



Instrumentation of a geosynthetically reinforced roadway  
by Joseph Andrew Lapeyre

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering

Montana State University

© Copyright by Joseph Andrew Lapeyre (1996)

Abstract:

Reinforcing flexible pavement roadways with geosynthetics has been proposed to reduce the thickness of the base course layer. Mechanisms of reinforcement have been identified, but not quantified. A design procedure that incorporates the reinforcement provided by geosynthetics would provide more efficient use of aggregate and geosynthetics than those currently available. Research at Montana State University has been initiated in this area. Its goal is to quantify the reinforcing benefit of geosynthetics leading to the development of a roadway design procedure.

This thesis, which is the first phase of the research, is the study of possible strain sensors and installation techniques that can be used to monitor the performance of a geosynthetically reinforced roadway. With suitable strain sensors identified, the follow on phases of research at Montana State University will quantify the reinforcing benefit of geosynthetics.

Research was conducted in two areas. A full scale reinforced flexible pavement roadway was built and instrumented with vibrating wire, foil strain gauge, and LVDT technologies. The instruments were monitored over a four month period while the roadway was subjected to heavy truck traffic. The evaluation of mounting techniques used to fasten the strain sensors to the geosynthetics was accomplished with the use of a wide width uniaxial tension facility.

Results from the study show that all three of the technologies are viable candidates for use in further research. The effect of mounting techniques used to fasten the strain sensors to the geosynthetics was seen to have a major impact on the strain measured by the transducer. Calibration factors were developed to convert the strain measured by a sensor to the global strain in the geosynthetic. The need to account for temperature effects regarding thermal strain and signal distortion was also identified.

INSTRUMENTATION OF A GEOSYNTHETICALLY REINFORCED ROADWAY

by

Joseph Andrew Lapeyre

A thesis submitted in partial fulfillment  
of the requirements for the degree

of

Master of Science

in

Civil Engineering

MONTANA STATE UNIVERSITY  
Bozeman, Montana

December 1996

N378  
L3134

APPROVAL

of a thesis submitted by

Joseph Andrew Lapeyre

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Dr. Steven W. Perkins

Steven W. Perkins  
(Signature)

12-2-96  
Date

Approved for the Department of Civil Engineering

Dr. Donald A. Rabern

Donald A. Rabern  
(Signature)

12/3/96  
Date

Approved for the College of Graduate Studies

Dr. Robert L. Brown

Robert L. Brown  
(Signature)

12/14/96  
Date

## STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University-Bozeman, I agree that the Library shall make it available to borrowers under rules of the Library.

If I have indicated my intention to copyright this thesis by including a copyright notice page, copying is allowable only for scholarly purposes, consistent with "fair use" as prescribed in the U.S. Copyright Law. Requests for permission for extended quotation from or reproduction of this thesis in whole or in parts may be granted only by the copyright holder.

Signature

Joseph A. Lapeere

Date

9 Dec 96

## TABLE OF CONTENTS

	Page
1. INTRODUCTION .....	1
Background and Problem .....	1
Scope of Work .....	3
Outline of Thesis .....	4
2. LITERATURE REVIEW .....	5
Introduction .....	5
Strain Theory .....	5
Roadway Instrumentation .....	6
Strain Sensors for Cemented Material .....	7
H-Gauges .....	7
Foil Strain Gauges on Carrier Block .....	8
Foil Strain Gauges Mounted on Cores .....	9
Strain Gauges for Granular Material .....	10
Inductance Coils .....	10
LVDT's .....	11
Multidepth Deflectometers .....	11
Instrumented Roadways .....	14
Full Scale Tests .....	14
MN/ROAD .....	14
Center for Transportation Research, Univ of Texas .....	16
North Carolina Instrumented Highway .....	16
Alberta Instrumented Highway .....	17
TRRL Instrumented Highway .....	17
Laboratory Tests .....	18
Virginia Polytechnical Institute .....	18
Danish Road Testing Machine .....	19
U.S. Army Engineer Waterways Station .....	21
University of Waterloo .....	21
Tension Testing of Geosynthetics .....	22
Introduction .....	22
ASTM Standards .....	23
Laboratory Testing .....	24
Related Instrumented Geosynthetic Studies .....	27
3. RESEARCH METHODOLOGY .....	30
Introduction .....	30
Instrumented Roadway .....	30
Instrument types .....	30

	Page
Asphalt Concrete .....	30
Instrumentation in the Base Course .....	32
Instrumentation on the Geosynthetics .....	34
Data Logging Systems .....	38
Long Term Data Logger .....	39
Dynamic Data Logger .....	39
Roadway Monitoring .....	40
Long Term Monitoring Program .....	40
Dynamic Monitoring Program .....	41
Roadway Construction and Gauge Locations .....	45
Introduction .....	45
Roadway Construction Overview .....	46
Instrumentation Layout .....	47
Instrumentation Installation .....	50
Instruments Attached to the Geosynthetics .....	50
Instruments Embedded in Base Course .....	51
Instruments Embedded in Asphalt Concrete .....	53
Wide Width Tension Testing .....	54
Loading Frame .....	54
Sensors Used for Local Strain Measurement .....	58
Tests Performed .....	61
<b>4. RESULTS.</b> .....	<b>63</b>
Introduction .....	63
Wide Width Tension Testing .....	63
Accuracy and Repeatability .....	63
Comparison of Global Strain to Manufacturer's Specifications ..	64
Strain Response of the Vibrating Wire Strain Gauges .....	64
Strain Response of the Vibrating Wire Displacement Gauges ..	66
Strain Response of the LVDT Gauges .....	68
Strain Response in the Foil Strain Gauges .....	68
Summary .....	70
Roadway Results .....	72
Long Term Results .....	72
Truck Traffic Loading .....	72
Strain in the Geosynthetics .....	72
Strain Gauges in the Base Course .....	76
Strain in the AC .....	78
Dynamic Testing Results .....	79
Truck Pass Tests .....	79
Road Rater Tests .....	81

	Page
5. CONCLUSIONS AND RECOMMENDATIONS .....	85
Conclusions .....	85
Recommendations .....	86
REFERENCES CITED .....	89
APPENDICES .....	92
A Wide Width Tension Testing Results .....	93
B Roadway Results .....	116

## LIST OF TABLES

Table	Page
1. Chronological Order of Events For Roadway Construction and Testing .....	42
2. Vehicles Used for Truck Pass Tests .....	44
3. Instrumentation Specifications .....	50
4. Geosynthetic Instrument Cover Options .....	52



## LIST OF FIGURES

Figure	Page
1. Dynatest H-Gauge .....	8
2. Foil Strain Gauge mounted in a Carrier Block .....	9
3. LVDT .....	12
4. Cross section of MDD after installation .....	13
5. The Danish Road Testing Machine .....	20
6. ASTM approved Sanders Clamp .....	25
7. ASTM approved Wide Width Clamp .....	26
8. Vibrating Wire Embedment AC Strain Gage (Geokon Model VCE-4200-HT) .....	31
9. Vibrating Wire Embedment Strain Gage (Geokon Model VCE-4200) .....	32
10. Vibrating Wire Embedment Displacement Gage (Geokon Model 4430) .....	33
11. LVDT Embedment Displacement Gage (RDP Electronics Model D5/400W) .....	34
12. Vibrating Wire Strain Gage (Geokon Model VSM-4000) .....	35
13. Vibrating Wire Displacement Gage (Geokon Model 4420) .....	36
14. LVDT Displacement Gage (RDP Electronics Model D5/200W) .....	37
15. Plan View of Roadway Test Sight .....	48
16. Roadway Instrumentation Layout .....	49

Figure	Page
17. Schematic of Wide Width Tension Testing Frame .....	56
18. Dimensional Placement of Instruments on a Geosynthetic Specimen ...	60
19. Global Strain From Two Sets of Celesco Gages: Geogrid, Machine Direction .....	94
20. Global Strain From Two Sets of Celesco Gages: Geogrid, Transverse Direction .....	94
21. Global Strain From Two Sets of Celesco Gages: Geotextile, Machine Direction .....	95
22. Global Strain From Two Sets of Celesco Gages: Geotextile, Transverse Direction .....	95
23. Global Strain From Two Tests: Geogrid, Machine Direction .....	96
24. Global Strain From Two Tests: Geogrid, Transverse Direction .....	96
25. Global Strain From Two Tests: Geotextile, Machine Direction .....	97
26. Global Strain From Two Tests: Geotextile, Transverse Direction .....	97
27. Comparison of Results to Manufacturer's Data: Geogrid, Machine Direction .....	98
28. Comparison of Results to Manufacturer's Data: Geogrid, Transverse Direction .....	98
29. Comparison of Results to Manufacturer's Data: Geotextile, Machine Direction .....	99
30. Comparison of Results to Manufacturer's Data: Geotextile, Transverse Direction .....	99

Figure	Page
31. Vibrating Wire Strain Gage: Geogrid, Machine Direction .....	100
32. Vibrating Wire Strain Gage: Geogrid, Transverse Direction .....	100
33. Vibrating Wire Strain Gage: Geotextile, Machine Direction .....	101
34. Vibrating Wire Strain Gage: Geotextile, Transverse Direction .....	101
35. Calibrated Vibrating Wire Strain Gage: Geogrid, Machine Direction .....	102
36. Calibrated Vibrating Wire Strain Gage: Geogrid, Transverse Direction .....	102
37. Calibrated Vibrating Wire Strain Gage: Geotextile, Machine Direction .....	103
38. Calibrated Vibrating Wire Strain Gage: Geotextile, Transverse Direction .....	103
39. Comparison of Vibrating Wire Strain Gage With 6, 4 and 2 Bolts Fastened .....	104
40. Vibrating Wire Displacement Gage: Geogrid, Machine Direction .....	104
41. Vibrating Wire Displacement Gage: Geogrid, Transverse Direction .....	105
42. Vibrating Wire Displacement Gage: Geotextile, Machine Direction .....	105
43. Vibrating Wire Displacement Gage: Geotextile, Transverse Direction .....	106
44. Calibrated Back-to-Back Vibrating Wire Displacement Gage: Geogrid, Machine Direction .....	106

Figure	Page
45. Calibrated Back-to-Back Vibrating Wire Displacement Gage: Geogrid, Transverse Direction .....	107
46. Calibrated Back-to-Back Vibrating Wire Displacement Gage: Geotextile, Machine Direction .....	107
47. Calibrated Back-to-Back Vibrating Wire Displacement Gage: Geotextile, Transverse Direction .....	108
48. LVDT Displacement Gage: Geogrid, Machine Direction .....	108
49. LVDT Displacement Gage: Geogrid, Transverse Direction .....	109
50. LVDT Displacement Gage: Geotextile, Machine Direction .....	109
51. LVDT Displacement Gage: Geotextile, Transverse Direction .....	110
52. Calibrated LVDT Displacement Gage: Geogrid, Machine Direction .....	110
53. Calibrated LVDT Displacement Gage: Geotextile, Machine Direction .....	111
54. Calibrated LVDT Displacement Gage: Geotextile, Transverse Direction .....	111
55. Foil Strain Gage: Geogrid, Machine Direction .....	112
56. Foil Strain Gage: Geogrid, Transverse Direction .....	112
57. Calibrated Foil Strain Gage: Geogrid, Machine Direction .....	113
58. Calibrated Foil Strain Gage: Geogrid, Transverse Direction .....	113
59. Unloading-Reloading Response From Foil Strain Gage: Geogrid, Transverse Direction .....	114
60. Calibrated 1/4 Bridge Foil Strain Gage: Geogrid, Machine Direction .....	114

Figure	Page
61. Calibrated Foil Strain Gage With Environmental Protection: Geogrid, Machine Direction .....	115
62. Calibrated Foil Strain Gage With Environmental Protection: Geogrid, Transverse Direction .....	115
63. Daily Traffic Loading History .....	117
64. Weekly Truck Traffic Loading History .....	117
65. VW Displacement Gage #2 on Geogrid (on wheel-path) .....	118
66. VW Displacement Gage #1 on Geotextile (off wheel-path) .....	118
67. VW Strain Gage #6 on Geogrid (off wheel-path) .....	119
68. VW Strain Gage #5 on Geotextile (on wheel-path) .....	119
69. LVDT Displacement Gage #31 on Geogrid (on wheel-path) .....	120
70. LVDT Displacement Gage #32 on Geogrid (off wheel-path) .....	121
71. LVDT Displacement Gage #29 on Geotextile (on wheel-path) .....	122
72. LVDT Displacement Gage #30 on Geotextile (off wheel-path) .....	123
73. VW Embedment Displacement Gage #3 in Base Above Geogrid (off wheel-path) .....	124
74. VW Embedment Displacement Gage #4 in Base in Non-Reinforced Section (on wheel-path) .....	124
75. VW Embedment Strain Gage #8 in Base Above Geogrid (on wheel-path) .....	125
76. VW Embedment Strain Gage #7 in Base Above Geotextile (on wheel-path) .....	125

Figure	Page
77. LVDT Embedment Displacement Gage #27 in Base Above Geogrid (off wheel-path) .....	126
78. LVDT Embedment Displacement Gage #28 in Base Above Geogrid (on wheel-path) .....	127
79. LVDT Embedment Displacement Gage #25 in Base Above Geotextile (on wheel-path) .....	128
80. LVDT Embedment Displacement Gage #26 in Base in Non-Reinforced Section (on wheel-path) .....	129
81. VW Embedment Strain Gage #10 in AC Above Geogrid (on wheel-path) .....	130
82. VW Embedment Strain Gage #11 in AC Above Geogrid (off wheel-path) .....	131
83. VW Embedment Strain Gage #9 in AC Above Geotextile (on wheel-path) .....	132
84. VW Embedment Strain Gage #12 in AC in Non-Reinforced Section (on wheel-path) .....	133
85. Foil Strain Gage #36 on Geogrid (on wheel path): Truck Pass Test 1 .....	134
86. Foil Strain Gage #35 on Geogrid (below centerline): Truck Pass Test 1 .....	134
87. Foil Strain Gage #36 on Geogrid (on wheel path): Truck Pass Test 2 .....	135
88. Foil Strain Gage #35 on Geogrid (below centerline): Truck Pass Test 2 .....	135
89. Foil Strain Gage #36 on Geogrid (on wheel path): Truck Pass Test 3 .....	136
90. Foil Strain Gage #35 on Geogrid (below centerline): Truck Pass Test 3 .....	136

Figure	Page
91. Foil Strain Gage #34 on Geogrid (on wheel path): Truck Pass Test 3 .....	137
92. Foil Strain Gage #36 on Geogrid (on wheel path): Truck Pass Test 4 .....	137
93. Foil Strain Gage #35 on Geogrid (below centerline): Truck Pass Test 4 .....	138
94. Foil Strain Gage #34 on Geogrid (on wheel path): Truck Pass Test 4 .....	138
95. Foil Strain Gage #36 on Geogrid (on wheel path): Truck Pass Test 5 .....	139
96. Foil Strain Gage #35 on Geogrid (below centerline): Truck Pass Test 5 .....	139
97. Foil Strain Gage #34 on Geogrid (on wheel path): Truck Pass Test 5 .....	140
98. Foil Strain Gage #36 on Geogrid (on wheel path): Truck Pass Test 6 .....	140
99. Foil Strain Gage #35 on Geogrid (below centerline): Truck Pass Test 6 .....	141
100. Foil Strain Gage #34 on Geogrid (on wheel path): Truck Pass Test 6 .....	141
101. Foil Strain Gage #36 on Geogrid (on wheel path): Truck Pass Test 7 .....	142
102. Foil Strain Gage #35 on Geogrid (below centerline): Truck Pass Test 7 .....	142
103. Foil Strain Gage #34 on Geogrid (on wheel path): Truck Pass Test 7 .....	143
104. Foil Strain Gage #36 on Geogrid (on wheel path): Truck Pass Test 8 .....	143

Figure	Page
105. Foil Strain Gage #35 on Geogrid (below centerline): Truck Pass Test 8 .....	144
106. Foil Strain Gage #36 on Geogrid (on wheel path): Truck Pass Test 9 .....	144
107. Foil Strain Gage #35 on Geogrid (below centerline): Truck Pass Test 9 .....	145
108. LVDT Displacement Gage #31 on Geogrid (on wheel path): Truck Pass Test 4 .....	145
109. LVDT Displacement Gage #31 on Geogrid (on wheel path): Truck Pass Test 5 .....	146
110. LVDT Displacement Gage #32 on Geogrid (off wheel path): Truck Pass Test 5 .....	146
111. LVDT Displacement Gage #29 on Geotextile (on wheel path): Truck Pass Test 4 .....	147
112. LVDT Displacement Gage #29 on Geotextile (on wheel path): Truck Pass Test 5 .....	147
113. LVDT Displacement Gage #29 on Geotextile (on wheel path): Truck Pass Test 6 .....	148
114. LVDT Embedment Displacement Gage #27 in Base Above Geogrid (off wheel path): Truck Pass Test 3 .....	148
115. LVDT Embedment Displacement Gage #27 in Base Above Geogrid (off wheel path): Truck Pass Test 6 .....	149
116. LVDT Embedment Displacement Gage #27 in Base Above Geogrid (off wheel path): Truck Pass Test 7 .....	149
117. LVDT Embedment Displacement Gage #28 in Base Above Geogrid (on wheel path): Truck Pass Test 2 .....	150
118. LVDT Embedment Displacement Gage #28 in Base Above Geogrid (on wheel path): Truck Pass Test 3 .....	150



Figure	Page
119. LVDT Embedment Displacement Gage #28 in Base Above Geogrid (on wheel path): Truck Pass Test 4 .....	151
120. LVDT Embedment Displacement Gage #28 in Base Above Geogrid (on wheel path): Truck Pass Test 5 .....	151
121. LVDT Embedment Displacement Gage #28 in Base Above Geogrid (on wheel path): Truck Pass Test 6 .....	152
122. LVDT Embedment Displacement Gage #25 in Base Above Geotextile (on wheel path): Truck Pass Test 1 .....	152
123. LVDT Embedment Displacement Gage #25 in Base Above Geotextile (on wheel path): Truck Pass Test 2 .....	153
124. LVDT Embedment Displacement Gage #25 in Base Above Geotextile (on wheel path): Truck Pass Test 3 .....	153
125. LVDT Embedment Displacement Gage #25 in Base Above Geotextile (on wheel path): Truck Pass Test 4 .....	154
126. LVDT Embedment Displacement Gage #25 in Base Above Geotextile (on wheel path): Truck Pass Test 5 .....	154
127. LVDT Embedment Displacement Gage #25 in Base Above Geotextile (on wheel path): Truck Pass Test 6 .....	155
128. LVDT Embedment Displacement Gage #25 in Base Above Geotextile (on wheel path): Truck Pass Test 7 .....	155
129. LVDT Embedment Displacement Gage #26 in Base of Non-Reinforced Section (on wheel path): Truck Pass Test 1 ...	156
130. LVDT Embedment Displacement Gage #26 in Base of Non-Reinforced Section (on wheel path): Truck Pass Test 2 ...	156
131. LVDT Embedment Displacement Gage #26 in Base of Non-Reinforced Section (on wheel path): Truck Pass Test 3 ...	157
132. LVDT Embedment Displacement Gage #26 in Base of Non-Reinforced Section (on wheel path): Truck Pass Test 4 ...	157

Figure	Page
133. LVDT Embedment Displacement Gage #26 in Base of Non-Reinforced Section (on wheel path): Truck Pass Test 5 . . .	158
134. LVDT Embedment Displacement Gage #26 in Base of Non-Reinforced Section (on wheel path): Truck Pass Test 6 . . .	158
135. Foil Strain Gage #34 on Geogrid, July 31st Test . . . . .	159
136. Foil Strain Gage #35 on Geogrid, July 31st Test . . . . .	159
137. Foil Strain Gage #36 on Geogrid, July 31st Test . . . . .	160
138. Foil Strain Gage #34 on Geogrid, September 21st Test . . . . .	160
139. Foil Strain Gage #35 on Geogrid, September 21st Test . . . . .	161
140. Foil Strain Gage #36 on Geogrid, September 21st Test . . . . .	161
141. VW Displacement Gage #2 on Geogrid, September 21st Test . . . . .	162
142. VW Strain Gage #5 on Geotextile, September 21st Test . . . . .	162
143. VW Embedment Displacement Gage #3 in Base Above Geogrid, September 21st Test . . . . .	163
144. VW Embedment Strain Gage #7 in Base Above Geotextile, September 21st Test . . . . .	163
145. VW Embedment Strain Gage #9 in AC Above Geotextile, September 21st Test . . . . .	164
146. Resilient Modulus Values From July 21 Road Rater Test . . . . .	164
147. Average Resilient Modulus Values From July 21 Road Rater Test . . . . .	165
148. Resilient Modulus of AC Layer From September 21 Road Rater Test . . . . .	165
149. Resilient Modulus of Base and Subgrade Layers From September 21 Road Rater Test . . . . .	166

Figure	Page
150. Average Resilient Modulus of AC Layer From September 21 Road Rater Test .....	166
151. Average Resilient Modulus of Base and Subgrade Layers From September 21 Road Rater Test .....	167

## ABSTRACT

Reinforcing flexible pavement roadways with geosynthetics has been proposed to reduce the thickness of the base course layer. Mechanisms of reinforcement have been identified, but not quantified. A design procedure that incorporates the reinforcement provided by geosynthetics would provide more efficient use of aggregate and geosynthetics than those currently available. Research at Montana State University has been initiated in this area. Its goal is to quantify the reinforcing benefit of geosynthetics leading to the development of a roadway design procedure.

This thesis, which is the first phase of the research, is the study of possible strain sensors and installation techniques that can be used to monitor the performance of a geosynthetically reinforced roadway. With suitable strain sensors identified, the follow on phases of research at Montana State University will quantify the reinforcing benefit of geosynthetics.

Research was conducted in two areas. A full scale reinforced flexible pavement roadway was built and instrumented with vibrating wire, foil strain gauge, and LVDT technologies. The instruments were monitored over a four month period while the roadway was subjected to heavy truck traffic. The evaluation of mounting techniques used to fasten the strain sensors to the geosynthetics was accomplished with the use of a wide width uniaxial tension facility.

Results from the study show that all three of the technologies are viable candidates for use in further research. The effect of mounting techniques used to fasten the strain sensors to the geosynthetics was seen to have a major impact on the strain measured by the transducer. Calibration factors were developed to convert the strain measured by a sensor to the global strain in the geosynthetic. The need to account for temperature effects regarding thermal strain and signal distortion was also identified.

## CHAPTER 1

## INTRODUCTION

Background and Problem

The use of geosynthetics (geotextiles and geogrids) has become prevalent in geotechnical and transportation projects in recent years. It has been proposed that it may be possible to reinforce the base course layer in paved roadways with geosynthetics. If true, this would be of great benefit in certain projects. Some areas, such as Eastern Montana, have limited natural sources of quality aggregate for base course construction. It often is cost prohibitive to transport aggregate to these areas. For these areas, reducing base course thickness with reinforcement through the use of geosynthetics may be a cost effective alternative to bringing in outside aggregate.

Currently, the improvement in performance gained by adding geosynthetics to the base layer reinforcement is poorly understood. Studies have shown conflicting results with regard to geosynthetic reinforcement of base courses in paved roadways. This situation is partially due to the lack of understanding of the mechanical performance of geosynthetically reinforced roadways. Research at Montana State University has been initiated in this area with the goal of describing the reinforcement performance of geosynthetics in paved roadways and providing a design tool for geosynthetically reinforced flexible pavements.

The research program at Montana State University involves several areas of study. To examine the interaction between geosynthetics and base course, a confined geosynthetic

pullout facility has been constructed. The facility is a 6 walled steel box in which a geosynthetic is sandwiched in base material. An air bladder provides confining pressure to the top of the base course material. Once the desired level of confinement is achieved, the geosynthetic is pulled through the box by means of a low geared electric motor. Strain instrumentation on the geosynthetic and a load cell in the pull out mechanism provides measurements of the geosynthetic performance. In addition to providing information on the interaction between the geosynthetic and base course, creep and stress relaxation effects in geosynthetic may be studied.

To identify conditions under which geosynthetic reinforcement is seen to offer improvement, a cyclic load plate facility is being constructed. This facility is a reinforced concrete box in which a roadway structure is built and instrumented. A pneumatically activated circular plate mounted on a steel H beam is used to apply loads to the roadway. Through the use of rollers, the steel plate will be able to move over the surface of the roadway to apply the load at specific locations. The performance of the roadway structure will help identify types of test sections that are necessary to advance the understanding of geosynthetic reinforcement.

With knowledge gained from the two laboratory tests a design procedure will be established. Finite element analysis will be important in developing the design procedure. A finite element model of the cyclic load plate facility will be created and verified against the measured performance. The model will then be used to develop the design procedure. Once the design procedure is established, it will be verified by constructing a full scale test road.

To study the mechanisms of reinforcement in a geosynthetically reinforced roadway the mechanical performance of the roadway must be measured. Parameters such as stress, strain, pore water pressure, moisture content, and temperature need to be measured at select locations in the roadway cross section. For many geotechnical structures involving only granular materials and long term static loading, measurement of these parameters is well established. For geosynthetics and roadway studies however, the methodology is not as clearly established. In addition to the granular base course of the roadway, measurements need to be made in the asphalt concrete (AC) pavement, and on the geosynthetic. Long term measurements as well as short term dynamic responses from individual axle loadings need to be made. During the initial research at Montana State University, particular concerns existed regarding strain measurements. The appropriate strain gauges for use in roadways and attendant installation techniques had to be determined before the research could continue. Therefore the topic of this study is examination of the proposed strain measuring instrumentation and installation techniques for use in follow on research.

#### Scope of Work

The study consists of two areas. First, a fully instrumented geosynthetic reinforced roadway was constructed and monitored. The roadway study provided information in two areas. Gauge performance, including both strain measurement and reliability was evaluated. Second, installation techniques for the strain gauges were evaluated. The roadway carried over 7000 passes of heavy truck traffic during its 4 month life. It consisted of a geogrid reinforced section, a geotextile reinforced section, and a control section. The roadway

contained a total of 24 strain gauges located in the AC, base course, and mounted on the geosynthetics. Two types of strain measurements were made. Static long term cumulative strain measurements were recorded over the life time of the roadway as well as dynamic short term measurements of specific events, such as the loading from a single axle.

To support the in-field study, a wide width tension testing facility was constructed in the laboratory. This facility was used to study the strain gauges mounted on the geosynthetics. The facility was able to test geosynthetic specimens up to 1.83 m wide and 3 m long. Tests in the facility covered three objectives. First, it allowed comparison of the local strain in a geosynthetic (measured by a strain gauge) to the global strain experienced by the geosynthetic when subjected to a uniaxial load. Second, the mounting techniques used for the strain gauges in the field were evaluated. Third, the stress strain response of the geosynthetic provided by the manufacturer was verified.

#### Outline of the Thesis

The thesis is organized into 5 chapters. Chapter 2 is a literature review to provide background information concerning instrumentation of roadways and geosynthetics. Its main topics are strain gauge types, previous instrumented roadway studies, and tension testing of geosynthetics. Chapter 3 provides a detailed discussion of the experimental work performed by the author. Topics include instrumentation used in the study, roadway construction, and the wide width tension testing facility. Chapter 4 provides results of the study. Chapter 5 is devoted to conclusions and recommendations for further work.



## CHAPTER 2

## LITERATURE REVIEW

Introduction

The literature review consists of five sections. In section one, a brief presentation of the calculation of strain is made. Section two presents the types of strain sensors used in roadway studies. Previous instrumented roadway studies from both the field and laboratory are discussed in section three. Section four looks at the ASTM tension test for geosynthetics and the significant parameters for tension tests in general. Section five discusses other geosynthetic instrumented projects with regards to bonding foil strain gauges to geogrids.

Strain Theory

Strain ( $\epsilon$ ) is a measurement of the relative change in length of an object. It is defined as the ratio of the change in length ( $\delta L$ ) of an object to its original length ( $L$ ). This relationship can be written as:

$$\epsilon = \frac{\delta L}{L} \quad (1)$$

The relationship of the strain of an object to the force causing the strain is in general non-linear. For many engineering situations however, the magnitude of the strains is small, covering only the linear portion of the material's stress-strain diagram. Hooke's Law governs the stress-strain relationship of a material in this region. It states that the stress is

directly proportional to the strain. It is written as the following:

$$\sigma = \epsilon E \quad (2)$$

The importance of this relationship is that it allows the calculation of stress ( $\sigma$ ) based on the measured strain and the material property  $E$ , the modulus of elasticity.

Several technologies are used to measure strain. Electrical and mechanical are most common but optical, acoustical, and pneumatic strain sensors exist. Regardless of the phenomena, all strain gauges rely on the measurement of the displacement between two points a known distance apart and then the computation of strain using equation 1.

#### Roadway Instrumentation

Due to the different materials in a roadway structure, there are several types of strain sensors typically used. In granular material the technology used is different from that used in cemented material such as AC or concrete. The profile of a strain sensor for granular material is large in order to produce an accurate measurement. Strain sensors in cemented material do not always have this luxury due to the small thickness of the surface material. Additionally, the installation of strain sensors in cemented material typically occurs when the hot mix is placed. This requires high temperature resistance of both the instrument and its electrical cables.

## Strain Sensors for Cemented Material

H-Gauges. H-gauges are given their name from their appearance (See figure 1). They consist of a strip of material onto which a foil strain gauge is bonded. On each end of the strip, metal bars are fixed at their midpoint. The metal bars serve as anchors in the cemented material. Thus when the material is strained the metal bars move relative to each other and the resulting strain in the strip material is measured by the foil strain gauge. The length of the gauge should depend on the size of the aggregate in the AC. For pavement materials it is commonly believed that the gauge length should be at least 4 to 5 times the maximum particle diameter (Van Deusen, 1992). To ensure that accurate strain readings are being made it is important that the stiffness of the strip be the same or less than that of the cemented material. If it is greater, the H-gauge will under measure the actual strain of the cemented material.

The first H-gauges were designed by the Transportation Road Research Laboratory (TRRL) in Great Britain (Sebaaly, 1989). Important aspects of their evolution include better matching of gauge and material stiffnesses, and survivability of the foil strain gauge. To this end current H-gauges manufactured by Dynatest Corporation use epoxy reinforced fiberglass as the strip material (Van Deusen, 1992). Fiberglass has the desired properties of low stiffness and high flexibility. To increase survivability, the foil strain gauge is embedded in the fiberglass. Additionally, various layers of waterproofing compounds and aluminum plates are placed around the fiberglass strip.

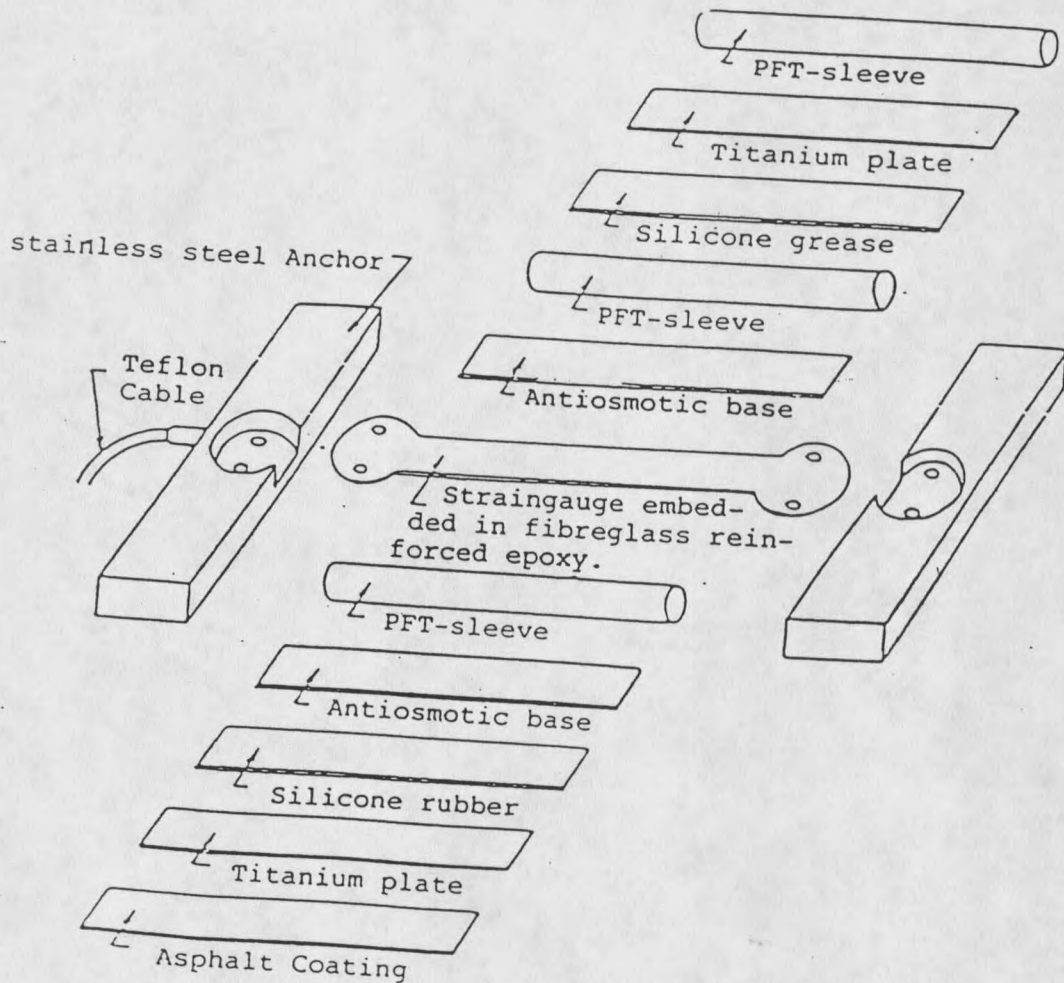


Figure 1. Dynatest H-Gauge (from Van Deusen et al., 1992)

Foil Strain Gauges on Carrier Block. Carrier blocks are laboratory compacted AC bricks to which foil strain gauges have been attached. When the hot mix lift is being constructed, the carrier block is placed on the base course in the proper location and orientation. As the hot mix surrounds the carrier block the heat softens the carrier block and the hot mix and carrier block bond forming a monolithic layer of AC.

A drawback of carrier blocks is protection of the foil strain gauge when the hot mix softens the block. Debonding and mechanical damage of the gauge are possible. A technique to overcome this dilemma is to cut the carrier block in the lab and mount the foil strain gauge on the cut surface as seen in figure 2. The carrier block is then glued back together. The location of the foil strain gauge in the middle of the carrier block gives it protection from aggregate in the hot mix. The location also minimizes temperature change around the gauge, which can be detrimental to the bonding agent.

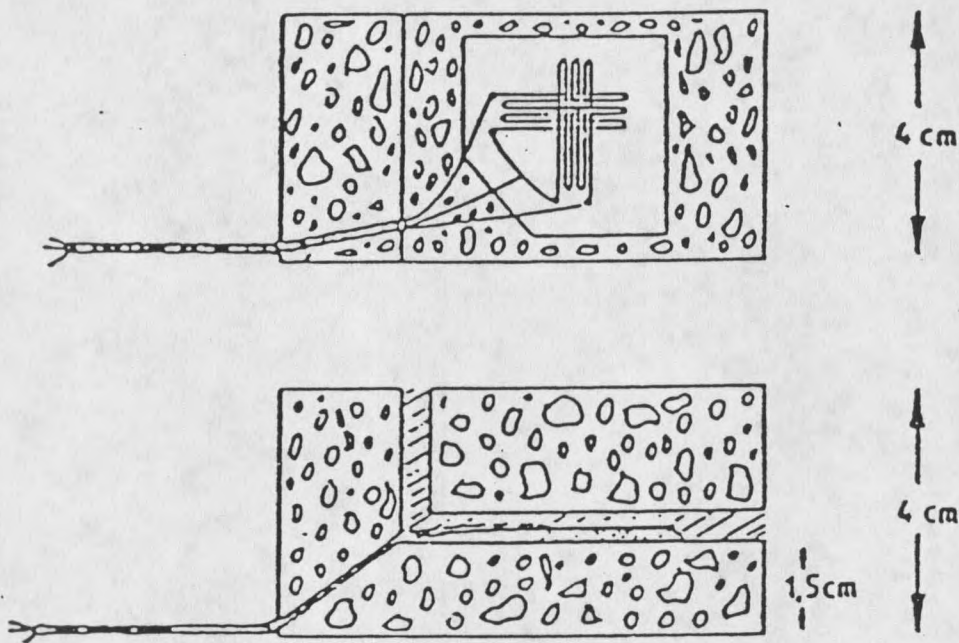


Figure 2. Foil Strain Gauge mounted in a Carrier Block (from Sebaaly et al., 1989)

Foil Strain Gauges Mounted on Cores. This technique is similar to a carrier block except that the core is cut out of the existing roadway. Bonding the core back to the AC is a significant problem. The stiffness of the bonding agent and that of the AC must be closely

matched. If the bonding agent is soft relative to the AC the core tends to act as a rigid body immersed in a monolithic material. If the bonding agent is stiff relative to the AC, stress concentrations will occur in the core, which induce cracking and premature failure of the core. A major advantage of using cores is that the instruments can be easily placed after the roadway is constructed.

### Strain Gauges for Granular Material

Inductance Coils. Inductance coils are two disc shaped coils that produce an electromagnetic output proportional to the distance between them. They are available commercially from Bison Instruments, Inc. The discs may be oriented coplanar, orthogonal, or most commonly coaxial. Typical distance between the disks is 1 to 4 times the diameter of a single disk (Selig, 1975). One of the disks acts as a transmitter and the other as a receiver. As the distance between them changes, the response of the coil in the receiver changes which is converted to a displacement. Inductance coils have a unique advantage in that the two discs are not mechanically connected. Therefore disturbance and altering of the tested material is not an issue. They have good stability for long term measurements, but are subject to error when used for certain dynamic measurements. Poor performance in dynamic measurements can be caused by the movement of the vehicle applying the load through the gauge's electromagnetic field. The metal and electrical system of the vehicle induces changes in the field of the gauge. The strain resolution for long-term and dynamic measurements is 0.003 % and 0.1 % respectively (Brown, 1977). Inductance coils appear to have excellent durability. Selig (1975) notes a roadway study in which less than 1% of



































































































































































































































































































































































