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

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 geo synthetics 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.

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APPROVAL

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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.

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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.

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

$$\epsilon = \frac{\delta L}{L} \tag{1}$$

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:

$$\sigma = \epsilon E \tag{2}$$

The importance of this relationship is that it allows the calculation of stress (σ) 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 stiff nesses, 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.

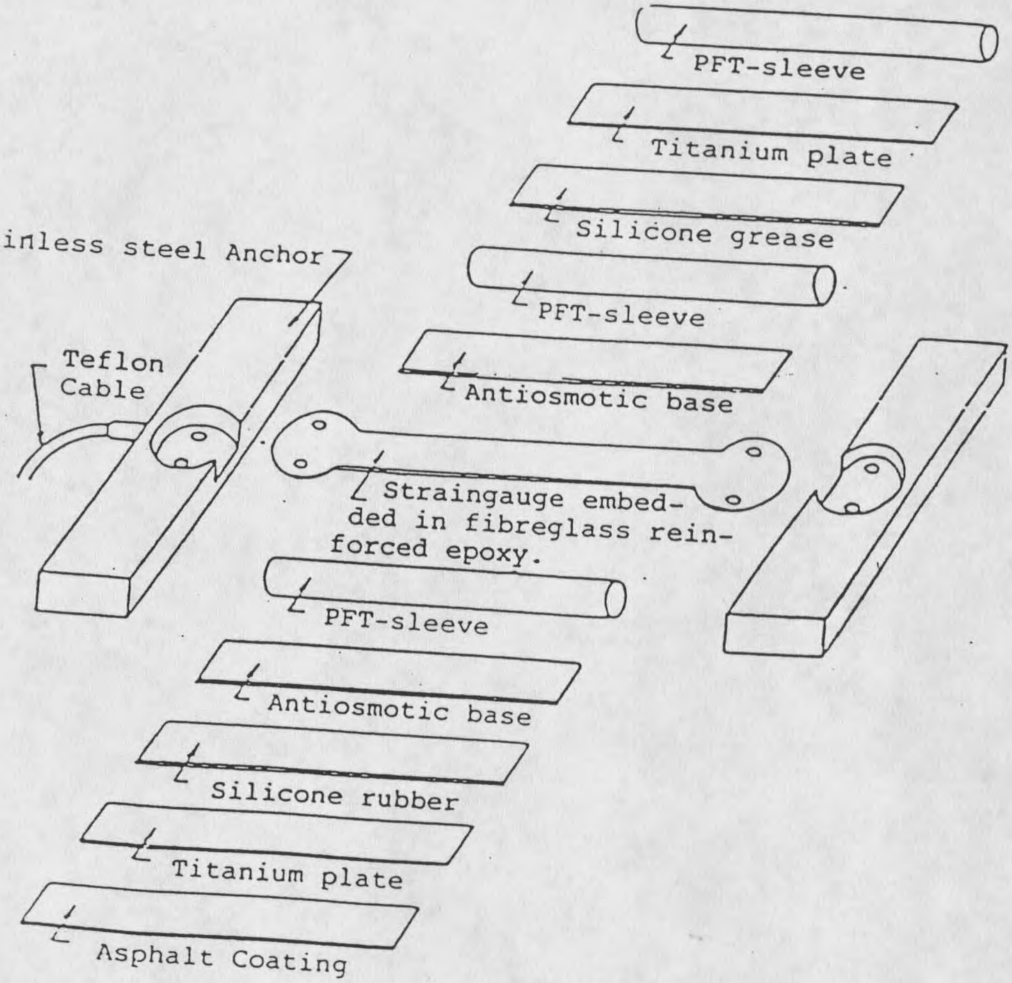

Figure 1. Dynatest H-Gauge (from Van Deusen et al., 1992)

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.

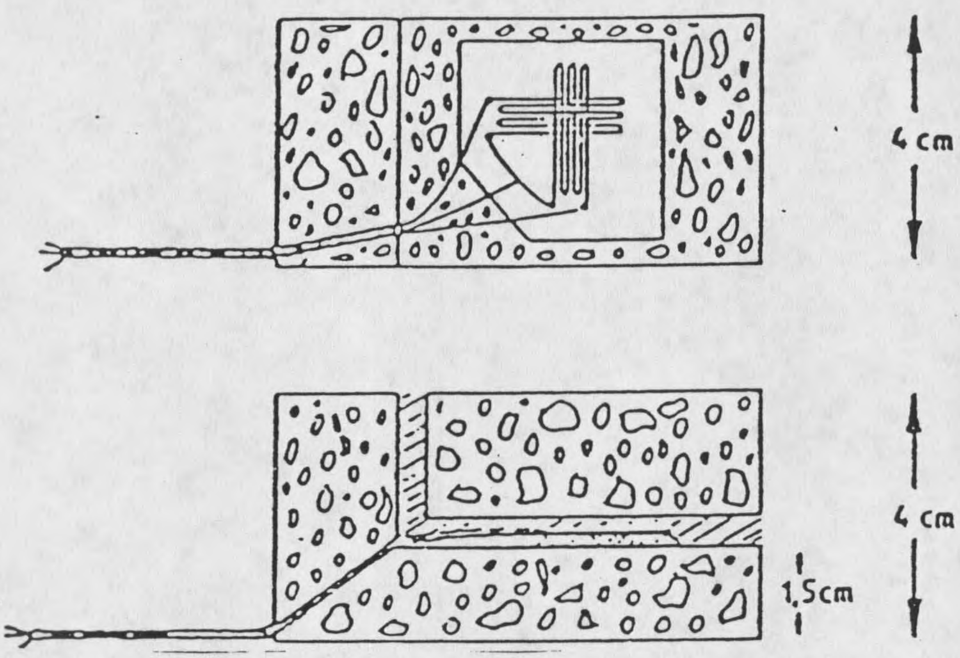

Figure 2. Foil Strain Gauge mounted in a Carrier Block (from Sebaaly et al., 1989)

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