STABILITY AND COST ASPECTS OF GEOGRID REINFORCED EARTH RETAINING WALL OF FLYOVER

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Abstract: For construction of approaches to flyovers and renewal of Bridges (ROBs), reinforced earth technology has almost completely replaced conventional retaining structures. Geogrid reinforced earth wall retaining structures have gained wide acceptance in India as a technically proven and cost effective alternative to conventional concrete retaining walls. The ongoing and planned initiatives of central and state governments for improving the road infrastructure in the country are likely to give a major boost for the demand for Geogrid RE wall systems. In this paper, a methodological design of a retaining earth wall structure using geogrid for a flyover near Agriculture College, Pune, is tackled through external, internal, wedge and seismic stability. Finally, design of R.C.C. cantilever retaining wall is carried out and the cost comparison is made.

Keywords: critical failure surface, failure mechanism, friction coefficient, geogrid reinforcement, reinforced earth retaining wall, seismic design.

INTRODUCTION

Internally stabilized soil retaining systems are also known as Reinforced earth systems. They stabilize the soil mass by introducing tensile reinforcing elements such as geosynthetic, steel straps, or soil nails into the backfill soil. It receives local support (reinforcing) from the closest reinforcement as soon as any local yielding occurs; the local yielding is confined by the nearby reinforcement before it develops into major yielding of the entire backfill soil. Geosynthetic materials are able to provide the same (may be even better) reinforcing effect than the steel reinforcement with easier and more cost effective construction procedures.

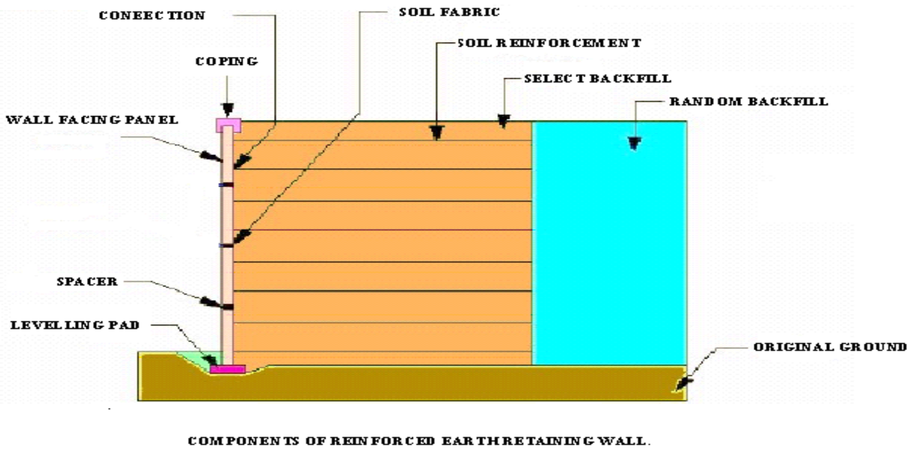

Figure 1. Reinforced Earth Retaining wall

Advantages

The advantages of Geogrid Reinforced Earth technology include

- Flexibility - Distribute loads over compressible soils, No deep foundations require.
- High load-carrying capability, both static and dynamic
- Ease and speed of installation - Prefabricated materials, simplify construction.
- Pleasing appearance - Panels may be given a variety of architectural treatments
- Economy - 15-50% savings over cast-in-place concrete walls.

BRIEF DESCRIPTION OF FLYOVER PROJECT

The organisation 'Managing Seismic Risk in Developing Countries' (MSRDC) is taking up a programme of Integrated Road Development Projects that consists of construction of a number of flyovers. As a part of traffic improvement scheme in Pune, a flyover at Agriculture College road has been planned to improve the capacity of this intersection. This junction collects traffic from Shivajinagar, F.C. Road and University Road. The maximum traffic approaches the junction from all sides is anticipated to increase at 10% per annum in future. The project consist of a dual two lane flyover from Agriculture college to University Circle at a distance of approximately 0.6 km. the elevated section of the flyover consists of prestressed concrete deck 16.4 m wide. The structure is divided into one unit of 400m consisting of 6 spans of 35.5m and two ramps. At the starting phases of the work the detailed drawings including L-section, typical cross-sections at various chainage, materials properties were studied thoroughly and understood. The project involves the provisions of earthfill of height ranging from 3.5 to 7m.

- Soil properties:
  - Retained backfill soils $\gamma_b = 20.00$ kN/m^3, $\phi_b = 34^0$
  - Reinforced backfill $\gamma r = 20.00$ kN/m^3, $\phi_r = 34^0$
  - Foundation Soil $\gamma_f = 20.00$ kN/m^3, $\phi_f = 30^0$
- Geogrid: ACE geogrid are continuous grid structures with oval apertures.
- Seismic data- Seismic zone III, maximum ground acceleration 0.16.
- Traffic surcharge = 24.00 kN/m^2
- Parapet loading = 12.00 kN/m

STABILITY OF RE WALL

Stability is assured by providing a reinforced granular mass of sufficient dimensions and structural capacity, bearing on adequate foundation material, having a durable facing material, well-chosen drainage systems, and proper embedment of the toe of the wall. Reinforced soil Earth structures are evaluated for external stability, internal stability, wedge stability and seismic stability. Each type of stability will be discussed separately.

External Stability

The Reinforced soil -geogrid volume is assumed to act as a rigid block, subject to the conventional retaining wall failure mechanisms such as: Sliding, Overturning and Bearing Capacity failure. The External stability comprises of evaluation of the base width 'B' required for height 'H' of the wall. It is necessary that minimum factor of safety of 2 against overturning, 1.5 against sliding and 2.5 for Bearing Capacity failure.

- Factor of safety against overturning (FOS1) = M_{RO} / M_O
  M_{RO} = Resisting moment against overturning M_O = Overturning moment
- Factor of safety against sliding (FOS_2) = $\sum_{PR} / \sum_{PD}$
- Factor of safety against Bearing capacity of foundation soil. (FOS_3) $= q_{ult} / \sigma_V$
  q_{ult} = Ultimate bearing capacity of foundation soil, σ_V = Maximum bearing pressure.

Table 1. Factor of safety with respect to wall height, following results can be drawn.

Sr. No	Height of wall H (m)	Theoretical width 'B'(m)	FOS_1	FOS_2	FOS_3	Adopted (width)'B'(m)
1	3.5	2.45	3.081	1.403	3.357	2.50
2	4.0	2.80	3.246	1.529	3.511	2.80
3	4.5	3.15	3.387	1.636	3.640	3.20
4	5.0	3.50	3.509	1.729	3.750	3.50
5	5.5	3.85	3.616	1.809	3.845	3.90
6	6.0	4.20	3.710	1.879	3.928	4.20
7	6.5	4.55	3.793	1.940	4.000	4.60
8	7.0	4.90	3.550	2.030	3.910	5.00

The practice is to provide minimum value of 'B' as 0.7 H but not less than 2.45m.

Internal Stability

Internal stability design consists of the determination of Geogrid size, quantity, and lengths. Internal stability analyses are: the Geogrid layers layout, tension failure and the Pullout failure. There is two possible limiting or failure conditions for reinforced walls: rupture and pullout of the Geogrid. The corresponding properties are the tensile strength and its pullout resistance.

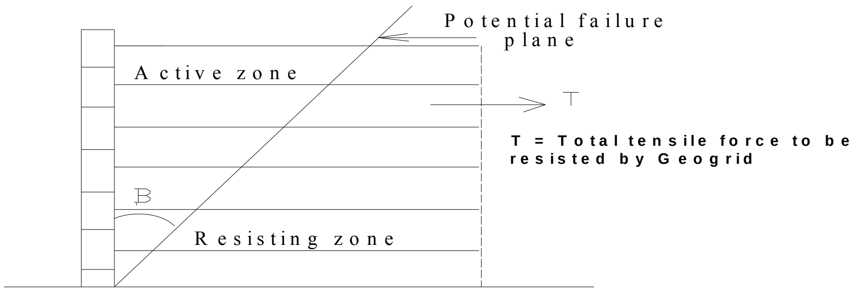

Figure 2. Adherence capacity of geogrid reinforcement

- Consider Geogrid layer vertical spacing (Vs) = 0.47m
- Tension calculation at each Geogrid reinforcement level $T_{(Max)}$
  $T_{(Max)} = \sigma_H \times V_i$ (Ref. Section 4.3 B–FHWA-Demo 82)

- Allowable strength (Tall) = [Ultimate strength (T_{ult}) x R_C / FS $_{uncertain}$ x FS_{ID} x Creep reduction factor]
  Where, FS $_{uncertainties}$ = 1.5, FS_{ID} = 1.1, R_C = the percent coverage ratio (100 % coverage is assumed for this case) So R_C = 1, Creep reduction factor = 3.10
- Pullout calculation at each layer $T_{max} \leq$ (1/ FS_{PO}) (tan ϕ Ci) (γ_r) (di) (Le) (C) (Rc) (α)
  Where, FS_{PO} = factor of safety against pullout = 1.5,
  Ci = interaction coefficient determined from pullout testing for a particular reinforcement type. Ci = 0.8,
  γ_r = unit weight of reinforced soil mass, di = depth below top of wall.
  Le = length of reinforcement in resistance zone. C = 2 for Geogrids.
  Rc = % coverage of Geogrid (may vary from 100% to 70%). Rc assumed to be 100%
  α = scale effect correction factor (α = 1.0)
- Length of Geogrid in active zone L_A = (H – di) x tan (45^o - ϕ / 2).

Table 2. Output for 7.04 m wall for type and length of geogrid at each layer

Layer No	Depth (di) from Top (m)	T_{max} (kN/m)	Type of ACE Geogrid	T(all) (kN/m)	L(required) $L_A + L_e$ (m)	L (provided) (m)
1	0.47	6.64	GG40-I	7.82	4.495	5.0
2	0.94	5.67	GG30-II	5.86	4.245	5.0
3	1.41	6.86	GG40-I	7.82	3.995	5.0
4	1.88	8.10	GG60-I	11.73	3.745	5.0
5	2.35	9.34	GG60-I	11.73	3.495	5.0
6	2.82	10.58	GG60-I	11.73	3.245	5.0
7	3.29	11.81	GG80-I	15.64	2.995	5.0
8	3.76	12.97	GG80-I	15.64	2.745	5.0
9	4.33	14.29	GG80-I	15.64	2.495	5.0
10	4.70	15.52	GG80-I	15.64	2.245	5.0
11	5.17	16.76	GG100-I	19.55	1.995	5.0
12	5.64	18.00	GG100-I	19.55	1.795	5.0
13	6.10	19.23	GG100-I	19.55	1.495	5.0
14	6.58	30.27	GG150-I	39.10	1.245	5.0

It is observed that total length of Geogrid required at each layer is less than length required from external stability analysis. So length of Geogrid provided is equal to 5 m at each layer.

Wedge Stability

It is essential to ensure safety of geogrid reinforced earth wall against failure over potential sliding plane. Stability of any wedge is maintained when frictional forces acting on the potential failure plane in connection with the tensile resistance or bond of the group of reinforcing elements embedded in the fill, bed and the plane are able to resist the applied force tending to cause the movement (figure 3).

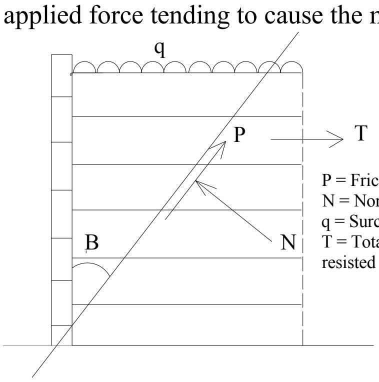

Figure 3. Forces acting on Potential failure planes

- Resolving the forces vertically. W_T = N Sin β + P Cos β
- Resolving the forces horizontally. T + P Sin β - N Cos β – F3 =0
- Residual length (effective length) Lr = L – (H - di) Tan β
- Calculation of resisting force at each layer

The resistance provided by any layer of reinforcing element is taken as the smaller value of either the adherence or frictional resistance of the geogrid embedded in the fill outside the failure plane or the tensile resistance of the geogrid.

  - $R_f = T_{all}$ x Lr ,
  - R_f = μ x Lr (γ_r x di + q) [Ref.B.S 8005: 1995 (Cl. 6.6.4.2.5)]

The lesser value for each layer should be used in the summation.

Based on the procedure listed under illustrative computation, a computer programme is developed to calculate R_f for all reinforcement layers & min. value of each layer is consider for summation. The output is obtained for 7.0 m height of wall.

Table 3. Output for wedge stability analysis

Sr. No.	Depth of layer (di) (M)	Resisting Force (kN)
1	0.47	11.76
2	0.94	10.27
3	1.41	15.64
4	1.88	26.43
5	2.35	29.37
6	2.82	32.30
7	3.29	46.92
8	3.76	50.90
9	4.23	54.74
10	4.70	58.72
11	5.17	78.20
12	5.64	83.18
13	6.10	88.07
14	6.58	185.92
		$\sum R_f$ = 760.66 kN

$$FOS = \frac{\sum R_f}{T} = \frac{760.66}{267.63} = 2.84 > 1.5 \quad \text{(Hence O.K)}$$

FOS against wedge stability for height 7m is greater than 1.5; hence structure is safe.

Seismic Stability

During an earthquake, acceleration of the backfill material may occur; in time these may be cause additional forces to develop in the reinforcing elements. The total force in each reinforcement element can be assumed to be the sum of the static force before the seismic event, plus the dynamic forces generated during the earthquake activity. These additional forces may result in excessive lateral displacement of a wall or even collapse of structure.

During an earthquake, the backfill exerts a dynamic horizontal thrust P_{AE}, on the RE wall in addition to static thrust. Moreover, the reinforced soil mass is subjected to a horizontal inertia force $P_{IR} = M \times A_m$, where M is the mass the active portion of the reinforced wall section assumed at base width of 0.5H and A_m is the maximum horizontal acceleration of the reinforced soil mass. Force P_{AE} can be evaluated by the pseudo-static Mononobe-Okabe analysis (figure 4) and added to the static forces acting on the (weight, surcharge and static thrust). The dynamic stability with respect to external stability is then evaluated.

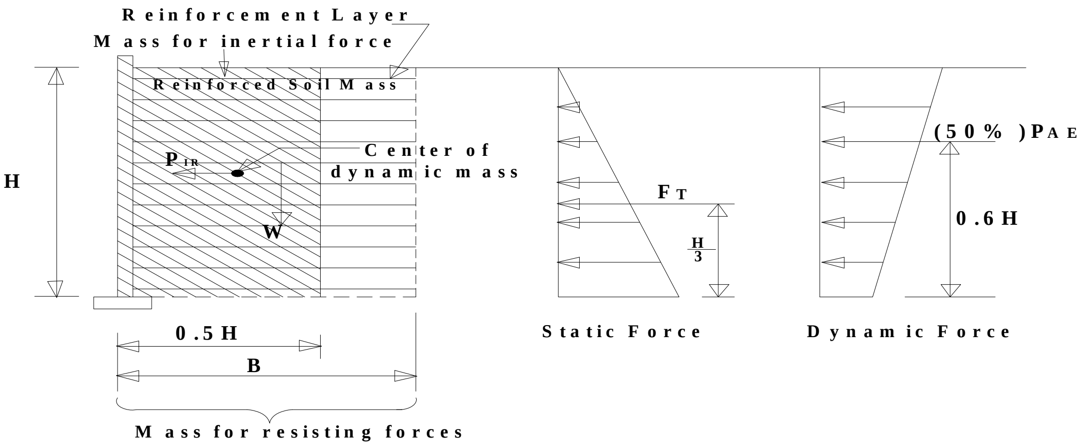

Figure 4. Forces acting during earthquake

- Total active horizontal force $\sum_{AF} = (P_{SL} + P_q) + P_{IR} + 0.5\ P_{AE}$
- $\sum_{RF} = \mu \times W \quad (\mu = \tan 34^o = 0.674)$
- Factor of safety against sliding $FOS_1 = \sum_{RF} / \sum_{AF} = 1.369 > 1.1$ (Safe against sliding)
- Overturning moment due to seismic effect = $M_o = M_{o(st)} + M_{o(AE)} + M_{o(IR)}$
- Resisting moment against overturning $(M_R) = W \times B / 2 + Wq \times B / 2$
- Factor of safety against overturning $FOS_2 = M_R / M_o$
- Pullout / Adherence resisting force offered by the geogrid Pr = 2.03 > 1.1

- Resistance against seismic pullout (Rp) = T_{all} x Lri
- Factor of safety against pullout = Rp / Pr = 2.03 > 1.1 (Hence OK)

Similarly at each layer of geogrid factor of safety against pullout is calculated.

Table 4. Factor of safety against pullout for seismic analysis

Sr. No.	Depth (m)	Lr	Pr	Pr (seismic)	Rp	FOS (Pullout)
01	0.47	1.504	5.78	4.625	11.761	2.03
02	0.94	1.754	11.56	9.251	10.278	1.12
03	1.41	2.004	17.347	13.877	17.626	1.27
04	1.88	2.254	23.129	18.503	26.439	1.42
05	2.35	2.504	28.912	23.129	29.371	1.22
06	2.82	2.754	34.694	27.775	32.304	1.16
07	3.29	3.005	40.476	32.381	46.998	1.45
08	3.76	3.255	46.259	37.007	50.908	1.37
09	4.23	3.505	52.041	41.633	66.157	1.58
10	4.70	3.755	57.824	46.259	73.508	1.58
11	5.17	4.005	63.606	50.885	78.297	1.53
12	5.64	4.255	69.388	55.511	83.185	1.49
13	6.11	4.505	75.048	60.038	119.25	1.98
14	6.58	4.755	80.953	64.762	185.72	2.86

After analysis output files, factor of safety with respect to wall height, following results can be drawn.

Table 5. Factor of safety against Seismic Sliding and overturning

Sr. No	Height of wall H in (m)	Theoretical width ‘B’(m)	FOS_1	FOS_2	Adopted (width) ‘B’(m)
1	3.5	2.45	1.100	1.905	2.50
2	4.0	2.80	1.148	1.913	2.80
3	4.5	3.15	1.189	1.921	3.20
4	5.0	3.50	1.225	1.927	3.50
5	5.5	3.85	1.255	1.932	3.90
6	6.0	4.20	1.281	1.937	4.20
7	6.5	4.55	1.304	1.941	4.60
8	7.0	4.90	1.325	1.945	5.00

The factor of safety against seismic sliding for height 3.5m is less than 1.1. Hence to bring that factor of safety above 1.1 the corresponding base width should be adopted 2.5m. All other values are greater than 1.1 for seismic sliding and overturning.

DESIGN RCC CANTILEVER WALL

Design of R.C.C Cantilever wall with uniform surcharge by using limit state method.
Design Data :

- Total height H = 7.04 m
- Unit weight of earth retained γ_b = 20 kN / m^3
- Angle of Repose $\Phi_b = 34^0$
- Safe Bearing Capacity of Soil = 250 kN / m^2
- Coefficient of Friction μ = 0.57
- Uniform intensity of Surcharge q = 25kN/m^2
- Materials M20 , Fe415

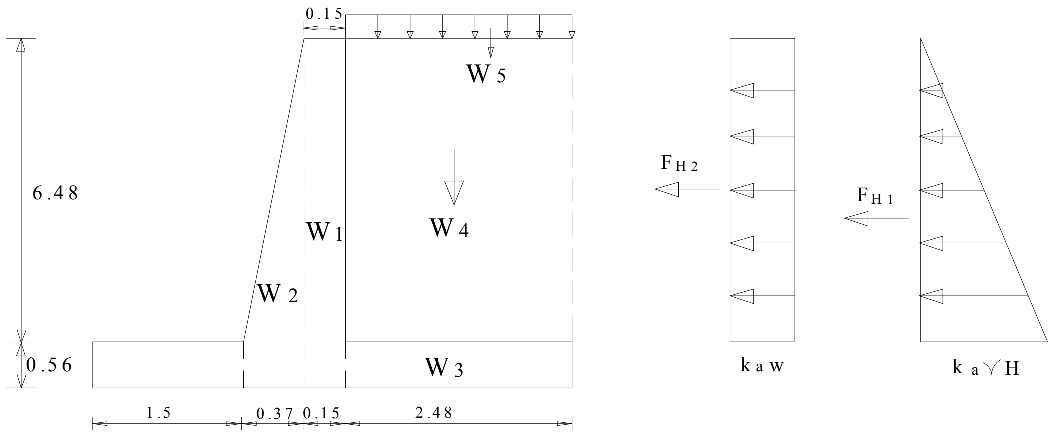

Figure 5. Forces acting on a RCC wall

Details of RCC wall

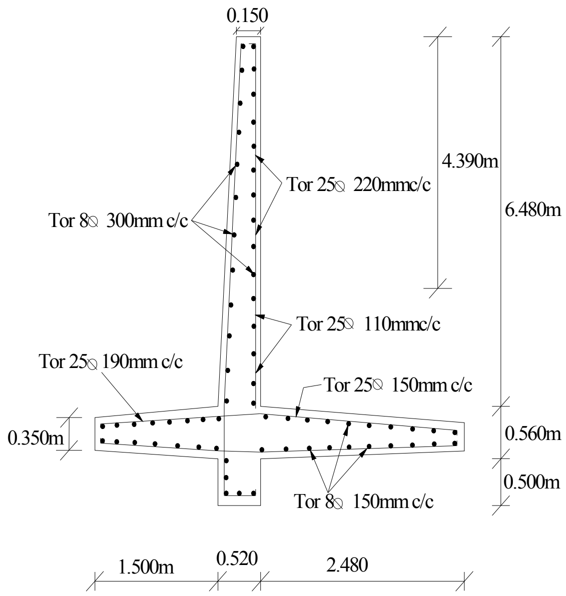

Figure 6. Details of RCC wall

COST COMPARISON OF GEOGRID, WITH R.C.C. CANTILEVER WALL

In order to compare cost involved in the construction of RE wall by Geogrid & Metallic strip with that of the conventional RCC cantilever retaining wall, Wall height of 7 m is selected.

Cost of RE wall by Geogrid:

- As per design calculation total number of layer of Geogrid = 14
- Total quantity of Geogrid per layer = 5 x 1 = 5 m^2 and total area of for 7m height = 70 m^2
- Cost of Geogrid upto 6th layer = 30 x Rs.110/ m^2 = Rs.3300/-
- Cost of Geogrid from 7th to 10th layer = 20 x Rs.130/ m^2 = Rs.2600/-
- Cost of Geogrid from 11th to 13th layer = 15 x Rs.190/ m^2 = Rs.2850/-
- Cost of Geogrid upto 14th layer = 5 x Rs.260/ m^2 = Rs.1300/-
- Total cost of Geogrid = Rs.10050/-
- Cost of precast panel of thickness 14 cm = 7 x 800/ m^2 = Rs.5600/-
- Cost of accessories per meter length of wall 5% of total cost = Rs.785/-

Total Cost of Reinforced Earth wall by Geogrid per meter length = Rs.16435/-

Cost of R.C.C Cantilever wall:

As per design calculation,

- Total length of 8 ℜ for 7m height per meter length = 174m. Weight = 0.395 kg/m.
- Total length of 25 ℜ for 7m height per meter length = 65m. Weight = 3.85 kg/m.
- Quantity of steel = (174 x 0.395) + (65 x 3.85) = 320 kg.

- Total cost of tor steel = 320 x 35 = Rs. 11200/-
- Quantity of M20 concrete per meter length of wall = 4.23 $M^{3.}$ Rate = Rs. 2500/ M^3
- Cost of concrete = 2500 x 4.24 = Rs.10600/-
- Add 10% towards shuttering, bar bending, form work and curing etc. = 2180/-

Total cost of R.C.C Cantilever wall per meter length = Rs.23980/-

CONCLUSION

From above calculation it is observed that deployment of the Reinforced Earth wall by Geogrid reduce the cost 32% and by metallic strips reduce cost upto 25% as compare to conventional RCC cantilever retaining wall. It has been experienced that the saving in terms of time was about 50%, since the RE wall was constructed much rapidly with the use of prefabricated concrete elements.

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