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Measurement of prop loads in a large braced excavation during construction of the JLE station at Canada Water, East London

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ABSTRACT: The loads generated in temporary steel tubular props during the construction of the Jubilee Line Extension at Canada Water were monitored using vibrating wire strain gauges. In this paper, the preliminary results are presented and discussed with particular reference to temperature effects.

1 INTRODUCTION

The sides of deep excavations in urban areas are usually supported by retaining walls, in order to minimise landtake. The retaining walls are in turn often supported during the excavation stage and construction of the permanent works by temporary props at one or more levels. The need to support the wall in this way must be balanced against the cost (in terms of money, time and the potential hazard to site personnel) of providing, installing and removing the props, which can be large and heavy. Temporary props are typically made of steel tubes, often more than one metre in diameter.

Field observations suggest that in practice, prop loads may be rather smaller than those anticipated on the basis of the methods of analysis typically used in design (e.g. Glass and Powderham, 1994). As part of an EPSRC/construction industry sponsored project to investigate the reasons for this apparent discrepancy, prop loads have been monitored during the construction of the London Underground Limited (LUL) Jubilee Line Extension station at Canada Water in East London. The temperatures of the props have also been monitored, in order to investigate their influence on the loads.

The station has been constructed in a deep excavation, approximately 150m long and 27.6m wide. The excavation was approximately 17m deep in the research area, where the wall was supported at two levels by 1067mm diameter tubular steel props at 8.3m centres (Figure 1).

The loads in four props (two at each level) were monitored using a total of 32 vibrating wire strain gauges. Thermistors were incorporated into each gauge. Both the strain and the temperature at each gauge location were recorded at two-hourly intervals while the props were in place. Pore water pressures and wall movements were monitored manually, but these data are not presented in this paper.

2 GROUND CONDITIONS

2.1 Soil types

The soil types present are summarised in Table 1, and their geotechnical parameters in Table 2. These data

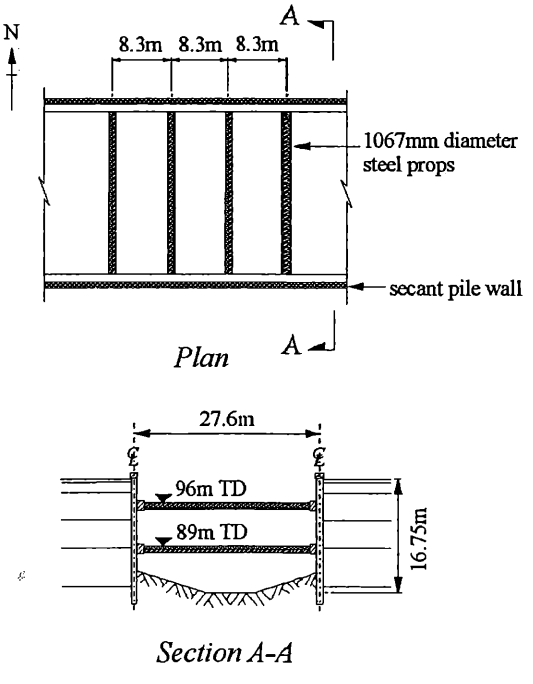

Figure 1: Excavation Geometry

have been taken primarily from the interpretative report associated with the Jubilee Line Extension site investigation (Geotechnical Consulting Group, 1991).

Table 1: Soil descriptions

Soil Type	Level at Top of Stratum (m TD*)	Description
Made Ground	105.5	Highly variable sand and clay
Alluvium	99.5	Silt and clay, with layers of peat
Thames Gravel	98	Gravels with sand
Woolwich and Reading Clays	94	Silty clay with sand
Woolwich and Reading Sands	90	Varies from coarse gravel to silty sand
Thanet Beds	84	Dense silty sand

* All levels are expressed relative to the Tunnel Datum, TD, which is 100m above Ordnance Datum (i.e. O.D. + 100m).

Table 2: Geotechnical parameters

Soil Type	Density, ρ (kg/m^3)	Critical State Shear Strength, ϕ'_{crit}
Made Ground	1800	25°
Alluvium	1850	25°
Thames Gravels	2000	38°
Woolwich and Reading Clays	2200	28°
Woolwich and Reading Sands	2200	34°
Thanet Beds	2200	40°

2.2 Groundwater conditions

The alluvium and the Thames Gravel comprise a shallow aquifer, linked to the River Thames. The groundwater level in the shallow aquifer varies, but is generally about 99.5m TD. The piezometric level for the lower aquifer, (comprising the Woolwich and Reading Sands, the Thanet Beds and the Upper Chalk), is estimated to be 94m TD, although this is steadily rising (Simpson *et al*, 1989). No piezometric data were available for the Woolwich and Reading Clays, but it is likely that the piezometric levels in this stratum would be in transition between the two aquifers, i.e. between 99.5 and 94m TD.

3 CONSTRUCTION DETAILS

Of the four props in which loads were monitored, two were at elevation 96m TD and two at elevation 89m TD. The props spanned 27.6 metres between temporary hard/soft secant pile retaining walls (Figure 1).

In the research area, the top of the wall was at 100m TD. The hard piles were 18 metres deep, giving a toe level of 82m TD. The alternate soft piles extended to 92m TD. The soft piles were installed to prevent the ingress of water from the upper aquifer, which was not dewatered due to the settlements that this might have caused. A 1200mm wide × 1250mm deep capping beam was constructed at the top of the wall, around the entire perimeter of the excavation.

The props were fabricated from 1067mm diameter × 14.3mm thick tubular section, grade 65 steel. The props were grouted against reinforced concrete waling beams, which resulted in the actual 'free length' of the props being approximately 24.1 metres (Figure 2).

3.1 Construction sequence

In May 1994 the original ground level was reduced from 105.5m to approximately 104m TD. The secant

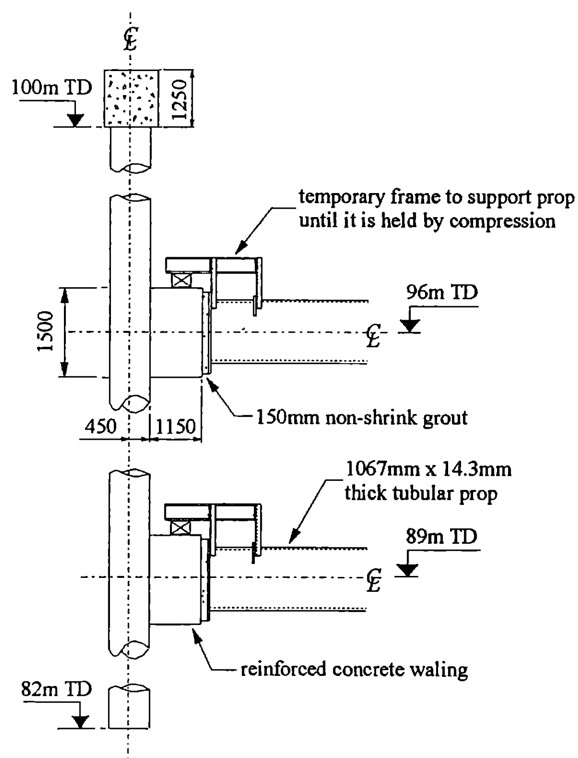

Figure 2: Prop end details

pile wall then was installed, with the top of the wall at 100m TD. The ground was then excavated to reveal the top of the wall and the capping beams were constructed (Figure 3.1).

By the end of 1994, the ground within the retaining walls had been excavated to about 94.2m TD, which coincided approximately with the top of the Woolwich and Reading Clays. The reinforced concrete waling beams were then constructed, and the props at elevation 96m TD were installed in mid-January 1995 (Figure 3.2).

Excavation then continued through the Woolwich and Reading Beds, reaching a level of 88.25m TD by 22 February 1995. The waling beams were constructed and the lower props, at elevation 89m TD, were placed and grouted by 10 March 1995 (Figure 3.3).

Excavation between the props continued and by mid-March the excavation was down to a level of 85.87m TD. The sides of the excavation were then battered at an angle of 15°, to form the profile shown in Figure 3.4. Final formation level of 83.25m TD was achieved by mid-April 1995.

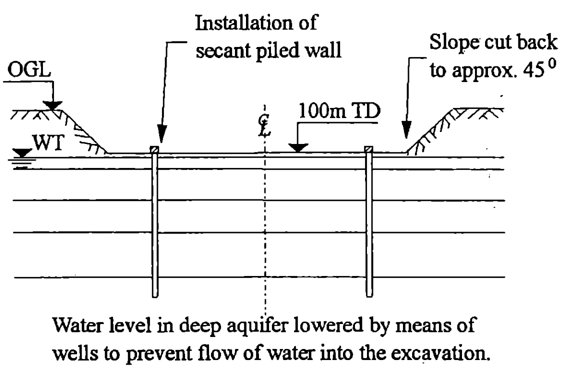

Figure 3.1: Excavation to 100m T.D.

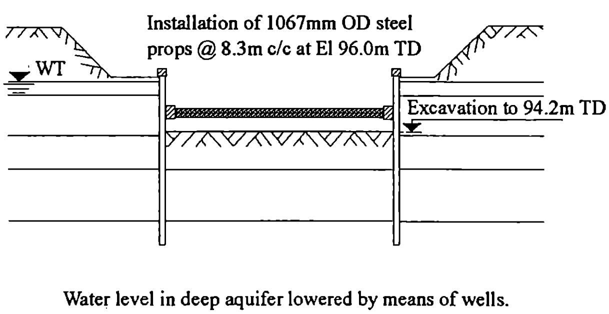

Figure 3.2: Installation of upper props

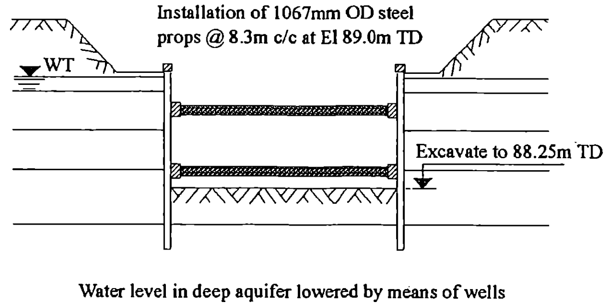

Figure 3.3: Installation of lower props

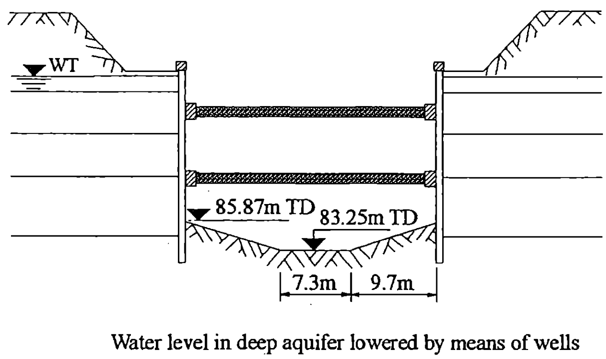

Figure 3.4: Final excavated profile

A layer of blinding concrete was then poured, and construction of the station began. The reinforced concrete base slab, which was designed to act as a permanent prop, was poured beneath the props in the research area in early May 1995.

The lower props were removed during June and July 1995 to allow the walls of the station box to be constructed. The upper props were removed in December 1995, after construction of an intermediate slab just below 96m TD and back-filling of the void between the secant pile wall and the permanent structure.

The excavation depth is shown as a function of time in Figure 4. Zero time is 13 January 1995, the date on which prop load monitoring began.

4 INSTRUMENTATION

The strain gauges (Geokon VK-4101) were connected to a Campbell Scientific CR10 data logger, which was battery operated to allow continuous, automatic recording at pre-determined regular intervals. The logger was programmed to

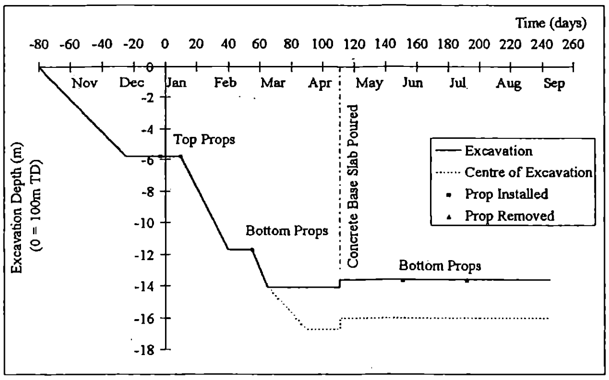

Figure 4: Excavation sequence

take readings of both strain and temperature at two hourly intervals so that the effects of temperature on the prop loads could be fully investigated. Strain datum readings were taken when the prop was in a substantially unloaded condition.

In order to carry out a complete investigation of the strains in the prop, including those due to differential temperature effects, four gauges were installed at each end of the four selected props. The gauges were located at the quarter-points of the cross section in order to investigate bending stresses about the xx (horizontal) and yy (vertical) axes, as well as the axial load. The gauges were installed approximately 1500mm from the ends of the props, which was considered to be far enough from the waling beam to eliminate the influence of end effects. In this paper, only the data from the upper props are presented.

5 RESULTS

5.1 Axial Load

The indicated axial load in each prop was estimated using Equation 5.1.

$$P = \varepsilon_{av}.AE \qquad (5.1)$$

where P is the axial load; ε_{av} is the average strain measured at a given cross section; $A = 0.0473\text{m}^2$ is the nominal cross-sectional area of the prop; and $E = 199\times10^6$ kN/m^2 is the measured Young's Modulus of the steel. Negative values indicate compression.

Localised variations in strain occurred at each gauge due to bending stresses, temperature differences across the prop and/or fabrication irregularities. However, the total axial load must be the same at each end of the prop, and the best estimate of the axial load is obtained by taking an average of all eight gauges on each prop. The average loads in the two upper props were almost identical, with a maximum difference of 5%. Figure 5 shows the axial load developed in one of the upper props as a function of time.

Notwithstanding temperature, the measured axial prop loads were considerably lower than those anticipated at the design stage (Bachy, 1994). However, prop loads similar to those measured can be calculated using the program WALLAP, by taking a reduced pre-excavation lateral earth pressure coefficient to allow for the effect of wall installation (Beadman, 1995).

The top props have been monitored for almost a year, allowing the full extent of seasonal variations in temperature to be determined (Figure 6).

The data presented in Figure 5 indicate the considerable effect of temperature on the measured prop load. As would be expected, an increase in temperature results in an increase in the compressive load in the prop, and a decrease in temperature in a decrease in compressive load.

Figure 6 shows that during the year, the prop temperature varied between approximately -4°C and 46°C. Taking the coefficient of thermal expansion for the prop steel as 11.3×10^{-6}/°C an increase in temperature of 50°C would, for an unrestrained prop

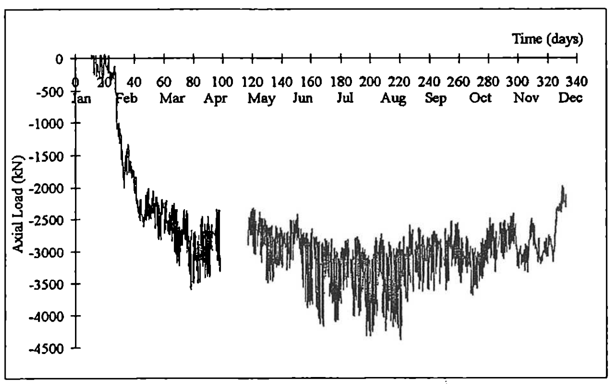

Figure 5: Axial load in upper props

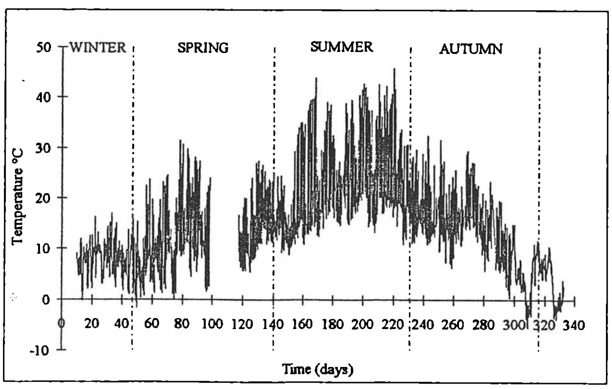

Figure 6: Seasonal variation in prop temperature

24.1m in length, result in an increase in length of 0.057% or 13.6mm. Alternatively, if the prop were fully restrained, the corresponding increase in load would be 5318kN.

If the indicated load is plotted against temperature for any single gauge, the effect of temperature is evident (Figure 7).

Figure 7 shows that there is generally an approximately linear relationship between temperature and load, with a series of defined lines representing the different depths of excavation. Once formation level had been reached, the effects of temperature alone caused the load indicated at this particular gauge location to vary between approximately 1750 and 4500kN. The data from the other gauges gave similar results). Thus temperature effects can contribute significantly to the load in a temporary prop.

The measured temperatures indicated that the prop was never at a uniform temperature, especially during the summer when the top of the prop was up to 10°C warmer than the underside. The tops of the props were subjected to a much greater range of temperature, usually becoming warmest during the day and coldest at night. The bottom gauges tended to be the most stable, while the east and west gauges varied during the day as the sun moved round the site. The north ends of the props also tended to be warmer than the south ends during the day. During the night, however, both ends of the prop fell to a similar temperature.

As a result of the differential temperatures within the prop, bending stresses were generated about the xx (horizontal) and yy (vertical) axes. These temperature dependent bending stresses will in general vary along the length of the prop.

5.2 Bending moments

Bending moments at the cross sections of the gauges have been calculated using Equations 5.2 and 5.3.

$$M_{xx} = \frac{EI}{y}\frac{(\varepsilon_T - \varepsilon_B)}{2} \qquad (5.2)$$

$$M_{yy} = \frac{EI}{y}\frac{(\varepsilon_W - \varepsilon_E)}{2} \qquad (5.3)$$

where ε_T, ε_B, ε_W and ε_E are the indicated strains at the top, bottom, west and east gauges; I is the second moment of area, y is the distance from the gauge point to the neutral axis and E is the Young's Modulus.

Figure 8 shows the bending moments measured about the xx axis, at one of the instrumented cross sections.

Figure 8 shows that the bending moment in the prop can vary considerably due to fluctuations in the temperature difference between the top and the bottom surfaces. The results also indicate that the props were subjected to some bending about the x-x axis due to effects other than temperature. Bending moments were probably induced by the rotation of the wall, which would have been transmitted to the ends of the prop by the wall-prop connection adopted. Further data indicate that the bending moments at each end of an individual prop were different. This is reasonable, since the wall rotations at prop level were different on each side of the excavation due to variations in ground conditions. The bending moments about the xx axis due to wall rotation and temperature effects shown in Figure 8 are comparable in magnitude with the sagging bending moment at the centre of the span due to the self weight of the prop which, for simply supported ends would be -264 kNm.

Figure 8 shows that initially there was a gradual increase in the negative (sagging) bending moment in the prop. This was probably caused by rotation of the wall, as its crest moved into the excavation. After the

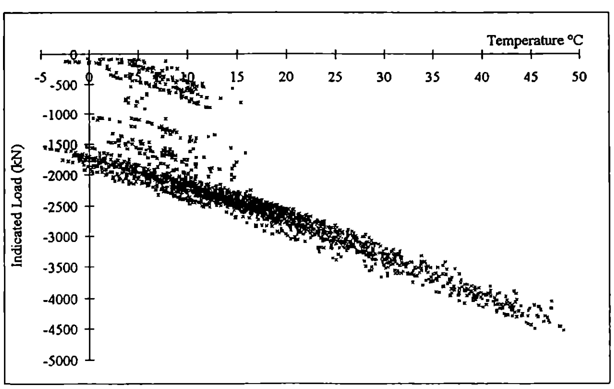

Figure 7: Temperature vs indicated load

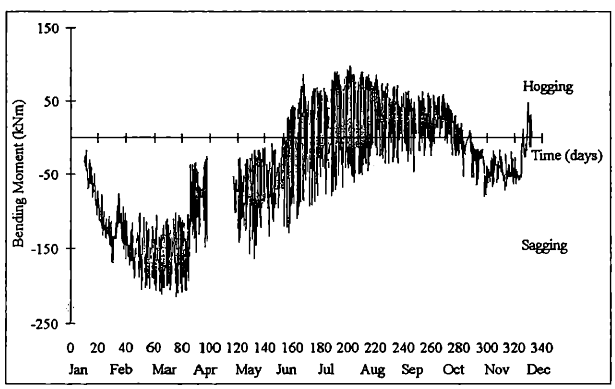

Figure 8: Bending moments about xx axis

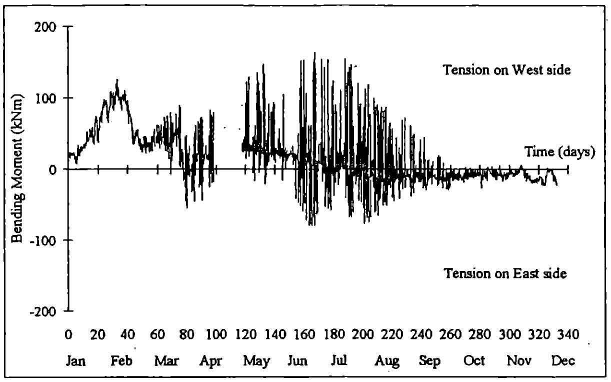

Figure 9: Bending moment about the yy axis

bottom props, were placed in March 1995, the bending moments began to decrease. Placement of the bottom props would have substantially prevented further inward displacement of the wall: a further possibility is that the top props actually begin to push the wall back into the retained soil as the temperature gradually increased. Following removal of the bottom props (with the concrete base slab now in place) in June and July 1995, the magnitude of the sagging bending moment was further reduced. Between July and October, a hogging bending moment was recorded. Data from the inclinometer embedded in the wall suggest that the development of a hogging bending moment was due to the movement of the wall into the excavation following removal of the lower temporary props.

As temperatures began to fall again, there was another reversal in the direction of the bending moment. This could have been due to the contraction of the prop, resulting in the wall moving back into the excavation at the level of the upper temporary props.

Figure 9 shows the measured bending moment about the yy (vertical) axis.

It would appear that, apart from during the early stages after placement of the prop, bending moments about the y-y axis were primarily due to the effects of temperature. Bending moments tended to fluctuate during the day as the sun moved from the east to the west side of the prop. The fluctuations were greatest during the summer months, when one side of the prop became considerably warmer than the other due to the effect of the direct sunlight.

6 CONCLUSIONS

The preliminary results presented in this paper have clearly indicated the dependence of loads in temporary props on temperature. Temperature not only influences the axial loads, but can also generate bending stresses as a result of temperature differences between opposite sides of the prop.

Despite the large variation in axial load due to temperature effects, the measured loads are apparently at the lower end of the range that would be calculated using common analytical methods.

Bending moments in the props can also, depending on the prop/wall connection, be induced by the rotation of the wall. In this case, the measured bending moments were generally of the same order as those due to self weight effects and therefore of little practical importance.

REFERENCES

Bachy Limited (1994). Jubilee Line contract 106, Canada Water station, Hard/soft secant wall analysis, gridline 16-17

Beadman, D. (1995). Private communication.

Geotechnical Consulting Group (1991). Sectional interpretive report 2.

Glass, P.R. & Powderham, A.J. (1994). Application of the observational method at the Limehouse Link. *Geotechnique* 44(4) pp571-776.

Simpson, B., Blower, T., Craig, R.N. and Wilkinson, W.B. (1989). The engineering implications of rising groundwater levels in the deep aquifer below London. *CIRIA Special Publication 69.*