The Instrumentation of Three Road Embankments on Soft Soils

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SUMMARY
This paper describes instrumentation of three embankments founded on soft soils. It discusses the purposes of the instrumentation as well as the equipment and installation techniques.

1.0 INTRODUCTION

Man's scientific endeavours are based on his use of the so-called "observational method", in which the behaviour of the item under study is noted, and a 'theory' formulated to cover its observed behaviour. The 'theory' is 'proved' by predicting behaviour outside the bounds previously observed, and comparing predictions with further observations. Geotechnical instrumentation is thus used to monitor the behaviour of soil and rock, and thereby advance our understanding of these materials.

Design and performance requirements have required the following three road embankments to be instrumented:

a) Frances Bay Road, Darwin, N.T.
b) Channel Island Access Road, Darwin, N.T.
c) Northern approach embankment for a new bridge over the Swan River at Bayswater, Perth, W.A.

The first two projects were carried out for the Department of Transport and Works, N.T. and the third was for the Main Roads Department, W.A.

2 FRANCES BAY ROAD

Preliminary site investigation showed mud with depths up to 3.2m, overlying gravelly clay and meta-siltstone. Analysis predicted slope stability problems and large settlements for a 'floating' embankment if the required bank height of up to 4m was to be installed in one lift. Since the construction programme permitted staged construction spanning an 18 month period, the embankment could be built, 'floating' on the underlying soft soil, in two stages.

It was decided to install instrumentation beneath the first stage of the embankment to supply data for the following purposes:

a) to identify positively the time at which the second stage of construction could proceed
b) to provide data and experience for the design of future embankments on similar materials in the Darwin area. (The alignment for the Channel Island Access Road had already been tentatively selected and it crossed a considerable length of mangrove mud)
c) to provide data on long-term bank performance.

In addition, the instrumentation would:

d) verify assumptions made during the design of staged construction procedures
e) guard partially against the onset of unforeseen failure

2.2 Suite of Instrumentation

The primary concern in the performance of any road embankment on soft soil is vertical movement, the pavement being particularly susceptible to damage.

Pore pressures beneath the bank affect the stability of a bank floating on a soft foundation.

Horizontal movement at depth beneath the bank can be a precursor of slope failure or, alternatively, can result from plastic flow beneath the bank.

The excess pore pressure is the difference between the measured pore pressure and the effect of the groundwater level. Therefore, the groundwater level must be determined for stability evaluation.
To this end, the following instruments were needed:

- Settlement indicators
- Surface monuments
- Piezometers
- Inclinometer casings
- Groundwater level indicators

It is a basic principle of instrumentation design that simple measurement systems should always be used rather than more complex ones, if feasible.

Settlement plates (as shown on Figure 2) are one of the simplest forms of settlement indicator, but the installation of such plates beneath the centre line of the embankment was not practical because the 'riser' would have been damaged by traffic etc. As the difference in calculated settlement at the centre line and at the shoulder of the bank was negligible, settlement plates could be installed beneath the shoulder, thus obviating the need for a 'remote' settlement gauge.

![Figure 2 Typical Settlement Plate](image)

Surface monuments provide another simple form of settlement indicator. They consist of a steel pin set in a block of concrete, cast on or near the surface. Vertical movements are measured by determining the movement of the pin, using conventional surveying techniques.

Standpipes could not be used to measure the excess pore pressures because:

a) they would have an unacceptably long response time

b) measurements of pore pressures are required beneath the centre line of the bank

c) standpipes are susceptible to vandalism and access to the site could not be avoided.

It was therefore decided to use pneumatic transducers to monitor pore pressures within the bank and in the underlying soft soils. (The principle of operation of pneumatic transducers is described in Hanna, 1973).

Inclinometer casing was installed to measure subsurface horizontal movement. An inclinometer is a device for measuring angles from the vertical with a high degree of accuracy. An inclinometer sonde is lowered in increments, down a casing, and the deviation from the vertical is determined at each increment. Subsequent comparison of the measured angles with previously obtained data gives a profile of horizontal movement. A full description of operation is given in Wilson and Mikkelsen (1978).

Commonly, groundwater level indicators are unsealed standpipes.

A typical instrumented section at Frances Bay is shown on Figure 3.

![Figure 3 Instrumented Section at Frances Bay](image)

3 CHANNEL ISLAND ACCESS ROAD

3.1 Background

An access road is currently being constructed to the site of Darwin's new power station on Channel Island. The road alignment crosses 2.3km of mangrove swamp and in those sections where the mangrove mud is deeper than 2m, stone columns have been installed beneath the embankment.

Typical sub-surface conditions beneath those bank sections founded on stone columns consist of soft mangrove mud up to 7m deep (4m average depth), overlying stiff cohesive weathering products of local sedimentary rock. This latter layer is assumed to be relatively incompressible.

Further considerations of the embankment are presented in another paper (Waterton and Foulsham, 1984), which outlines unsatisfactory aspects of currently accepted design procedures for stone columns. In light of the lack of reliable predictive theory, monitoring of the performance of the bank and its foundations was undertaken, in order to:

a) verify some of the assumptions made during design and provide information on the load carrying mechanism of the stone column/surrounding soil continuum.

b) measure the performance of the bank, in both the short and long term.

c) guard partially against the onset of unforeseen failure.

3.2 Suite of Instrumentation

As at Frances Bay, it was required to measure vertical and horizontal movements, pore water pressures and, in addition, the loads being carried by the stone columns.
The instrument access requirements were the same as at Frances Bay, in that settlement plates could be located beneath the shoulders of the bank, whereas pneumatic piezometers had to be used because of lack of access vertically above the required location.

Column and mud settlements were monitored by separate plates. Since the mud settlement would not be uniform between the columns, the plate on the mud was located at the centroid of the triangle formed by adjacent columns. In addition, surface monuments were installed to monitor surface bank movements.

The stone column load cells were pneumatically monitored 'flat jacks'. These are similar to conventional pneumatic earth pressure cells, in that they consist of two circular discs, welded together around their outer, with the space between them filled with oil. The oil pressure reflects the pressure on the disc, and this pressure is monitored by a pneumatic transducer.

Because of the vacuities of earth pressure cells, it was decided to instrument a single group of 4 adjacent columns, which would also assist in the investigation of column group behaviour.

Six instrumented cross-sections were installed at locations selected to reflect the range of mud depths and clay thickness; the stone column load cells being installed in one section beneath a high (5.5m) bank overlying 4m of mud.

The instrumentation installed beneath the Channel Island Access road consisted of:

- settlement plates
- surface monuments
- pneumatic piezometers
- inclinometer casings
- load cells

and a typical section is shown on Figure 4.

![Figure 4 Instrumented Section Channel Island Bank](image)

4 SWAN RIVER BRIDGE EMBANKMENT, BAYSWATER, PERTH

4.1 Background

It is planned that the proposed Beechboro-Gosnells Highway in Perth will cross the Swan River at Bayswater (Figure 5). The northern approach to the bridge will cross low lying river flats for 500m. Maximum bank height will be 11m and the bank will be founded on soft alluvial deposits up to 20m deep. These soils are predominantly soft clays but interbedded sand deposits occur close to the river. Dense sands underlie the soft clays.

![Figure 5 Location of Bayswater Embankment](image)

The Main Roads Department of W.A. (MRD) have amassed considerable experience constructing highways on soft soils. In view of difficulties of accurately predicting embankment performance from the results of laboratory tests, the MRD uses full scale and multiphase techniques based on the performance of full scale trial embankments (Cocks, 1983). Since calculations showed that this bank should be built in several stages so as to ensure stability, it was decided to use the first stage of preloading as a trial embankment requiring the deployment of instrumentation beneath the bank.

4.2 Suite of Instrumentation

The MRD had previously instrumented such trial embankments with settlement plates and standpipe piezometers. However, in view of previous damage to such installations by construction traffic and vandals, it was decided to instrument this bank using 'remote' type instruments. To this end, remote pneumatic settlement gauges and piezometers were utilised. (The principles and operation of remote settlement gauges are described by Gould and Dunnicliff, 1971).

The occurrence of horizontal movement in soft soils beneath loaded areas has long been recognised. Although the MRD traditionally uses filling techniques selected to minimise such movements, 'mud waves' still occur around banks under construction. These movements can cause significant lateral loads to develop on deep founding bridge piers and abutments. In an attempt to quantify lateral movements beneath the bank in the vicinity of the bridge abutment, inclinometer casings were installed through the soft soils.

The MRD also took the opportunity during the construction of this bank to conduct a 'load to failure' slope stability trial, so as to check design assumptions. This trial was fully instrumented and is reported elsewhere (Geidans and Kilvington, 1984).

Settlement plates and standpipes were also installed to provide further information and cross-checks on the data recovered from the remote instrumentation.

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A further benefit of using remote reading instrumentation is that the equipment can provide data continuously during the construction phase and when the bank is in service.

Although considerable investigation had already been undertaken at the site, static cone penetrometer tests were performed at each location to be instrumented. This enabled the precise positioning of each instrument.

The instrumentation was mainly concentrated close to the centre line of the road alignment and Figure 6 is a section along the bank, showing equipment location.

5 INSTALLATION TECHNIQUES

5.1 General Considerations

The selection of a suitable installation technique for an instrument is as important as the selection of the equipment itself. For an instrument to work properly it must:

a) operate in a manner which does not affect the variable being measured

b) avoid causing permanent change in the local 'state', thus giving rise to erroneous readings.

Both aspects are affected by the design of the equipment, but the second aspect is also dependent on installation technique. It is important to realise that there is no one way to install a particular piece of equipment. The installation technique must be chosen to suit the specific circumstances of each case.

One of the specifics common to each of the three banks considered in this paper is that they are road embankments constructed on soft soil and this causes a common range of problems for equipment installation.

5.2 Settlement Plates

The two banks built in Darwin were constructed on mangrove mud. Access requirements prevented instrument placement before construction, and therefore, they were not installed until after the bank was built. Pits were then dug with a backhoe down to the required depth. It was not possible to place the plate at the mud/bank interface, as the mud heaved into the pit. Therefore, the plate was placed as close to the interface as possible, so that the measured movement would not be affected by settlement within the bank. Post construction installation precludes the taking of measurements during filling, but total mud movements are obtained by measuring the level of the mud surface at the proposed plate location, before construction.

The plates beneath the Bayswater embankment were placed on the ground before fill placement started and riser pipes and casing were added as construction proceeded. Monitoring of plate levels was carried out regularly throughout construction.

When installing a settlement plate, care must be taken to ensure that it is level and evenly bedded. Backfilling should be carried out so as not to disturb the installation. Casing should be installed around the riser when frictional build-up on the riser could cause the plate to 'punch' into underlying soil. If casing is not installed, large stresses can build up in the joint between the riser and the plate. (Consideration of the forces involved often leads to the use of a 75mm diameter or larger riser pipe). The riser can be progressively extended during construction but if bank height and data requirements permit, it may be better to install the plate after initial construction. If this is not feasible, careful control is necessary to ensure proper placement and compaction of fill around the riser, at the same time ensuring that it does not get damaged. The MEU usually assigns a junior engineer full-time to monitor and protect such installations.

5.3 Piezometers

Piezometers are installed in three different ways, by:

a) burying in fill (as in an earth dam)
b) placing in a previously drilled core
c) pushing through soft soil to required position

Proper piezometer installation requires the placement of the instrument's sensing region within the zone to be monitored and the sealing off of this zone from other regions around it.

The necessary seal is provided for, in the case of a, by constructing a 'cut-off', usually using bentonite, around the lead from the piezometer, and for b a bentonite seal is usually formed in the bore, above a sand filter zone surrounding the transducer. Bentonite seals are often protected by placement of a further layer of cement and bentonite grout.

Because the soils beneath the embankments considered in this paper were soft, it was possible to push the piezometers into their required position. The pneumatic transducers used were sealed inside well points, as shown on Figure 7. A flush surface, at least 600mm long, was left above the perforated zone, to permit an adequate seal. The use of a protruding joiner below this region could cause sealing problems because of the formation of an oversize hole. Some piezometers available on the market are in a suitable configuration to be pushed in without a protective wellpoint, but many do not have an adequately long sealing zone.
Piezometers should only be pushed into position when the soil is sufficiently soft and plastic. (It is a corollary of this that it is difficult to stabilise a bore in these conditions, particularly during the exacting process of installing a piezometer). Hammering a piezometer into position should be avoided because of the possibility of instrument damage as well as resultant doubts about seal adequacy.

**Figure 7 Pneumatic Piezometer in Wellpoint**

At both Darwin embankments, a hole was augered through the bank material. When the mud was reached, it ‘heaved’ into the bore, but it was possible to push the wellpoint encapsulated piezometer manually through the mud to the required depth. The piezometer lead was led to the surface and laid in a small trench across the bank to the readout location on the side of the road.

At Baywater, because of the increased depth of soft soils as well as the presence of sand layers, a crawler mounted vibratory casing driving rig was used to drive 75mm casing to within 2m of the required depth. (The end of the casing was closed with a light circular steel disc, that could be readily pushed aside during instrument installation). The piezometer assembly was then lowered down inside the casing, pushed out past the bottom blanking plate, into position at its required depth, using the hydraulics of the rig. The casing was then removed, leaving only the lead coming up to the surface. Backfilling was not necessary as the hole ‘squeezed in’ when the casing was withdrawn. One of the major advantages of this rig is its ability to vibrate casing through dense sand layers. It is also extremely rapid, achieving penetration rates of 2m/min in soft soils.

5.4 Remote Settlement Gauges

These are commonly installed in fill or in a previously drilled bore. However, at Baywater, the vibratory casing driver was also used to install these instruments. The casing was driven to the required placement depth, filled with water, and the end blanking plate pushed aside. The settlement cell was then lowered to the bottom (its lead having been suitably measured and marked to ensure installation at the required depth) and the casing was then withdrawn about 1 metre, whilst checking to ensure that the cell was not raised. The unsupported bore immediately squeezed in around the cell and after this had been verified by probing, the casing was withdrawn.

It should be noted that, in this instance, the cells were not set in concrete because this would have caused the units to sink through the mud.

5.5 Inclinometer Casings

Inclinometer casing is available in either plastic or alloy. It has been found that alloy casing can corrode rapidly beneath the water table. As a result, expensive inclinometer sondes have become irretrievably lodged in casing when the spring loaded wheels on the sonde have burst through the corroded hole.

To overcome corrosion problems in alloy casing, some manufacturers have introduced an epoxy coated product. The effectiveness of this coating depends on absolute continuity and this could require special coupling procedures.

As a result, plastic inclinometer casing has become popular. In the main, this casing has been produced by cutting the sonde wheel tracks in the walls of thick walled plastic pipe with a broach pulled up through the pipe. However, despite rigid production controls, the broach tends to rotate and this causes rotation of the horizontal axis of the sonde and introduces major errors. Moulded glass reinforced plastic casing was introduced to overcome this problem and this was used in each of the embankments described in this paper.

Inclinometer casing is usually installed in a prebored hole which is then backfilled with a grout made of sand, bentonite and cement mixed in proportions to give a material with similar compliance to that of the surrounding natural material. In a soft soil, producing a suitable grout is difficult as is the task of backfilling the hole. Therefore, the two installations in Darwin were carried out by pushing the casing through the mud. In view of the flexibility of plastic inclinometer casing, it is necessary to bear on the bottom of the casing when pushing. To this end, a suitable mandrel is secured to the bottom of the casing, as shown on Figure 8. The prong on the end of the mandrel is driven into the horizontally stable layer in which the end of all inclinometer casings must be located. During installation, the casing is pushed down by a steel pipe or drill rod bearing directly on the mandrel, inside the casing. The mandrel prong can be hammered into the anchoring layer, if necessary.

**Figure 8 Inclinometer Casing Mandrel**

Inclinometer casing cannot be pushed in for depths of more than 6-8m, because frictional forces on the casing induce large shear forces across the
couplings. Therefore, at Bayswater closed ended drill casing was driven down using the casing driver and a string of inclinometer casing was run down inside the drill casing. The inclinometer casing was tipped with a mandrel (Figure 8) and this was driven through the blanking plate and into a stable layer. The drill casing was then slowly withdrawn, allowing the walls of the hole to squeeze back onto the inclinometer casing.

Before lowering the inclinometer sonde down the casing for the first time, its continuity was checked by tripping a dummy sonde, identical in wheel configuration and spacing, up and down the casing. Thus, if a break was to be encountered in the casing, all that would be lost would be a dummy rather than the expensive sonde.

5.6 Stone Column Load Cells

A group of four of these were to have been installed on adjacent 800mm diameter columns. It was considered desirable to have them function as load measuring rather than pressure measuring cells, i.e. to install them in such a way that all the load being carried by the column was transferred from the bank to the column through the cell. To this end, 600mm diameter cells were ordered. However, a subsequent change of plan required their installation on 1000mm diameter columns and they were therefore installed in a pressure cell configuration.

![Figure 9 Stone Column Load Cell Installation](image)

When selecting instrument types it is important to recognise that there can be major differences between seemingly similar products offered by different manufacturers. For example, there are at least 6 different operating systems for pneumatic transducers. In addition, specifications, operating ranges and accuracies can be vastly different for apparently similar equipment. Careful checking is needed to ensure proper design.

Geotechnical instrumentation always obeys Murphy's Law — if something can go wrong, it will. It is generally accepted that some of the installed equipment will, during its projected life, either fail completely or alternatively give unexpected results. If a success rate of 80% is achieved, the designer can be satisfied. It is mandatory that instrumentation be kept as simple as possible.

Systems should incorporate a certain level of redundancy, which would permit the cross checking of instrumentation performance as well as allowing some equipment malfunction. This redundancy should be arranged so that verification of data from more complex instruments is carried out by simpler equipment. For example, standpipes can provide confirmation of other piezometer data, alternatively, piezometers and settlement indicators together can monitor consolidation, which can be checked against the movement of surface monuments.

The three instrumented embankments described in this paper have been designed in accordance with these principals. Care and planning have resulted in all equipment functioning as expected, with the exception of one pneumatic piezometer at Bayswater. These installations could therefore be described as successful.

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8 REFERENCES


