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The instrumentation and measurement performance of synthetic polymers in reinforced soil structures

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ABSTRACT:This paper outlines the various types of instrumentation used to directly measure loads,deformations (strains) and operational temperatures in synthetic polymeric soil reinforcing materials. Also it details the methods of relating measured loads to strains and vice-versa by utilising data obtained from sustained load (creep) tests undertaken at the appropriate operational conditions. This is illustrated by reference to a number of case histories.

1. INTRODUCTION

The use of synthetic polymer reinforcements in reinforced soil structures has become widely adopted in the recent years. Due to the complex behaviour of synthetic polymeric materials, most of the designs carried out are conservative and based on limit equilibrium methods which do not take account of strain compatibility between the soil and the reinforcements. As a result, the prediction of the load-strain behaviour of the reinforcement and of the soil under both operational and failure conditions has proven difficult. To improve the understanding of the actual behaviours of both the reinforcements and the soil, direct measurements of the loads and deformations (or strains), has become an essential requirement for researchers and designers.

The development of instrumentation techniques together with the analysis and interpretation of the data obtained from them are by no means straightforward, particularly for the reinforcements. Inappropriate instruments in the wrong places can provide false information which is extremely misleading. Also instrumentation can introduce stress and strain discontinuities into a system and thereby alter the very quantities being measured. Such alterations may be significant or negligible, their extent depending on the nature of the phenomenon being observed and the installation procedures. In addition, there has to be sufficient instrumentation to allow for the inevitable losses resulting from malfunction and damage, and to provide a meaningful picture given that there is likely to be a significant scattering of results.

In this paper, the various methods of measuring the loads, deformations (strains) and operational temperatures for reinforcements in soil are reviewed. Details of the methods of laboratory testing to determine the load-strain-time-temperature behaviour using sustained load creep tests are given and the means of presenting this data for later analysis is described. In addition the effects of compaction and confinement of the reinforcements in soil are discussed together with the possibility of the build up of locked-in stresses and strains. On these basis recommendations for the instrumentation of synthetic polymeric reinforcements in soil structures are given.

TABLE I TYPES OF INSTRUMENTATION

TYPE	DESCRIPTION	OUTPUT	REFERENCES
LOAD MEASURING DEVICES			
Electrical Resistance Load Cells (Commonly used, and usually manufactured in-house for particular configurations)	Comprise strain gauges connected to form a Wheatstone Bridge (WB) and attached to a steel or aluminium body. Alternatively the WB may be housed in a transverse drilled hole within the cell body.	Usually in the form of voltage and is converted to loads via a pre-determined calibration curve.	Hendry (1964), Scott (1972), Basset & Yeo (1986), Loke (1991)
Vibrating Wire Load Cells (Seldom used in reinforced soil structures)	Comprise two magnets placed closed to a gauge wire, tensioned by a load. One magnet is used to excite the wire while the second picks up the frequency of oscillation.	The oscillation is converted to loads via pre-determined curves.	Cooling & Ward (1953), Ward (1955), NGI(1962)
DISPLACEMENT (STRAIN) MEASURING DEVICES			
Electrical Resistance Strain Gauges (Commonly used in structures to measure overall or local strains)	Available in various forms depending on the material they are to be attached to and the range of strains to be measured. Usually connected in the form of a Wheatstone Bridge to eliminate bending and temperature effects.	Voltage output is converted to loads via pre-determined calibration curves. Calibration curves can either refer to localised strains or overall strains.	Lescoutre (1986), Loke (1991),
Wire Gauges (Not commonly used in reinforced soil structures)	Comprise wire lengths which are selected such that breakage occurs at specific strains. The wires are attached at the required positions and the strains determined when breakage of the gauges occurs. No continuity of strain reading is obtainable.	Breakage of gauges signify the strain	Vischer et.al. (1975), Steward et.al. (1977),
Proximity Gauges (Commonly used individually or together with electrical resistance strain gauges)	Comprise two circular coils of wires attached to two points either in the orthogonal, coaxial or coplanar configurations. Displacement between the two points is measured by passing an electrical resistance through the coil.	Precalibration curves of voltage against strain or displacement allow the voltage readings to be converted to strains.	Selig (1975a),Lescoutre (1986), Andrawes et.al.(1990),
Hydraulic Strain Gauges (Seldom used in reinforced soil structures)	Consist of a tube similar to a hypodermic syringe, connected to a small diameter 'sight' tube. Small movements of the large diameter tube causes a large movement (approx 12X magnification) in the sight tube. The gauges are fitted to wooden blocks attached to the reinforcement.	The change of levels are precalibrated with deformation.	Basvaiy (1982), Rowe et.al. (1984a & b)
TEMPERATURE MEASURING DEVICES			
Thermocouples (Commonly used to measure variation in soil/structure temperatures)	Comprise two wires of different metals, with one end of each wire connected to form a junction. Small changes in temperature causes a change in voltage.	Voltage output is converted to temperature via data logging instruments, which have been precalibrated.	ASTM (1974), ISA (1974), Loke (1991)

2. TYPES OF INSTRUMENTATION

There are basically three types of instrumentation required to measure the performance of the synthetic polymer reinforcements viz;

(i) Load Measuring Devices

These are instruments for *directly* measuring loads and are employed in such a way that the load to be measured passes through them.

(ii) Displacement (Strain) Measuring Devices

These are instruments for directly measuring deformations (strains) of synthetic polymer reinforcements at specific points or over specific gauge lengths.

(iii) Temperature Measuring Devices

These are instruments for directly measuring temperatures of the synthetic polymer reinforcements or the surrounding soil.

In each group of measuring devices, various types of instruments are employed and are details of these are given in Table 1

3. INTERPRETATION OF MEASUREMENTS

Synthetic polymeric reinforcements are temperature dependant, visco-elastic materials. Under operational conditions their load-strain-time behaviour is affected by ambient temperature, load and strain levels, load and strain paths, installation damage and long term durability. Their behaviour is complex thus simplified mathematical models are often adopted in order to overcome this. Deciding what simplifications are allowable in any behaviourial model presents a significant challenge to engineers. In the following sections, an approach is recommended for interpreting instrumentation readings.

3.1 Reinforcement Test Procedures

Sustained load (creep) data for synthetic polymeric materials are obtained by applying constant loads to samples under controlled temperature conditions (McGown et.al. 1984). The most common and effective methods of displaying the interdependency of load, strain and time are to plot load versus strain at constant time or at constant strain, Fig. 1. The two most commonly used are known as the isochronous and isometric curves and at specific conditions relate load to strain at specific times and load to time at specific strains, respectively. Normally these plots are smooth curves indicating that the materials exhibit "non-linear viscoelasticity". Isochronous and isometric relations can be used to examine the long term performance of the reinforcements.

3.2 Temperature effects

The reinforcements in soil structures are usually buried at depth in partially saturated backfills. Such soils are, with no flow of water, relatively poor conductors of heat and it can usually be assumed that the temperature will remain constant throughout its design life. In the United Kingdom an approximately constant temperature of 10°C can be assumed, however, in other geographical areas approximately constant temperatures can be in the range of 0° to 40°C. Isochronous or isometric curves at the appropriate constant temperatures must be used to examine the long term performance of reinforcements.

3.3 Rate of loading effects

The loads and strains imposed on the reinforcement will usually gradually increase during the construction period which may extend over weeks or even months. If a surcharge layer is applied to the structure, then the reinforcement will be unloaded by its removal in the final stage of construction, for example in an embankment. The rate and path

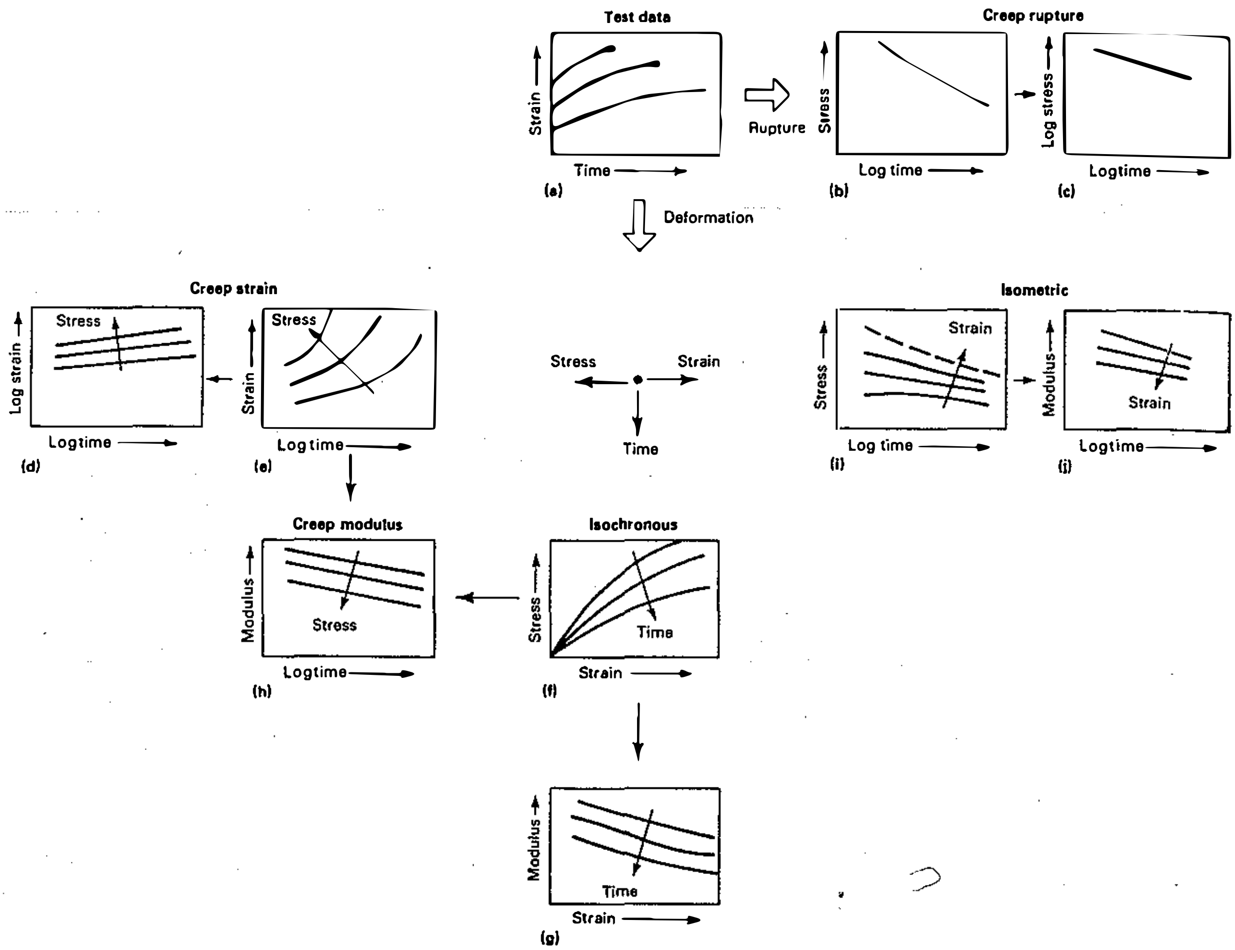

Fig. 1 Graphical representation of Isochronous and Isometric curves. (ASM International 1987)

of loading of a reinforcement, may be dependant upon a number of factors and may therefore vary appreciably from place to place, but within a localised area it can be assumed that during a particular stage of construction the load applied to the reinforcement will be either constant or changed monotonically at a reasonably slow rate. The isochronous or isometric curves described above, can be used to plot these load-strain-time variations

3.4 Compaction and confinement in soil effects

Compaction of fill over synthetic polymeric reinforcements can 'lock-in' stresses (McGown et. al. 1990). Also for some geotextiles and geomeshes, the influence of confinement in soil on the load-strain-time behaviour can be significant (McGown et.al. 1982). Thus isochronous or isometric curves used to interpret instrumentation should be obtained under the same conditions.

4. CASE HISTORIES

Four cases with details of type of structure, method of instrumentation and comments on the load-strain relationship of the polymeric reinforcements are summarised in Table 2.

5. CONCLUSION

This paper has identified the various methods of measurement of loads, deformations (strains) and operational temperatures for synthetic polymeric reinforcements. It has

TABLE 2 CASE HISTORIES

Case Histories	Structure	Instrumentation	Comments
Kingston, Canada (Bathurst, Wawrychuk and Jarret 1988)	3.0m wide by 2.4m high wall reinforced with 4 layers of Tensar SR2 geogrid.	1) Extensometers and strain gauges to measure strains along reinforcement 2) Thermocouples to measure temperature in soil	Loads along the reinforcement were predicted via in-isolation isochronous curves
Strathclyde/TRRL, UK (Loke 1991)	2.0m wide by 2.0m high wall reinforced with 3 layers of Tensar SR80 geogrid	1) Strain gauges and proximity gauges to measure strains along reinforcement 2) Thermocouples to measure soil temperature	Loads along the reinforcement were predicted via in-isolation isochronous curves
Stanstead Abbot, UK (Basset and Yeo 1986)	7.5m high embankment reinforced with a layer of Tensar SR2 geogrid	1) Proximity gauges to measure strains along reinforcement 2) Load cells to measure load along reinforcement	Strains predicted from measured loads through in-isolation isochronous curves compared well to the measured strains
NGI, Norway (Fanin 1988)	4.8m high soil slope with a face slope of 2:1 reinforced with 8 layers of Tensar SR2 geogrid	1) Proximity gauges to measure strains along reinforcement 2) Load cells to measure load along reinforcement	The ratio of measured loads and measured strains were used to obtain the moduli of the reinforcement and compared to the moduli obtained from in-isolation curves.

NB. In all these structures, additional instrumentation were installed to measure earth pressures, horizontal and vertical movements and pore water pressures (as in Stanstead Abbot).

been shown that the isochronous or isometric plots of sustained load (creep) test data should be used in order to interpret direct loads from strains measured in-situ or vice-versa. The sustained load test data used must be obtained under the same operational conditions as pertained in-situ. An alternative approach would be to measure both loads and strains directly.

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