

Reinforced Soil Wall Design: A Comparison Between British Code BE 3/78 and Draft Australian Standard DR 91273

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ABSTRACT: The concept of reinforced soil is a relatively recent development in the fields of geotechnical and structural engineering. A draft Australian Standard has been developed for reinforced soils based on a limit state design approach. A British Code, based on working stress design, already exists. The design of a typical 'Freyssisol' wall using Paraweb reinforcement, is presented, based on the British Code. A comparative design, based on the Draft Australian Standard, is currently in progress.

1. INTRODUCTION

Following developments in the reinforced soil industry, the need for an Australian Standard dealing with this subject was recognised some time ago. Currently in draft form (DR91273), the Australian Standard covers all types of soil reinforcement including applications for walls, abutments, slopes and foundations. The British Standard BE 3/78 is currently being used in Australia for design of some types of reinforced soil retaining walls. This paper presents a typical design of a 'Freyssisol' reinforced soil retaining wall based on the British Standard. Work is currently in progress to prepare a design based on the Draft Australian Standard DR 91273 so that the two methods can be compared.

2. SOIL REINFORCED WALLS

DR 91273 defines reinforced soil as "the use of placed or in-situ soil or other material in which tensile reinforcement acts through interface friction or other means to improve stability" (Standards Australia, 1991). Various reinforcement systems can be used, including:

- Metallic strip or grid
- Polymeric strip, sheet, grid or mesh
- Anchors or multi-anchors
- Soil nailing.

The 'Freyssisol' wall uses Paraweb reinforcement and concrete facing panels. Paraweb is a polyester filament fibre encased in a polyethylene sheath.

The strength of a reinforced soil mass is essentially a function of "the stress distribution and interaction between the reinforcement and the soil" (Standards Australia, 1991). When a load is placed on the reinforced soil mass, a tensile restraining force is induced within the reinforcement. The stability of the reinforced soil structure is based on the lateral strain, the reinforcement stiffness and the soil (backfill) type.

3. TYPICAL DESIGN BASED ON BRITISH CODE

3.1 Input Parameters

The design presented below is for a typical reinforced soil wall bridge abutment at a highway

overpass. Refer Figure 1 for a typical section. The nominal height of the wall is 10m and the length 88m. In total there are approximately 1100 square metres of facing in the two abutments.

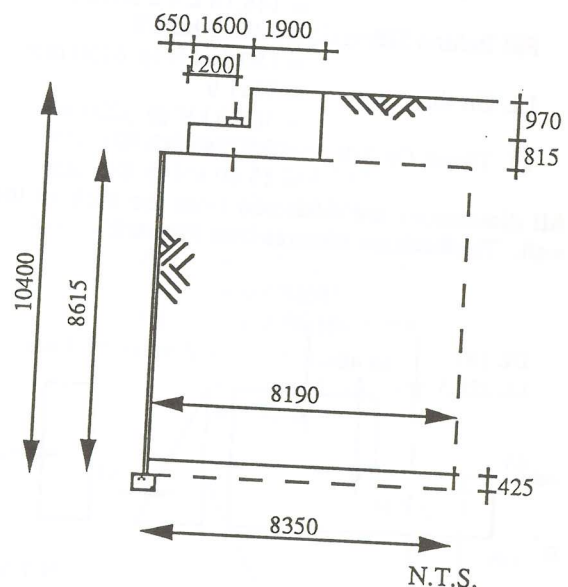


Figure 1 : Typical Section

All relevant dimensions are shown in Figure 1. The design loads are presented below:

Platform Load HLP 320 = 31 kN/m²

Vertical Loads:

Dead Load (S.W.) = 175 kN/m

Dead Load (Slab) = 16 kN/m

Live Load = 225 kN/m

Wind Load = 1.5 kN/m

Horizontal Loads:

Temperature = 3 kN/m

C & S = 2 kN/m

Live Load = 60 kN/m

Soil Properties: the angle of friction of the backfill $\phi = 35$ degrees, the unit weight is taken to be 20 kN/m³ and the active earth pressure coefficient $k_a = 0.271$. These are assumed to be consistent throughout the backfill.

The clear wall to wall opening is 12m. The overall length of the bridge deck is 20 290mm (i.e. to

rear of sill) and the sill is 10 500mm long. The transverse load spread is fully developed. The maximum and minimum transient pressures under the sill are 250 kPa and 150 kPa respectively.

3.2 Load Model

An equivalent sill beam is calculated to take into account the eccentric loading. This is done by first summing all the vertical, horizontal and moment loads:

Sill Upstand	= 24x1.9x0.970
	= 44.23 kN @ 3200 mm
Sill Base	= 24x3.5x0.815
	= 68.46 kN @ 2400 mm
Earth Pressure	= 0.271x20x1.79 ² /2
	= -8.63 kN @ 595 mm
Fill Replacing Sill	= 20x4.15x1.79
	= 148.16 kN @ 2075 mm
Fill Behind Sill	= 20x4.20x1.79
	= 150.36 kN @ 6250 mm
LL On Sill	= 31x1.9
	= 58.90 kN @ 3200 mm
LL Thrust On Sill	= 0.271x31x1.79
	= 15.00 kN @ 893 mm

All dimensions are measured from the back of the wall. The loads are illustrated on Figure 2.

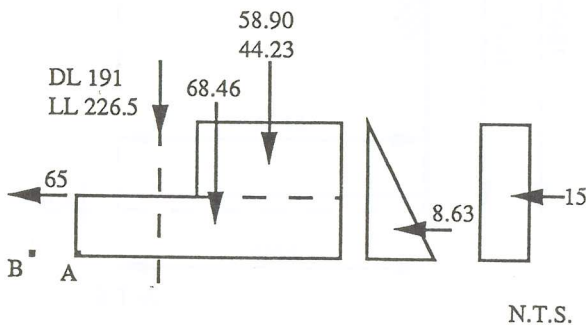


Figure 2 : Loads acting on the sill beam

The sum of vertical forces on the sill is given below:

$$\begin{aligned}\Sigma V &= 44.23+68.46+58.9+191+226.5 \\ &= 589.09 \text{ kN}\end{aligned}$$

The sum of horizontal forces is:

$$\begin{aligned}\Sigma H &= 65+8.63+15.04 \\ &= 88.67 \text{ kN}\end{aligned}$$

The sum of vertical moments about B (where B is the top of the back of the wall) is:

$$\begin{aligned}\Sigma M_{VB} &= 44.23 \times 3.2 + 68.46 \times 2.4 + 58.9 \times 3.2 + \\ &191 \times 1.85 + 226.5 \times 1.85 \\ &= 1266.7 \text{ kNm}\end{aligned}$$

The sum of horizontal moments about A (where A is the front of the base of the sill) is:

$$\begin{aligned}\Sigma M_{HA} &= 8.63 \times 0.595 + 15.04 \times 0.893 + 65 \times 0.815 \\ &= -71.54 \text{ kNm}\end{aligned}$$

The sum of horizontal moments about the footing is:

$$\begin{aligned}\Sigma M_{HF} &= 8.63 \times 9.21 + 15.04 \times 9.508 + 65 \times 9.43 \\ &= 835 \text{ kNm}\end{aligned}$$

For bearing calculations, it is necessary to find the eccentricity about the front of the sill ('A') rather than the rear of the wall ('B').

$$\begin{aligned}\Sigma M_{VA} &= (1266.7/589.09 - 0.650) \cdot 589.09 \\ &= 883.8 \text{ kNm}\end{aligned}$$

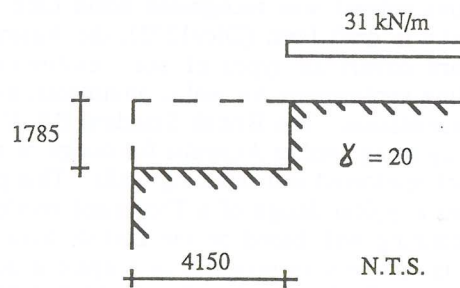
Note: $\bar{x}_A = 1500 \text{ mm}$

Thus, the nett moment about 'A' and the resulting eccentricity are:

$$\begin{aligned}M(\text{nett}) &= 883.8 - 71.54 \\ &= 812.26 \text{ kNm} \\ \bar{x} &= 812.26/589.09 \\ &= 1379 \text{ mm from 'A'} \\ e &= 3500/2 - 1379 \\ &= 371 \text{ mm}\end{aligned}$$

The vertical stress at the base of the sill, based on the effective width, is:

$$\begin{aligned}\Omega_V &= 589.09/(3500 - 2 \times 371) \\ &= 214 \text{ kN/m}^2\end{aligned}$$



Extension zone: all loads in here = ΣV

Figure 3 : Sill beam model

For load modelling considerations, we do not want the Live Load and the Fill Behind Sill as partial Uniformly Distributed Loads. We avoid this by continuing them all the way to the wall and then subtracting the extra load off the total sill loading. The load model is developed below (refer to Figure 3):

$$\begin{aligned}\Sigma V' &= 589.09 - 31 \times 4.150 - 20 \times 4.150 \times 1.785 \\ &= 312.29 \text{ kN}\end{aligned}$$

$$\begin{aligned}\Sigma M'_{\text{nett}} &= 1195.2 - 31 \times 4.15^2/2 - 20 \times 4.15^2/2 \times 1.785 \\ &= 620.8 \text{ kNm}\end{aligned}$$

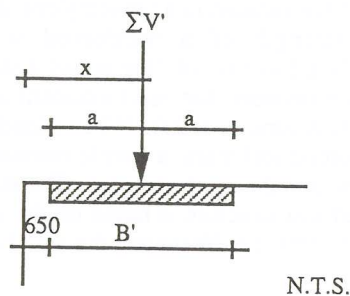


Figure 4 : Effective footing width

Calculate the effective width of the footing (refer Figure 4):

$$\begin{aligned} \bar{x} &= 620.8/312.29 \\ &= 1988 \text{ mm} \\ &= B'/2 + 650 \\ \text{Thus, } B' &= 2\bar{x} - 650 \times 2 \\ &= 2(x - 650) \\ B' &= 2(1988 - 650) \\ &= 2676 \text{ mm} \end{aligned}$$

So, the model becomes as shown in Figure 5.

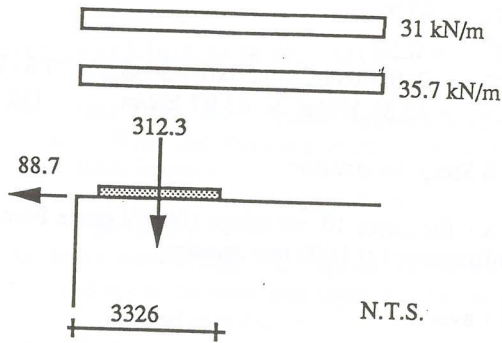


Figure 5 : Load model

3.3 Internal Stability - Layer 10

Considering the 10th layer of reinforcement, which is the second layer from the top of the wall, we will calculate the total applied force, assess the grade of reinforcement required and check the effect of friction.

The dimensions and the loads are shown in Figures 6 and 7 respectively.

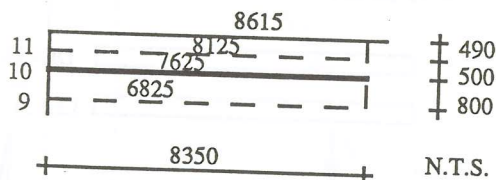


Figure 6 : Layer 10

3.3.1 Loads and earth pressures

The applied loads acting on the block are given below:

$$\begin{aligned} \text{HLP } 320 &= 31 \times 8.35 \\ &= 258.9 \text{ kN} \\ &= (128.7 + 130.2) \end{aligned}$$

$$\text{H}'_{\text{bridge}} = 88.7 \text{ kN}$$

$$\text{V}'_{\text{bridge}} = 312.3 \text{ kN}$$

The internal loads acting on the block are given below:

$$\begin{aligned} \text{Fill in Block} &= 20 \times 0.990 \times 8.350 \\ &= 165.3 \text{ kN} \end{aligned}$$

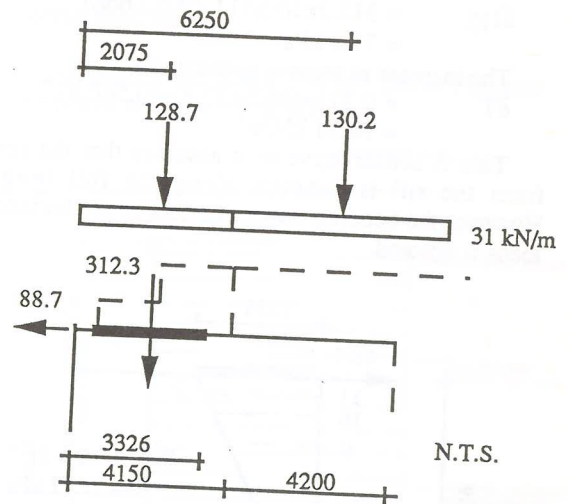


Figure 7 : Load diagram

Vertical Surcharge from Fill

$$\begin{aligned} &= 35.7 \times 8.350 \\ &= 298.10 \text{ kN} \end{aligned}$$

Earth Pressure from Fill (refer Figure 8)

$$\begin{aligned} P_1 &= 0.271 \times 20 \times 1.785 \\ &= 9.67 \text{ kN} \end{aligned}$$

$$P_2 = 0.271 \times 20 \times 2.775$$

Earth Pressure from Live Load

$$\begin{aligned} &= 0.271 \times 31 \times 0.99 \\ &= 8.32 \text{ kN} \end{aligned}$$

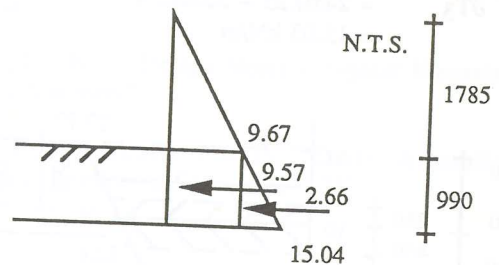


Figure 8 : Earth Pressure from fill

3.3.2 Tension from vertical loads

In calculating the tension force in the 10th strap, BE 3/78 neglects the bending moment effect of the horizontal loads. From the above loads, the total vertical force and stress are:

$$\begin{aligned} \Sigma V &= 128.7 + 130.2 + 165.3 + 298.1 \\ &= 722.3 \text{ kN} \end{aligned}$$

$$\begin{aligned} \Omega_{11} &= 722.3/8.35 \\ &= 86.5 \text{ kPa} \end{aligned}$$

When calculating the stress at layer 10 from the sill, a 1:2 (H:V) load spread is used. The stress thus becomes:

$$\Omega_{12} = 312.3 \times 10.5 / (11.490 \times 3.666) = 77.8 \text{ kPa}$$

The increase in tension is calculated thus:

$$\partial T = 0.271 \times (86.5 + 77.8) \times (0.5 + 0.8) / 2 = 28.94 \text{ kN/m}$$

This is conservative as it assumes that the stress from the sill is constant along the full length. However the bending moment effect of the horizontal loads is ignored.

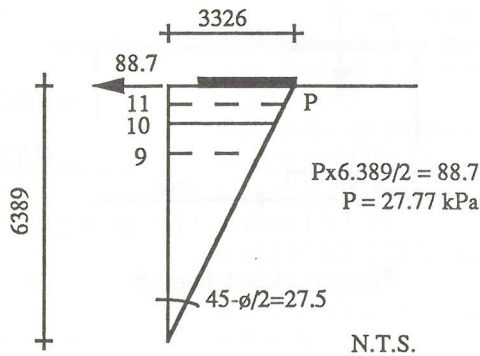


Figure 9 : Horizontal bridge load spread

3.3.3 Tension from horizontal loads

According to BE 3/78, the horizontal loading from the bridge is spread downwards at an angle equal to $(45 - \phi/2)$. Refer to Figures 9 and 10.

$$\partial T_3 = 24 \times 0.25 + 22.6 \times 0.4 = 15.03 \text{ kN/m}$$

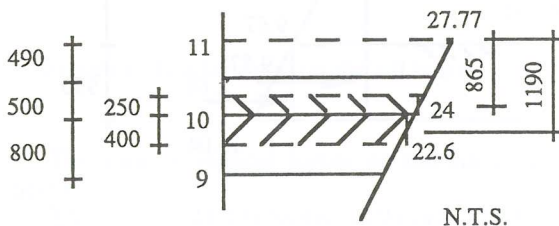


Figure 10 : Detail of horizontal load spread

3.3.4 Total tension

Thus the total applied force in layer 10 is:

$$T_{app} = 28.94 + 15.03 = 43.97 \text{ kN/m}$$

With reference to product tables (Austress Freyssinet, 1993), we trial the 100kN grade Paraweb at 1000 mm spacing. (i.e. try 100/1000).

$$T_r = (100/4) \times 2 \times 1000 / 1000 = 50 \text{ kN/m} > 43.97 \text{ kN/m} \text{ ...OK}$$

3.3.5 Friction check

For BE3/78, the maximum tension locus is taken as being at the back of the facing panels. The friction calculation includes all pressures from uniform surcharges irrespective of whether they coincide or not. The factor of safety against friction is taken as 2.0 for BE3/78.

$$\begin{aligned} L_o &= 0 \\ L_a &= 8350 \text{ mm} \\ f^* &= 0.50 \\ T_f &= 2 \times 0.90 \times (1/2) \times 0.50 \times (8.350 \times 86.5 + 77.8 \times 3.6) \\ &= 45.34 \text{ kN/m} > 43.97 \text{ kN/m} \text{ ...OK} \end{aligned}$$

3.3.6 Strap designation

So, for Layer 10, we adopt 100 kN grade Paraweb reinforcement at 1000 mm spacing.

3.4 Layer 1

3.4.1 Loads and earth pressures

Refer to Figure 11 for all relevant dimensions and load details. Loads are calculated below.

$$\begin{aligned} \text{Fill in block above layer 1} &= 20 \times 8.190 \times 8.350 \\ &= 1367.73 \text{ kN} \\ DL &= 35.7 \times 8.35 \\ &= 298.7 \text{ kN} \\ LL &= 31 \times 8.35 \\ &= 258.9 \text{ kN} \end{aligned}$$

Earth pressure:

$$\begin{aligned} P_1 &= (54.06 - 9.67) \times 8.190 / 2 \\ &= 181.78 \text{ kN} \\ P_2 &= 9.67 \times 8.190 \\ &= 79.20 \text{ kN} \end{aligned}$$

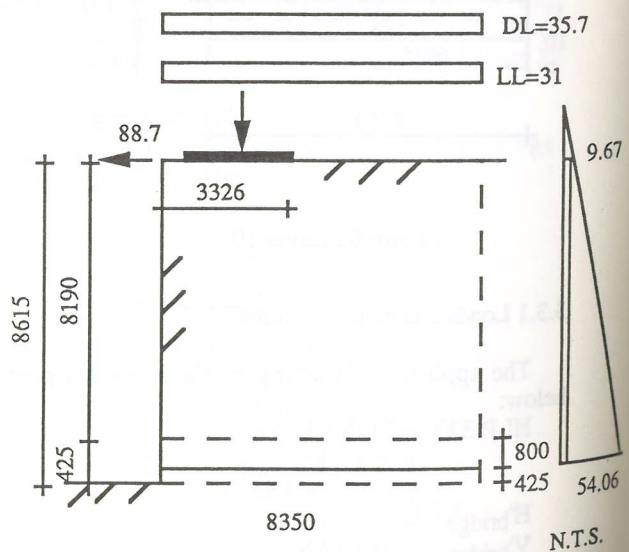


Figure 11 : Layer 1 details

Live load earth pressure:

$$\begin{aligned} LL &= 0.271 \times 31 \times 8.190 \\ &= 68.8 \text{ kN} \end{aligned}$$

3.4.2 Tension

When calculating the stress from the sill beam, the load is spread downwards at 1:2 (H:V). Refer Figure 12. A full sideways spread is achieved.

$$\begin{aligned} L_2 &= 10500 + 2 \times 4095 \\ &= 18690 \text{ mm} \\ \Omega_{12} &= 312.3 \times 10.5 / (18.69 \times 7.421) \\ &= 23.64 \text{ kPa} \end{aligned}$$

The stress from the vertical applied loads is calculated. Note the bending moment effect of horizontal loads is ignored.

$$\begin{aligned} \Omega_{11} &= (1367.73 + 298.7 + 258.9) / 8.35 \\ &= 230.6 \text{ kPa} \end{aligned}$$

The horizontal bridge load spread is shown in Figure 9 and it can be seen that layer 1 is below the influence of this load distribution.

The total applied tension force in layer 1:

$$\begin{aligned} T_{app} &= 0.271 \times (230.6 + 23.64) \times (0.4 + 0.425) \\ &= 56.84 \text{ kN/m} \\ &= 22.74 \text{ kN/strap @ 800 spacing} \end{aligned}$$

With reference to product tables (Austress Freyssinet, 1993), we trial 100kN grade straps at a spacing of 800 mm (i.e. try 100/800)

$$\begin{aligned} T_r &= (100/4) \times 2 \times 1000 / 800 \\ &= 62.5 \text{ kN/m} > 56.84 \text{ kN/m} \quad \dots \text{OK} \end{aligned}$$

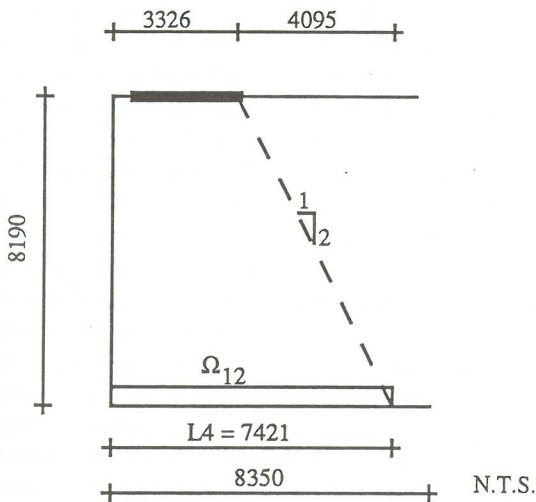


Figure 12 : Sill beam load spread

3.4.3 Friction check

The calculation is similar to the calculation for layer 10.

$$\begin{aligned} T_f &= 2 \times 90 \times 50 \times (1/2) \times (23.64 \times 7.421 + 230.6 \times 8.35) \\ &= 94.5 \text{ kN/strap} \\ &= 118.2 \text{ kN/m} > 56.84 \text{ kN/m} \quad \dots \text{OK} \end{aligned}$$

3.4.4 Strap designation

So, for layer 1 we adopt 100 kN grade Paraweb reinforcement at a spacing of 800 mm.

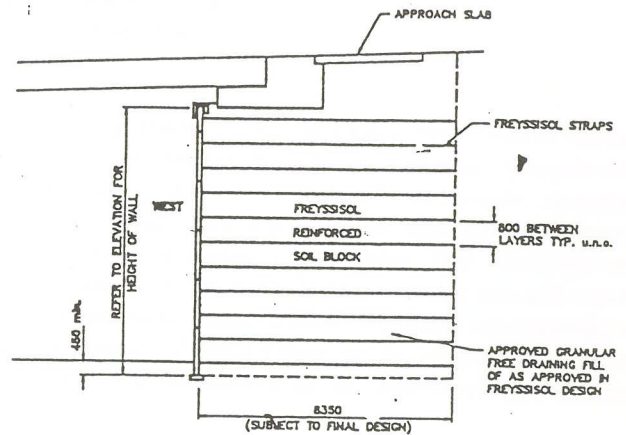


Figure 13 : Preliminary design section

3.5 Conclusion

The design of the reinforcement for a typical reinforced soil bridge abutment according to the British code BE3/78 has been performed. The preliminary design is illustrated in Figure 13.

REFERENCES

- Austress Freyssinet (1993), "Freyssisol Design Manual"
- Drew, I (1993), "Design Notes - Typical Freyssisol Bridge Abutment"
- Standards Australia (1991), "Draft Australian Standard: Reinforced Soils - DR 91273"