# Evaluation of prop loads at Channel Tunnel Rail Link Contract 430 – Ashford tunnels

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Conventional design methods for braced excavations are commonly found to overestimate the prop loads measured during subsequent construction (Powrie & Batten, 2000, Twine & Roscoe, 1999). This may result in the over-design of support systems. The distributed prop load (DPL) method provides an alternative method of estimating temporary prop loads based on case histories.

This paper compares loads found using the DPL method and those given by conventional wall analysis with loads measured during the early stages of construction of the Channel Tunnel Rail Link (CTRL) Contract 430. It demonstrates that the DPL loads are greater than those measured, but significantly less than those found by analysis. The DPL method is then applied to forthcoming areas of construction. The subsequent reduction in prop load predictions allowed review of the method of propping and resulted in cost savings of approximately £175,000.

## Project context

Section 1 of CTRL will connect the Channel Tunnel to existing Railtrack infrastructure near Gravesend. Rail Link Engineering awarded Contract 430, the largest contract on Section 1 worth £150M, to Skanska (then Kværner Construction) in 1998. C430 comprises 14.4km of high speed rail link through east Kent. Some 1.8km of cut and cover tunnels and retaining structures are needed to pass through central Ashford to connect to Ashford International Station. Structures include 570m of four track tunnel, 420m of two track tunnel and 800m of two track propped retained cut and retained cut (**Figure 1**).

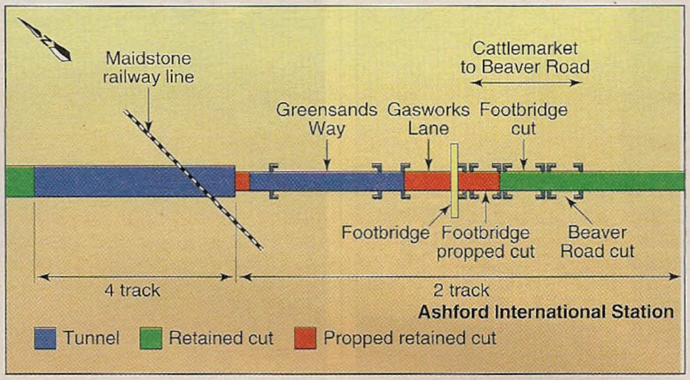



**Figure 1: Plan of CTRL C430.**

**Figure 2: Fabric in Weald Clay.**

## Ground conditions

Ground conditions comprise three main units from the Lower Cretaceous system. The succession with typical depths below ground level is given below: Geotechnical parameters are given in **Table 1**.

| | |
|---|---|
| Hythe Beds | from 0m to 6m |
| Atherfield Clay | from 6m to 19m |
| Weald Clay | from 19m |

The Hythe Beds consist of loose silty and clayey fine sand and soft to firm sandy clay with occasional weak calcareous sandstone beds and thin limestone bands. Sandstone boulders were also encountered during piling. The Hythe Beds exhibit a large scatter in their geotechnical parameters, including a range of plasticity from low to very high.

The Atherfield Clay is stiff to very stiff closely fissured sandy clay. The deposit is divided into two materials according to its plastic behaviour. The upper deposit is predominantly of very high plasticity, having a plasticity index of 54%. The lower deposit is of intermediate plasticity with a plasticity index of 32%.

The Weald Clay underlies the site and is of considerable thickness. The deposit is stiff to very stiff thinly laminated closely fissured clay of intermediate to high plasticity with numerous silt laminae and partings. Silt pockets and bands of fissured siltstone up to 200mm thick are also present.

The water table is 1m to 2m below ground level. Although all the deposits are principally fine grained, field trials showed that ejector

**Table 1: Design soil parameters**

| Soil type | Young's Modulus kN/m (and gradient) | $\gamma$ kN/m$^3$ | $\phi'$ (plain strain) | c' kP$_a$ | $k_a$ Active $\delta/\phi = +2/3$ | $K_p$ Passive $\delta/\phi = -2/3$ |
|---|---|---|---|---|---|---|
| **Rail Link Engineering design soil parameters** | | | | | | |
| Hythe Beds | 1800 (4860) | 20 | 32 | 0 | 0.26 | 5.8 |
| Atherfield Clay (high plasticity) | 3600 (3640) | 20 | 26 | 0 | 0.33 | 3.75 |
| Atherfield Clay (Intermediate plasticity) | 3600 (3640) | 20 | 23 | 4 | 0.38 | 3.1 |
| Weald Clay | 18200 (3200) | 20 | 25 | 0 | 0.35 | 3.5 |
| **Skanska design soil parameters for observational analysis** | | | | | | |
| Hythe Beds | 1800 (4860) | 20 | 35 | 0 | 0.23 | 7.3 |
| Atherfield Clay (high and intermediate plasticity) | 3600 (3640) | 20 | 24 | 10 | 0.37 | 3.3 |
| Weald Clay | 18200 (3200) | 20 | 25 | 0 | 0.35 | 3.5 |

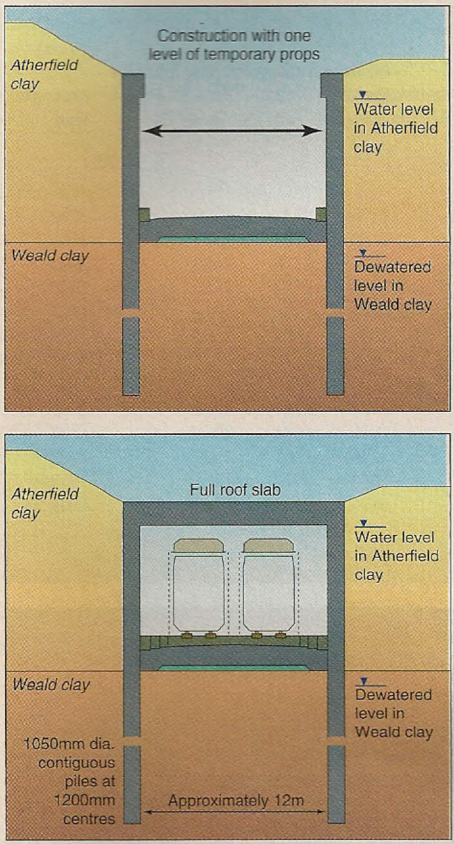



Figure 3: Section at Greensands Way.

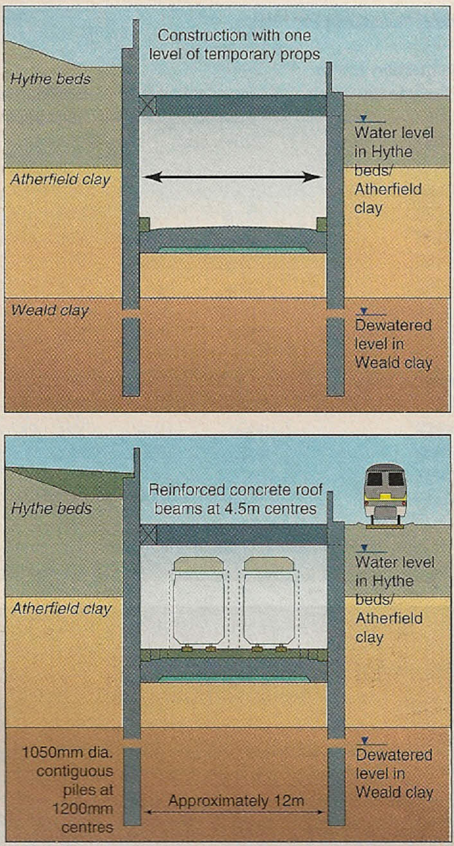



Figure 4: Section at Gasworks Lane.

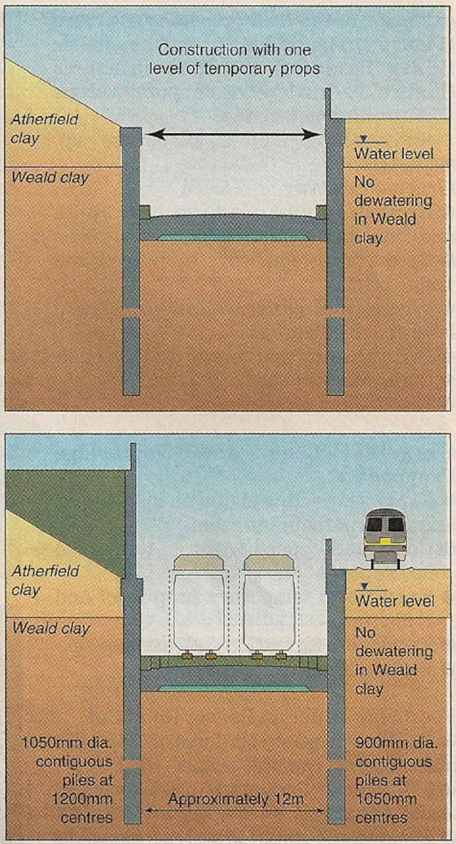



Figure 5: Section at Beaver Road Cut.

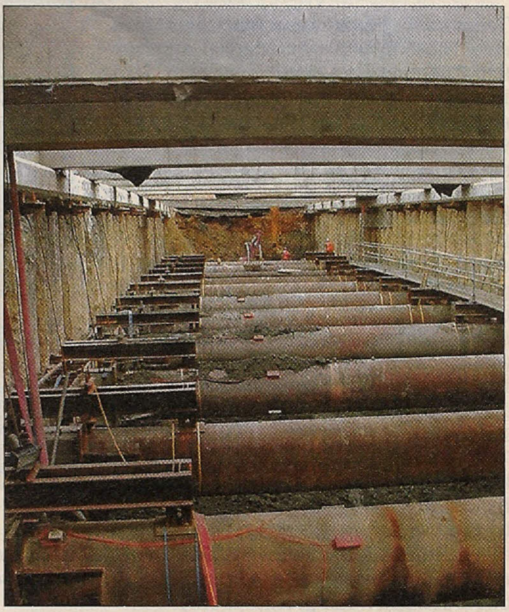


Figure 6 and 7: Construction at Gasworks Lane.

system dewatering was an effective method of groundwater control in the Weald Clay. This is due to anisotropic permeability resulting from the natural fabric of the deposit, which includes silt partings and fissured siltstone bands (**Figure 2**). Dewatering of the Weald Clay generally maintained a water level of a few metres below tunnel formation.

The majority of the excavations take place within the Atherfield Clay, with the Weald Clay generally lying below the tunnel formation. The Hythe Beds do not occur throughout the site. Where present, they are encountered at the very top of the excavation, commonly forming the batter above the capping beam.

## The two track structures

The two track tunnel includes three types of structure, those with a full roof slab, propped retained cuts and retained cuts. The first structures to be constructed were Greensands Way and Gasworks Lane. Greensands Way is shown in Figure 1 with a cross-section through the structure in **Figure 3**. The initial 30m of the tunnel was constructed using two levels of temporary props. The remaining 250m of tunnel was constructed with one level of temporary props using the observational method (Nicholson et al, 1999).

A cross-section through Gasworks Lane is shown in **Figure 4**. It was constructed with permanent discrete reinforced concrete roof beams at 4.5m spacing and one level of temporary props (see **Figures 6 and 7**). Construction of Gasworks Lane forms the only two track excavation in the Hythe Beds. Measurements of prop loads from both structures are given below.

Work began on the Cattlemarket to Beaver Road section in spring 2001. The section includes three main structures, Footbridge Propped Cut, Footbridge Cut and Beaver Road Cut. Footbridge Propped Cut is an extension of the Gasworks Lane structure (**Figure 4**). Footbridge Cut and the smaller Beaver Road Cut are open structures (**Figure 5**). One level of temporary props was used in construction.

Construction follows a 'bottom up' sequence.

**Greensands Way**

- Excavate to piling platform, install piles and construct capping beams
- Excavate to temporary prop level and install props
- Where required excavate to second prop level and install props
- Excavate to formation and cast base slab
- Construct roof slab
- Remove temporary props

**Gasworks Lane and Footbridge Propped Cut**

- Excavate to piling platform, install piles and construct capping beams
- Construct permanent reinforced concrete props
- Excavate to temporary prop level and install props
- Excavate to formation and cast base slab
- Remove temporary props

**Footbridge Cut and Beaver Road Cut**

- Excavate to piling platform, install piles and construct capping beams
- Excavate to temporary prop level and install props
- Excavate to formation and cast base slab
- Remove temporary props

Temporary props were fabricated from steel tubes of 1016mm external diameter and 83,116mm² cross-sectional area. Prop installation details are shown in **Figures 8 and 9**. The props were not pre-loaded and were installed at a 4.5m spacing for all structures

## Measurement of prop loads

Prop loads were monitored during construction by vibrating wire strain gauges. Three or four adjacent props were each fitted with four gauges at equal spacing around the prop (**Figure 5**). This provides an average load for each prop that is independent of any bending that may occur (Batten et al, 1999, Richardson et al 1999).

Base readings were taken before casting of the concrete thrust block. Following installation, readings were taken by a data logger every ten minutes. Built-in thermistors allowed temperature variations to be measured and hence removed (Batten et al, 1999, Richards et al 1999). The resulting loads are due to soil and water pressures only.

All prop load measurements were considered before construction of the base slab. Prop loads were found to vary by up to 1000kN in each set of monitored props (**Table 2**). Typical prop load fluctuations are shown in **Figure 10**.

The loads developed in a set of three reinforced concrete roof beams were also measured at one location in Gasworks Lane. The maximum average load recorded before casting of the concrete base slab was 607kN.

## Comparison of prop loads

### Design predictions

The cut and cover designs were carried out using the flexible earth retaining wall program FREW (Oasys, 1998). During all stages of construction the ground was assumed to be fully drained. The moderately conservative geotechnical parameters determined by Rail Link Engineering following ground investigation and testing (London and Continental Engineering, 1997) were adopted in design. Improved

**Table 2: Measured prop loads**

| Construction details CTRL chainage | Observational method used in design? | Dewatering of Weald Clay? | Maximum measured prop loads kN Prop 1 | Prop 2 | Prop 3 | Prop 4 | Average load |
|---|---|---|---|---|---|---|---|
| **Greensands Way** | | | | | | | |
| 89+370 | Yes | Yes | 2170 | 2547 | 1529 | | 2028 |
| 89+434 | Yes | Yes | 2159 | 2844 | 2680 | | 2561 |
| 89+465 | Yes | Yes | 1847 | 3778 | 2000 | | 2808 |
| 89+532 | Yes | Yes | 1859 | 2124 | 1858 | | 1947 |
| 89+550 upper | No | Yes | 1464 | 1482 | 1618 | | 1521 |
| 89+550 lower | No | Yes | 1869 | 1627 | 1691 | | 1729 |
| **Gasworks Lane** | | | | | | | |
| 89+675 | No | Yes | 2222 | 1741 | 2243 | 1789 | 1999 |
| 89+760 | No | Yes | 1816 | 1681 | 2032 | | 1843 |
| 89+800 | No | Yes | 2126 | 1351 | * | | 1739 |
| 89+825 | No | No | 1664 | 2514 | 789 | | 1659 |
| 89+850 | No | No | 1870 | 2123 | 1420 | | 1804 |

* third prop strain gauges damaged during construction

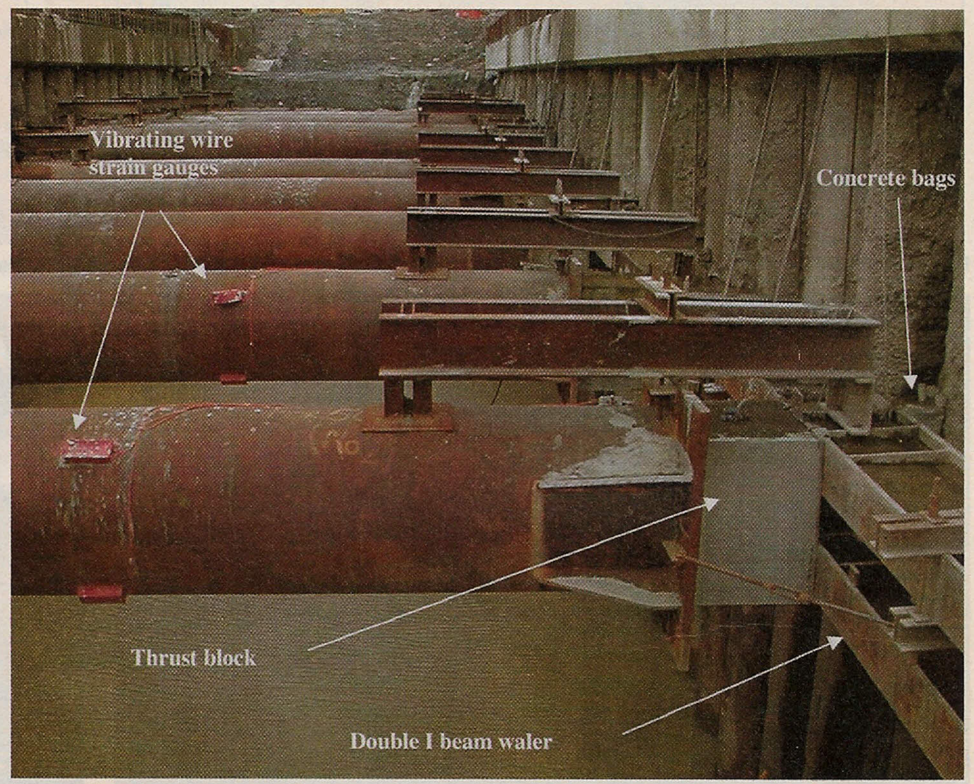



**Figure 9: Propping at Greensands Way.**

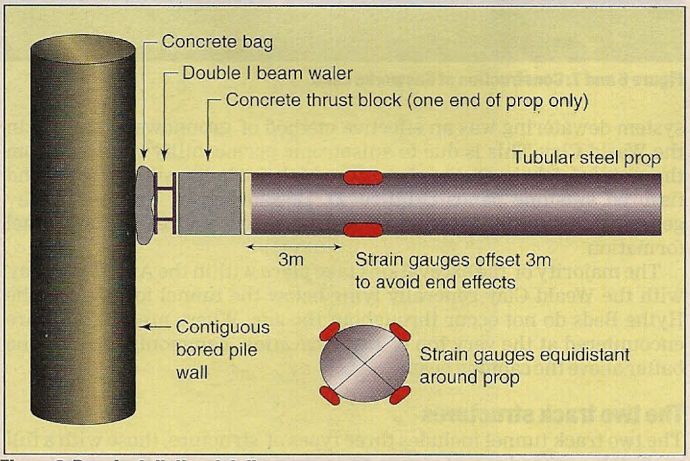



**Figure 8: Prop installation details**

**Table 3: Comparison of prop loads**

| Chainage | Observational Method used in design? | Dewatering of Weald Clay? | Measured maximum prop loads kN | Design prop loads kN | DPL Predicted prop loads kN |
|---|---|---|---|---|---|
| **Greensands Way** | | | | | |
| 89+370 | Yes | Yes | 2028 | 3510 | 4651 |
| 89+434 | Yes | Yes | 2561 | 3510 | 4475 |
| 89+465 | Yes | Yes | 2808 | 3300 | 4751 |
| 89+532 | Yes | Yes | 1947 | 3300 | 3908 |
| 89+550 upper | No | Yes | 1521 | 2331 | 1799 |
| 89+550 lower | No | Yes | 1729 | 3325 | 2243 |
| **Gasworks Lane** | | | | | |
| 89+675 | No | Yes | 1999 | 4450 | 2819 |
| 89+760 | No | Yes | 1843 | 4450 | 2819 |
| 89+800 | No | Yes | 1739 | 4450 | 2819 |
| 89+825 | No | No | 1659 | 3510 | 2163 |
| 89+850 | No | No | 1804 | 3510 | 2163 |

**Table 4: Predictions of prop loads at Cattlemarket to Beaver Road**

| CTRL chainage | Predicted prop loads kN: Design prop loads (FREW) | DPL predictions |
|---|---|---|
| **Footbridge Propped Cut** | | |
| 89+870 | | 2052 |
| 89+900 | 4133 | 2646 |
| 89+930 | | 2408 |
| **Footbridge Cut** | | |
| 89+940 | 3571 | 2271 |
| **Beaver Road Cut** | | |
| 90+080 | 1800 | 1405 |
| 90+110 | 1148 | 1298 |
| 90+150 | 1512 | 807 |

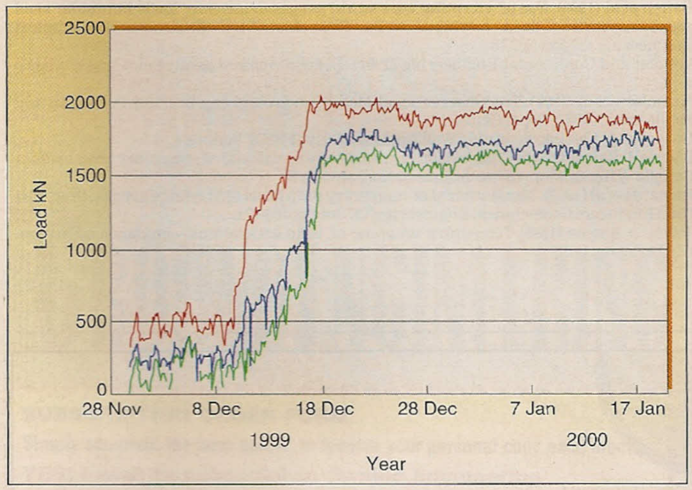
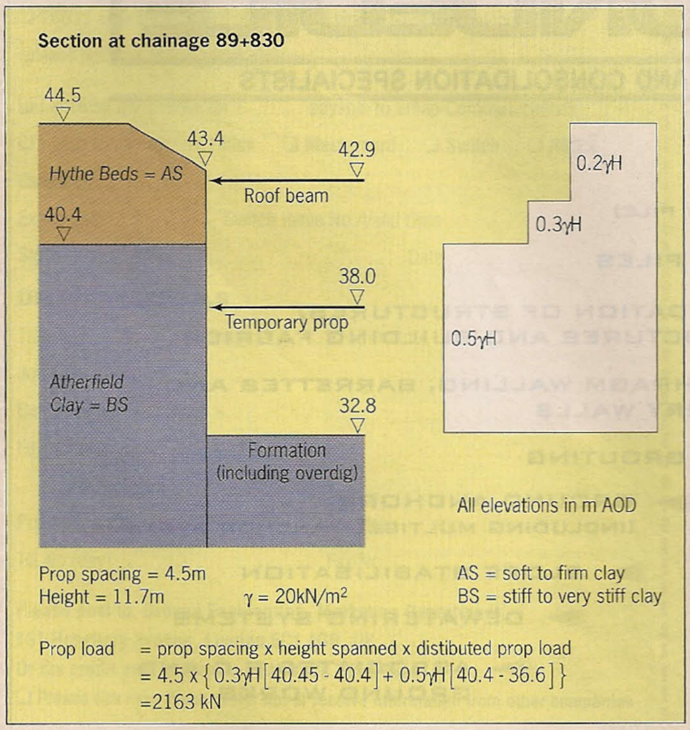



**Figure 10: Prop load fluctuations at Greensands Way, temperature corrected.**




**Box 1: DPL diagram for Gasworks Lane.**

geotechnical parameters were derived by Skanska after back-analysis of construction monitoring. The design soil parameters are detailed in **Table 1**.

**Distributed Prop Load (DPL) method**

The DPL method is based on case histories of deep braced excavations worldwide. **Box 1** gives a typical DPL diagram for Gasworks Lane and illustrates prop loads derived by the method. Where the two sides of the structure were asymmetrically loaded, the DPL method was applied to the side with the more onerous loading. The excavations at Greensands Way and Gasworks Lane are generally 13m wide and 11m to 15m deep. This falls well within the range of excavation sizes of the case histories (Twine & Roscoe, 1999). 10 kPa integral live load is allowed for in the DPL method. No additional surcharges were imposed in the analysis.

**Comparison of prop loads**

The measured and predicted prop loads for Greensands Way and Gasworks Lane are shown in **Table 3**. The measured loads decrease up chainage as the size of the structures decreases. Where two temporary props were used instead of one, the sum of the loads is greater than the load in a single prop.

The moderately conservative design prop loads are up to twice the corresponding measured loads. This is independent of the number of props used in construction and whether the ground was subjected to temporary dewatering.

The DPL method generally provided conservative predictions of prop loads compared to the measured loads. However, three DPL predictions of prop loads were greater than twice the measured load. The temporary dewatering at these locations may have caused this effect.

The DPL predicted loads were less than the moderately conservative design loads and greater than the observational design loads. Based on back-analysis the observational method made every effort to match both measured deflections and prop loads. To achieve this the prop stiffness was reduced by a factor of two in the observational analysis. This resulted in the observational design loads providing the closest predictions of measured prop loads.

## Predictions of prop loads

The measured prop loads at Greensands Way and Gasworks Lane provided a calibration for the DPL method and confirmed the reliability of the predictions. The DPL method was then used to predict loads for the propped retained cuts and retained cuts at Cattlemarket to Beaver Road.

Moderately conservative soil parameters have been used in the design for Cattlemarket to Beaver Road. No dewatering has taken place during construction. Prop load estimates from FREW are compared with DPL predictions in **Table 4**. The DPL predictions are significantly lower than the design loads.

The DPL loads for Beaver Road Cut, the smallest 100m of the structure, are within the capacity range of hired props. Due to programme restraints, construction at Cattlemarket to Beaver Road was scheduled for a time of maximum prop usage. Use of hired props instead of fabrication of additional props provided a significant cost saving.

Construction at Beaver Road Cut was planned to proceed using Storey

Super Props. Each prop comprised four chords of twin rolled steel channels. Two Super Props at 4m centres were installed on 5m walers, as shown in **Figure 11**. The cost of this method of propping is outlined in **Box 2**. It was estimated that it would provide savings of £175,000.

## Conclusions

Design analyses tend to overestimate prop loads. At C430 moderately conservative design prop loads were up to twice those measured during construction.

The DPL method provides rapid conservative determinations of prop loads that are generally less than conventional design predictions.

Use of DPL prop load predictions in prop design at C430 resulted in a significant cost saving by allowing the use of hired props instead of specially fabricated props.

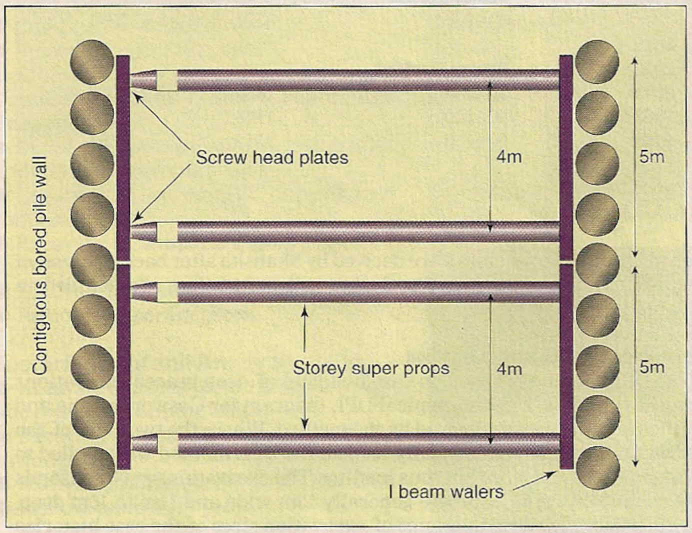



**Figure 11: Propping arrangement at Beaver Road Cut.**

**Box 2: Cost of propping system**

**1. Fabricated propping system**

| | | |
|---|---|---|
| length of section | = 100m | |
| number of props | = 23 | |
| (steel props at 4.5m c/c) | | |
| cost per prop | =£10,000 | |
| fabrication cost | = £230,000 | total cost = £230,000 |

**2 Hired propping system**

| | | |
|---|---|---|
| length of section | = 100m | |
| number of props sets | = 20 | |
| (two props on 5m water) | | |
| lump sum hire | = £17,200 | sub-total = £17,200 |
| (for 20 prop sets for four weeks) | | |
| additional hire (per week) | = £860 | |
| construction period | = 12 weeks | |
| additional hire | | |
| (for eight weeks) | = £34,400 | sub-total = £34,400 |
| | | total cost = £51,600 |

## References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