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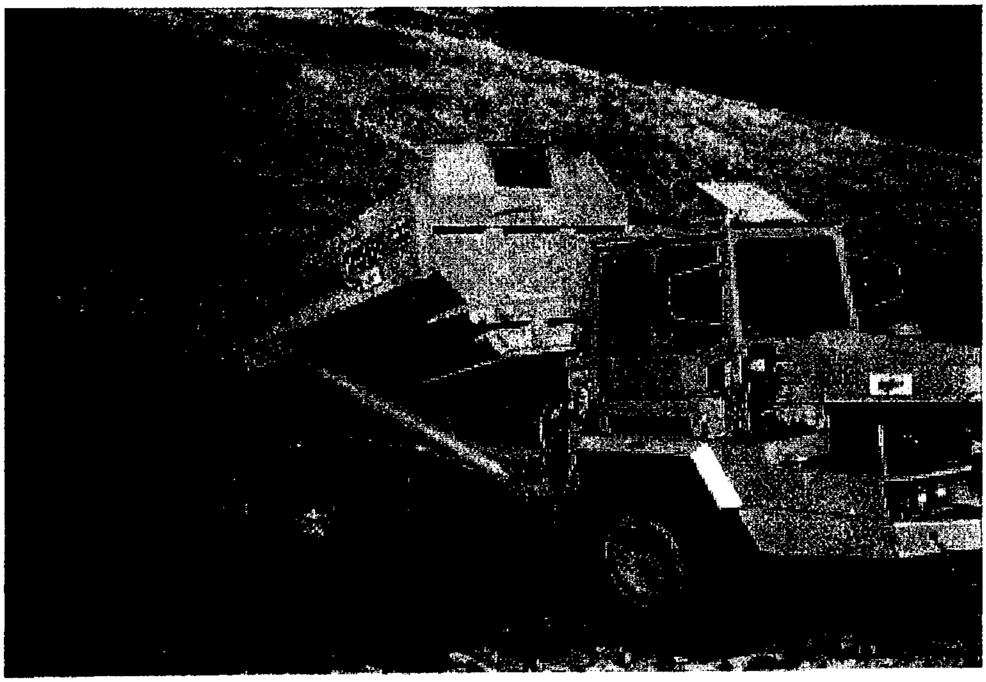
# FINAL REPORT

# FHWA-WY-00/01F

State of Wyoming
Department of Transportation

U.S. Department of Transportation
Federal Highway Administration



# EVALUATION OF SHREDDED TIRES AS BACKFILL AT DOUBLE NICKEL SLIDE

By:

Geology Program
Wyoming Department of Transportation
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January, 2000

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Supplementary Notes

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Abstract

A project, involving the use of shredded tires as lightweight fill material for control of an active landslide, was completed in the summer of 1995. The slide repair is located along State Highway 28, at reference marker 55, 32 kilometers south of Lander, Wyoming. A 3 meter high fill was constructed using 6,350 cubic meters (500,000 tires) of coarsely shredded tires to reduce driving forces and add stability to the existing embankment.

The tire fill is the subject of a monitoring program by the Geology Program, of WYDOT. Inclinometers were placed to detect possible movement along the original slide plane. A surveying program has been established to monitor settlement of the tires. Additionally, two thermistor strings, consisting of temperature probes, have been placed in the tire fill to monitor any rise in temperature indicative of an exothermic reaction. They have been monitored monthly since December 1995. In August of 1996, the amounts of oxygen, carbon monoxide, hydrogen sulfide and combustible gasses were measured from the underdrain system within the tires.

All of the temperature and gas monitoring accomplished so far has indicated that the tire fill at the Double Nickel Slide is stable and shows no signs of heating up. The use of larger tire pieces may have been an advantage, as the lower density and the thinner section of tires will aid in heat dissipation produced by exothermic reactions within the fill. Although it may allow more oxygen into the system, the use of larger tire pieces reduces the amount of exposed steel versus the double-cut smaller pieces. The gas sampling study indicated that there was very little oxygen (<4%) in the tires, thereby reducing the possibility of spontaneous combustion.

Shredded tires are still a good material for lightweight fills less that 4.5 meters thick. The insulating ability of the rubber in fills below this thickness will not be sufficient to allow a significant buildup of heat by exothermic reactions.

| | |
|---|---|
| Key Words<br>WYOMING, Double Nickel Slide, exothermic reaction, active landslide, Geology, inclinometer, thermistor, oxygen, carbon monoxide, hydrogen sulfide, shredded tires, lightweight fill, rubber. | Distribution Statement<br>Unlimited |

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# SI* (Modern Metric) Conversion Factors

## Approximate Conversions from SI Units

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| **Length** | | | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| **Area** | | | | |
| mm$^2$ | square millimeters | 0.0016 | square inches | in$^2$ |
| m$^2$ | square meters | 10.764 | square feet | ft$^2$ |
| m$^2$ | square meters | 1.195 | square yards | yd$^2$ |
| ha | hectares | 2.47 | acres | ac |
| km$^2$ | square kilometers | 0.386 | square miles | mi$^2$ |
| **Volume** | | | | |
| ml | milliliters | 0.034 | fluid ounces | fl oz |
| l | liters | 0.264 | gallons | gal |
| m$^3$ | cubic meters | 35.71 | cubic feet | ft$^3$ |
| m$^3$ | cubic meters | 1.307 | cubic yards | yd$^3$ |
| **Mass** | | | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg | megagrams | 1.103 | short tons (2000 lbs) | T |
| **Temperature (exact)** | | | | |
| °C | Centigrade temperature | 1.8 C + 32 | Fahrenheit temperature | °F |
| **Illumination** | | | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/m$^2$ | candela/m$^2$ | 0.2919 | foot-Lamberts | fl |
| **Force and Pressure or Stress** | | | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | pound-force per square inch | psi |

## Approximate Conversions to SI Units

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| **Length** | | | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| **Area** | | | | |
| in$^2$ | square inches | 645.2 | square millimeters | mm$^2$ |
| ft$^2$ | square feet | 0.093 | square meters | m$^2$ |
| yd$^2$ | square yards | 0.836 | square meters | m$^2$ |
| ac | acres | 0.405 | hectares | ha |
| mi$^2$ | square miles | 2.59 | square kilometers | km$^2$ |
| **Volume** | | | | |
| fl oz | fluid ounces | 29.57 | milliliters | ml |
| gal | gallons | 3.785 | liters | l |
| ft$^3$ | cubic feet | 0.028 | cubic meters | m$^3$ |
| yd$^3$ | cubic yards | 0.765 | cubic meters | m$^3$ |
| **Mass** | | | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lbs) | 0.907 | megagrams | Mg |
| **Temperature (exact)** | | | | |
| °F | Fahrenheit temperature | 5(F-32)/9 or (F-32)/1.8 | Celsius temperature | °C |
| **Illumination** | | | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/m$^2$ | cd/m$^2$ |
| **Force and Pressure or Stress** | | | | |
| lbf | pound-force | 4.45 | newtons | N |
| psi | pound-force per square inch | 6.89 | kilopascals | kPa |

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# EXECUTIVE SUMMARY

A project involving the use of shredded tires as lightweight fill material for control of an active landslide was completed in the summer of 1995. The Double Nickel Slide is located along State Highway 28, at reference marker 55, 32 kilometers south of Lander, Wyoming. The slide repair consisted of a shift in the centerline alignment and construction of a lightweight embankment using shredded tires.

The Double Nickel Slide has been active since 1987, when the highway was realigned and upgraded to meet primary roadway design standards and specifications. A contract was let in 1994 to remediate the landslide utilizing several earth stabilization techniques. A 3 meter high fill was constructed using 6350 cubic meters (500,000 tires) of coarsely shredded tires to reduce driving forces and add stability to the existing embankment.

The tire fill is the subject of a monitoring program by the Geology Program of WYDOT. Inclinometers were placed to detect possible movement along the original slide plane. A surveying program has been established to monitor settlement of the tires. Additionally, two thermistor strings, consisting of temperature probes, have been placed in the tire fill to monitor any rise in temperature indicative of an exothermic reaction. They have been measured monthly since December 1995. In August of 1996, the amounts of oxygen, carbon monoxide, hydrogen sulfide and combustible gases were measured from the underdrain system within the tires. This paper summarizes the design, construction, and research monitoring of the Double Nickel Slide repair.

All of the temperature and gas monitoring accomplished so far has indicated that the tire fill at the Double Nickel Slide is stable and shows no signs of heating up. The use of larger tire pieces at the Double Nickel project may have been an advantage, as the lower density and the thinner section of tires will aid in heat dissipation produced by exothermic reactions within the fill. Although it may allow more oxygen into the system, the use of larger tire pieces reduces the amount of exposed steel versus the double-cut smaller pieces. The gas sampling study indicated that there was very little oxygen (< 4%) in the tires, thereby reducing the possibility of spontaneous combustion.

Shredded tires are still a good material for lightweight fills less than 4.5 meters thick. The insulating ability of the rubber in fills below this thickness will not be sufficient to allow a significant buildup of heat by exothermic reactions.

## BACKGROUND

Since it was reconstructed in 1985, a section of State Highway 28, south of Lander, Wyoming, has caused more than a few headaches for Wyoming Department of Transportation officials. A large fill was constructed over gravelly clay colluvial deposits from which a naturally occurring spring discharges. The spring flows 1135 liters per minute and is a registered State water right. An underdrain system at the base of the fill was designed to allow unrestricted flow of the spring, however, the drainage system was constructed improperly and did not function as it was intended. Stability problems soon developed, and the road and fill began to settle at a rapid rate. A head scarp developed in the backslope above the road and a toe bulge formed below the spring, evidence that a slide was threatening the roadway and integrity of the spring. Accelerated movement in late 1992 prompted construction of three heavy rock toe trenches which provided additional drainage and created resisting forces to stabilize the slide. An abundant source of heavy iron ore rock for use in the toe trenches was readily available from the nearby U.S. Steel Pit.

## DESIGN AND CONSTRUCTION

In January 1994, renewed movement was detected immediately east of the toe trenches. Additional test holes were drilled as part of a geotechnical investigation to come up with mitigation recommendations. To save the road and the spring, a $1.76 million contract was let on July 7, 1994 to shift the roadway alignment into the hill, construct additional toe berms, and rebuild a portion of the embankment using lightweight shredded tire fill. Figure 1 shows the location of the various slide mitigation features and instrumentation. The project was completed in September, 1995 and is now part of a research project to evaluate the stability and temperature changes within the shredded tire fill.

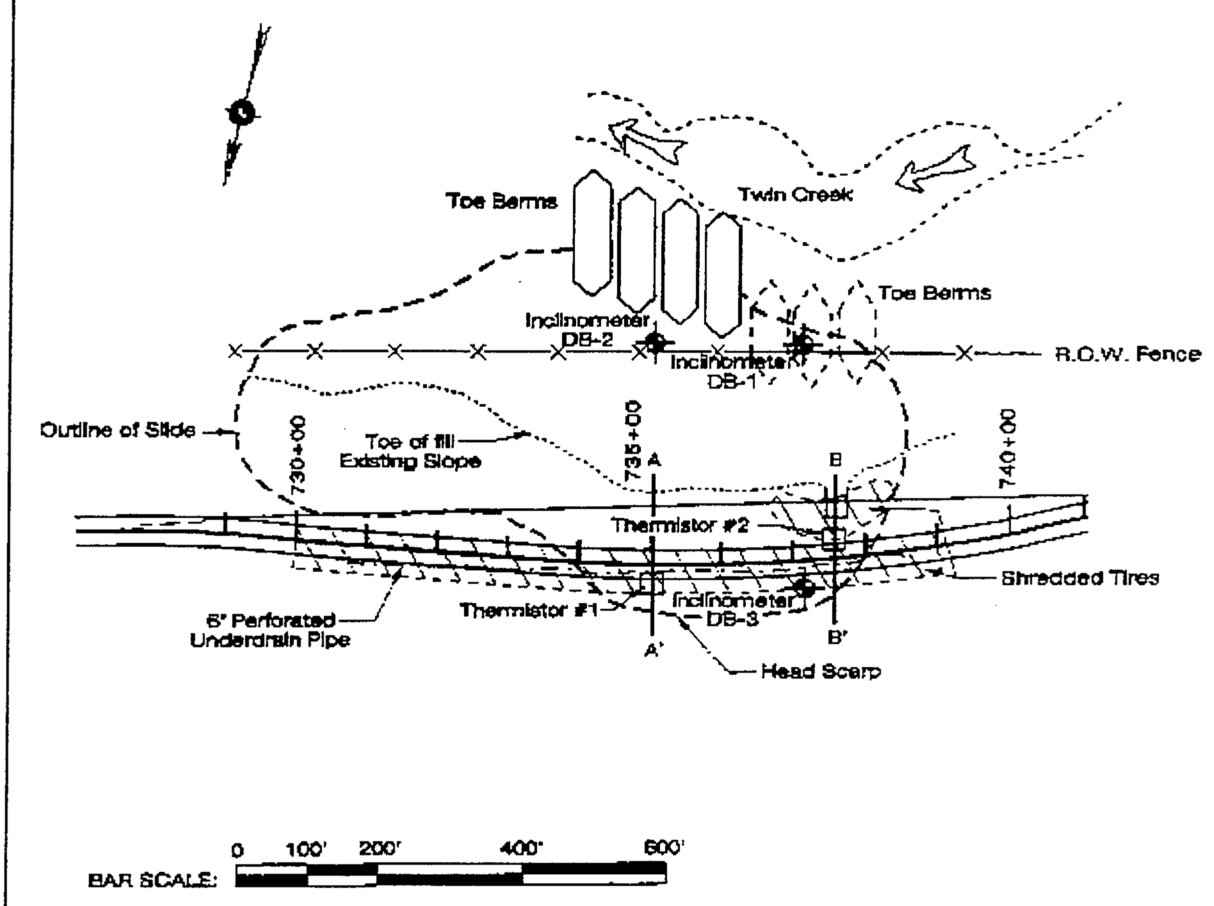

Figure 1. Plan view of Double Nickel Slide mitigation features and instrument locations.

The toe trenches were installed first to increase the stability within the slide system. Four trenches were dug east of the original three toe trenches, where the new movement was greatest. The trenches were backfilled with the iron ore rock from the nearby mine ( maximum size 1 meter) and covered up with topsoil. Water was intersected in each trench and was allowed to flow out the bottom of the trench (see Figure 2).

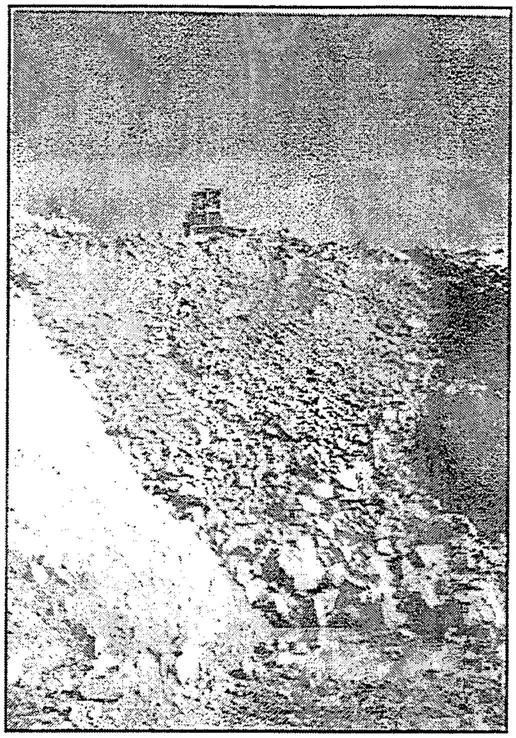

Figure 2. Excavated toe trench being backfilled with iron ore rock. Water is flowing from bottom of trench.

A 26 meter alignment shift was integrated into the design to remove as much of the existing fill as possible. This would unload the top of the slide and allow access to the spring. The existing ditch to the north of the alignment was over 4.5 meters deep and would need to be filled with a lightweight material to minimize driving forces (see Figure 3).

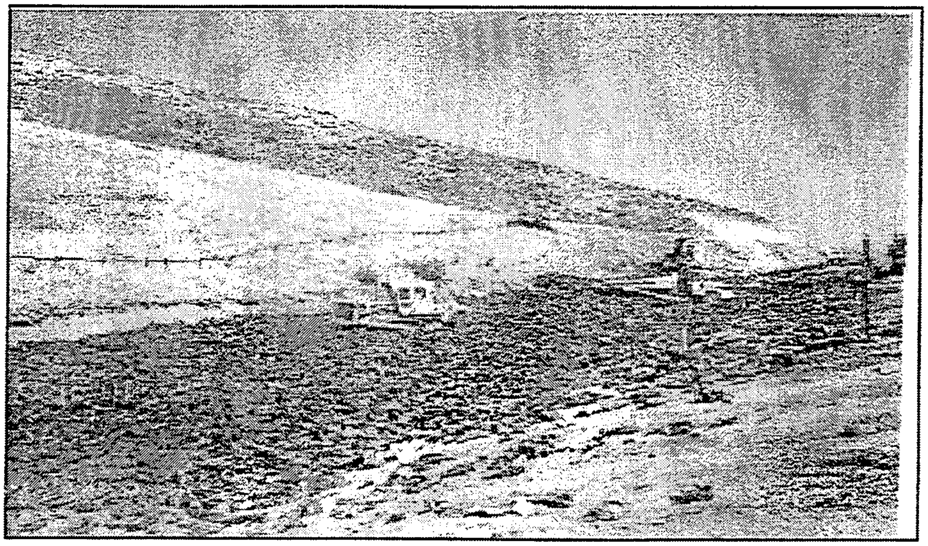

Figure 3. Ditch north of alignment being filled with shredded tires and compacted with a bulldozer.

In 1994, when the design of the lightweight fill was under discussion, shredded tires were proposed to be used at the Double Nickel Slide. At a base cost of $4.78 per cubic meter, shredded tires were more economical than other lightweight fill materials, including wood chips ($9.50 to $18 per cubic meter) and expanded polystyrene blocks ($36 to $60 per cubic meter). Including the haul, the final in-place cost of tires ended up to be $31.10 per cubic meter.

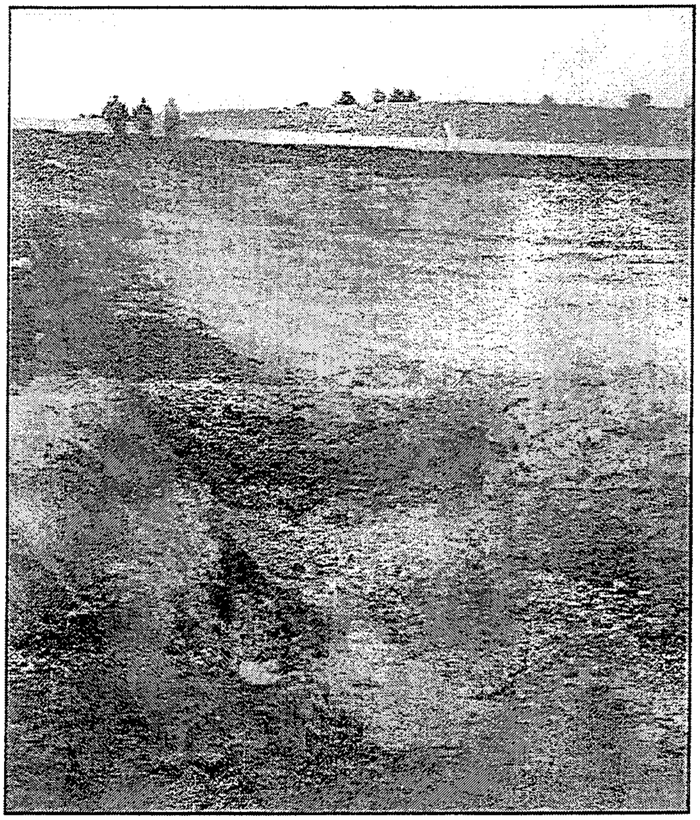

Figure 4. Excavation to expose spring and build box culvert to span spring outlet. Spring flowing 1135 liters per minute shown at lower center of photo.

The stability analysis, showed that the shredded tires would need to be 4.5 meters thick to provide a 1.5 factor of safety when constructed in conjunction with additional toe trenches and an alignment shift into the hill. Although the alignment was shifted, the embankment still covered the spring, and a large, three-sided concrete box (open at the front and the bottom) was designed to allow the spring to emerge from the ground under the box and flow unrestricted from under the fill (see Figure 4). At 3.05 meters high and 6.1 meters wide, the box was designed to be large enough to allow inspection of the spring. Shredded tires were placed directly over the box to reduce the overburden pressures on the box. During construction, adjustments to the original design were made and the spring now flows into a .61 meter CMP

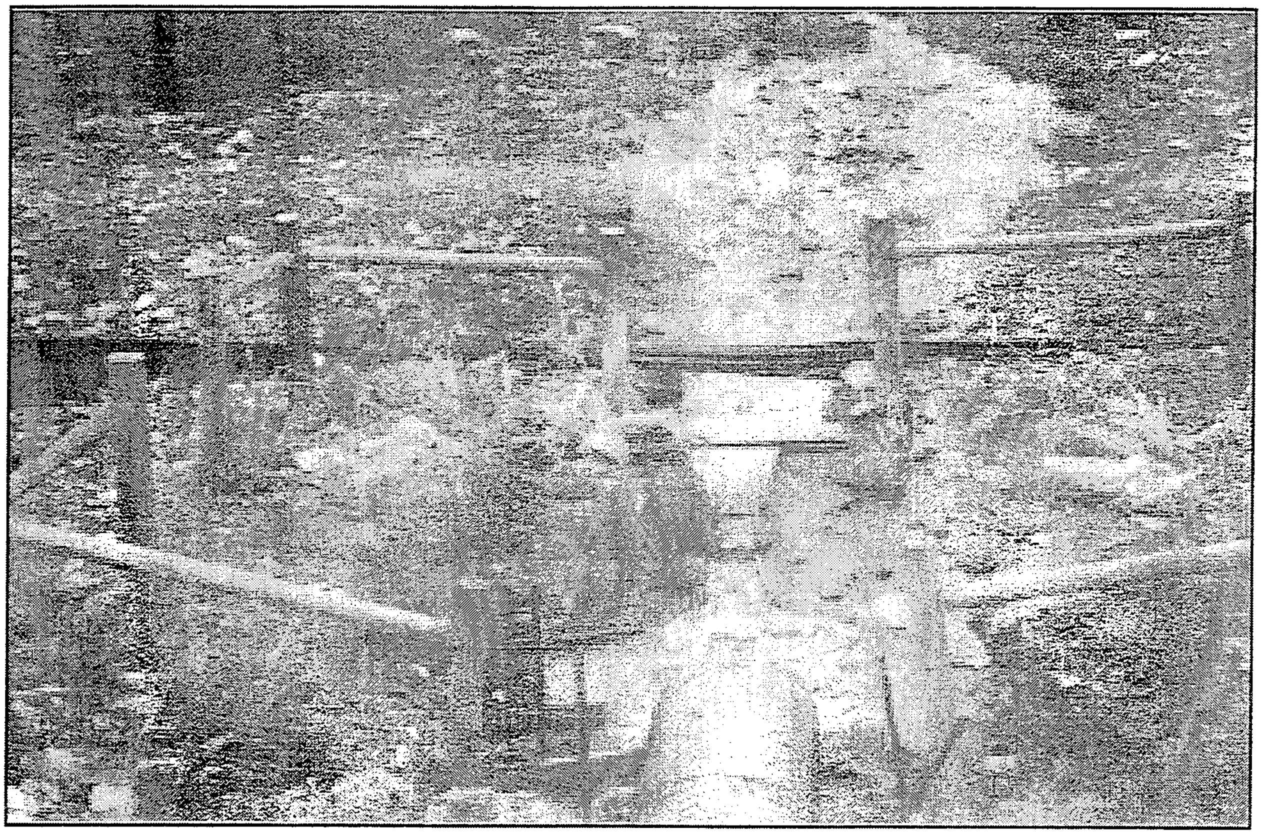

Figure 5. Spring outlet channeled into weir to measure flow rates. Fence built to protect weir from livestock.

underneath the box culvert, and the flows have increased to over 1135 liters per minute (see Figure 5).

To allow for better compaction, a maximum 100 mm tire shred width was specified. When the machine cut the tires to specifications, the shreds were comprised of very long strips derived from the sides of the tire. Some of the tire shreds were larger than the 100 mm specification (see Figure 6). Compaction was achieved by a specification that required five passes of a crawler type tractor with a minimum 56.5 kPa ground pressure for every 300 mm lift of tires. Three passes were parallel to the highway and two passes were perpendicular to the highway (see Figure 7). A late spring storm dropped 25 mm of snow on the newly placed tire shreds and the melting snow facilitated compaction by lubricating the tires when the fill was recompacted. The top grade of the tires dropped 30 mm after recompaction.

Figure 6. Typical tire shreds from 100 mm wide tire shredder.

With a total Wyoming population of under 500,000 people, the entire state's supply of stored discarded tires was consumed in the project. A shortage of available tires resulted in the thickness of the lightweight fill being reduced from 4.5 to 3.4 meters.

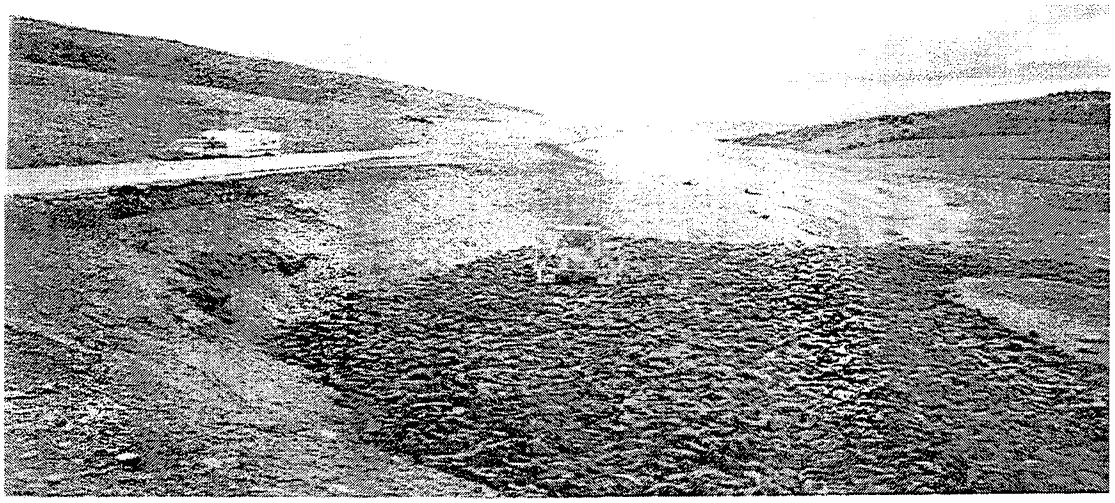

Figure 7. Lightweight tire fill under construction over the spring box culvert.

## RESEARCH TOPICS

A research project was proposed and accepted to study the effects of the tire fill on the highway. Three groups within WYDOT are involved: District Five survey personnel are measuring the profile grade monthly to evaluate possible settlement, Materials Program personnel are performing Falling Weight Deflectometer (FWD) studies on the asphalt to see if the tire fill beneath the highway is affecting the performance of the surfacing section, and Geology Program personnel have installed slope inclinometers to measure internal movement within the slide and tires. At the same time the inclinometers were being installed, major tire fill fires occurred in Washington (*1*) and Colorado (*2*). As a result of these fires, the Geology Program added thermistor strings to the research project, and temperature readings have been taken monthly since installation in December 1995. Geology personnel have also measured gases, water pH and temperatures from within the tire fill, via the .76 meter culvert and underdrain system.

## INSTRUMENTATION AND MONITORING

### Thermistor Installation andTemperature Readings

Two electronic thermistor strings were installed in the tire fill. Each thermistor string consists of a cable which contains five separate temperature probes to give a vertical profile of temperatures within the shredded tire fill, as well as the soils above and below. The cables were taped to the outside of 2.5 mm PVC casing which allowed the probes to be placed at known depths. Covered, recessed readout boxes placed near the shoulder of the road allow all five channels to be read from the surface. One thermistor string was placed on the north side of the road near the middle of the slide where the deepest layer of tires was placed, as shown in plan in Figure 1 and in cross-section in Figure 8. The thermistors were located at depths of 2.83, 3.84, 4.72, 5.88 and 6.86 meters.

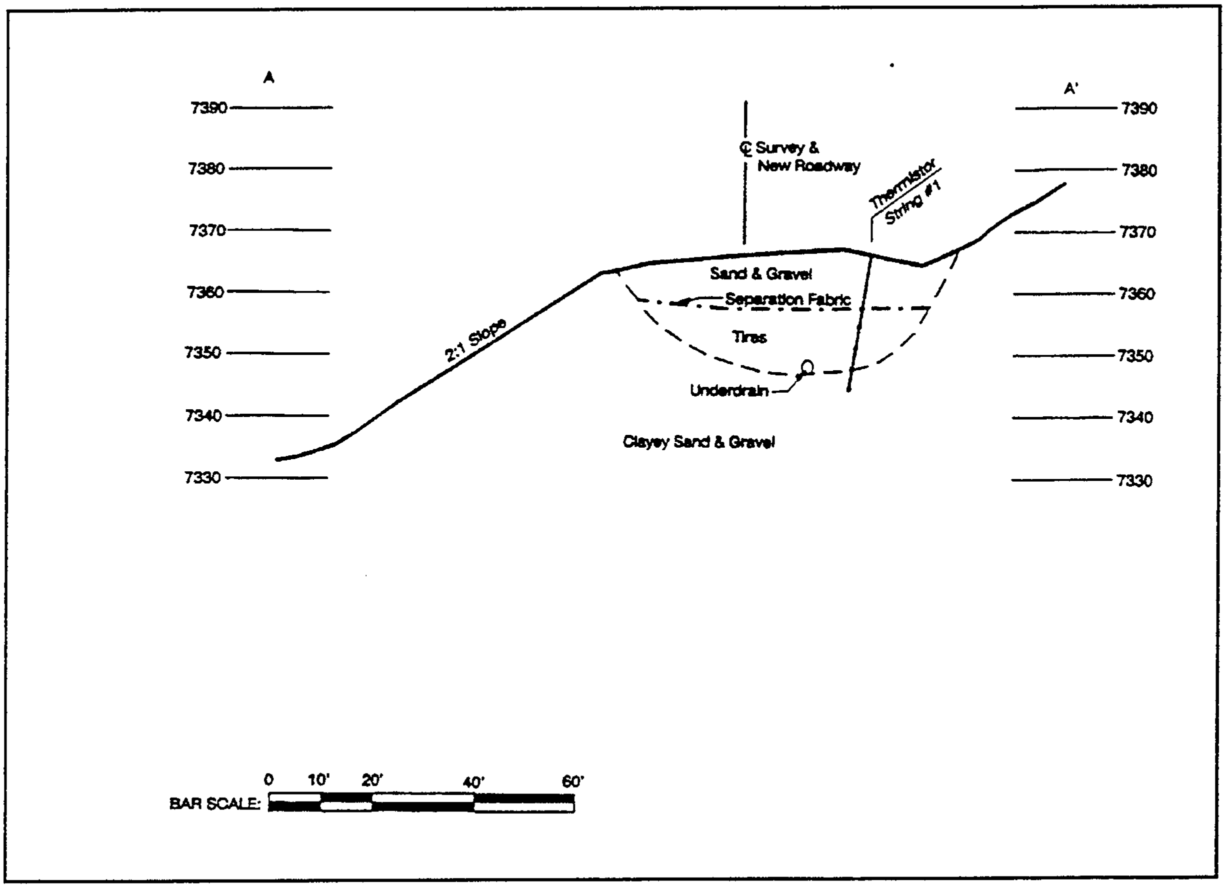

Figure 8. Cross-section at Station 735+00 showing Thermistor String No. 1. Three of the five thermistors are within the tire fill.

Thermistor string No 2 was placed on the south side of the road, just behind the back wall of the box, which is a potential route for additional oxygen to enter the tires (see Figures 1 and 9). The thermistors are located at depths of 3.66, 5.64, 7.1, 8.63 and 9.91 meters. The tires were found to be only slightly moist at thermistor site #1, but were moist to saturated at the site above the box. At thermistor site No.1, 2.44 meters of tires were penetrated and 2.13 meters of tires at thermistor site No.2. The initial readings showed temperatures as high as 71.1 degrees C within the tires, however, the high readings are attributed to the residual heat left from friction between the rubber and the augers during drilling.

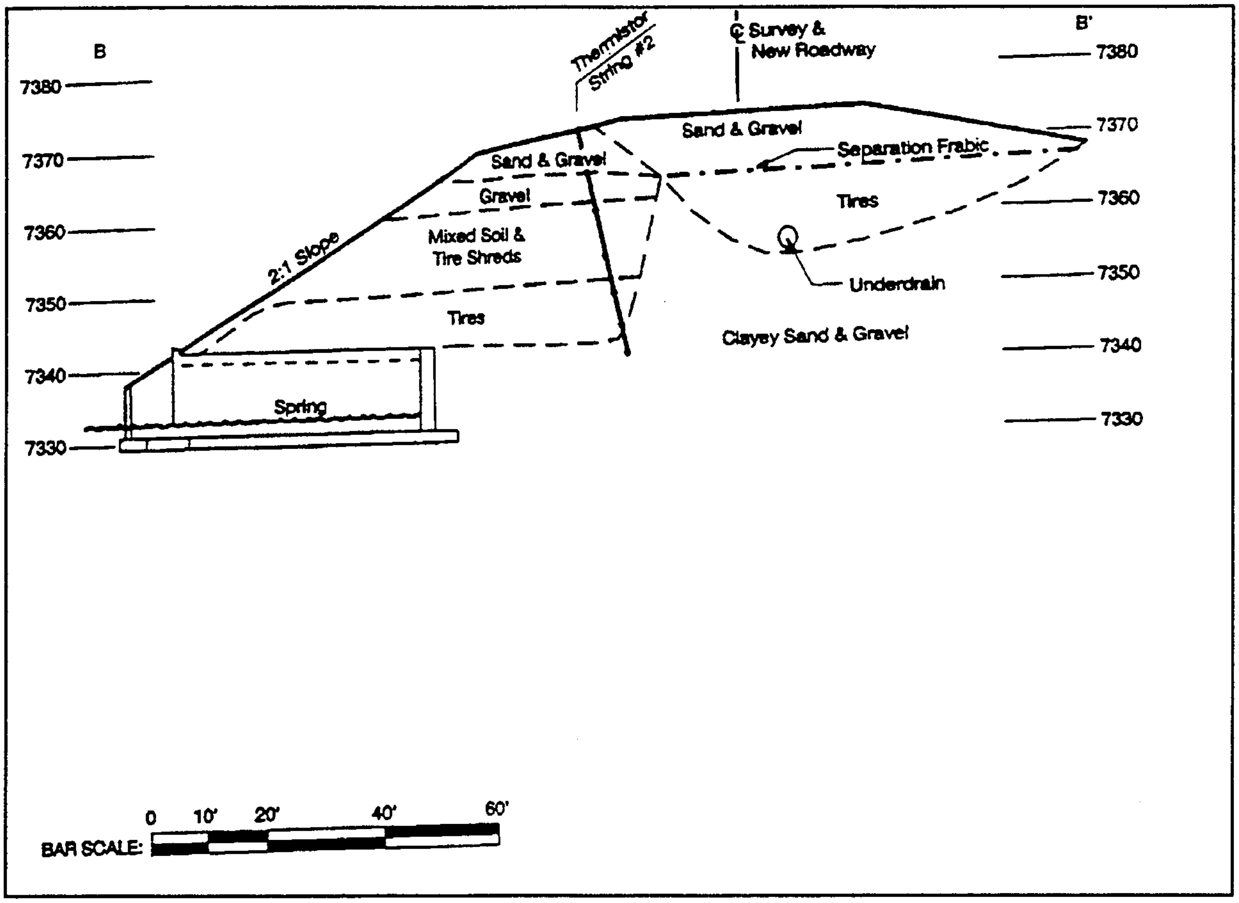

Figure 9. Cross-section through B-B', showing the location of Thermistor String No. 2. Two of the five thermistors are within the tire fill.

Subsequent readings obtained once a month since December of 1995 have shown a yearly rise and fall in temperature, and the average annual temperature is roughly 10.6 degrees C. However, it is possible that scattered hot spots are present in the fill, which are not penetrated by the two widely spaced thermistors. Figures 10 and 11 illustrate the temperature fluctuations of the thermistors at various depths to-date. It is interesting to note that due to the thermal properties of the soil and the tires the thermistors nearest the surface peak in temperature nearly two months after the summer highs in August, and the deepest thermistors don't register the change for five to six months. The same delay is seen for the detection of cold surface temperatures. June is the month when all thermistors are reading within two degrees of each other. To search for evidence of a hot spot undetected by the thermistors, Geology personnel have

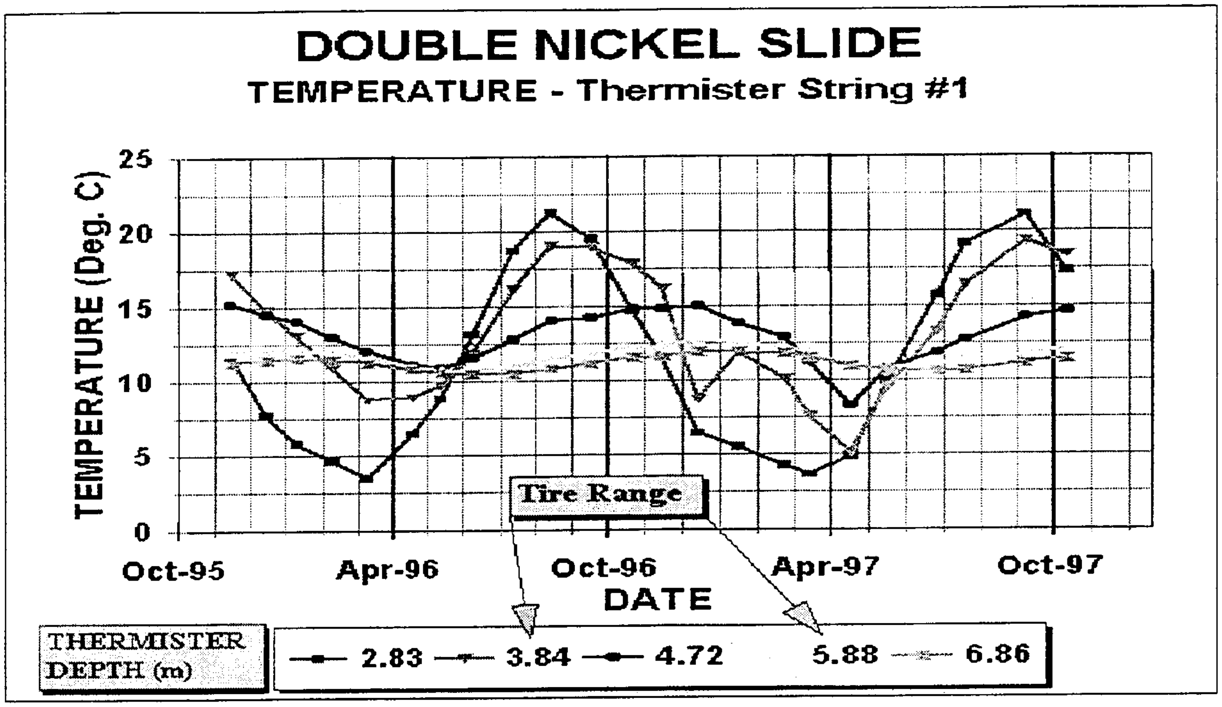

Figure 10. Twenty three months of Thermistor String No. 1 readings.

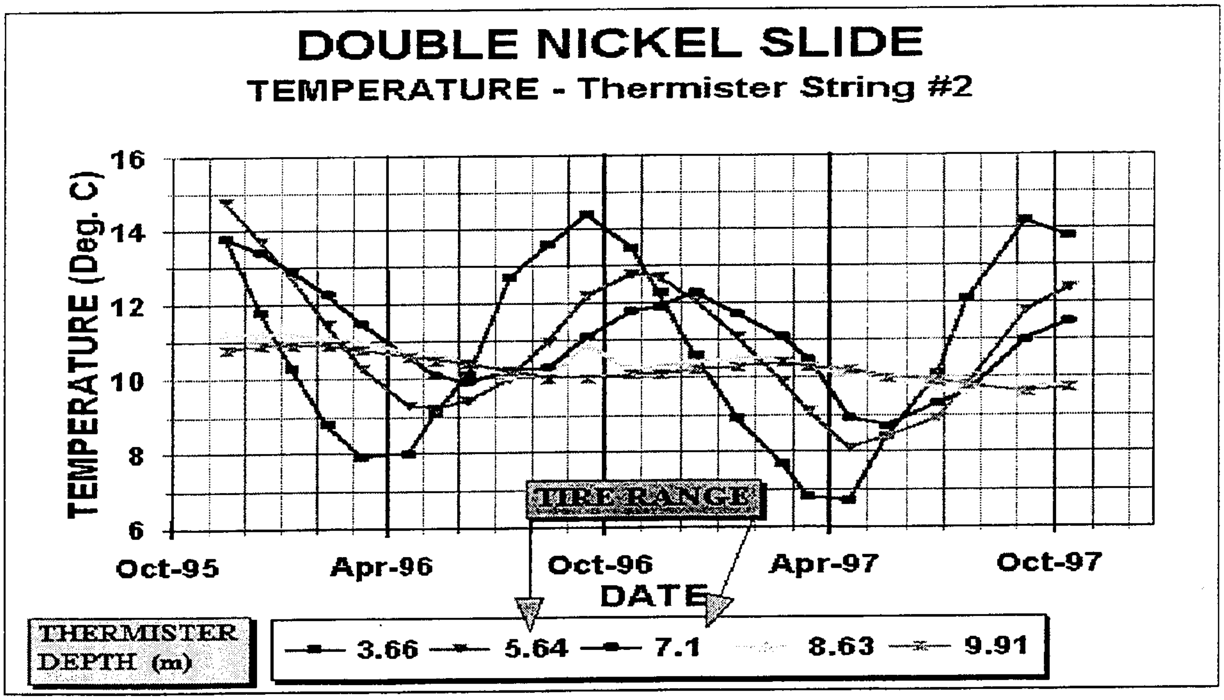

Figure 11. Twenty three months of Thermistor String No. 2 readings.

tested for heavier-than-air gas by-products of an exothermic reaction emerging from an underdrain that runs beneath the thickest section of tires along the length of the fill. Hydrogen sulfide, carbon monoxide, combustible hydrocarbons, and oxygen were monitored for safety, as well as scientific reasons, since the outlet of the underdrain can only be accessed by crawling into a .76 meter culvert. Carbon monoxide and oxygen were the only gases detected, and read 1 ppm and 3.4%, respectively. This testing has been done only once so far, on August 15, 1996

When present, water emanating from the tire fill will be measured for pH and compared to the pH of the natural runoff above the project. If the pH of water emerging from the tires is significantly lower than the pH going in, it is an indication that some type of reaction is occurring. The reaction could be either oxidation of sulphur or combustion of rubber, evidence that conditions exist to accelerate oxidation of the steel and further increase the heat output. As of this date, no water has been detected in the underdrain system. Since the culvert passes through the shredded tires, it was also checked for any evidence of heating. An electronic temperature probe was pushed 3.05 meters into the underdrain and measured temperatures equal to ground temperatures.

## Survey and Settlement Readings

Survey monuments were set along the highway to detect and measure potential settlement of the tire fill. Three monuments were set before construction and 3 more were set after construction was complete. They have been measured every month since February 1995. One the of the initial monuments was destroyed during construction. The roadway shows very little evidence of settlement and this is reflected in the survey measurements which have indicated a maximum 5.5 millimeters of settlement. Figure 12, is a plot of the survey measurements and an analysis of the plot indicates that there is a seasonal vertical movement of as much as a 2 millimeters drop every February and August. The general settlement trend is flattening out and stabilizing.

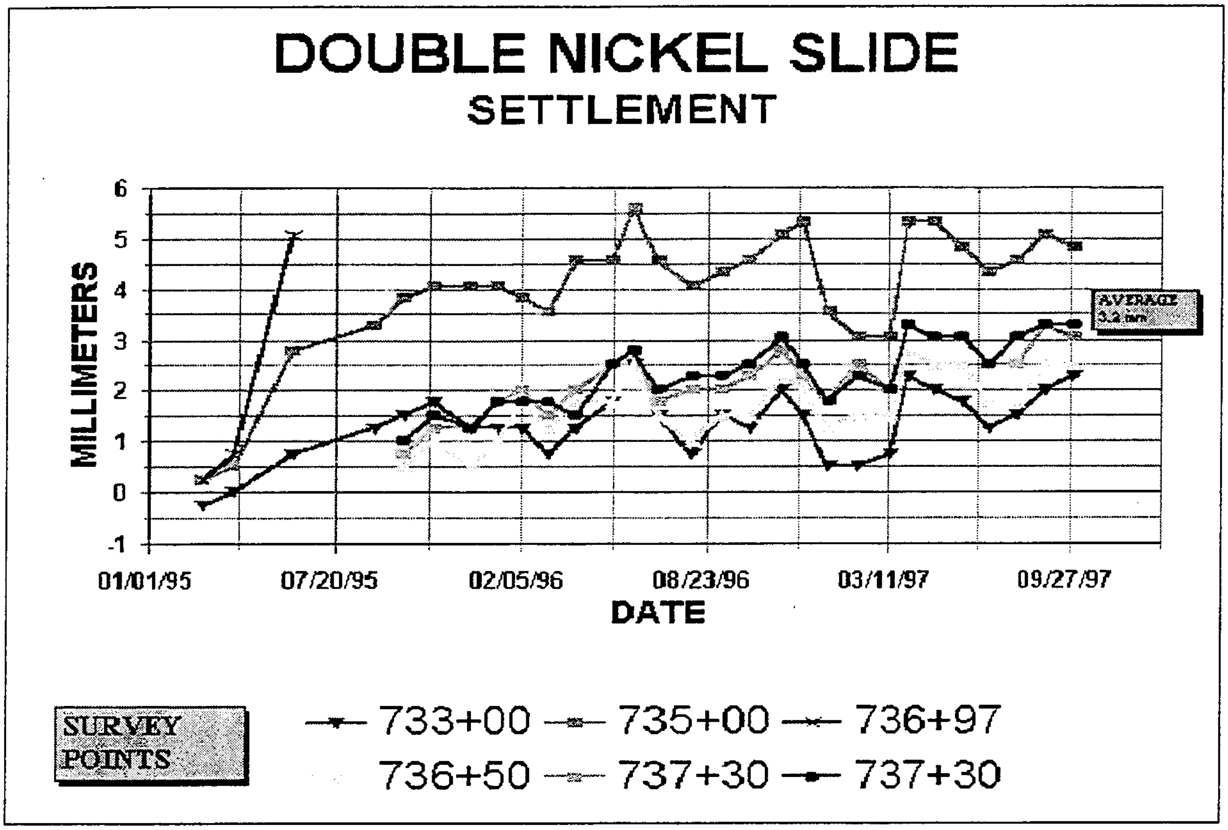

Figure 12. Graph of the settlement measurements taken at six survey monuments along the highway. The maximum settlement registered is 5.5 millimeters and the average is 3.2 millimeters.

## FWD Testing

The Materials Program at WYDOT conducted FWD tests on the surfacing section above the shredded tire fill in May of 1997. The surfacing section consists of 152 mm of Type I hot plant mix bituminous pavement overlying 305 mm of crushed base. Below the crushed base is 1.5 meters of pit run subbase which was placed on top of separation type geotextile. The geotextile prevents the loss of subbase material into the shredded tires.

The results of the FWD testing are very preliminary and indicate an average Ep reading of 100,000 and Mr readings between 4000 and 8000. Another set of FWD tests are planned for May 1998 and will be compared to the previous readings.

# DISCUSSION

There are several possible exothermic reactions that are discussed in Dr. Dana N. Humphrey's report, "Investigation of Exothermic Reaction in Tire Shred Fill". The first, and probably most important, involves the oxidation of exposed steel wires. Every kilogram of steel that is oxidized produces approximately 5,776 BTU's. By comparison, a typical piece of low sulphur Wyoming coal produces roughly 22,000 BTU/pound. Every cubic meter of tire shred fill contains about 80 kgs of steel, however only a small percentage of this is immediately accessible to oxygen. This reaction, and subsequently the heat liberated, is increased by environmental factors including acidic conditions, higher temperatures, the presence of organic materials and dissolved salts (*1*).

Other potential factors for spontaneous ignition involve the minimum overall thickness of tires, as well as a maximum shred size (*1*). Above a certain thickness of tires, heat loss is less than the rate of heat production by exothermic reaction. Smaller shred sizes can be compacted to a greater overall density, resulting in excellent insulating properties, as well as providing a higher percentage of exposed steel belts. Results from previous investigations indicate hot spots have developed only in shredded tire stockpiles more than 4.5 meters high, and only when the material was composed of 51 mm tire chips (*1*).

The maximum thickness of tires in the Double Nickel Slide is 3.35 meters. The two shredded tire fills in Washington which have experienced detrimental heating reactions were both over 7.6 meters thick and were subjected to other aggravating factors (*1*). The tire retaining wall site in Colorado was 18.3 meters high and the wall was covered with earth and compost (*2*).

# CONCLUSIONS

All of the temperature and gas monitoring accomplished so far has indicated that the tire fill at the Double Nickel Slide is stable and shows no signs of heating up. The use of larger tire pieces at the Double Nickel project may have been an advantage, even though they do not compact as closely as the small chips that were used in the Washington and Colorado projects. The lower density and the thinner section of tires will aid in heat dissipation produced by exothermic reactions within the fill, although it may allow more oxygen into the system. There is also less exposed steel than the double-cut smaller pieces. The gas sampling study indicated that there was very little oxygen (< 4%) in the tires, thereby reducing the possibility of spontaneous combustion.

We are cautiously optimistic that shredded tires are still a good material for lightweight fills less than 4.5 meters thick. The insulating ability of the rubber in fills below this thickness will not be sufficient to allow a significant buildup of heat by exothermic reactions. To date, there has been only minor settlement over the tire fill (less than 6 mm), no discernable movement along the previous failure plane, and water continues to flow from the spring at over 1135 liters per minute.

## REFERENCES

(*1*) Humphrey, Dr. Dana N., Ph.D., P.E., “Investigation of Exothermic Reaction in Tire Shred Fill Located on SR 100 in Iwaco, Washington”, Prepared for: Federal Highway Administration, Washington, D.C. (1996)

(*2*) Kolodner, Herbert J., Dr., “Preliminary Report, Re: Hanging Lake Restoration and Comfort Station Project, Date of Fire - October 30, 1995”, Knott Laboratory, Inc. (1995)