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Observation of diaphragm wall movements in Lias Clay during construction of the A4/A46 bypass in Bath, Avon

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ABSTRACT: New highway schemes are often constructed in cuttings in order to minimise their environmental impact. The sides of these cuttings are frequently supported by retaining walls constructed using *in situ* techniques such as diaphragm walling. In the permanent condition the retaining walls may be supported at formation level by concrete props. The design of retaining walls supported at formation level is largely governed by the stability and serviceability requirements during construction, before the permanent props are installed. In appropriate situations the use of berms in conjunction with careful monitoring can be an economical and effective means of construction. The magnitude of movements can be limited by construction control. Results from monitoring show that berms are effective in supporting retaining walls during temporary construction stages.

1. INTRODUCTION

In 1982 the Department of Transport commissioned Sir Alexander Gibb & Partners Limited to design the A4/A46 Batheaston - Swainswick Bypass. The purpose of this bypass is to provide relief to the villages of Batheaston, on the A4, and Swainswick on the A46 as seen in Figure 1. Amey Construction Limited were appointed as main contractor and commenced construction of the bypass in March 1994.

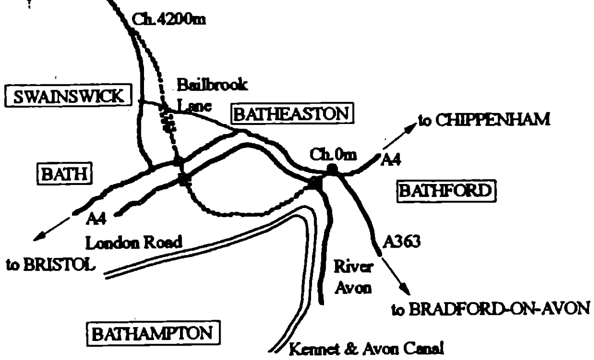

Figure 1 - Schematic route map

In order to minimise the land take and keep the environmental impact of the bypass to a minimum, an 800m length of cutting is supported by diaphragm walling with retained heights between about 4m and 9m.

On being awarded the contract Amey Construction Limited with the aid of Ove Arup & Partners put forward a proposal to use earth berms as a temporary method of diaphragm wall support in place of the temporary steel props. This proposal, which included the use of the observational method as defined by Peck (1969), was accepted by the Engineer.

As part of a research project sponsored by the EPSRC in collaboration with Sir Alexander Gibb & Partners Limited, the effectiveness of employing earth berms within the observational method as temporary works design is being investigated. The earth berms, in conjunction with the observational method, were proposed by the Contractor as an alternative to the use of temporary steel propping which was incorporated in the initial design of the walls.

Within the total length of diaphragm walling, which includes slip road and bridged sections, earth berms were extensively employed as a means of temporary support. This paper focuses on the performance of one length of wall between chainages 2800 and 2850m which was carefully instrumented. This section is just south of the northern limit of the retaining walls at chainage 2869 m and has retained heights of between 4m and 7.5m.

In this paper the performance of the wall to date is described and compared with the predicted wall movements, with particular reference made to the influence of the construction sequence.

Further details may be found in papers by Armstrong *et al.* (1996), Gosney *et al.* (1996) and Nicholson *et al.* (1996).

2. GROUND CONDITIONS

The sequence of Jurassic rocks in the Batheaston area outcrops with Great Oolitic Limestone forming the flat Solsbury Hill Top (an ancient hill fort owned by the National Trust), underlain by Fuller's Earth, Inferior Oolite, Midford Sand and finally Lower Lias Clay. As part of the route selection process which commenced in 1982, a series of site investigations was carried out from which the geological and geomorphological nature of the area was deduced.

The area is characterised by slope instability with valley bulging and cambering of the soil strata, as described by Chandler *et al.* (1976). Landslipped Lias Clay is also found in the upper region of the Lias in the study area.

Intact Lias Clay directly underlies the majority of the road route, although it is often obscured by superficial deposits or landslip material. The Lias Clay consists mainly of grey silty micaceous clays with occasional clayey silts and thin beds of grey clayey limestone. At depth, the clays verge on weak mudstones and are almost black in colour.

The clay may be very fissured leading to rapid drainage and the potential for relatively rapid dissipation of pore water suctions.

Superficial deposits of Midford Sand and reworked Midford Sand overlie the Lias Clay, for depths of 2 to 8 m. Depths of up to 3m are retained by the diaphragm wall section north of Bailbrook Underpass. The intact and reworked material are sometimes visually identical and can only be distinguished by the materials against which they are juxtaposed.

In the study area the unit of Midford Sand actually consists of fairly uniform medium dense yellow sandy and coarse silts. Angular blocks of moderately strong to strong sandstone up to 0.5 m across are irregularly distributed throughout the sand. It is probable that these blocks are the remains of lenses or beds of sandstone disrupted during cambering.

A typical section through the road corridor which shows the retaining walls in the study area is given in Figure 2.

3. DESIGN

The design of the diaphragm walls was carried out in accordance with the Department of Transport Standard BD42/89. This sets out design principles and methods and refers the designer to CIRIA Report 104 (Padfield and Mair, 1984).

Stability analyses were carried out for both the construction stages and the final stage. BD42/89 requires the temporary stages to be checked for stability using the "worst credible" soil parameters and groundwater conditions (Design Approach B of Table 5, CIRIA Report 104). This tends to lead to a conservative embedment length for low propped cantilever retaining walls.

Temporary top propping was incorporated in the design to increase the stability of the wall during construction and minimise the embedment length.

Consideration was given to the deflection of the walls but in this situation it was not a limiting factor.

The parameters given below were adopted for permanent works design. Some allowance was made for low strength landslipped material near the surface of the Lias Clay stratum in the study area: these parameters are given in brackets if they vary from the Intact Lias.

In the long term, the groundwater profile at the wall was assumed to correspond to steady state seepage conditions.

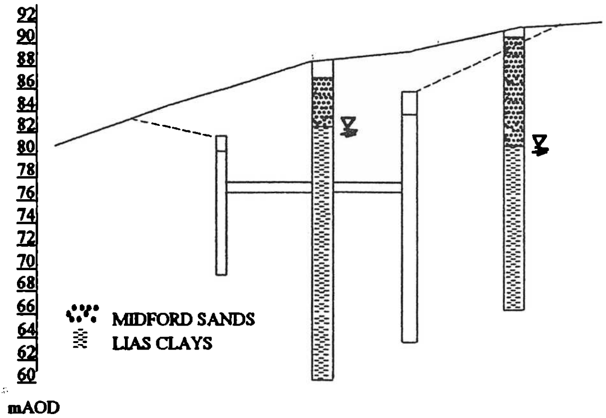

Figure 2 - Cross section at Chainage 2835m

ias Clay
' = 2 kN/m^2
' = 27° (17°)
${}_u$ = 50 + 8.2y (50) kN/m^2
${}_u$ = 500 s_u (12y+12 MN/m^2)
v' = 0.15

idford Sands
' = 32°
= 0
= 10 + 10y MN/m^2
vhere y = depth below ground level

The temporary works put forward by Amey used arth berms in conjunction with the observational echnique as a substitute for the top propping nticipated in the Engineer's design.

The observational method is based on onsideration of "most probable" and "most nfavourable" conditions for the site and the roposed work. The excavation sequence is then leveloped using the most probable conditions and ontingency plans are developed based on the most nfavourable conditions. Ground movements are nonitored on site and compared with expectations ased on the most probable predictions. If these novements are exceeded then the contingency plans re implemented.

Peck (1969) defined the most probable parameters s the most likely soil parameters to be encountered *n situ* with the most unfavourable parameters eflecting credible deviations from the likely onditions.

Within both the intact and landslipped Lias Clay he primary difference between the most probable nd most unfavourable parameters used in the bservational method, was related to the rate of lissipation of pore water suctions and thus to the ate of reduction of strength associated with the hange from undrained to fully drained conditions. Design for the most probable case was based on the doption of the full undrained shear strength of the ias Clay on both sides of the wall. Using these parameters the berm option was assessed as being easible, and analyses were carried out to predict wall novements during the different stages of onstruction.

The most unfavourable case was based on the omplete dissipation of pore water suctions on the etained side of the excavation and partial dissipation nd softening on the excavated side. Therefore fully lrained parameters were adopted on the retained side nd 70% of the undrained shear strength for the excavated side of the wall. Using these parameters the berm option was assessed as being unstable in some situations and so comprehensive contingency plans were developed to deal with this possibility should it arise.

For both scenarios, allowance was made for stress relief in the soil during installation of the diaphragm wall.

4. CONSTRUCTION

The diaphragm walls in the study area were made up of panels which were 1.5m and 1.0m thick on opposite sides of the excavation. The length of the panels varied from 7.5m to 5.1m and the overall panel depths varied from approximately 11m to 25m.

Careful control of the construction sequence is crucial to effective and safe use of the observational method. Procedures were put in place to permit the use of contingency measures should performance dictate. Simplification of the construction process enabled the works to progress rapidly, with benefits in limiting wall deformation. The construction sequence in the study area was as follows:

- Bulk excavation between the walls to berm profile over an 80m stretch
- Excavate the berm for one 5m bay
- Cut to formation level
- Cast grade level concrete prop

In this area the earth berms were left in place against the taller wall panels only. The ground level in front of the shorter wall panels was excavated down to 1m above formation level and the wall was allowed to cantilever freely until the permanent prop was cast. This is illustrated in Figure 3.

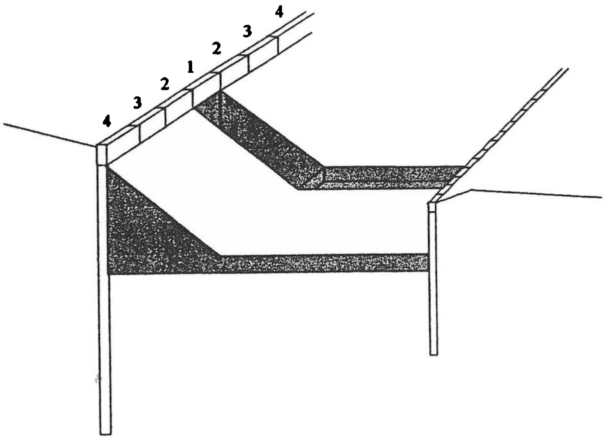

Figure 3 - Excavation sequence

During the initial construction/excavation new props were cast every 2 to 3 days. During this process the movement of the wall was monitored on a daily basis, to ascertain that it was behaving within tolerable limits. Initial results were within expectations and enhanced confidence in the performance of the walls then enabled larger bays to be excavated, speeding up the construction process.

5. FIELD OBSERVATIONS

At the Batheaston site, tachometric stations are mounted in the tops of selected diaphragm wall panels on both the east and the west side of the carriageway, enabling wall crest movements to be monitored. Fixed survey points, running at some distance from, but parallel to, the route alignment are installed as a datum reference. In addition, inclinometer tubes are cast in to the full depth of selected wall panels. The crest displacement of the opposite diaphragm wall panels H5 and G1, at chainage 2835m, are shown in Figure 4.

Monitoring commenced prior to any excavation between the walls in order to establish base line readings.

The monitored inclinometer profiles give an indication of the mode of deformation of the walls. Figure 5 indicates that wall bending effects are generally more significant in the case of the deeper wall.

The stages indicated in Figures 4 and 5 are:

Stage 1 - Excavation to berm profile
Stage 2 - Excavation of berm
Stage 3 - Cast formation level prop

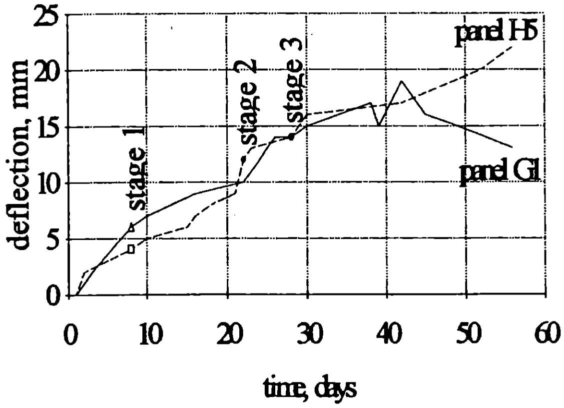

Figure 4 - Wall Deflection Ch 2835m

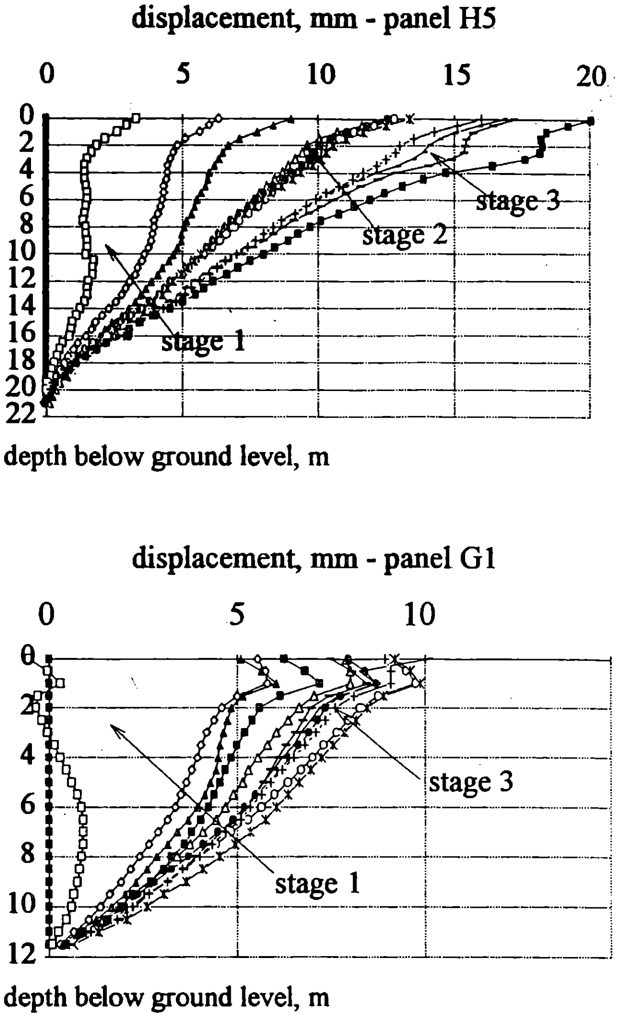

Figure 5 - Inclinometer Profiles Ch 2835m

6. DISCUSSION

The results from the monitoring show that the berms are effective in supporting the walls with retained heights of up to 7.5m in the study area and subsequently up to 9m in other areas. The magnitude of the measured wall movements was typically between 20 and 26mm during the construction stage. This compares well with the predicted wall movements of 32 mm at the end of construction.

Approximately 30% to 50% of this movement occurred during the excavation to the berm profile, with the remainder of the movements occurring when the support from the berm was completely removed.

In the study area small lengths of berm were removed before the prop was installed. Accordingly further movements of the wall occurred gradually as sections of berm were removed on either side of the instrumented section.

As might be expected it appears that the movements are very construction control dependent with longer excavation times allowing more softening and larger excavated bays enabling greater wall deformation to take place. This would suggest that practical benefits can indeed be achieved by careful control of the construction process, with movements limited, where appropriate, or advantage taken of less stringent controls, permitting more rapid progress.

ACKNOWLEDGEMENTS

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