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Analysis and Design of Reinforced Earth wall

Vijay Kumar[1], Dr. Bharat Nagar[2]
[1] Student of M.Tech final year of Jagannath University Jaipur, India
[2] HoD Civil Engineering Department of Jagannath University Jaipur, India
beniwalvijayjatt@gmail.com

Abstract -- The main objective of this research work is to use the available limited land space for engineering task as Reinforced Earth wall for grade separator in roads/highway projects. Reinforced Soil wall is an improved step of Cast in situ Retaining wall with limited time and resources, which tends more progressive and productive with less skilled workers on site. Design of RE wall is done by elaboration of various field data and objective of grade separator construction by M/s IRB Infrastructure Developers Ltd at Ch. 411+935 of NH-08 (Old). Design and analysis of RE wall manually is typical and done as step by step. With help of GEO-5, Design and Analysis of RE wall becomes less time consuming task. After getting data for soil strata from field and required product criteria, GEO-5 enable us quick designing and analysis for External stability, Internal Stability, pull out of connections and seismic resistance. Design and Analysis observations of RE wall is done manually with FHWA-043 code, BS8006-1:2010, IS 1893-1:2002. Calculation for active earth pressure, Passive earth pressure and Earthquake analysis are done by Meyerhoff, Caquot-Kerisel and Mononobe-Okabe respectively.

Keywords - Active earth pressure, Passive earth pressure, angle of internal friction, Internal stability, External stability, Seismic stability, Overturning, Base sliding, Bearing capacity, Global Stability, Fascia, Connections, Embedment depth etc.

1. INTRODUCTION

Insertion of reinforcements into the earth for the purpose of building RE wall having vertical face or nearly vertical face (>70˚) which enable soil to resist high compressive and tensile stresses. The reinforcements improve the earth properties by preventing tensile failures. The synthetic type of reinforcement material provide greater durability, strength, proven experience and good theoretical design approach.

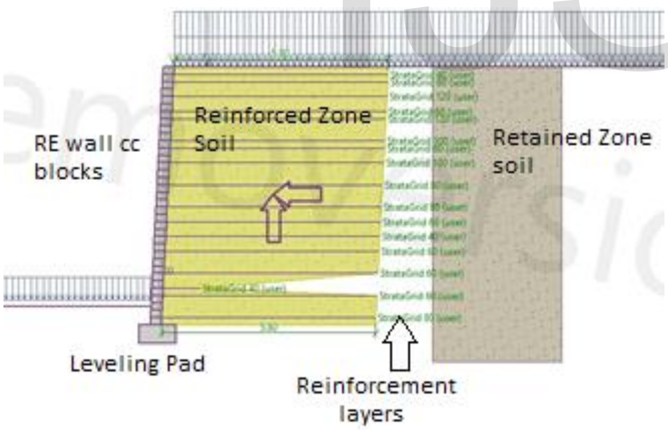

Fig 1 Components of RE wall

The main advantage of such reinforced earth / retaining wall is to have simple and fast progress with less skilled manpower in field. The final overall structure is flexible and ductile allowing differential settlements without sudden failure.

- *Vijay Kumar currently pursuing masters degree program in structural engineering in Jagannath University,Jaipur, India, PH-9018051446. E-mail: beniwalvijayjatt@gmail.com*

Design Theory

Reinforced Earth wall design is based on limit state method of analysis as per BS8006-1:2010 and FHWA-043 code for static and seismic analysis incorporating all necessary recommendations of MoRTH and other relevant codes. Design Methodology for the reinforced earth wall focuses on following stability analysis

1.1 **External Stability** Base Sliding, Overturning, Bearing Capacity and Global Stability.
1.2 **Internal Stability** Rupture, Pull out and internal sliding.
1.3 **Local Fascia Stability** Fascia connection, Bulging and Maximum unreinforcement height
1.4 **Seismic Stability** Mononobe-Okabe (M-O) method and IS: 1893(Part-1):2002

Input Design Parameter

Live Load = 24.0 kPa, Dead Load = 13.2 kPa, Strip load due to crash barrier with 1.885m length of friction slab = 14.7 kPa.

Reinforced backfill

Unit weight γ, (kN/m3) = 20, Angle of Internal friction, ϕ ≥32°, Cohesion, c (kN/m2) = 0

Retained backfill

Unit weight γ, (kN/m3) = 20, Angle of Internal friction, ϕ ≥30°, Cohesion, c (kN/m2) = 0

Foundation earth (Assumed)

Unit weight γ, (kN/m3) = 18, Angle of Internal friction, ϕ ≥30°, Cohesion, c (kN/m2) = 0

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The ground water table is not considered. The Project location is in Seismic Zone Ill and accordingly zone factor of 0.16 is considered. Block fascia is considered for design.

2. MATERIAL USED

Soils and Fills

In reinforced soil walls and abutments acting as earth retaining structures, consideration should be given to both the properties of the retained fill and of the selected fill forming the reinforced soil mass.

Reinforcing Materials

Reinforcing elements must have resistance to degradation when buried. The reinforcement shape may be as sheets, grids, meshes, strips, bars, rods, etc. that are capable of sustaining tensile loads and the effects of deformation developed in the fill.

Facings

The facing of segmental block walls should usually be made of un-reinforced dense concrete blocks of high durability, appropriate for the more aggressive environments commonly required for highway retaining structures. The blocks should not be those commonly used for internal walls in buildings.

Minimum concrete cube strength 30 N/mm^2 at 28 days.

Maximum water absorption of 6% when tested.

Minimum density: 22 KN/m^3

Minimum cement content: 365 kg/m^3

Maximum water/cement ratio 0.5

3. DESIGN PROCEDURE OF REINFORCED EARTH WALL (MANUALLY)

Coefficient of active earth pressure, Ka = (1-Sinθ) / (1+Sinθ)

For reinforced backfill,
Wall batter θ = 4.23°, K_1 = 0.307, ϕ1 = 30°,

For retained backfill, Wall batter θ = 4.23°, K_2 = 0.333

Wall Ht. H = 7.105m, Length of reinforcement L = 5.80m, Minimum embedment Dm = 1m

3.1 External Stability by Static Analysis

Calculate vertical loads due to self-weight, strip load due to crash barrier, live load and dead load.

Calculate horizontal loads due to earth pressure behind fascia blocks, live load and dead load.

Sliding along the base checking

For long term stability where there is earth to earth contact at the base of the structure by

$fsF_D \leq F_R(\tan\phi'p/fms)+(c'L/fms)$

f_D = Horizontal factored disturbing load, F_R = Vertical factored resultant load, ϕ'p = Peak angle of shearing resistance under effective stress conditions, fms = Partial materials factor applied to tanØ'p,¢',cu, fs = Partial factor against base sliding, L = Effective base width for sliding

F_D = Sliding force, F_R = Resisting force

$FR/FD \geq 1.2$

Bearing failure check

M_D = Overturning Moment, M_R = Resisting Moment, R_v is the resultant vertical load

Eccentricity of Rv from the center line of the base having width L

$e = L/2 - ((M_R-M_D) / (R_v))$

Bearing pressure qr due to Meyerhoff distribution

$qr = R_v / L-2e$

fms is partial material factor applied to qult

Ultimate bearing capacity of foundation earth

$qr' \leq qult/fms + \gamma^* Dm$

$qult = cN_c + \gamma\, Dm\, N_q + 0.5\, \gamma\, B\, N_\gamma$

qr ≤ qr' Foundation safe against bearing failure

3.2 Internal Stability by Static Analysis

Check for internal sliding

Calculation for bottom layer of Geogrid

Fs = FoS against base sliding = 1.2

$(F_R(a'\tan Ø')) / F_D \geq 1.20$

Check for rupture

M_D = Overturning Moment, M_R = Resisting Moment

Eccentricity

$e = L/2 - ((M_R-M_D) / (R_v)\ 1.5)$

Elevation of Geogrid Layer

E_1 = First layer from bottom, E_2 = Second layer from bottom

$Svj = 0.5 \times (E_2-E_1) + E_1$, $\sigma vj = Rvj / (L-2e)$, $Tpj = K_1 \times \sigma vj \times Svj$

$Tsj = (ka \times Svj \times fs \times S_L)/Dj$

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Where Dj = ((hj+b)/2) + d

Calculation of Tsj for bottom first Grid layer

b = width of panel strip, Crash Barrier Area = A, Concrete density = γ_c

$S_L = \gamma c \times A$, $Tj = Tpj + Tsj$

$T_{Design} = T_{ult} / (RF_{CH} \times RF_{ID} \times RF_{CR})$

$fn = T_D / Tj > 1.1$

Check for Pullout

Inclination for failure surface w.r.t. horizontal $\delta = 45+\phi/2$

Elevation from bottom = Ei, Wall batter (w):- 4.23°

Effective length, $Le = L - (Ei / \tan \psi) + Ei \times \tan w$

Perimeter of jth layer:

$Pj \geq Tj (((\mu\ Lej\ (ffs\ \gamma 1\ hj + ff\ \omega s)) / fp\ fn) + (abc'\ c'\ Lej / fms\ fp\ fn))$

C'=Cohesion of Earth, ffs & fp = 1.5 & 1.3 from table 11 of BS 8006-1: 2010

fn = 1.1 from table 9 of BS 8006-1 : 2010

fms = 1 from table 11 of BS 8006-1 : 2010

$\mu = \alpha' \tan ø'p / fms$

ff = 1.5 (table 11 BS 8006)

$fp' \leq Pj\ \mu\ Le\ (ffs\ \gamma 1\ hj + ff\ Ws) / Tj\ fn$

$fp \leq fp'$

Case A

Connection Strength check

As per 3.3.3.3 page 38 of BS 8006-1: 2010 connection strength analysis were done by using NCMA code.

$T_{ult\ conn.} = Acs + Ww\ (n)\ \lambda cs$

Connection calculations for bottom most Grid:-

H= wall height, γ_u =Density of plain concrete, Wu = Block unit width front to back = 0.305m

Tj < Tconn.

T conn. / Tj > 1

3.3 External Stability under Seismic loading

Horizontal Seismic Coefficient Ah = (ZISa) / (2Rg) IS 1893 (Part 1)-2002

Sa/g = Average response acceleration coefficient

Ah = Design Horizontal seismic coefficient (As per IRC 6-2014).

A= Maximum ground acceleration coefficient = Ah

Am = Coefficient of max Wall acceleration at the centroid

Coefficient of Active earth pressure

The total seismic active earth pressure coefficient K_{AE} is computed from the following Mononobe Okabe equation.

$K_{AE} = \cos^2(\phi-\xi-90+\theta) / ((\cos\xi \cos^2(90-\theta) \cos(I+90-\theta+\xi)) (1+(\sin(\phi-I) \sin(\phi-\xi-I) / \cos(I+90-\theta+\xi) \cos(I-90+\theta))^{1/2})^2$

$P_{IR} = 0.5 \times Am \times \gamma 1 \times H^2$

$P_{AE} = 0.5 \times \gamma^3 \times H^2 \times \Delta K_{AE}$

Where:-

P_{IR} = Hor. Inertia Force, P_{AE} = Seismic Thrust

Check for Sliding

Factor of safety against sliding = Resisting Force / Sliding Force > 1.125 (1.125 is 75% of 1.5 for static condition)

Check for Overturning

M_D = Overturning Moment

M_R = Resisting Moment

$F.S.ovr = M_R/M_D > 1.125$

Check for Bearing Capacity

Calculation of bearing pressure

Meyerhoff stress, σv or $qr = Rv / L-2e$

Ultimate bearing capacity of foundation earth

$qult = cN_c + 0.5\ \gamma_f\ (L-2e)\ N_\gamma$
(As per FHWA, effect of embedment is neglected)

Factor of safety FS = qult / qr > 1.875

3.4 Internal Stability under Seismic loading

Check for Rupture for bottom most Geogrid

Seismic Loads produce an inertial force so Pi acting horizontally in addition to static force

Pi = Wa x Am

Wa= Weight of active zone

Total Max tensile load Tmax per unit width

$Tmax = \sigma h \times Sv = K_1 \times \sigma v \times Sv$

Where:-

σv = Vertical stress at the level of reinforcement, Sv = Vertical spacing of the Reinforcement

Dynamic Increment (T_{md}) is computed by disturbing Inertia force Pi in the Geogrid layer proportional to the resistant area (Le)

Max tension in the reinforcement layer

$T_{total} = T_{max} + T_{md}$

$Ta = T_{ult} / (R_{Fd} R_{Fid} R_{Fcr} fs)$

FoS against rupture = Ta / Ttotal> 1.125

Pullout check for bottom first reinforcement layer

Available pullout resistance $Pr = C \times (Ci \tan ø1) \times Le (\gamma z) \times Rc \times \alpha$

Where:-

C = reinforced effective unit perimeter e.g., C =2 for strip, grids and sheets

α = scale effect correction factor = 0.8

Geogrid Earth friction coefficient is reduced by 80% of its static value

Available pullout resistance $Pr = 2x(0.8\ Ci \tan ø1) \times Le (\gamma z) \times Rc \times \alpha$

FoS against Pullout = Pr / Ttotal

Check for connection strength for bottom most layer

For Seismic loading, long term connection strength to be reduced to 80% of static value

FoS against connection strength = Tult con / Ttot ≥ 1.125

4. DESIGN OF REINFORCED EARTH WALL USING GEO-5

Stability Analysis

Verification methodology: Limit state (LSD)

Geometry of Structure
Numbers of blocks n = 35
Block height h = 0.203 m
Block width b = 0.300 m
Block offset o_1 = 0.01 m
Structure foundation
Foundation width bb = 1.00 m
Foundation height Ib = 0.50 m
Foundation offset ab = 0.30 m

Material

Block material
Unit weight γ = 23.00 kN/m³
Cohesion c = 0.00 kPa
Friction f = 0.533
Shear bearing capacity of joint Rs = 0.00 kN/m

Table 1
Summary of partial factors to be used (Table 11 of BS 8006.1:2010)

Partial factors		Ultimate limit state
Earth material factors:	to be applied tan ø'p	fms = 1.0
	to be applied to c'	fms = 1.6
	to be applied to cu	fms = 1.0
Earth / reinforcement interaction factors	Sliding across surface of reinforcement	fs = 1.3
	Pull-out resistance of reinforcement	fp = 1.3
Partial factors of safety	Foundation bearing capacity: to be applied to qult	fms = 1.35
	Sliding along base of structure or any horizontal surface where there is earth-to-earth contact	fs= 1.2

Table 2
Load factors for load combinations associated with walls (Table 12 of BS 8006.1:2010)

Effects	Combinations		
	A	B	C
Mass of the reinforced earth body	ffs= 1.5	ffs= 1.0	ffs= 1.0
Mass of the backfill on top of the reinforced earth wall	ffs= 1.5	ffs =1.0	ffs= 1.0
Earth pressure behind the structure	ffs= 1.5	ffs= 1.5	ffs= 1.0
Traffic load: on reinforced earth block	fq = 1.5	fq = 0	fq = 0
behind reinforced earth block	fq = 1.5	fq = 1.5	fq = 0

Table 3
Properties of Geogrid

Geogrid	T_{ult} (KN/M)	Reduction Factors				T_{design} (kN/m)
		RF_{CR}	RF_{ID}	RF_{CH}	RF	
SGi40	40	1.51	1.1	1.1	1.8	22.51
SGi60	60	1.51	1.1	1.1	1.8	33.76
SGi80	80	1.51	1.1	1.1	1.8	45.01

SGi100	100	1.51	1.1	1.1	1.8	56.27
SGi120	120	1.51	1.1	1.1	1.8	67.52
SGi150	150	1.51	1.1	1.1	1.8	84.4
SGi180	180	1.51	1.1	1.1	1.8	101.28
SGi200	200	1.51	1.1	1.1	1.8	112.53

Soil parameters

Retained Zone Soil
Unit weight γ = 20.0 kN/m^3
Angle of internal friction ϕ_{ef} = 30°
Cohesion of soil c_{ef} = 0
Angle of friction struc.-soil δ = 10°
Saturated unit weight γ_{sat} = 20.0 kN/m^3

Reinforced Zone Soil
Unit weight γ = 20.0 kN/m^3
Angle of internal friction ϕ_{ef} = 32°
Cohesion of soil c_{ef} = 0
Angle of friction struc.-soil δ = 10°
Saturated unit weight γ_{sat} = 20.0 kN/m^3

Foundation Zone Soil
Unit weight γ = 18.0 kN/m^3
Angle of internal friction ϕ^{ef} = 30°
Cohesion of soil c_{ef} = 0
Angle of friction struc.-soil δ = 10°
Saturated unit weight γ_{sat} = 18.0 kN/m^3

Resistance on front face of the structure

Resistance on front face of the structure: at rest

Soil on front face of the structure - Retained Zone Soil

Soil thickness in front of structure h = 1.00 m

Terrain surcharge f = 10.00 kN/m^2

Terrain in front of structure is flat.

Earthquake

Factor of horizontal acceleration K_h = 0.1100

Factor of vertical acceleration K_v = 0.1100

Water below the GWT is restricted.

Settings of the stage of construction

Coefficient for structure types: wall

Verification 1

For Combination A

Verification of complete call

Place of verification: **bottom of blocks**

Check for overturning stability

Resisting moment M_{res} = 6013.16 kN-m/m

Overturning moment M_{ovr} = 1255.37 kN-m/m

Wall for overturning is satisfactory

Check for Slip

Resisting horizontal force H_{res} = 819.27 kN/m

Active horizontal force H_{act} = 403.17 kN/m

Wall for slip is satisfactory

Overall check - wall is satisfactory

For Combination B

Verification of complete call

Place of verification: **bottom of block**

Check for overturning stability

Resisting moment M_{res} = 4241.69 kN-m/m

Overturning moment M_{ovr} = 1255.37 kN-m/m

Wall for overturning is satisfactory

Check for Slip

Resisting horizontal force H_{res} = 556.71 kN/m

Active horizontal force H_{act} = 403.17 kN/m

Wall for slip is satisfactory

Overall check - wall is satisfactory

Verification 2

For Combination A

Verification of complete call

Place of verification: **bottom of levelling pad**

Check for overturning

Resisting moment M_{res} = 6421.83 kN-m/m

Overturning moment M_{ovr} = 1484.33 kN-m/m

Wall for overturning is satisfactory

Check for slip

Resisting horizontal force H_{res} = 822.56 kN/m

Active horizontal force H_{act} = 438.02 kN/m

Wall for slip is satisfactory

Overall check - wall is satisfactory

For Combination B

Verification of complete wall

Place of verification: **bottom of levelling pad**

Check for overturning

Resisting moment M_{res} = 4327.05 kN-m/m

Overturning moment M_{ovr} = 1311.61 kN-m/m

Wall for overturning is satisfactory

Check for slip

Resisting horizontal force H_{res} = 562.80 kN/m

Active horizontal force H_{act} = 438.02 kN/m

Wall for slip is satisfactory

Overall check - wall is satisfactory

Dimensional Verification

For Combination A

Verification of complete wall

Place of verification: **bottom of block**

Check for overturning stability

Resisting moment M_{res} = 2569.02 kN-m/m

Overturning moment M_{ovr} = 1260.85 kN-m/m

Wall for overturning is satisfactory

Check for slip

Resisting horizontal force H_{res} = 603.80 kN/m

Active horizontal force H_{act} = 396.84 kN/m

Wall for slip is satisfactory

Overall check - wall is satisfactory

For Combination B

Verification of complete wall

Place of verification: **bottom of block**

Check for overturning stability

Resisting moment M_{res} = 2553.04 kN-m/m

Overturning moment M_{ovr} = 1260.85 kN-m/m

Wall for overturning is satisfactory

Check for slip

Resisting horizontal force H_{res} = 591.53 kN/m

Active horizontal force H_{act} = 396.84 kN/m

Wall for slip is satisfactory

Overall check - wall is satisfactory

Bearing capacity for foundation soil

Verification of Foundation soil

Stress in the footing bottom: **rectangle**

Eccentricity verification

Max. Eccentricity of normal force e = 0.042

Maximum allowable eccentricity e_{alw} = 0.333

Eccentricity of the normal force is satisfactory.

Verification of bearing capacity

Bearing capacity of foundation soil R = 1500 kPa

Partial factor on bearing capacity γ_{Rv} = 1.35

Max. stress at footing bottom σ = 304.72 kPa

Bearing capacity of foundation Soil R_d = 1111.11 kPa

Bearing capacity of foundation soil is satisfactory

Overall verification – bearing capacity of foundation soil is satisfactory

Check for slip along geo reinforcement with the maximum utilization

Inclination of slip surface = 87°

Overall normal force acting on reinforcement = 1085.98 kN/m

Coefficient of reduction of slip along geotextile = 0.60

Resistance along georeinforcement = 407.16 kN/m

Wall resistance = 22.26 kN/m

Overall bearing capacity of reinforcement = 0.00 kN/m

Check for slip

Resisting horizontal force H_{res} = 331.47 kN/m

Active horizontal force H_{act} = 296.40 kN/m

Slip along geotextile is satisfactory

Calculation for internal stability

Check for tensile strength

Tension strength R_t = 22.66 kN/m

Force in reinforcement F_x = 21.80 kN/m

Reinforcement for tensile strength is satisfactory

Check for pull out resistance

Pull out resistance T_p = 8.66 kN/m

Force in reinforcement F_x = 8.39 kN/m

Reinforcement for pull out resistance is satisfactory

Overall verification – reinforcement is satisfactory

Global stability analysis

Slip surface parameters

Center S = (-2.53;-0.69) m

Radius r = 8.60 m

Angle α_1 = -33.32°

Angle α_2 = 85.43°

Slope stability check (Bishop)

Utilization = 62.39%

Slope stability is satisfactory

5. CONCLUSION

1. Design and Analysis of RE wall can be done by conventional methods using different formula and standards for design as well as verification.
2. Using same data for analyse of RE wall using GEO-5 software make it easy and speedy.
3. Approach length for grade separator is 230 meters having varying heights from 1.6 meters to 7.105 meters.
4. GEO-5 make it easy for design and analysis for different sections of wall height.
5. Three type of filling soil used behind wall, Foundation soil (up-to levelling pad), Retained soil and reinforced zone soil.
6. Different grade of Strata-grid used as reinforcement.
7. L shaped crash barrier are used at top of cooping beam over block layer.
8. Overall behavior of RE wall found satisfactory for External stability, internal stability, Seismic stability and Global stability by GEO-5 results.
9. Proper drainage for seepage water also required to prevent wall failure due to pore water pressure.

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