JOHN, N.
City of Southampton, Southampton, UK
JOHNSON, P. and RITSON, R.
Portsmouth Polytechnic, Portsmouth, UK
PETLEY, D.
University of Warwick, Warwick, UK

Behavior of Fabric Reinforced Soil Walls

Comportement des murs en terre armée avec des géotextiles

Metal is used extensively in the construction of reinforced soil walls, but concern about corrosion under certain environmental conditions has prompted the development of alternative reinforcement systems. One such alternative is the "Websol" System of soil reinforcement. The system is based on the use of "Paraweb" polyester fibre strips and "Terram" non-woven fabric. Instrumentation has been developed to monitor the behaviour of three soil walls constructed using the Websol System. In 1979 instruments were installed during the reconstruction of a river bank at Southampton, England. In 1980 a new harbour wall was instrumented in Jersey, Channel Islands. Monitoring of this wall is still continuing. In 1981-82 an experimental wall was constructed at Portsmouth, England and monitoring of the instruments is proceeding. In this paper details of the field instrumentation and observations to date are presented. The early results suggest that the behaviour of the structures is somewhat at variance with theoretical predictions.

Le métal s'emploie beaucoup pour la construction des murs en terre renforcés, mais à cause de la corrosion sous certaines conditions d'environnement, on a dévelopé des systèmes alternatifs de renforcer. Un projet de ce geuve c'est le système "Websol" de renforcer la terre. Ce système s'est basé sur l'emploi de bandes de fibres de Polyester et d'étoffe non-tissée. On a dévelopé l'instrumentation pour contrôler le fonctionnement des trois murs en terre construits selon le système Websol. En 1979 les instruments étaient installes pendant la reconstruction d'une rive à Southampton, Angleterre. En 1980 on a installé des instruments dans un nouveau mur de quai à Jersey, les Îles de la Manche. Le contrôle de ce mur continue toujours. En 1981-82 on a construit à titre d'essai un mur à Portsmouth, Angleterre et on est entrain de contrôler les instruments. Dans cet exposé on donne les détails de l'instrumentation sur le terrain et les observations des derniers progrès. Les premiers résultats suggèvent que le fonctionnement des structures est assez en désaccord des prédictions théoriques.

INTRODUCTION

The technique of reinforced soil has seen many applications over the past decade, but has primarily been used for the construction of retaining walls. Extensive use has been made of metal reinforcement in these walls, but this can lead to corrosion problems under certain environmental conditions. To overcome this difficulty alternative reinforcement systems have been developed. One such alternative is the "Websol" System of soil reinforcement. This system comprises reinforced concrete facing panels, "Paraweb" polyester fibre strips, "Terram" nonwoven fabric and suitable fill material (Fig. 1). Soil walls constructed with these types of reinforcing materials are likely to behave differently to those using metal reinforcement. To monitor the behaviour of fabric reinforced structures, instruments have been developed and installed in three walls, each constructed using the Websol System.

In 1979 a 4 m high wall was constructed in a tidal river environment at Southampton, England. Instruments were installed to monitor the forces at the connections of the reinforcement and the facing panels, and to measure the strain along the reinforcement. In 1980 a new harbour wall, 8 m high, was constructed in Jersey, Channel Islands. The instrumentation used was similar to that installed at Southampton with the addition of earth pressure cells and inclinometer tubes. In 1981/82 an experimental wall, 2½ m high, has been built at the Geotechnics Field Centre, Portsmouth Polytechnic, England. Several different reinforcement configurations are being monitored. Pull-out tests will be carried out and part of the wall will be tested to failure.

Fig. 1 Jersey wall under construction. Rock fill being placed over Paraweb and Terram

1. SOUTHAMPTON WALL

In 1979 a reinforced soil retaining wall was constructed to form part of an outfall structure on the bank of the River Itchen at Southampton. The outfall site is reclaimed land and the sub-soil consists of about 5 m of soft organic clay. The tidal range is about 4 m. The retaining wall was constructed on a 600 mm thick fabric reinforced raft foundation, consisting of three layers of gravel rejects separated by Terram 2000 sheet. The reinforced soil retaining wall, 4 m high and 20 m long, was constructed using the Websol System which was selected because of the environmental conditions. Single size 15 mm gravel aggregate was used as a free-draining fill material in the lower part of the wall. For the upper part graded crushed rock was specified. Reinforcement of the wall was provided by 6 m long Paraweb strips and Terram 1000 sheet.

In the Websol System the Paraweb reinforcing strips are attached to the facing panels using mild steel anchorage pins, or toggle bars. Each facing panel has a number of anchorage points, each consisting of two loops through which the horizontal toggle bar is located. In order to measure the force on the Paraweb connections at the facing panel some of the standard toggles were replaced by specially fabricated strain gauged toggle bars (Fig. 2). These special toggles were commercially produced shear transducers using foil strain gauges. Five were installed on one large (approximately 2½ m square) facing panel - one in each corner and one near the centre. The cables from the end of each special toggle bar were taken into a vertical plastic pipe, set close behind the facing panels, and thence to the surface.

Monitoring of the toggle loads took place for many months after construction. Although the average load remained fairly constant the distribution across the panel changed slowly with time. This trend continued for some time after construction (Fig. 3) and was most marked immediately after the first spring tides. Readings taken at high and low spring tides showed a small consistent difference, which was less marked during neap tides.

A magnet extensometer system has been developed to measure the strain distribution in the Paraweb strips.

Fig. 2 Strain gauged toggle bar and magnet extensometer used for Southampton wall

Small magnets are placed in a plastic housing and bolted through the strip prior to construction. Twelve magnets were bolted to each of eight Paraweb strips. A long 12 mm diameter plastic access pipe was placed over each strip and located through each magnet housing (Fig. 2). A special probe, consisting of multicore cable and twelve Reed switches, can then be inserted in each pipe in turn to locate the magnet positions. Typical results from the magnet extensometer system (Fig. 4) show a considerable amount of scatter.

To monitor the tidal draw-down effects within the wall vertical perforated standpipes were installed. Readings showed that the water level within the wall was always horizontal and at the same level as the tide.

Settlement was monitored by taking levels on top of the facing panels. The line of panels settled between 40 and 80 mm during the first six months, with most of this occurring in the initial three months.

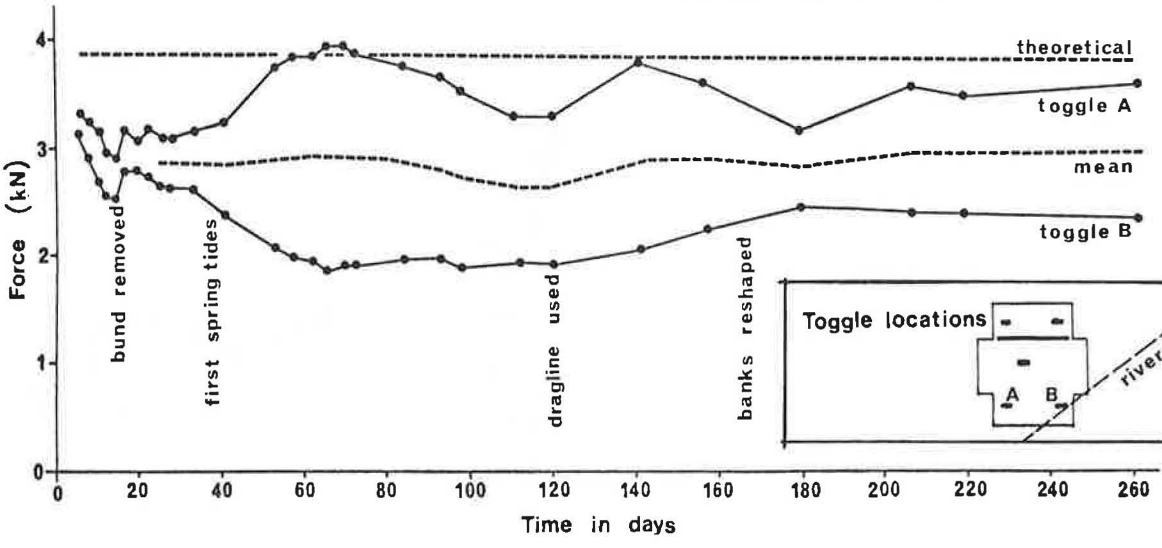

Fig. 3 Toggle loads at low tide, Southampton wall.

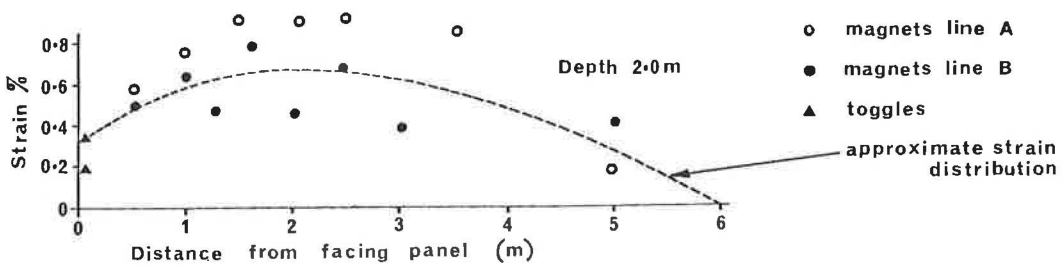

Fig. 4 Magnet extensometer results, Southampton wall

2. JERSEY WALL

In 1980 the opportunity arose to instrument a much larger wall at St. Helier, Jersey, Channel Islands. This new harbour wall is approximately 250 m long, 8 m high and varies in width from 7 m at the base to 5 m at the top. The tidal range here is about 11 m. The method of construction was the Websol System of soil reinforcement, which was offered as an alternative to the traditional rock fill bund usually used in the harbour. The wall is founded on an imported rock fill embankment. The same rock has been used as fill material in the reinforced soil wall. The seaward (front) face of the wall comprises reinforced concrete panels, and the landward (rear) face utilizes temporary plywood panels (Fig. 1). It is intended that landfill will abut the rear of the wall within a few years.

A complete vertical section of the wall was instrumented (Fig. 5). This section of the wall is 8 m (5 No. facing panels) in height and 2 m (1 No. panel) wide. Monitoring of the instruments has continued at regular intervals since installation and is still proceeding. The instrumentation was a development of that used at Southampton and consisted of the following:-

(i) Strain gauged toggle bars attached to the facing panels,
(ii) Earth pressure cells buried within the rock fill,
(iii) Inclinometer tubes sited within the fill,
(iv) Strain gauged Paraweb,
(v) Magnet extensometers bolted to Paraweb.

(i) Strain gauged toggle bars

In the Jersey Wall each facing panel has six anchorage points. In the instrumented section of 5 No. panels it was proposed that each of the 30 No. standard toggle bars would be replaced by specially fabricated strain gauged toggle bars. This would enable the loads on each toggle and facing panel to be assessed. The commercially produced toggle bars used in the Southampton wall were very expensive, and it was decided to fabricate similar special toggles in the workshops at Portsmouth Polytechnic. Each special toggle bar is 200 mm long and fabricated from 50 mm square bars. Each bar was carefully cut and drilled to provide mounting surfaces for strain gauges and associated wiring. The gauges and wiring were protected with a suitable rubber compound. The complete toggle bars were blast cleaned before being finally protected with the various coats of epoxy paint and polyurethane specified for the standard toggles. Although the original intention had been to install 30 No. special toggles, difficulties encountered on site meant that it was possible to install only 25 No. The cables from the end of each toggle bar were taken into a vertical 100 mm diameter plastic pipe, set close behind the facing panels. Monitoring of the strain gauged toggle bars has been carried out regularly during construction and at regular intervals since installation. At the present time 24 of the toggle bars are still functioning satisfactorily. The toggle bar results obtained to date, taken at various states of the tide, suggest that the performance of the structure is somewhat at variance with the predicted behaviour (Fig. 6).

(ii) Earth pressure cells

300 mm diameter oil filled earth pressure cells were installed within the rock fill to monitor pressures at various levels (Fig. 7). A group of 5 No. cells were placed towards the middle of the wall at a depth of about 7 m. A group of 3 No. cells were installed at a depth of about 4 m. Single cells were placed immediately behind the facing panels at depths of 4 m and 7 m. The cables from the cells were extended horizontally to a 75 mm diameter vertical plastic tube placed behind the facing panels, and thence to the surface. Although with one exception the pressure cells seem to be working satisfactorily the results obtained to date are not very encouraging.

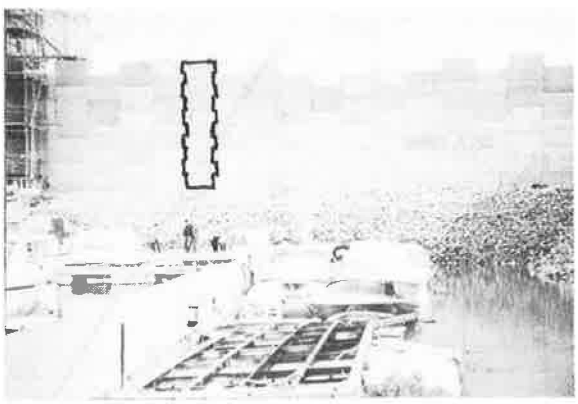

Fig. 5 Jersey wall showing instrumented section

(iii) Inclinometer tubes

2 No. square section inclinometer tubes were installed behind the facing panels. These extend to the full depth of the wall (Fig. 7). Readings have been taken at regular intervals during and since installation, using the Norwegian Geonor system. The results to date suggest that small movements of the wall are taking place. Readings are continuing.

(iv) Strain gauged Paraweb

It had been intended that some layers of the Paraweb strips within the test section should be strain gauged in order to monitor load distribution. However considerable problems were encountered in obtaining a suitable adhesive for bonding the gauges to the polyester fibre. Just prior to the start of site work an adhesive was located in Japan, but there was only time to strain gauge a short experimental length of Paraweb. The strain gauges are giving readings but the results are not encouraging. Even if it had proved possible to strain gauge long lengths of Paraweb it is unlikely that useful results could have been obtained. The placing of the rock fill caused considerable distortion to the Paraweb strips and may well have damaged the strain gauges.

(v) Magnet extensometers

Magnet extensometers were successfully used to monitor the extension of the Paraweb strips in the Southampton wall. In Jersey 3 No. of these magnets were incorporated in each of 10 layers of Paraweb. A 15 mm diameter plastic pipe was laid over each line of magnets and protruded through a small hole in the rear timber facing panels. It had been intended to insert a probe, incorporating a Reed Switch, into each pipe to locate the magnets. Unfortunately the severe and unexpected tortuosity created in the Paraweb by the use of rock fill prevented the subsequent monitoring of these magnets.

In an effort to record vertical settlement of the rock fill 5 No. 300 mm diameter ring magnets were placed horizontally around a vertical sectional 30 mm diameter plastic pipe, in three locations across the instrumented section. It proved very difficult to successfully install this system because of the plant being used to construct the wall. The rock fill appeared to be continuously moving as additional layers were placed. As a result two of the vertical pipes "walked" to the outer limits of the wall, and the magnets were displaced.

The work at Jersey has highlighted some of the considerable difficulties associated with carrying out scientific research on a working construction site. Even during the short period available for development and fabrication of instruments there were specification and design changes on the structure that caused last minute problems to the instrumentation programme. As a result some of the instruments have not performed as expected. On several occasions instruments were inadvertently damaged by plant on site after installation.

The experience gained during the Jersey work has proved very beneficial in the design, construction and instrumentation of an experimental wall recently completed at Portsmouth.

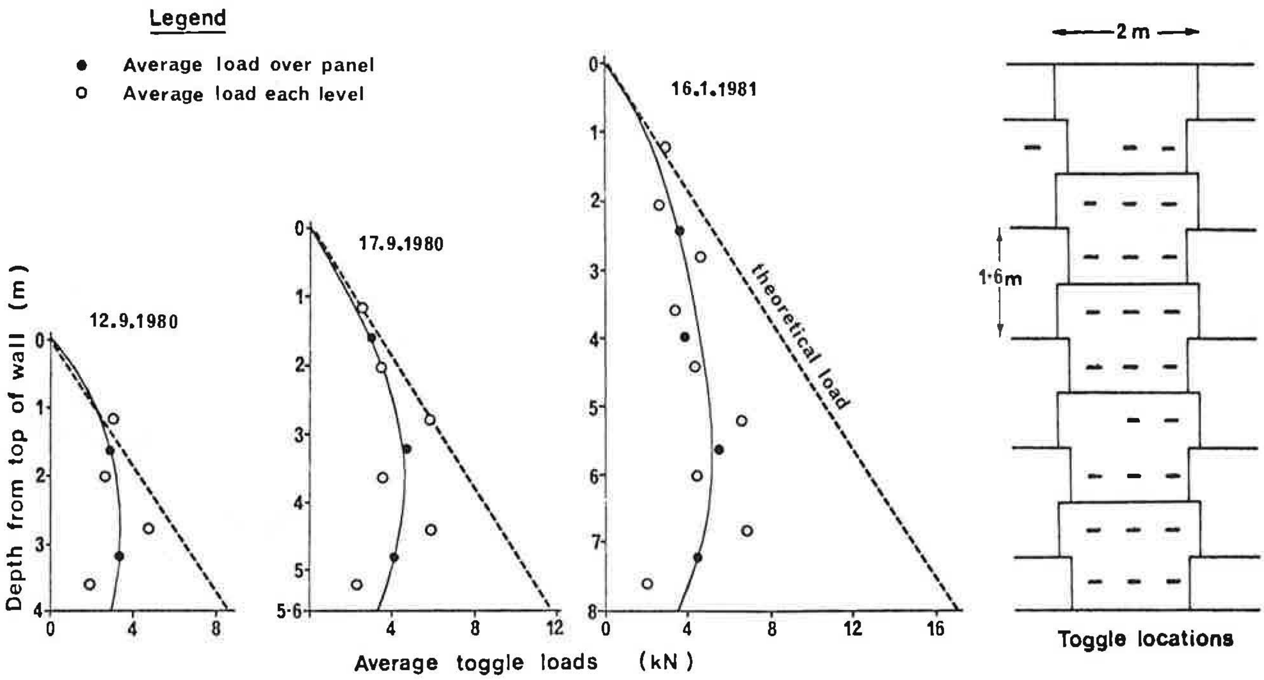

Fig. 6 Toggle Loads, Jersey Wall

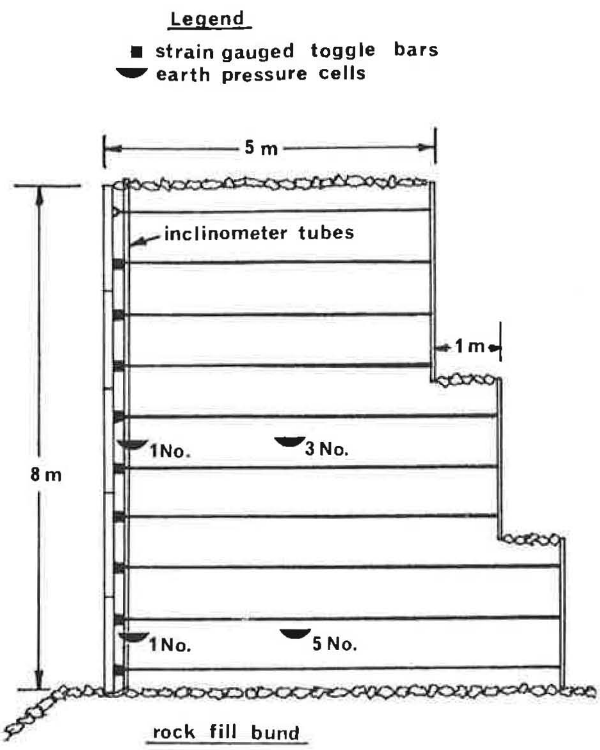

Fig. 7 Schematic of cross-section of Jersey wall showing instrument positions.

Fig. 8 Portsmouth wall nearing completion

3. PORTSMOUTH WALL

This experimental wall has been constructed at the Geotechnics Field Centre, Portsmouth Polytechnic (Fig. 8). The design is based on the Websol System and incorporates several different reinforcement configurations. The wall is approximately 20 m long, 5 m wide and 2½ m high. The facing panels are of timber construction and the fill material is single size 20 mm gravel aggregate.

Without the sea-water environment it was possible to develop a relatively simple strain gauged toggle bar, located outside the timber panels. Although fabrication and calibration was a major task 224 No. special toggles have been incorporated in the structure to monitor the various reinforcement configurations. The initial difficulties associated with attaching and waterproofing strain gauges on the Paraweb has largely been overcome and one section of the wall is instrumented in this way. Inclinometer tubes have been installed within the fill material at various locations. Terram sheet has been utilized in part of the wall and omitted from a directly comparable section. In this way it is hoped to more accurately assess the contribution of the Terram to the reinforcing function. Pull-out tests will be carried out on single and multiple Paraweb strips.

The northern end of the wall has been constructed with Paraweb strips crossing at right angles in a similar manner to that of a reinforced soil bridge abutment. In the southern end provision has been made to enable the Paraweb strips to be progressively shortened until failure is induced at that end of the wall.

Land survey marks have been incorporated in the facing panels, and when all the survey and instrument readings have stabilized the pull-out and failure tests will be carried out.

ACKNOWLEDGEMENTS

The authors wish to thank the following for their interest, support and help during the research programme:-

The Science and Engineering Research Council (SERC) for providing the major part of the finance for the testing programme.

Soil Structures International Ltd.

I.C.I. Fibres Ltd.

City of Southampton

States of Jersey Harbours and Airport Committee

Department of Civil Engineering, Portsmouth Polytechnic.