FIELD INSTRUMENTATION OF GEOTEXTILE SYSTEMS

By Gregory N. Richardson

Abstract

Design procedures for geotextile systems evolve by a parallel development of theoretical analysis and the generation of actual field data to qualify the assumptions made. Geotextiles and geomembranes are routinely placed in field situations that are too complex for analysis by manual procedures but are also too mundane to justify the significant engineering effort that would be required to perform a numerical analysis. Since construction practice cannot be made to wait for theory, many current design procedures must be empirical in origin and are therefore very dependent upon field observations or performance measurements. Field instrumentation of actual geotextile systems provides the required data upon which empirical design procedures can be based.

Instrumentation Objectives

A typical field instrumentation system is designed to measure the changes in a single physical property of the geotextile system without influencing the performance of the overall system. Typical system physical parameters monitored might include displacements, strains, earth pressures, and soil moisture contents. Each instrument system must be designed such that it is particularly sensitive to changes in the target parameter and relatively insensitive to changes in other system parameters. The cross-sensitivity of a given instrument to changes in non-target variables is a major source of possible errors in the interpretation of field data. Thus the objectives in the design of a given instrumentation system are as follows:

1—Maximum sensitivity to target variable.
2—Minimum cross-sensitivity to other field variables.
3—Minimum impact on the performance of overall system.

Additional criteria such as minimum cost, reliability, and ease of installation are assumed as in all design efforts.

Field instrumentation is designed to measure changes in a single physical property.

Time Factors

The design and monitoring of an instrumentation system is influenced by the speed of the response to be measured and the period over which data must be acquired. If the geotextile system is subjected to dynamic loads, such as those generated by moving vehicles, then the measurement systems may be required to provide a significant number of data points over a relatively short time period. Both the design of the instrument and the data logging system will be influenced by the maximum sampling rate. This occurs with conventional testing within the laboratory, where many tests can be comfortably recorded manually and others require the use of plotters or data loggers to keep up with the data generation rate.

The design life of an instrumentation system is a function of the time period over which data must be monitored. Field tests that may be years in duration require instruments that incorporate significant environmental control factors. Corrosion of gages due to airborne moisture maybe tolerable for tests lasting weeks but will not be acceptable in systems that must perform for years. Long term instrument reliability is of particular concern in many recent geotextile installations where hazardous waste materials are contained. Long term creep of cements used in assembling gages, electrical drift of monitoring systems, and the inevitable failure of gage readout boxes are typical considerations that must be faced in long term tests.

Types of Measurements

Variables typically targeted for monitoring within a geotextile system are determined by the anticipated role or function being played by the fabric. Thus instrumentation measuring strains or displacements would be typical in systems where the geotextile provides reinforcement, while soil moisture gages would be common in systems where the geotextile provides filtration or drainage. In general, instrumentation systems placed in field geotextile systems will be designed to monitor the following parameters:

1—displacements,
2—strain at a point,
3—soil moisture,
4—earth pressures, and
5—hydrostatic pressures.

Mechanical, electrical, and hydraulic based instrumentation systems are available for most of these parameters. The selection of a particular type of system is dependent upon the rate of sampling required, cost, and related installation requirements.

Displacement Measurements

Displacements measured in the field are almost entirely relative. That is, the displacement reflects the movement of one point in the system with respect to a second point in the same system. Instruments commonly used to measure displacements in the field rely on optical, hydraulic, mechanical, or electrical systems to convert physical movements into measurable units. The **optical** systems are typically based on

the use of survey equipment common to construction sites. Monuments or targets established on the surface of a geotextile system can be optically surveyed to evaluate movements at the surface of such systems. The obvious limitation of such optical systems is the inability to measure movements that occur within the geotextile/soil structure itself. The advantage to the optical systems is the ready availability of firms that provide this type of service.

Hydraulic displacement measuring systems date back to the ancient Egyptians where hollow reeds filled with water were used to establish a common level at various points within large structures. Modern man improved this ancient system by substituting more durable plastic components for romantic but frail reeds. The design of a hydraulic settlement platform[1] used to monitor the vertical movements of points within a reinforced earth wall is shown on Figure 1. By flushing the device prior to reading, the water level at the manometer external to the wall would accurately reflect the true elevation of the settlement gage embedded within the wall. In applications where the gage is significantly higher than the manometer, the manometer or readout station can be placed at a convenient location beneath the gage with a pressure gage used to read the head of water acting between the two points.

Mechanical displacement gages rely on tension or compression rods to indicate internal movements of a system. A vertical settlement system used by the Department of the Interior[2] for many years is shown on Figure 2. The vertical rods are attached to plates embedded within the soil. The rods are then brought up through the overlying soil within collapsible tubes to ensure free movement of the rods. Horizontal movements can be monitored using a simple cable anchor system as shown in Figure 3. Cables are attached to anchors and led to the surface through tubing. Weights attached to the cables maintain a constant tension in them and enables small movements of the cable to be readily measured. The use of multiple cables at a given elevation enables the relative movements of the soil at one elevation to be evaluated. Mechanical displacement systems are the most reliable but require clear access at the ground surface and obviously would be difficult to incorporate in geomembrane systems.

Electrical displacement gages offer the advantages of being able to quickly track dynamic displacements and being able to operate in systems having limited access. Electrical displacement systems rely on either variable resistance devices that operate like slide volume controls on modern stereo equipment or magnetic inductance devices that relate movements to changes in magnetic fields. A vertical displacement system used to measure the dynamic movement at the interface of the soil and ballast in a track support system is shown on Figure 4[3]. Systems such as this are capable of measuring displacements as small as 0.0001-inch and can track the dynamic movements as a train moves over the system.

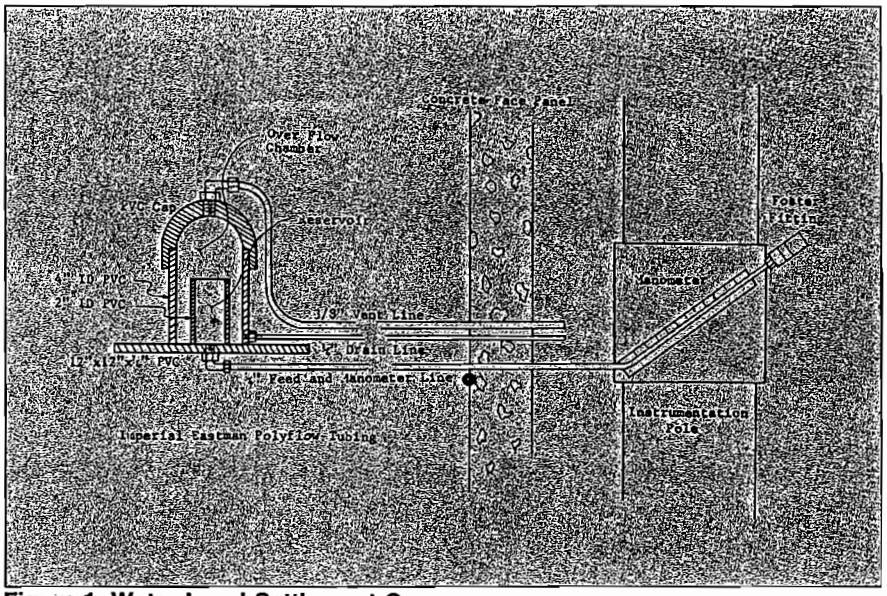

Figure 1. Water Level Settlement Gage

Soil Moisture

Geotextile systems are commonly used to control the movement of moisture through soil systems. The effectiveness of these systems can be measured by monitoring the moisture content of the soil. Moisture within the soil influences the electrical resistance and capacitance of the soil itself. Resistance type soil moisture gages function by measuring the direct resistance of a soil moisture cell emplanted in the ground[4]. An example of such a soil moisture cell is shown on Figure 5. A major deficiency of this type of cell is the lag time that can exist between the change in moisture content of the soil and the time required for the moisture cell to normalize. These cells are typically calibrated in the laboratory for the specific soil encountered in the field.

An alternate soil moisture gage using soil capacitance is shown on Figure 6[5]. This gage has the advantage of no lag time between a change in moisture of the soil and gage reading.

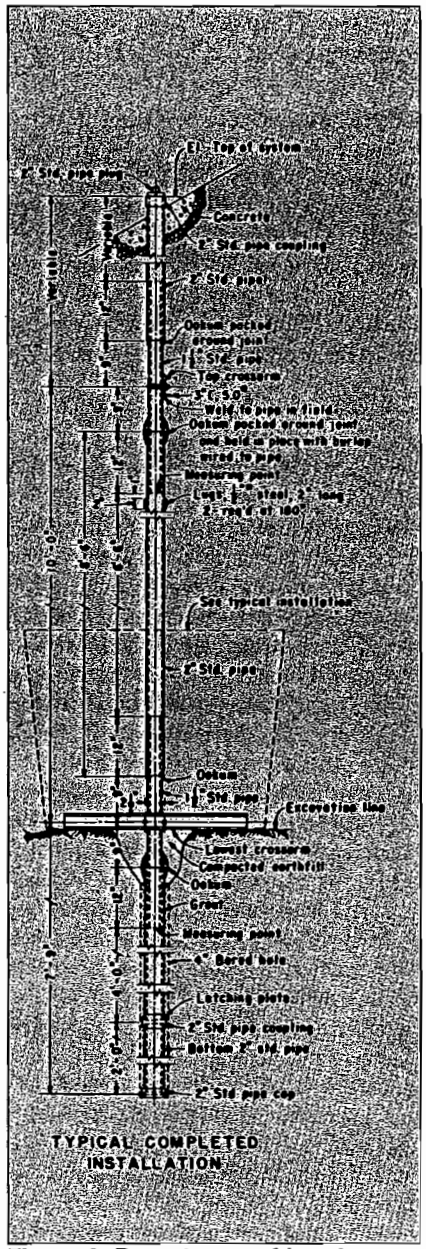

Figure 2. Department of Interior Settlement Gage

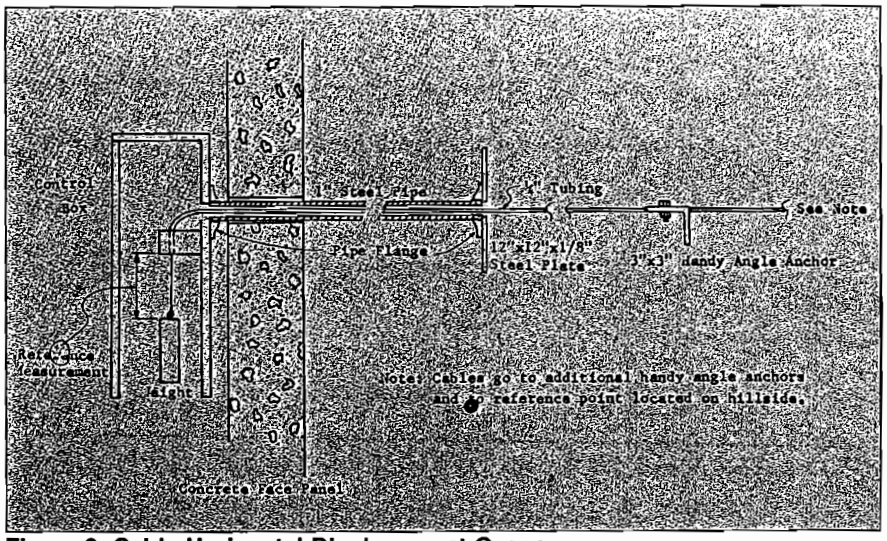

Figure 3. Cable Horizontal Displacement Gages

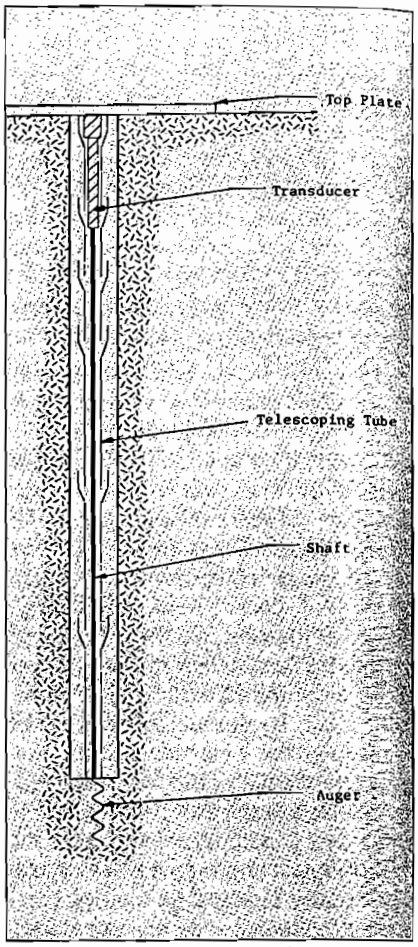

Figure 4. Electric Vertical Displacement Gage

The disadvantages of the capacitance soil moisture gage are a significant increase in cost and equipment complexity.

Earth Pressure

The use of geotextiles, geogrids or other reinforcement media can alter the distribution of earth pressures acting within or at the boundary of the reinforced system. Earth pressures are commonly measured using cells that employ a flexible diaphragm to convert the earth pressure into a measurable strain or fluid pressure. An electrical earth pressure cell[6] employing resistance strain gages is shown on Figure 7. The cells can be placed anywhere within the soil/geotextile system that an electrical cable can be placed.

Implanted earth pressure cells must be designed so that the size and stiffness of the gage do not significantly alter the stress state within the soil mass. Additional factors such as diaphragm stiffness and cross-sensitivity of the cell to stresses in the plane of the diaphragm must be considered in the design of each cell. Calibration of earth pressure cells is typically performed in the laboratory using a pressure chamber containing soil similar in density and properties to that found in the field.

Earth pressures acting against rigid walls can be measured using a simple strain gaged rod and plate as shown on Figure 8. This system would be appropriate for monitoring the lateral earth pressures acting against a geotextile drainage layer placed on the side of a basement or retaining wall. Boundary earth pressure gages such as this must be designed to have a stiffness approximately equal to that of the surrounding wall. It is possible to design these gages such that the shear forces acting on the face on the gage can also be monitored. Thus shear forces caused by the settlement of soil adjacent to the face can be observed.

Hydrostatic Pressures

The flow of water through a geotextile/soil system is controlled by the hydrostatic pressures that exist in the pore fluids found within the soils. These pore water pressures can be monitored using gages that employ a sensing diaphragm much like the earth pressure cells. Unlike the earth pressure cells however,

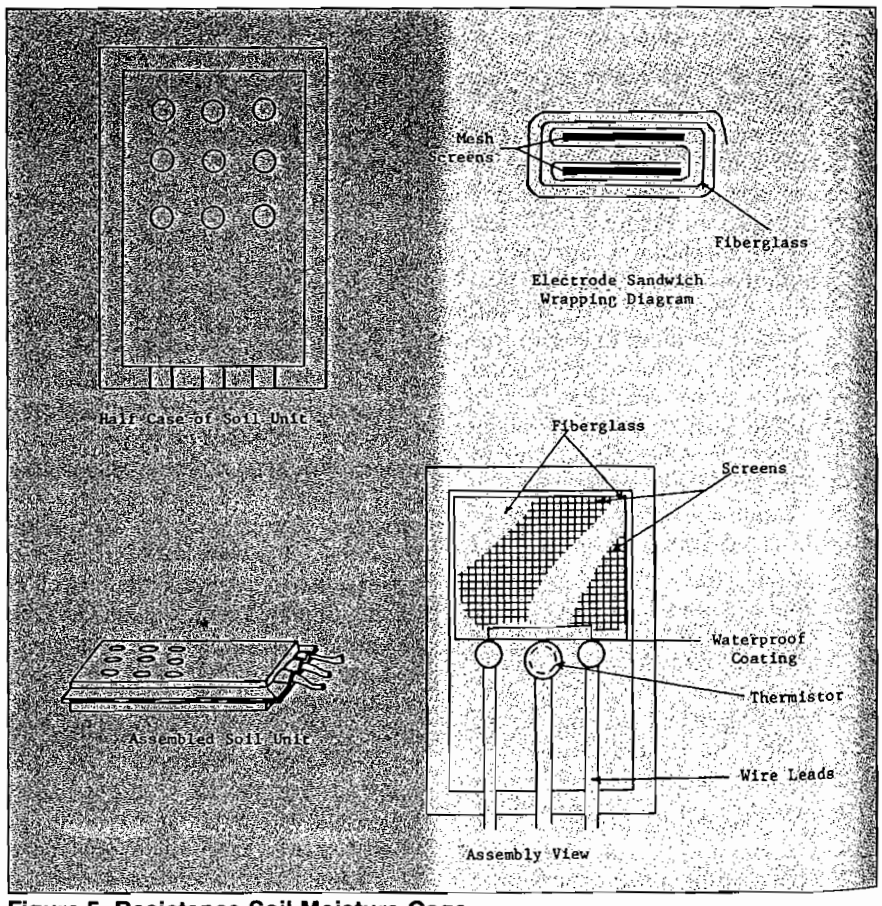

Figure 5. Resistance Soil Moisture Gage

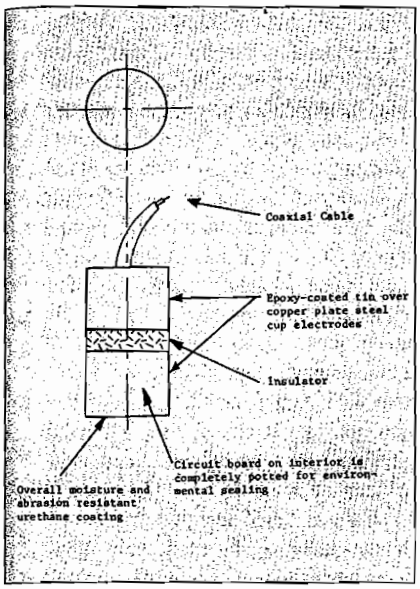

Figure 6. Capacitance Soil Moisture Gage

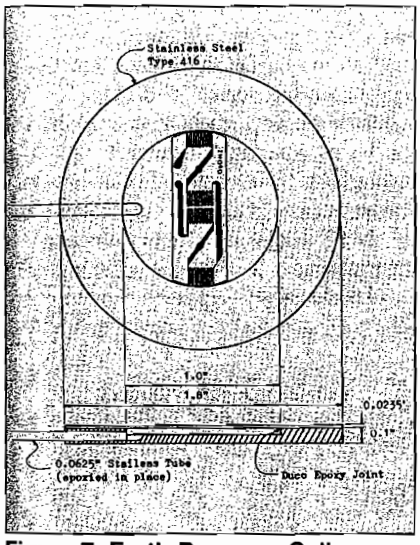

Figure 7. Earth Pressure Cell

the pore pressure gages cover the diaphragm with a porous material that allows the fluid pressures to reach the diaphragms yet prevents the soil or earth pressures from acting on the diaphragm. These gages maybe electrical like the earth pressure gage shown on Figure 7 or pneumatic[7] as shown on Figure 9. The pore water pressure gage shown on Figure 9 is mounted in a cylinder that is used in the laboratory to calibrate each gage.

Pneumatic pore water pressure gages typically operate by applying a pressure to the back face of the diaphragm and increasing the back pressure until it equals the pore water pressure. This equilibrium is noted when the diaphragm returns to its unloaded configuration. Pressure relief valves are attached to the diaphragms to automatically register this point. The

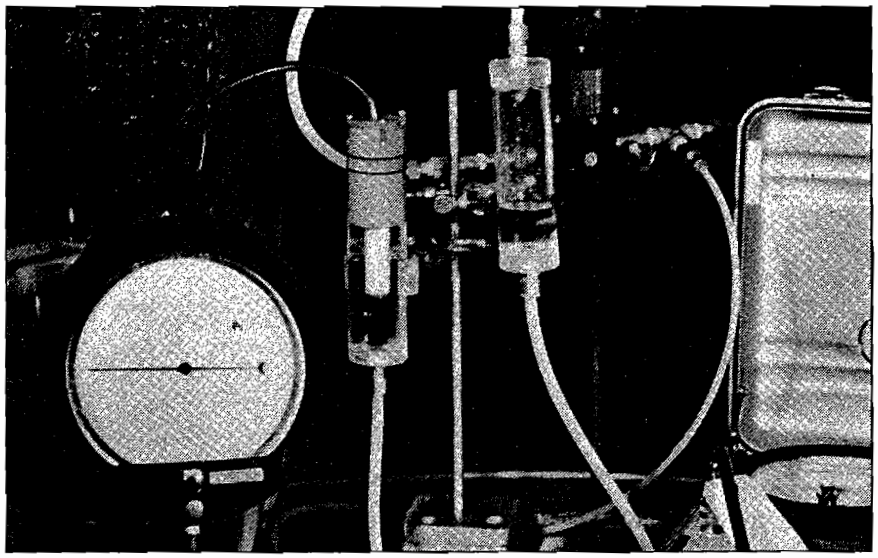

Figure 9. Pneumatic Pore Water Pressure Cell

gage shown is also equipped to measure negative pore water pressures such as are commonly generated in near surface clayey soils. The flexibility of the diaphragm and the permeability of the soil control the lag time that may exist between actual pore water pressure changes and when the change registers on the gage. A flexible diaphragm requires a large volume of water to flow from the soil to deflect it. In clayey soils this large volume of water may require a substantial period of time to flow. Thus pore water pressure gages in clayey soils will normally use a stiff diaphragm that requires only a small volume of fluid.

Data Logging Systems

Data generated by the gages must be recorded accurately to be of any value. For gages that do not provide electronic output this will typically mean manual readings recorded by hand. Gages that are fitted with some form of electrical readout can be monitored on many types of automated data loggers. Electronic data loggers are available with sampling rates varying from one sample per hour to high speed units providing up to 10,000 samples per second. A high speed data logger used by the author in research of geotextiles in track systems is shown on Figure 10. This particular system can handle 40 channels of data at a maximum sampling rate of 250 samples per channel per second. Each input channel requires an amplifier/conditioner to interface the particular gages to the data logger. The selection of a data logging system must reflect the anticipated life expectancy of the monitoring program. The use of a high speed data logger on a project requiring continuous monitoring for years would be as inappropriate as the use of manual readings to monitor train induced deformations.

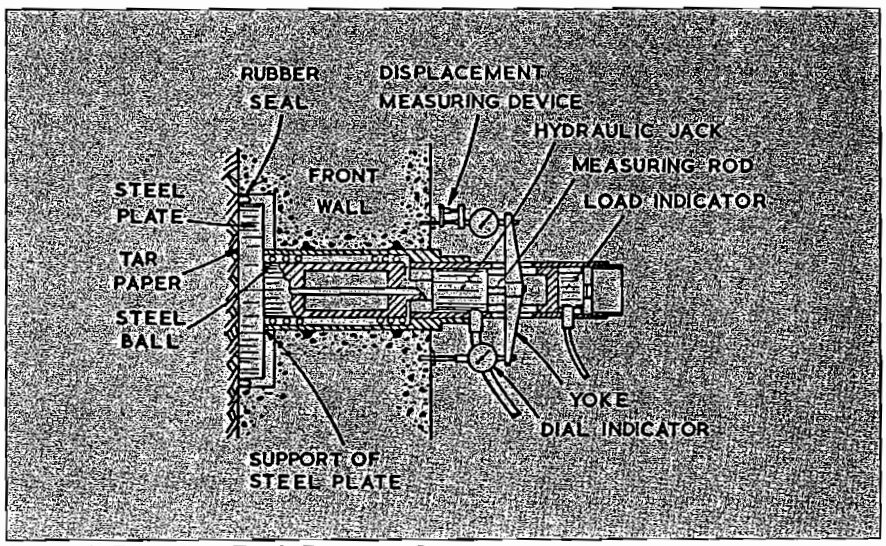

Figure 8. Boundary Earth Pressure Cell

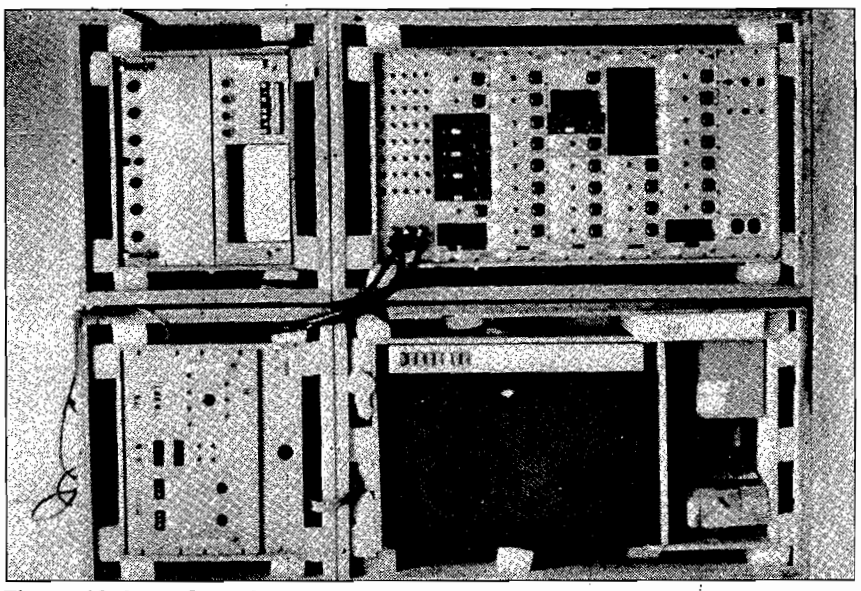

Figure 10. High Speed Data Logger

Summary

The performance of geotextile/soil systems can be accurately monitored by the proper design and installation of a field monitoring system. The importance of the actual installation of each gage cannot be overstated. Each gage type requires some form of calibration prior to installation. The actual installation procedures for each gage must attempt to closely replicate the laboratory calibration conditions in the field.

Typical field instrumentation clusters will also attempt to provide redundant measurements of important parameters using dissimilar gage types. Thus, if earth pressures are critical, two independent systems of earth pressure cells may be installed; one system using electrical strain gaged earth pressure cells and the second system using pneumatic earth pressure cells. A full instrumentation array used by the author in research on the performance of geotextiles in track systems is shown in Figure 11. This array provides redundant systems for soil moisture and displacement measurements. Additional instrumentation was installed to monitor dynamic earth pressures, soil strains, rail stresses, tie plate loads, tie strains, accelerations, and rail displacements.

A final consideration that is critical to the success of a monitoring program is integration of the instrument installation into the actual construction program. Provisions must be made to compensate general contractors for the down time common during gage installation and for the use of equipment required to install the gages. Frequently the instrumentation contract will be let as a separate contract with little thought to its integration into the actual construction program. Inevitably this leads to major conflicts between the instrumentation specialty contractor and

the general contractor. Conversely, the general contractor will rarely possess the skills required to install even basic instrumentation systems. Provisions must be made for the two contractors to work on the same project site concurrently. ■

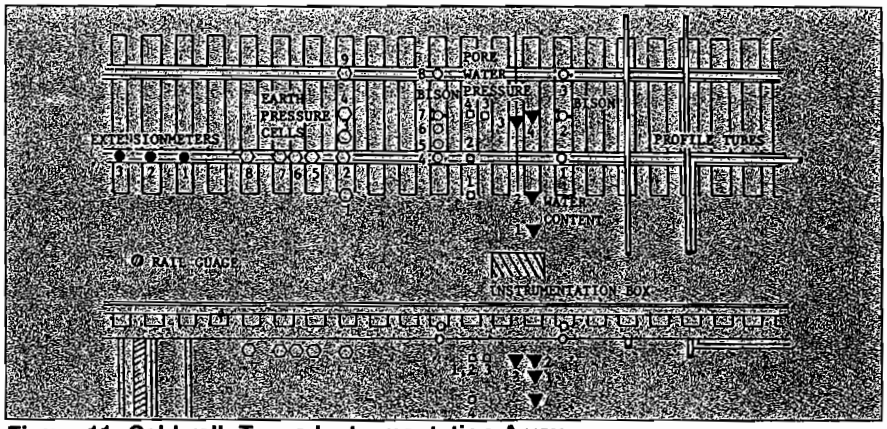

Figure 11. Caldwell, Texas Instrumentation Array

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