WORK INSTRUCTIONS FOR ENGINEERS

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OP-024. DESIGN OF REINFORCED SOIL WALL

24.0 DESIGN OF REINFORCED SOIL WALL

24.1 INTRODUCTION

The design of reinforced soil wall (RS Wall) generally takes into consideration the following:

1) Design variables such as reinforcement length and spacing.
2) External Loads imposed on top of the retained ground by the RS Wall.
3) Check for different failure modes (external stability).
4) Check for internal failure modes (internal stability).
5) Check settlement.

The design of RS Wall involves the following design variables (see Figure 1 for illustration):

1) Reinforcement Length and lateral/vertical spacing
2) Reinforcement Tensile Strength
3) Backfill Shear Strength parameters.
4) Anchor Block Size.
5) Embedment depth of the Reinforced Soil Wall.

24.2 DESIGN VARIABLES

24.2.1 Structure Sizing

- For economical reasons, the minimum retaining height for RS Wall is four metres.
- If less than four metres, use conventional RC wall or rubble wall.
- If wall height is more than 10 metres, recommend using multi-tiered RS Wall.
- Maximum RS Wall height for practical and economical reasons is limited to 20 metres. If RS Wall is too high, cost is prohibitive and require expensive foundation treatment – in this case – try raising the wall founding platform. (43 metre high RS Wall has been built but failed due to corrosion).

24.2.2 Reinforcement Length

1) The minimum reinforcement length is 0.7*H for normal retaining structures (Figure 2).
   where H is the maximum height of the wall or higher than the wall if there is sloping backfill (see figure 19, BS8006:1995).

2) For Abutments (bridges), the minimum length is (whichever is longer):
   - $L \geq 0.6*H + 2$
   - $L \geq 7.0$ metres
3) If the reinforcement length is to be stepped profile, the maximum difference between the steps shall be less than 0.15*H.

24.2.3 Reinforcement Spacing

The vertical and lateral spacing is generally 0.75 metres as most common RS Wall manufacturers use 1.5m X 1.5m face panel with two anchor points per panel per plane.

24.2.4 Reinforcement Type

Reinforcement is categorized into two types:

(i) Extensible reinforcement	Reinforcement that sustains design loads at strains greater than 1% Example: geosynthetics
(ii) Inextensible reinforcement	Reinforcement that sustains design loads at strains less than or equal to 1%. Example: Metallic reinforcements.

24.2.5 Reinforcement Tensile Strength

The reinforcement tensile strength is based on the allowable tensile stress of the reinforcement multiplied by the effective cross-sectional area. Take into consideration of corrosion if metallic reinforcement is used - use 0.015 mm/side/year [BS 8002: 1994 (cl.4.4.4.4.3)].

24.2.6 Backfill Shear Strength Parameters

Backfill used is generally well compacted cohesionless fill (clean river sand or quarry dust). No sea sand shall be used for corrosion reasons. Other deleterious materials such as shale and chalk should not be used as backfill.

Cohesive fill can only be used for structures where failure would result in minimal damage and serviceability. For bridge structures and RS Walls near dwellings (public life at risk), Cohesive Fill shall NOT be used.

24.2.7 Anchor Block

Anchor block is a passive restraining structure placed at the end of the embedded reinforcement. Generally most embedded blocks used are concrete. More types can be found in Figure 32, BS8006:1995.

24.2.8 Embedded Depth

The minimum embedment depth depends on whether there is a slope at the toe of the reinforced soil wall (Table 20, BS8006:1995).

For flat ground: H/20 for walls

H/10 for Abutments

For slopes:

	Minimum Embedment, D_m	Minimum Embedment, D_m/q_r (m^3/kN)
$\beta = 18°$	H/10	2.7×10^{-3}
$\beta = 27°$	H/7	4.0×10^{-3}
$\beta = 34°$	H/5	5.9×10^{-3}

Minimum embedment depth, regardless of slopes or flat ground, is 0.45m unless governed by the above.

24.3 EXTERNAL LOADS

24.3.1 Surcharge

Minimum surcharge of 10kPa should be used at the Retained Side if there is no structure or dead loads placed on top of the reinforced soil wall,

For structures or slopes on top of the RS Wall, surcharge shall be based on the expected dead load and influence of the slope using RANKINE block.

For live load, the minimum value used is 10 kPa unless specified otherwise (which may be 20 kPa for truck loading).

24.3.2 Strip Loading

Strip loading shall be considered if there is concentrated load parallel along the wall like another brick wall or reinforced soil wall on top.

24.3.3 Horizontal Shear

Horizontal shear is considered if there are forces which are to be transmitted laterally at the top of the reinforced soil wall. Not commonly encountered except in complex wall geometries.

24.4 EXTERNAL STABILITY

External Stability check consists of (Figure 3) :

1) Bearing Capacity Failure
2) Sliding Failure
3) Overturning
4) Slip Failure

24.4.1 Bearing Capacity Failure

Bearing capacity check can be carried out using Meyerhof's (conservative) or Vesic's method using founding subsoil's long term parameters.

If founding subsoil has inadequate bearing capacity, the following are commonly used to increase the bearing capacity (in ascending order to cost magnitude):

1) Subsoil replacement up to 2m depth using non-sea sourced sand and well compacted.
2) Pile foundation using RC Piles at close spacing (commonly 150mm X 150mm RC at 1.0m spacing or spun piles for sensitive structures on slopes like petrol stations).

24.4.2 Sliding Failure

Sliding check carried out by checking either:

- Sliding between RS Wall backfill soil and foundation soil (no reinforcement at the interface)
- Sliding between RS Wall reinforcement and foundation soil.

Length of sliding plane is taken as the length of the lowest reinforcement layer for sliding check consideration.

24.4.3 Overturning

Check overturning about the toe of the RS Wall. Forces causing overturning are the soil lateral pressure, water pressure, surcharge, water pressure in tension crack and external loadings (strip loading, horizontal shear loads).

24.4.4 Slip Failure

1) Global stability is carried out using slope stability software to analyse the overall factor of safety of the RS Wall, especially RS Wall on slopes.
2) Minimum required FOS:

short term	1.2
long term	1.4

24.4.5 Excavation near RS Wall Toe

If any excavation is near a partially completed or completed RS Wall, analysis shall be carried out to check whether the excavation at the toe will cause RS Wall to bulge, slide forward or possible collapse. Use short term subsoil parameters obtained from SI information.

1) Short term stability analysis for slip failure.
2) Bearing capacity check.
3) Sliding check.

24.5 INTERNAL STABILITY

Internal Stability check is by two methods (Figure 5):

1) Coherent Gravity Method
2) Tie Wedge Back Method

Coherent gravity method generally gives shorter reinforcement as the failure plane is based on the wall height while Tie Wedge Back method failure plane is based on the backfill properties.

24.5.1 Coherent Gravity Method

Coherent gravity should only be used for inextensible reinforcements and for simple wall geometry. Where complex wall geometry, curved RS walls or multi-tiered wall is used, comparison shall also be made using Tie Wedge Back Method. Use the most conservative reinforcement design.

24.5.2 Tie Back Wedge Method

Tie wedge back method is used for extensible reinforcements and for complex wall geometries where the failure surface is not planar. Examples include at RS Wall corners and curved geometries.

24.6 SETTLEMENT

Settlement of the RS Wall should be assessed to check the estimated maximum differential settlement of the structure. Excessive settlement may cause distress and impairment of the RS Wall.

The critical check should be the long term settlement, especially if the RS Wall is founded on clayey subsoil which may undergo consolidation settlement.

For RS Wall which varies with height along an alignment or significantly varying clayey subsoil, check differential settlement. For RS Wall with RC panels and metallic reinforcements, the maximum differential settlement is limited to 1% or $\Delta/L = 1/100$.

24.7 SUBSURFACE INVESTIGATION

24.7.1 During Design

During the design stage the following SI are required for foundation and stability analysis:

1) Subsoil strength (SPT N', Mackintosh Probes, MP). More MPs can be carried out to supplement the few boreholes and typically MPs are carried out at 10-20m intervals directly under RS Wall alignment. Depth of MPs must be greater than the subsoil replacement depth or excavation depth.
2) Consolidation parameters for clayey soils to calculate long term settlement (obtain adequate undisturbed samples for consolidation tests on clayey soil profile).
3) Long Term stability of RS Wall on slopes (carry out CIU tests to obtain c' and ϕ').
4) Short tem stability of RS Wall (Mackintosh probes or vane shear test on soft subsoil).

24.7.2 During Construction

During construction, the following tests are specified to validate the design parameters and construction control:

1) Direct shear box test on cohesionless backfill or triaxial test on cohesive backfill to validate the C' and ϕ' parameters.
2) Field density test to validate the compaction effort for the backfill.
3) Tensile strength test for metallic reinforcements to validate the allowable tensile strength.

24.8 REFERENCES

1) BS 8006 (1995): Code of Practice for Strengthened/reinforced Soils and Other Fills
2) Victor Elias, Barry R. Christopher, and Ryan R. Berg (2001): Mechanically Stabilized Earth Walls and Reinforced Soil Slopes: Design & Construction Guidelines, U.S. Department of Transportation, Federal Highway Administration.
3) Clayton, CRI, Milititsky, J. and Woods, RI (1993): Earth Pressure and Earth-Retaining Structures, 2^{nd} ed., Blackie Academic & Professional.

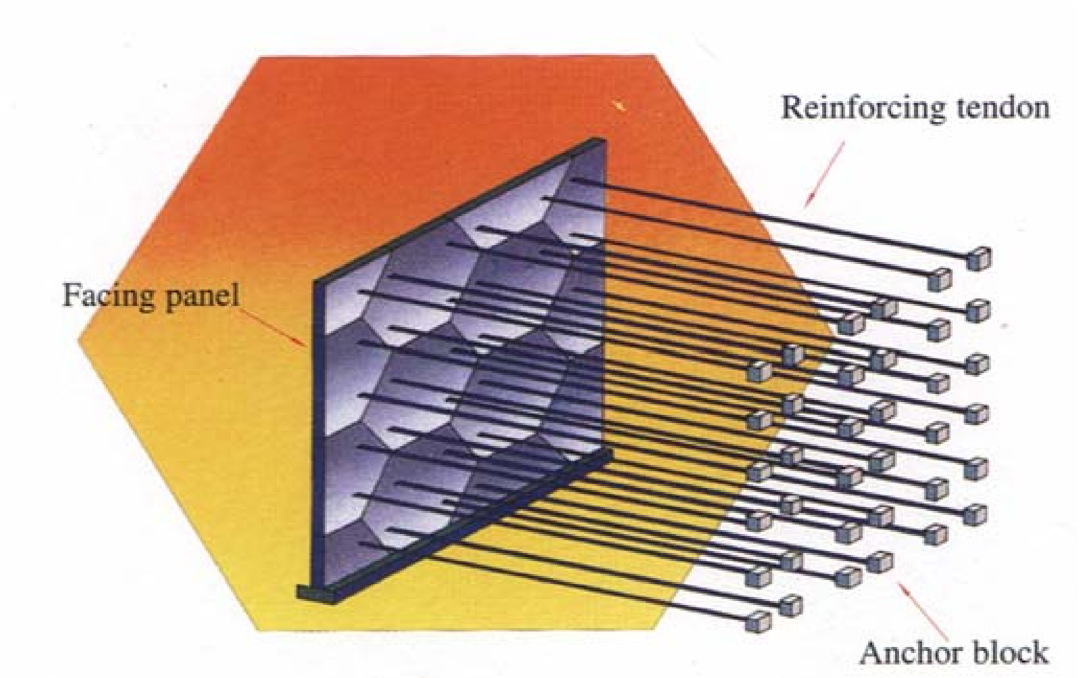


Figure 1: Common Elements of Reinforced Soil Wall

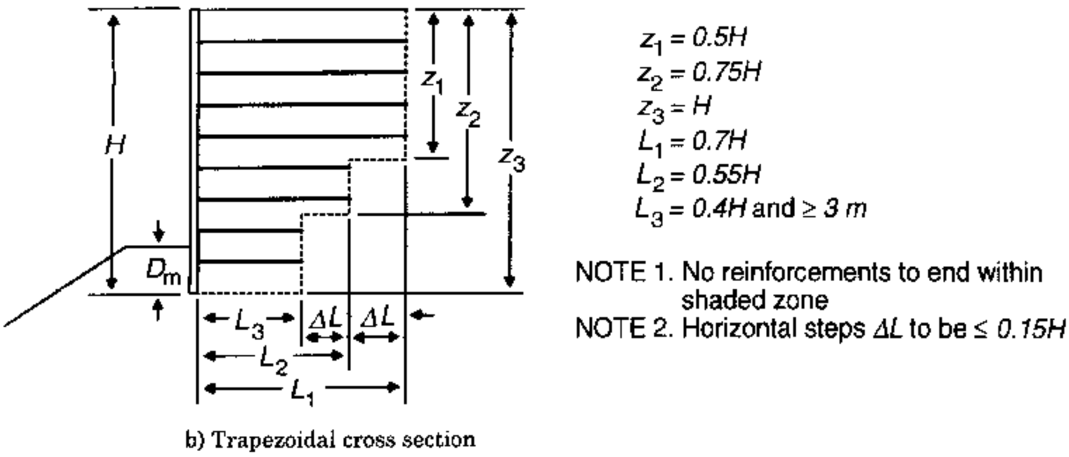
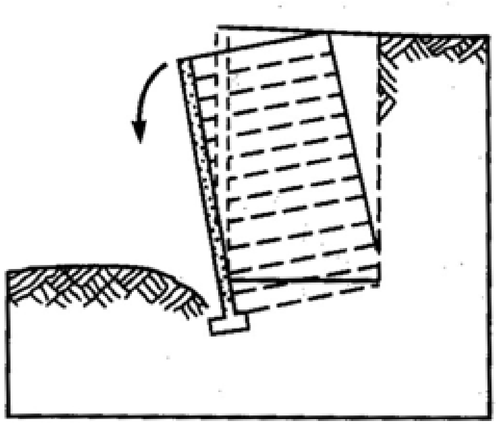
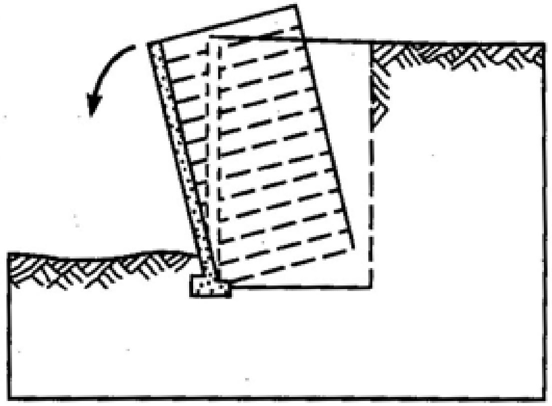


Figure 2: Dimensional Check

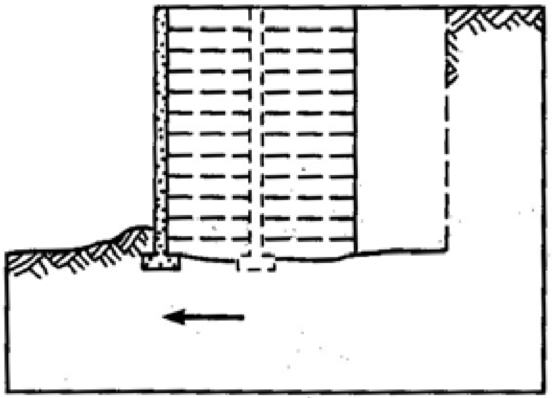
Figure 3: External Stability



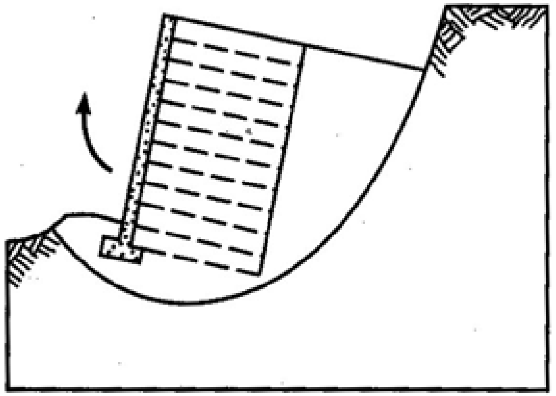
■ **Bearing Capacity Failure**



■ **Overturning Failure**

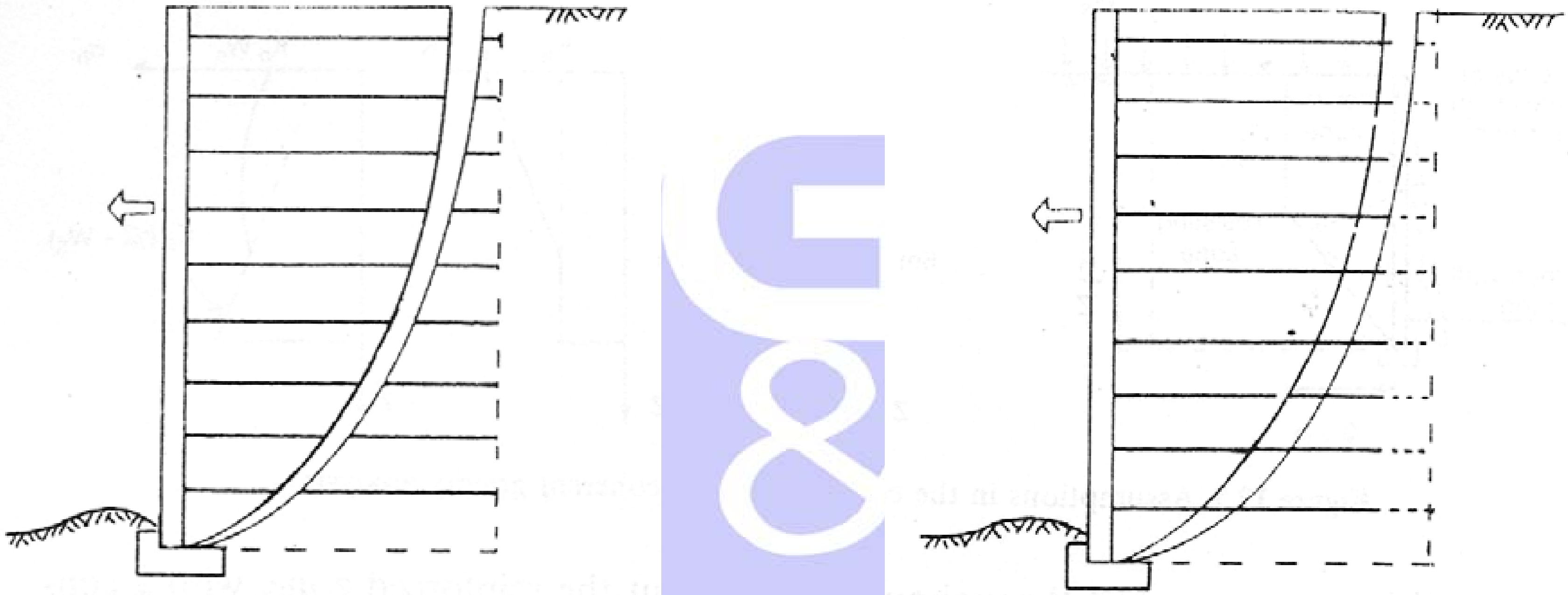


■ **Sliding Failure**



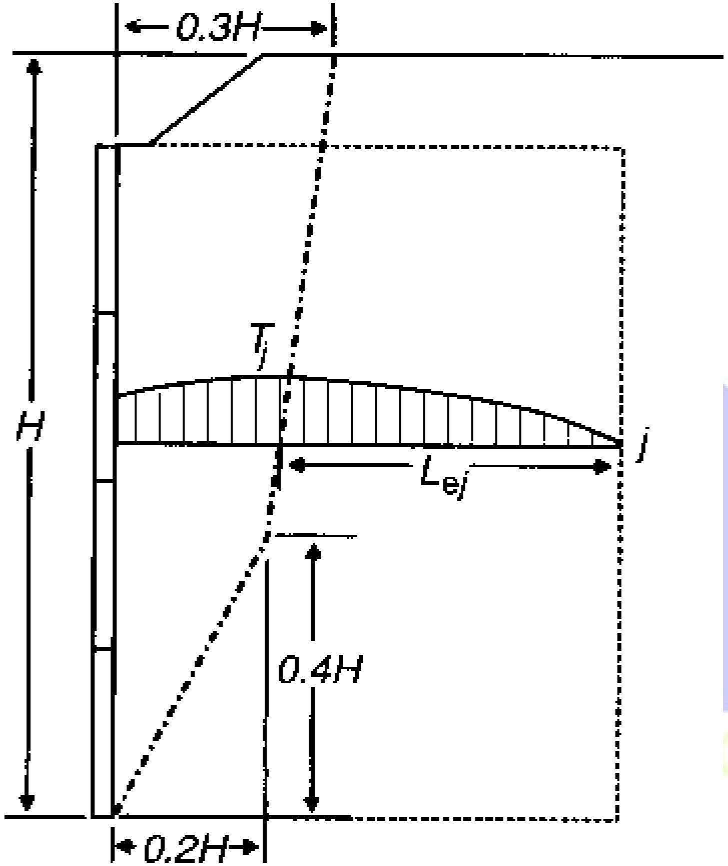
■ **Slip Failure**

Figure 4: Internal Stability

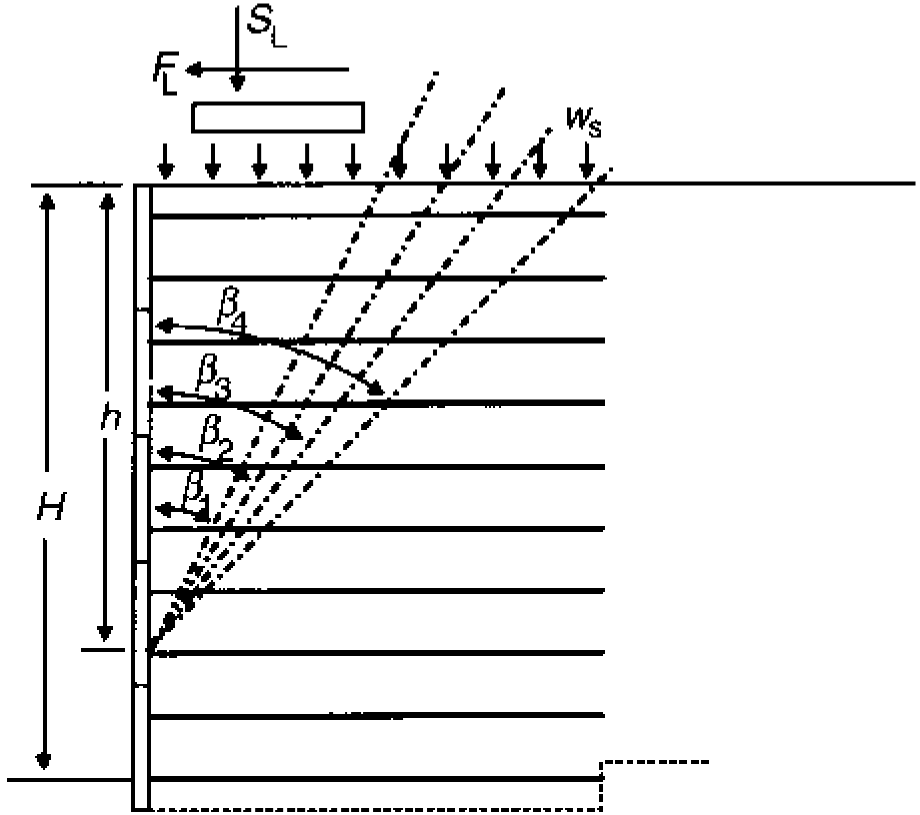


■ **Rupture** ■ **Adherence**

Figure 5: Analysis Methods (Internal Stability)



Coherent Gravity Method



Tie Wedge Back Method