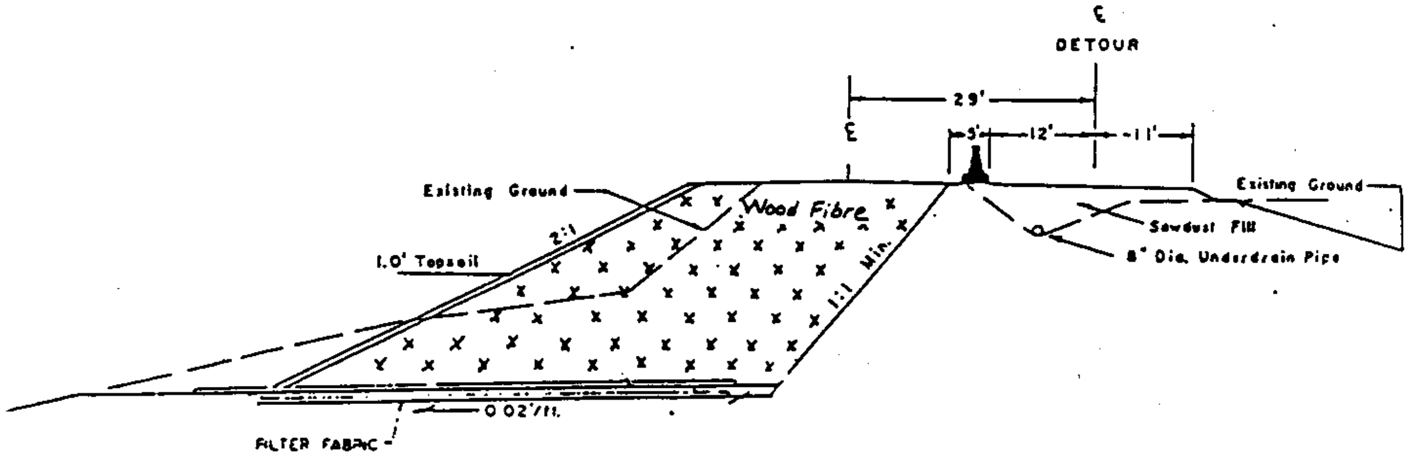


FIGURE 15
Victor Cutoff Road
MP 5.38 to MP 5.46



SR 505



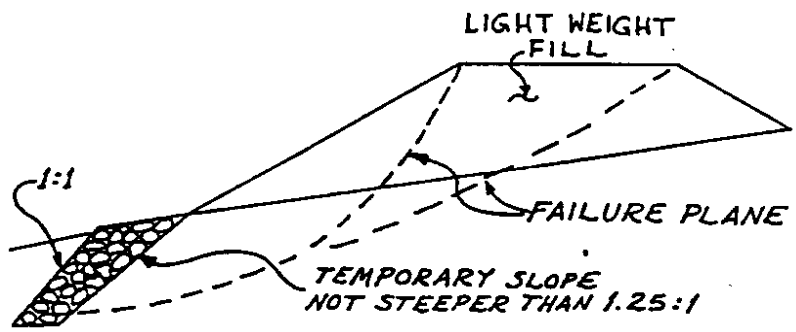


FIGURE 16
Cedar Creek Slide
MP 14.2 to MP 14.3