Design guidance on soil berms as temporary support for embedded retaining walls

Prepared for Quality Services, Civil Engineering, Highways Agency

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Executive Summary

Three dimensional finite element modelling has been undertaken with the aim of improving current design procedures for the use of soil berms as temporary support during the construction of embedded retaining walls permanently propped at carriageway level. The use of soil berms as an alternative to temporary props during bulk excavation in front of retaining walls has already been employed on several major road schemes in the UK. Generally measured performance at these schemes has demonstrated soil berms to be a cost effective alternative, although limited design guidance is currently available.

This study seeks to provide engineers with less empirically based methods of incorporating soil berms into temporary works design. Results from finite element analyses, together with factor of safety calculations, have been combined creating sets of ‘user-friendly’ design aids in the form of charts, aimed at both rationalising and producing economy in the design of soil berms.

The serviceability limit state of temporary works using soil berms was investigated using three dimensional finite element analysis. Comparison of the magnitude of the wall movements when using soil berms of different dimensions with movements obtained for a reduced dredge right across the cutting enabled an appropriate design chart to be derived relating the two. The use of up-to-date pre and post processing facilities has enhanced the modelling capabilities, leading to more accurate and representative modelling.

Factors of safety, using recognised and appropriate practices, were determined for cantilever walls with a level dredge in front of them. These calculations were based upon the ‘typical’ wall geometry and soil strength parameters adopted in the finite element study. This information was then utilised in quantifying the design process when using berms as temporary support to embedded retaining walls. In this way, the engineer has been provided with a correlation between berm design and the factor of safety.

The proposed design approach is described and illustrates the use of simple ‘look-up’ charts which enable the engineer to determine suitable soil berm sizes to give the required factor of safety. The improved design procedure is expected to lead to an increased use of soil berms for the temporary support of embedded retaining walls and further economy in their construction costs.
1 Introduction

For retained cuttings, permanent support is often provided by a structural slab cast just below carriageway level and spanning between embedded walls on each side. With this form of construction, cost savings are achieved by significant reductions in the wall embedment depth required for stability from that necessary for cantilever walls. This, however, has the consequence that temporary support for the wall is needed during bulk excavation in front of it. Traditionally this support has been provided by temporary props installed horizontally and spanning between the opposing walls of an underpass. However there are many construction situations where temporary propping is either excessively costly or impractical, e.g. if there is no opposing wall to react against or if the excavation is very wide. For this reason the use of soil berms as an alternative method of temporary support to embedded retaining walls has already been employed on several major road schemes in the UK.

A review of three such schemes at A4/A46 Batheaston-Swainswick Bypass, the A406 East of Fallooden Way, and the A50 Blythe Bridge to Queensway has been reported by Easton and Darley (1999). Other studies into the effectiveness of soil berms include centrifuge model testing (Daly, 1998) and finite element studies by Clough and Denby (1977), Potts et al (1993), Carder and Bennett (1996) and Gourvenec (1998). The general conclusion from these studies is that soil berms are an effective alternative to full width temporary props, although only limited design guidance is currently available.

In this report, the serviceability limit state of temporary works using soil berms has been investigated using three dimensional finite element analysis. Comparison of the magnitude of the wall movements when using soil berms of different dimensions with movements obtained for a reduced dredge right across the cutting has enabled an appropriate design chart to be derived relating the two. Evaluation of the ultimate limit state condition can then take place using the approaches of CIRIA 104, BD42, BS8002 and EC7 in the usual manner. In this way the temporary works engineer can conveniently determine either factors of safety for various berm configurations and soil types, or required berm geometries to achieve pre-selected factors of safety.

2 Review of current design methods

Current design methods employed in assessing the performance of soil berms for the temporary support of retaining walls during construction are summarised in CIRIA 104. The methods either involve fairly complex numerical calculations or are more empirically based.

The methods which are based on numerical calculations are as follows:

- Using a slope stability method taking into account the weight of the berm and the forces from the wall.
- Using a Coulomb wedge analysis for a number of trial failure surfaces emanating from the toe of the wall. The minimum passive thrust on the front of the wall is then converted into a triangular stress distribution acting between the top of the berm and the wall toe.

Two empirical methods which have been successfully used are as follows:

- Converting the weight of the berm to an effective surcharge acting at the final excavation level on the potential passive failure zone (Fleming et al, 1992).
- Considering the berm as an increase in the effective ground level on the passive side of the wall. The design height of the berm is limited to one third of the berm width and the increase in the effective ground level is then taken as one half of this design height (Fleming et al, 1992).

The above empirical methods tend to be over-conservative due to the lack of consideration given to the lateral resistance provided by the soil berm. Furthermore methods based on limit equilibrium calculation using active and passive earth pressures only provide guidance for ultimate limit state design: little or no information is available on performance of the berms under working loads which is equally significant. For this reason, a combination of finite element work and factor of safety calculations have been undertaken to provide a more realistic approach to the design of soil berms.

3 Finite element analysis

Finite element analysis was performed using the SAGE CRISP 97 engine, with pre and post processing using FEMGV software. Soils were treated as elastic, perfectly plastic materials with the yield surface being defined by the Mohr-Coulomb yield criterion. This soil model is generally considered to give a reasonable estimate of embedded wall movements provided that a soil stiffness is adopted which has either been determined from back analysis of similar schemes or is representative of behaviour under small strains.

3.1 Finite element mesh

A three dimensional view of the mesh is represented in Figure 1. Construction geometries were based upon ‘typical’ dimensions such as would commonly be employed by the Highways Agency in a road scheme, i.e. the width of the underpass was taken as 24m and the base of the berm was taken as 8m. These dimensions permitted the use of an 8m wide central haul road by the construction traffic. The detailed geometry of the wall, prop slab and soil berm is illustrated in Figure 2.

The overall dimensions of the finite element mesh represented a soil mass 93.5m by 96m by 75m, sub-divided into 1422 20-noded linear strain brick elements. Consolidating element models were employed for the soil strata (68 degrees of freedom) and non-consolidating element models (60 degrees of freedom) were employed for the structural elements. The x-y plane (Figure 1) consisted of 79 elements, the geometry of which was maintained along the z axis. In the z-direction the three central bays were 5m in length with the two outermost bays being 30m in length.
Vertical side boundaries were on roller supports restraining horizontal movements, the horizontal base being fixed in all directions. The distances between the construction extremities and mesh boundaries were more than five times the height of the retaining wall (SAGE CRISP Technical Reference Guide, 1996) to minimise the risk of end effects.

3.2 Material properties

3.2.1 Soil parameters

Generally embedded walls are founded in cohesive soils, conventional reinforced concrete walls are normally employed as being more cost effective where soil conditions are granular. For this reason, soil parameters were adopted for the study which were typical of stiff to very stiff clays and firm to stiff clays. A summary of these parameters is given in Table 1.

For both soil types, one set of analyses were carried out using effective cohesion, $c'$, in the other the $c'$ was reduced to zero. In this way, analyses were completed which were broadly compatible with both moderately conservative and worst credible soil strength parameters (CIRIA 104). The reduction of $c'$ to zero also enabled an assessment of likely behaviour if the effective cohesion within the soil berm was reduced by softening of the clay.

As shown in Table 1, soil stiffnesses ($E'$) and their rate of increase with depth ($mE'$) were employed which were typical of those which would be determined from back analysis of similar schemes and would be representative of behaviour under small strains (Burland and Kalra, 1986; Carder and Bennett, 1996). Throughout the study, the horizontal permeability ($k_x$) was assumed to be greater than the vertical permeability ($k_y$). All the soil types used had common values for Poisson’s ratio ($\nu$) and bulk density of 0.2 and 19.9 kN/m$^3$ respectively.

3.2.2 Structural components

Linear elastic isotropic elements were used to represent the two structural components, namely the reinforced concrete retaining wall and the reinforced concrete prop slab at carriageway level. Dimensions for the structural elements were those typically employed in highway schemes.

The wall comprised 1.5m diameter bored piles at 1.7m centres with a flexural stiffness of 7.6 $\times 10^6$ kNm$^2$ per pile. This was modelled using a 1.5m thick rectangular section with an equivalent stiffness of 1.6 $\times 10^7$ kN/m$^2$ per metre run of wall. These values were calculated using a concrete stiffness of 2.6 $\times 10^7$ kN/m$^2$ and assuming that the concrete remained uncracked at the small strain levels involved.

Table 1 Soil parameters used in the analysis

<table>
<thead>
<tr>
<th>Soil type</th>
<th>$E'$ (MN/m$^2$)</th>
<th>$mE'$ (MN/m$^2$/m)</th>
<th>$\phi$ ('')</th>
<th>$c'$ (kN/m$^2$)</th>
<th>$k_x$ (m/sec)</th>
<th>$k_y$ (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiff to very stiff clay</td>
<td>01 32 8.4 22 20</td>
<td>5 $\times 10^{10}$</td>
<td>1 $\times 10^{-10}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>02 32 8.4 22 0</td>
<td>5 $\times 10^{10}$</td>
<td>1 $\times 10^{-10}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Firm to stiff clay</td>
<td>03 16 4.2 28 10</td>
<td>1 $\times 10^{5}$</td>
<td>1 $\times 10^{-7}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>04 16 4.2 28 0</td>
<td>1 $\times 10^{5}$</td>
<td>1 $\times 10^{-7}$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The permanent prop slab was 0.65m thick reinforced concrete and modelled as being installed horizontally. The connection between the wall and the slab was represented as a pin joint, allowing the wall to rotate about the prop accommodating the heave beneath the carriageway (Powrie and Li, 1991). A typical stiffness was taken as $3 \times 10^7$ kN/m$^2$ (Watson and Carder, 1994). A Poisson’s ratio $\nu$ of 0.15 and a bulk density of 22.6kN/m$^3$ were adopted throughout for the concrete elements.

3.3 In situ ground conditions

The water table was taken to exist at 1m below ground level. High lateral stresses present in overconsolidated clay deposits are a result of their geological history which has involved removal of overburden after their initial deposition and consolidation. A range of in situ $K$ values (ratio of horizontal to vertical effective stress) was adopted for this study which was typical of that existing in the sedimentary clays such as the London, Oxford, Lias, Weald and Gault Clays as well as the glacial clays of lower plasticity. A $K$-value of 2 was used for the stiff to very stiff clays and this value was reduced to 1 for the firm to stiff clays. Figure 3 shows the variation of in situ ground stresses and pore water pressures with depth.

3.4 Construction sequence

All analyses were conducted with the retaining wall ‘wished in place’, i.e. assuming wall installation had a negligible effect on the in situ stresses within the soil. This assumption is appropriate for design purposes in so far as it errs on the conservative side in taking no account of the lateral stress reduction that normally occurs during wall installation (Symons and Carder, 1992).

Two sets of 3D finite element analyses were carried out. In one case, a construction sequence using berms of varying height was modelled. In the other case, a construction sequence using a level dredge across the cutting (ie. no berm) was investigated. This latter approach is, in places, referred to as an ‘increased effective ground level above formation’. It must be noted that, in both cases, excavation to formation level for permanent prop slab installation is carried out using the same ‘bay’ sequence.

The following construction sequence was adhered to for both berm and effective ground level methods of analysis:

**Stage 1** Either excavation of haul road along the centre of the underpass for berm analysis, or a level dredge to the effective ground level as required (30 days).

**Stage 2** Excavation to formation level at central bay (30 days).

**Stage 3** Installation of prop slab at central bay (1 day).

**Stage 4** Excavation to formation level at far bay (30 days).

**Stage 5** Installation of prop slab at far bay (1 day).

**Stage 6** Excavation to formation level at near bay (30 days).

**Stage 7** Installation of prop slab at near bay (1 day).

**Stage 8** Excavation to formation level of remaining bays and installation of prop slab over remaining bays (30 days).

In all cases, permanent support was offered in the long term by a reinforced concrete slab at formation level. For the purpose of this study of temporary works, long term consolidation modelling of the performance of the finished structure was not considered relevant.

### 4 Predicted wall movements

Retaining wall behaviour was quantified by the consideration of lateral movements away from the retained soil. Nodal displacement on the front face of the retaining wall at the central bay was investigated immediately at the end of the construction period. Plots showing lateral displacement towards the excavation were produced as the height of temporary support, provided by either berms or effective ground level above formation, was varied. The two methods were then correlated by comparing lateral movement at the top of the retaining wall with varying heights of temporary support.

4.1 Using soil berms

Generally deflected shapes of the retaining wall immediately after construction showed lateral movements of the top and toe of the wall varying within the ranges of 13mm to 27mm and 5mm to 8mm respectively according to the geometry and soil type being analysed. Example distributions of wall lateral movement with depth are given in Figure 4a for the stiff to very stiff clay (soil type 01, Table 1), the movement profiles for soil types 02, 03 and 04 are given in Appendix A.

Figure 5a shows a colour contour plot of lateral displacement of the ground towards the excavation after the three central 5m bays have been removed from a 6m high
berm and the permanent prop slab installed at these locations. As would be expected the maximum lateral displacement occurs at the top of the wall in the centre of the completed section.

4.2 Using an increased effective ground level above formation

Results when using an increased effective ground level as temporary support (ie. no berms) are displayed as deflected shape profiles for stiff to very stiff clay (soil type 01) in Figure 4b. Full graphical representations of movement profiles for soil types 02, 03 and 04 are included in Appendix A. Figure 5b displays the ground and wall movement in contour form during a series of level excavations.

4.3 Correlation between using berms and effective ground level

Figure 6a compares the lateral movements at the top of the wall when using soil berms for support with those obtained when an increased effective ground level is used as temporary support. For the same height of berm and effective ground level, larger movements are obtained in the former case. In both support situations, less wall movement occurs when there is a c’ primarily because this reduces the perturbing pressure on the side of the wall whilst extra passive resistance is developed below dredge level in front of the wall.

It is also interesting to note in Figure 6a, that with both moderately conservative (c’=20kN/m²) and worst credible (c’=0) parameters for the stiff to very stiff clay, very little additional wall movement occurs when the berm height exceeds 4m. This height varies with the soil parameters: the results for firm to stiff clays are discussed in Section 6. This finding has significant implications for optimising the dimensions of a soil berm during the design procedure for the temporary works.

From this chart the movements at the top of the wall can be determined for a particular height of berm or a specific effective ground level. An additional chart, Figure 6b, allows the user to ascertain the equivalent height of berm and increased effective ground level which will result in identical movements at the top of the wall. For example, following the lines indicated in Figure 6b, an increase in effective ground level of 2m is found to provide equivalent support to a 2.9m high soil berm. Implications of this function are dealt with in Section 6, where the finite element method is interlinked with factor of safety aspects used in the design process.

The finite element results in Figure 6b can be compared with those evaluated using an empirical method by which the berm height is converted into an equivalent surcharge acting on the excavated surface. This comparison is discussed in Appendix B and as expected the empirical method requires an additional berm height of up to 1m because the gain in lateral resistance is not considered over the berm height.

5 Factors of safety from limit equilibrium analysis

Having established the increase in effective ground level above formation which would give the same temporary support as a soil berm, it can be crudely assumed that the factor of safety against overall failure of the soil and structure will be the same. This factor of safety can be determined for cantilever walls with a level dredge in front of them following the usual design procedures. These calculations are now described for the wall geometry and soil strength parameters adopted in this study.
Figure 5a Lateral movements: 6m berm with central bays removed

Figure 5b Lateral movements: 6m effective ground level above formation with central bays removed
If a cantilever wall is to remain in equilibrium, its lower end must be fixed. Fixed-earth conditions are thus encompassed in factor of safety calculations. For any given excavation in front of the retaining wall, the embedded depth (d) was calculated by simply subtracting the excavated depth from the total wall height, h (16m in this case). Following the CIRIA 104 procedure, up to 20% of this embedded depth is needed to ensure fixed earth support and a safe reduced embedded depth for design purposes, \( d_o \), is therefore found by dividing d by 1.2. The effective design height of the wall, \( h_o \), used for factor of safety calculations is then the sum of the excavated depth and the depth to the point of rotation, \( d_o \).

Two different methods of calculating factors of safety were considered using the simplified pressure distributions considered at limiting equilibrium. The CP2 method is commonly used in practice and requires that a factor of safety is applied to the gross resisting soil force developed in front of the wall. The mobilised strength method applies a factor of safety to the strength properties of the soil. The factors of safety calculated using these two approaches are summarised in Table 2 for the stiff to very stiff clay and employ a \( c' \) of 20kN/m² (soil type 01, Table 1).

In the calculation of factors of safety, a hydrostatic distribution of pore water pressure has been assumed from 1m depth and dredge level on the retained and excavated faces of the wall respectively. This assumption, rather than the option of linear seepage around the wall toe, is considered appropriate for the short term condition as clays are impermeable in nature. It also errs on the conservative side for design purposes as the net perturbing force due to water pressure is greater.

Figure 7 shows the calculated variation in factor of safety with increasing excavation depth using the data from Table 2 for stiff to very stiff clay. From these graphs the factor of safety for any excavation depth for this typical retaining wall geometry can be interpolated.

### 6 Proposed design approach

The proposed approach to the design of soil berms when they are used for the temporary support of embedded retaining walls during their construction is outlined in the flow chart in Figure 8. The main decision stages in the approach are as follows:

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**Figure 6 Look-up charts for stiff to very stiff clay**

**Table 2 Factors of safety for stiff to very stiff clay**

<table>
<thead>
<tr>
<th>Depth of excavation (m)</th>
<th>Reduced embedded depth, ( d ) (m)</th>
<th>Effective design height of wall, ( h_o ) (m)</th>
<th>Mobilised strength method</th>
<th>CP2 method</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>11.25</td>
<td>13.75</td>
<td>3.23</td>
<td>8.02</td>
</tr>
<tr>
<td>3.0</td>
<td>10.83</td>
<td>13.83</td>
<td>2.67</td>
<td>5.88</td>
</tr>
<tr>
<td>3.5</td>
<td>10.42</td>
<td>13.92</td>
<td>2.27</td>
<td>4.49</td>
</tr>
<tr>
<td>4.0</td>
<td>10.00</td>
<td>14.00</td>
<td>1.96</td>
<td>3.53</td>
</tr>
<tr>
<td>4.5</td>
<td>9.58</td>
<td>14.08</td>
<td>1.72</td>
<td>2.82</td>
</tr>
<tr>
<td>5.0</td>
<td>9.17</td>
<td>14.17</td>
<td>1.52</td>
<td>2.89</td>
</tr>
<tr>
<td>5.5</td>
<td>8.75</td>
<td>14.25</td>
<td>1.37</td>
<td>1.87</td>
</tr>
<tr>
<td>6.0</td>
<td>8.33</td>
<td>14.33</td>
<td>1.23</td>
<td>1.53</td>
</tr>
<tr>
<td>6.5</td>
<td>7.92</td>
<td>14.42</td>
<td>1.12</td>
<td>1.26</td>
</tr>
<tr>
<td>7.0</td>
<td>7.50</td>
<td>14.50</td>
<td>1.02</td>
<td>1.04</td>
</tr>
<tr>
<td>7.5</td>
<td>7.08</td>
<td>14.58</td>
<td>0.93</td>
<td>0.86</td>
</tr>
<tr>
<td>8.0</td>
<td>6.67</td>
<td>14.67</td>
<td>0.86</td>
<td>0.70</td>
</tr>
</tbody>
</table>
Select appropriate factor of safety and soil parameters.
- Calculate effective ground level to give required factor of safety.
- Use look-up chart to find equivalent berm height.

These stages are now discussed in turn to illustrate the approach.

6.1 Selecting appropriate factors of safety and soil parameters
In order to achieve an appropriate temporary works design, the designer must consider all possible uncertainties and apply factors of safety accordingly. Designs are generally based on either effective or total stress parameters, although in some cases a mixed approach may be adopted. Designs based on total stress parameters need to be used with extreme caution because of difficulties both in selecting appropriate undrained soil strength values and in accounting for effects such as softening. For this reason the effective stress approach has been preferred in this report.

![Flow chart of proposed design approach](image)

**Figure 7** Variation of factor of safety with effective ground level above formation (stiff to very stiff clay)

**Figure 8** Flow chart of proposed design approach
Following the approach of CIRIA 104, BD 42 (DMRB 2.1) requires a sensitivity analysis selecting both moderately conservative and worst credible soil parameters, loads and geometry. Table 3 indicates the design factors of safety considered within the scope of this report. The two commonly used methods of analysis were adopted, these being the strength factor and the CP2 methods.

It should be noted that when using the strength factor method and moderately conservative parameters with a factor of safety of 1.2, identical results are obtained as those when employing BS8002 (British Standards Institution, 1994) provided that the same conditions of minimum surcharge and unexpected excavation are applied. Moderately conservative soil strength parameters are considered near identical to the representative values required by BS8002.

From Table 3, corresponding factors were calculated for the clay parameters used in this study. For stiff to very stiff clay (φ’=22°), factors of safety of 1.20 and 1.26 were calculated using the strength factor and CP2 methods. With firm to stiff clay (φ’=28°), factors of safety of 1.20 and 1.44 were determined respectively. For worst credible parameters, factors of safety will be unity in both cases.

6.2 Calculating effective ground level to give required factor of safety

After deciding upon the requisite factors of safety, the next stage establishes the effective ground level above formation which will ensure short term stability.

Figures 7 and 9 relate to the two different stiffness clays and shows how factor of safety varies with dredge level in front of the wall. Provision has been made in these factor of safety calculations for the additional depth of wall needed to assure fixed earth support for a cantilever structure (Section 5). Horizontal lines have been added to Figure 9 indicating each of the required factors of safety. Where these lines meet their respective curves, further vertical lines indicate the effective ground level above formation at which stability is achieved. These values are given in Table 4.

6.3 Using look-up charts to find equivalent berm height

The effective ground levels from Table 4 are then used to find the required height of berm. Figures 6b and 10b show the relationships between changing effective ground level and varying berm height for both moderately conservative and worst credible soil parameters for the different stiffness clays. Vertical lines corresponding to calculated effective ground levels above formation have been included and, where these intersect their associated curves, horizontal lines indicate the required heights of berm to provide adequacy of temporary support during bulk excavation in front of the wall prior to the permanent prop being installed. These data are shown in Table 5.

In using Table 5 for clays whose parameters may not correspond exactly to the classification used in this report, interpolation may be used providing sufficient care is exercised. Apart from differences in effective soil strength parameters, the parameters of soil stiffness and in situ K-value of the clay are likely to have particular influence on the relevance of the design charts in Figures 6 and 10.

The results in Table 5 also demonstrate that designs using moderately conservative parameters (ie. a positive c’ and the currently recommended factors of safety require smaller berm heights than those using worst credible parameters (c’=0). It can be argued that moderately conservative parameters are appropriate in the temporary works situation provided that the duration of construction is not protracted. Use of worst credible parameters may be

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**Table 3 Recommended factors of safety for temporary works in stiff clays (After CIRIA 104)**

<table>
<thead>
<tr>
<th>Method</th>
<th>Design approach A: Recommended range for moderately conservative parameters (c’, φ’)</th>
<th>Design approach B: Recommended minimum values for worst credible parameters (c’=0, φ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength factor method, F_s</td>
<td>Effective stress 1.1 to 1.2 (usually 1.2 except for φ’&gt;30° when lower value may be used)</td>
<td>1.0</td>
</tr>
<tr>
<td>CP2 method, F_p</td>
<td>Effective stress</td>
<td></td>
</tr>
<tr>
<td>φ’&gt;30°</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>φ’=20° to 30°</td>
<td>1.2 to 1.5</td>
<td></td>
</tr>
<tr>
<td>φ’&lt;20°</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>

---
Table 4 Effective ground levels above formation for corresponding factor of safety

<table>
<thead>
<tr>
<th>Method</th>
<th>Stiff to very stiff clay</th>
<th>Firm to stiff clay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Factor of safety</td>
<td>Effective ground level above formation (m)</td>
</tr>
<tr>
<td>Strength factor</td>
<td>Moderately conservative</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td>Worst credible</td>
<td>1.00</td>
</tr>
<tr>
<td>CP2</td>
<td>Moderately conservative</td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td>Worst credible</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 5 Relation between effective ground level and height of berm

<table>
<thead>
<tr>
<th>Method</th>
<th>Stiff to very stiff clay</th>
<th>Firm to stiff clay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Effective ground level above formation (m)</td>
<td>Equivalent berm height (m)</td>
</tr>
<tr>
<td>Strength factor</td>
<td>Moderately conservative</td>
<td>1.88</td>
</tr>
<tr>
<td></td>
<td>Worst credible</td>
<td>3.62</td>
</tr>
<tr>
<td>CP2</td>
<td>Moderately conservative</td>
<td>1.49</td>
</tr>
<tr>
<td></td>
<td>Worst credible</td>
<td>3.62</td>
</tr>
</tbody>
</table>

Figure 10 Look-up charts for firm to stiff clay
considered in the latter case or if, for site specific reasons, there is considered to be a risk of softening of the soil forming the berm.

In soil berm design, reliance is placed on an accurate knowledge of the soil strength and stiffness properties. In many cases there will be variation in these over the site and for this reason it is good practice during construction to operate under the Observational Method. Detailed guidance on the use of the Observational Method is given in CIRIA Report 185 (Nicholson et al, 1998).

7 Conclusions

The facility to incorporate factors of safety into berm design for temporary works has not been readily available to the practising engineer, who has traditionally relied more on empirical design methods. In this study, lateral movements predicted from 3D finite element analysis when excavating in front of the wall using soil berms for support have been compared with those for a level dredge in front of the wall. In both cases, construction has been modelled as occurring in discrete bays prior to the installation of a permanent prop slab.

Where the magnitudes of lateral movement of the top of the wall are equivalent, the performance using a berm of a particular size can then be related to that if the effective ground level had been higher than prop slab formation level. The factor of safety in the latter case can be established from standard design approaches for a cantilever structure and, when using an equivalent berm, the factor of safety may be assumed to be the same.

In this way, the designer is provided with a correlation between berm design and the factor of safety. The proposed design approach is described and illustrates the use of simple ‘look-up’ charts which enable the designer to determine suitable soil berm sizes to give the required factor of safety.

The improved design procedure is expected to lead to an increased use of soil berms for the temporary support of embedded retaining walls and further economy in their construction costs.

8 Acknowledgements

The work in this report forms part of the research programme of the Civil Engineering Resource Centre. The work was funded by Quality Services (Civil Engineering) of the Highways Agency. The Project Manager for the Highways Agency was Dr D I Bush.

The authors wish to thank the following for their invaluable assistance: Mr D Styles and Dr A Al-Rawe of FEMSYS Engineering Software, Dr D J Richards of Southampton University and Dr A M Britto of Cambridge University.

9 References


Design Manual for Roads and Bridges. BD 42 Design of embedded retaining walls and bridge abutments (unpropped or propped at the top). (DMRB 2.1)


Appendix B: Comparison with an empirical equivalent surcharge method

The finite element results from Figures 6b and 10b are reproduced in Figure 14. Also shown in this figure is a similar plot derived from an empirical equivalent surcharge method.

In this method, the self-weight of the berm was calculated from its geometry, assuming a bulk density ($\gamma_{bulk}$) of 19.9kN/m$^3$. This weight was then distributed uniformly over the 12m width between the wall and the centre of the cutting. In producing the plots for Figure 14, the distributed weight was then converted into an effective height of soil above formation level by dividing by the $\gamma_{bulk}$.

For both clay types, there was little difference between the empirical method and finite element results at berm heights of less than 1m. A significant difference was found for berm heights of between 1m and 5m. In both cases, the empirical method was more conservative and required additional berm heights of up to 0.5m for the stiff to very stiff clay and 1m for the firm to stiff clay respectively.

These results were not surprising as the empirical method only considered equivalence of surcharge loading and did not take into account the benefits of the extra lateral resistance offered by a berm. The differences in behaviour for the various soil types indicated by the more rigorous finite element approach is also not reflected by the empirical method which is independent of soil strength and stiffness parameters.

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**Figure 11** Maximum lateral wall movement at central bay immediately after construction (stiff to very stiff clay)

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Appendix A: Graphs of wall movement for different soil types

Figure 11 Development of lateral wall movement at central bay immediately after construction (stiff to very stiff clay)
Figure 12 Development of lateral wall movement at central bay immediately after construction (firm to stiff clay)
Figure 13 Development of lateral wall movement at central bay immediately after construction (firm to stiff clay)

---

**Figure 12** Development of lateral wall movement at central bay immediately after construction (firm to stiff clay)
Figure 12 Maximum lateral wall movement at central bay immediately after construction (firm to stiff clay)

Figure 13 Maximum lateral wall movement at central bay immediately after construction (firm to stiff clay)
Figure 14 Comparison between finite element work and an empirical equivalent surcharge method
Abstract

Three dimensional finite element modelling has been undertaken with the aim of improving current design procedures for the use of soil berms as temporary support during the construction of embedded retaining walls permanently propped at carriageway level. The analyses were based upon ‘typical’ berm and wall geometries and soil parameters that would be frequently encountered in highway construction schemes.

Results from the finite element work, together with factor of safety calculations, have been combined creating sets of ‘user-friendly’ design aids in the form of charts, aimed at both rationalising and producing economy in the design of soil berms for the temporary support of retaining walls during their construction.

Related publications

TRL 381  The long term performance of embedded retaining walls by D R Carder and P Darley.  
1998 (price £35, code H)

TRL 320  A comparison of embedded and conventional retaining wall design using Eurocode 7 and existing UK  
design methods by D R Carder.  1998 (price £25, code E)

TRL 213  The effectiveness of berms and raked props as temporary support to retaining walls by D R Carder and  
S N Bennett.  1996 (price £25, code E)

TRL 128  Doubly-propped embedded retaining walls in clay by D J Richards and W Powrie.  
1995 (price £35, code H)

RR 359  Design of embedded retaining walls in stiff clays by I F Symons.  1993 (price £35, code H)

RR 116  A parametric study of the stability of embedded cantilever retaining walls by I F Symons and H Kotera.  
1987 (price £20, code B)

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