Eight years of monitoring reactive soils along the Epping to Chatswood Rail Link

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ABSTRACT

In 2003, prior to the commencement of construction of the Epping to Chatswood Rail Link (ECRL), a series of instrument clusters were installed in the vicinity of the tunnel alignment. Fifteen locations were close to the route, while five (5) were installed several kilometres away in similar geological conditions. These instruments were intended to allow assessment of the shrink-swell behaviour of the residual clay soils, in particular for comparison purposes in the event that structural damage was claimed to be caused by tunnel construction. At each location, the instrumentation comprises a standpipe piezometer, a vibrating wire piezometer and a rod extensometer. The original monitoring program was finished with the completion of tunnel excavation in 2005, though PSM has continued to monitor these instruments. This paper summarises the extensometer data from these installations, discusses shrink-swell behaviour of the soils in relation to environmental conditions, and compares the results with current design standards for residential construction in Sydney.

Keywords: ECRL, geotechnical instrumentation, extensometer, AS2870, shrink-swell

1 INTRODUCTION

1.1 Background

Construction of the ECRL began in 2003 and consists of 12.5 km twin underground tunnels in Sydney's north-west. The tunnel route passes beneath 4 km of residential suburbs, which are typically underlain by residual clay soils subject to shrink-swell behaviour.

Prior to the commencement of tunnel construction a total of 20 instrument clusters were installed. Fifteen instrument clusters were installed within approximately 250 m of the tunnel route, while five were installed at least 2 km from the tunnel in similar geological conditions. At each location, the instrumentation installed comprised a standpipe piezometer, a vibrating wire piezometer and a rod extensometer. The focus of this paper is the extensometer data.

The purposes of these instruments included:

- record normal movements associated with shrink-swell behaviour (i.e. prior to any potential effect from the tunnel construction); and
- provide a benchmark against which an assessment of the effects of tunnelling (if any) on buildings founded on shallow foundations can be made.

Since the completion of the ECRL, PSM has continued to monitor these instruments. Of the original 20 instruments, two have recently been destroyed as a result of earthworks.

1.2 Location and geology

Figure 1 shows the locations of the instruments relative to the tunnel alignment and the main geological units. Sites were selected to coincide with residential areas which were underlain by residual clay soils derived from Ashfield Shale (denoted Rwa in Figure 1). The shale unit is underlain by Hawkesbury Sandstone (Rh), which is exposed where the tunnel passes beneath several

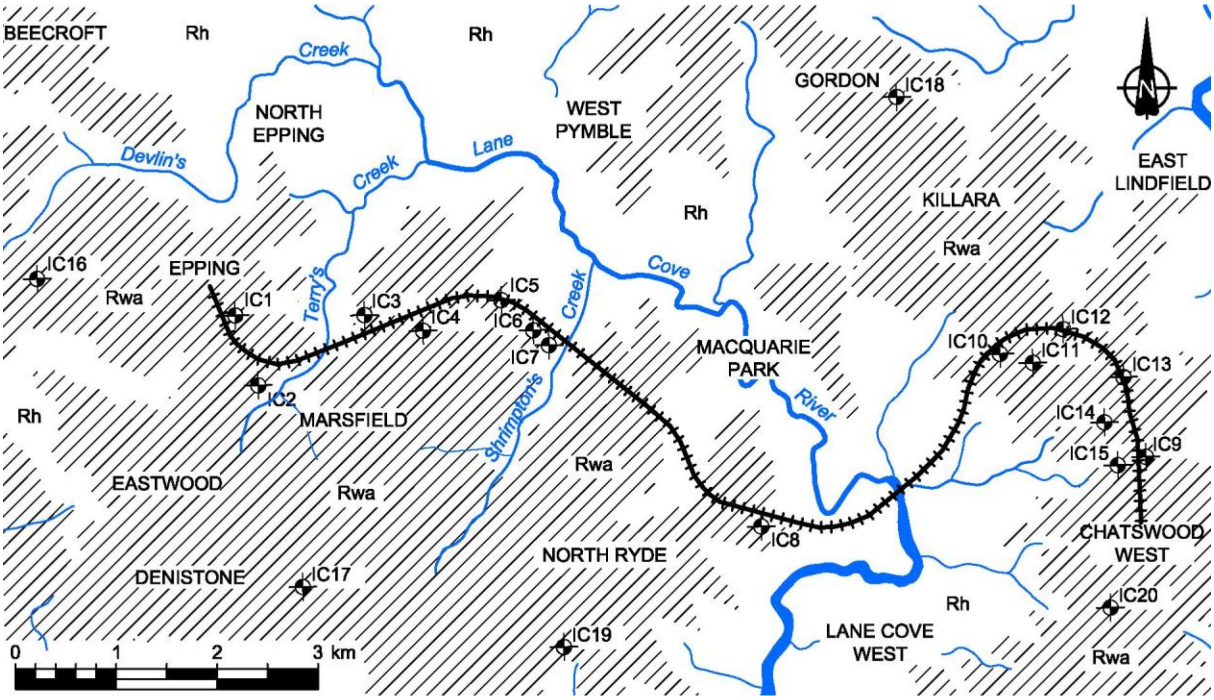


Figure 1. Plan of instrument cluster locations in relation to the tunnel alignment and geology

creeks and the Lane Cove River. The residual soils weathered from the Ashfield Shale are typically thicker and more reactive than soils derived from sandstone.

The majority of the instrument clusters were installed in public parks and road reserves. Locations were chosen to be at least 10 m away from trees, and checked to ensure that they were not irrigated. This was done to ensure that local environmental effects did not significantly affect the instruments.

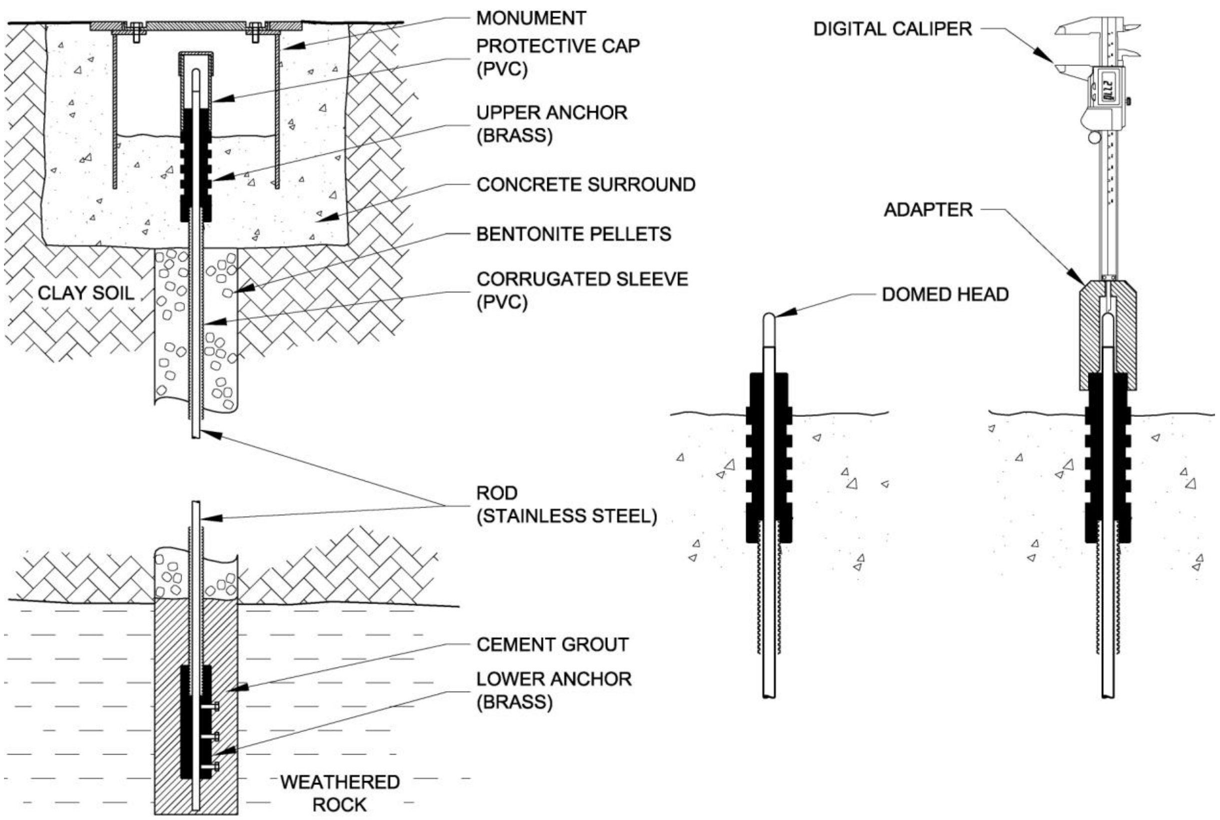
1.3 Instrument details

Figure 2 shows details of the extensometer construction. A standpipe piezometer and vibrating wire piezometer were also housed in the monument, though are not shown in Figure 2. For each instrument cluster a series of settlement pins were installed close by and oriented perpendicular to the tunnel alignment.

The bottom anchor depth ranged from 2 m to 8 m below the surface and was grouted into weathered bedrock. This allows the movement of the surface soils to be measured relative to the base of the instrument. The depth of natural clay varied from 0.7 m to 2.7 m. The base level of the concrete surrounding the top anchor was about 0.3 m below ground surface and was intended to correspond to the typical depth of footings employed in residential construction.

As indicated by Figure 2(b), the top of the extensometer was detailed so as to provide a stable benchmark for survey monitoring of the nearby settlement pins. The extensometer geometry and construction materials were selected to provide a robust and durable instrument which could provide reliable data over a long period of time.

As shown in Figure 2(c), a digital caliper and brass adaptor are used to measure the extensometer stick-up relative to the upper anchor. This arrangement has a repeatability of about 0.1 mm.



(a) Extensometer details (piezometers not shown) *(b) Benchmark configuration* *(c) Measurement of extension*

Figure 2. Extensometer details

2 MONITORING DATA AND INTERPRETATION

2.1 Movement

Data collected between September 2003 and August 2011 are summarised in Figure 3. Readings were typically performed on a monthly basis initially, though subsequently were reduced to every six to twelve months.

Figure 3 indicates that the overall range of movement was less than 40 mm, though the majority of extensometers indicated less than 20 mm deformation.

2.2 Comparison with rainfall

Figure 3 also shows a comparison between the ground surface movements with monthly rainfall recorded at the Macquarie Park meteorological site, located approximately at the midpoint of the tunnel route. Ground surface movements are shown relative to the initial readings.

2.3 Comparison with the Thornthwaite Moisture Index (TMI)

The relationship between the ground surface movement and climate has been explored using the Thornthwaite Moisture Index (TMI) (Thornthwaite 1948, Chan and Mostyn 2008). This index takes into account the effect of rainfall and evapotranspiration on soil moisture content.

Potential evapotranspiration is assessed based on correlations with average monthly temperature. The methodology requires adoption of water storage at the start of the period being considered,

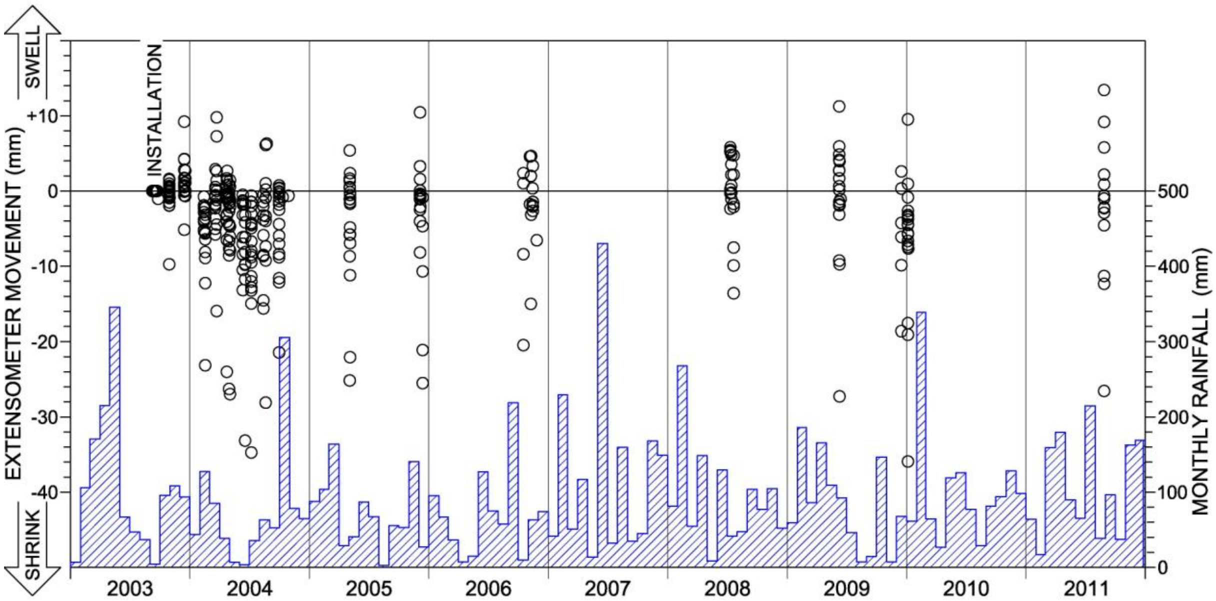


Figure 3. Summary of ground surface movement and monthly rainfall data.

though where long periods of data are used the results are insensitive to this value. The calculation procedure then involves sequential addition of rainfall, and subtraction of evapotranspiration, to estimate the current depth of water stored, though the stored value may not decrease below zero, nor exceed the storage capacity. The soil's moisture storage capacity is assumed to be 100 mm.

Where the calculated storage exceeds the storage capacity, the excess is termed the water surplus. Similarly when the calculated water storage becomes negative, the negative value is the water deficiency. The TMI is calculated based on the following relationship between water surplus (r), water deficiency (d) and potential evapotranspiration (e):

$$TMI = (100r - 60d) / e \quad (1)$$

Meteorological data over the past 30 years has been used for this assessment, and therefore the calculated TMI over the preceding 8 years is insensitive to the initial stored depth assumed in the calculation.

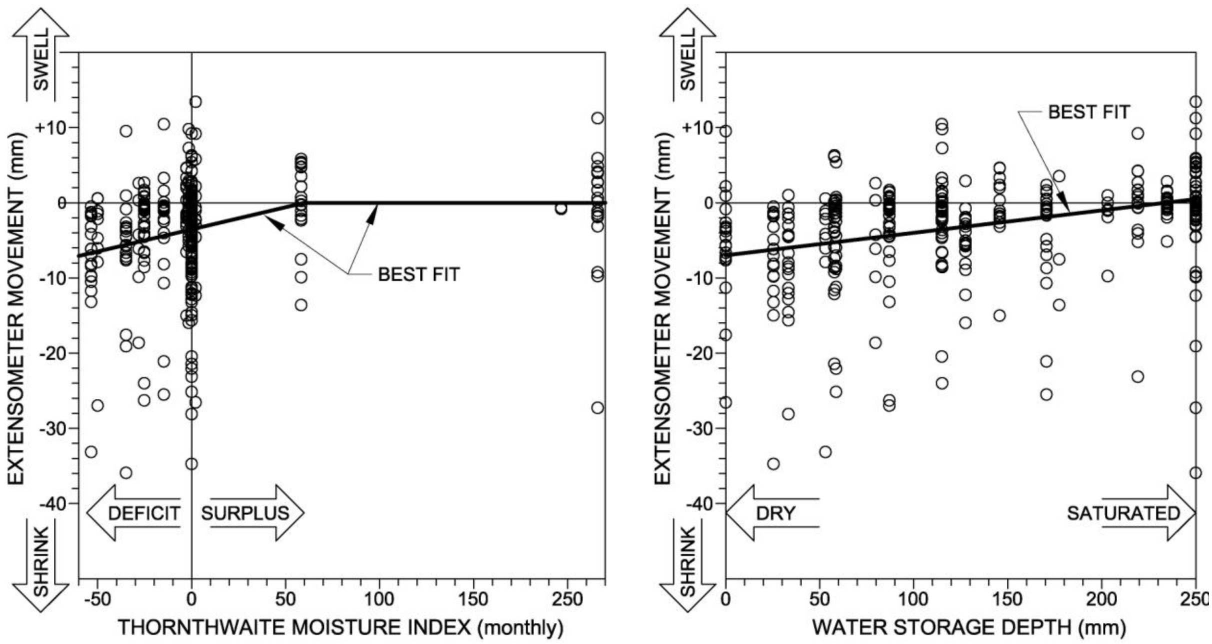
Figure 4(a) presents the comparison between ground surface movement and TMI (calculated on a monthly basis).

It is noted that TMI is zero when the calculated storage lies between the minimum and maximum values, and is evident in Figure 4(a) by the large proportion of data points lying on the TMI = 0 axis. As shrink-swell deformation of clay soils is related to variations in moisture content between the minimum and maximum (i.e. saturated) values, TMI cannot predict shrink-swell movement as TMI varies through zero.

2.4 Comparison with water storage

Extensometer movement data has been correlated with the soil water storage parameter employed in the TMI calculations.

Instead of using 100 mm as the soil water storage capacity, a value of 250 mm has been adopted. This is considered more realistic for clay soils in Sydney. Figure 4(b) presents a comparison between monthly storage and ground surface movement, and indicates a stronger correlation than the correlation with monthly TMI shown in Figure 4(a).



(a) Movement versus TMI *(b) Movement versus water storage depth*

Figure 4. Ground surface movement versus TMI and water storage depth

3 COMPARISON WITH AS2870

The extensometer data has been compared with the shrink-swell soil movements in Australian Standard AS2870-2011 "*Residential Slab and Footings*". For Sydney soils, the standard classifies site reactivity based on clay thickness; the authors consider this to be a poor indicator as, at best, clay thickness is an indirect measure of reactivity when it includes clay from below the zone of influence.

According to the standard, site classification includes a characteristic surface movement (y_s). This is defined as the 'movement of the surface of a reactive site caused by moisture changes from characteristic dry to characteristic wet condition in the absence of a building and without consideration of load effects'. This characteristic surface movement is used in the design of footings of lightly loaded structures (e.g. residential construction). The code states that the characteristic surface movement is to be interpreted as the characteristic value that has a 5% chance of being exceeded in the life of the building, which may be taken as 50 years (Ref. Section C2.2. – AS2870-2011).

Figure 5 shows the range of movement recorded at each of the instrument cluster sites versus the thickness of clay at each location. Also shown is the site classification based on the clay thickness, and the range of characteristic surface movement indicated by the standard for each classification.

The extensometer movement recorded over the period of monitoring is less than the characteristic values presented in the code. This is not necessarily a contradiction, as the extensometer measurements are not continuous (i.e. greater movement may have occurred and not been measured), only 8 years of data is available, and the extensometers do not record shrink/swell movement of the upper 0.3 m of the ground profile. It is noted that monthly TMI over the period of extensometer data indicates that characteristic wet and characteristic dry conditions had probably occurred.

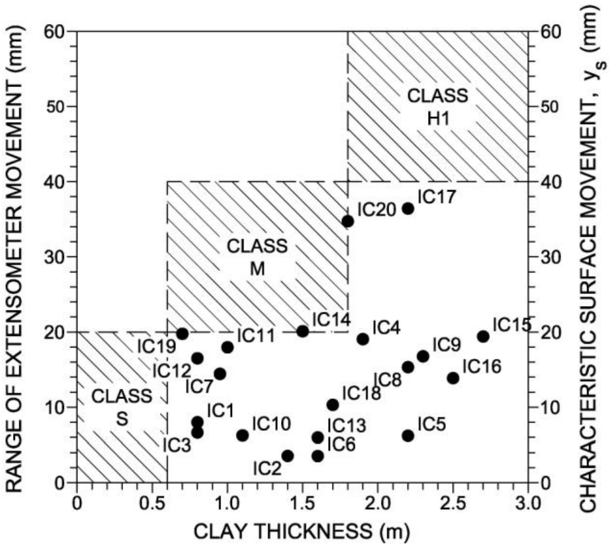


Figure 5. Clay thickness versus range of extensometer movement

4 CONCLUSION

The extensometers installed in 2003 continue to function and provide reliable data. The instruments have experienced a range of climatic conditions during this period and their movement correlates reasonable well with a simple moisture balance model.

The trend of movement with clay thickness corresponds reasonable well to AS2870-2011, though the magnitude of movement recorded to date is less than the ranges indicated by the standard for different site classifications.

Further monitoring is proposed, in particular to target climatic extremes. Analysis of instruments on an individual basis may provide a better understanding of shrink-swell movements, and enable development of a more useful moisture balance model. Ideally such a model could be used to assess whether environmental conditions during particular periods correspond to the minimum or maximum limits of shrink-swell behaviour, and enable more reliable assessment of problems associated with this mechanism (e.g. damaged houses).

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