Design and Economic analysis of reinforced earth wall

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ABSTRACT

Soil retention systems are very important elements for every highway design. Different types of soil retaining systems have evolved over the last two to three decades. For many years retaining structures were made of reinforced concrete. The cost of conventional retaining walls increases rapidly with increase in height of wall. Reinforced earth walls are cost effective soil retaining structures and can tolerate large settlements than conventional concrete retaining wall. Due to this reason Reinforced earth technology has completely replaced conventional concrete retaining structures. Geogrid reinforced earth wall retaining structures have gained wide acceptance. In this paper methodological design of Geogrid reinforced earth wall under the project for six lanning of Indore – Dewas section of NH-3. Similarly steel strips reinforced earth wall and concrete retaining wall are designed. Cost comparison is made which shows that Geogrid reinforced earth walls are more economical than concrete retaining walls. Cost calculation of Geogrid reinforced earth wall is done by varying angle of internal friction of reinforced soil.

Key words: Geogrid reinforced earth wall, reinforced soil, internal and external stability

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INTRODUCTION

Reinforced Earth is a composite material formed by cohesion less soil and flexible metallic reinforcing strips or geosynthetic (geogrid) reinforcements. The strength and stability are obtained from the frictional interaction between the granular backfill material and the reinforcements, which results in permanent and predictable bond that creates a unique composite construction material.

The visible part of the structure is structurally the least significant. The facing panels are made of precast concrete. Reinforced Earth retaining walls are an economical way to meet every-day earth retention needs for highway and bridge grade separations, railroads and mass transit systems, waterfronts, airports, loading docks, industrial facilities and commercial and residential developments. They are also used in response to difficult design conditions such as very high structures, restricted space, where obstructions within the MSE soil mass are present and poor foundation soils.

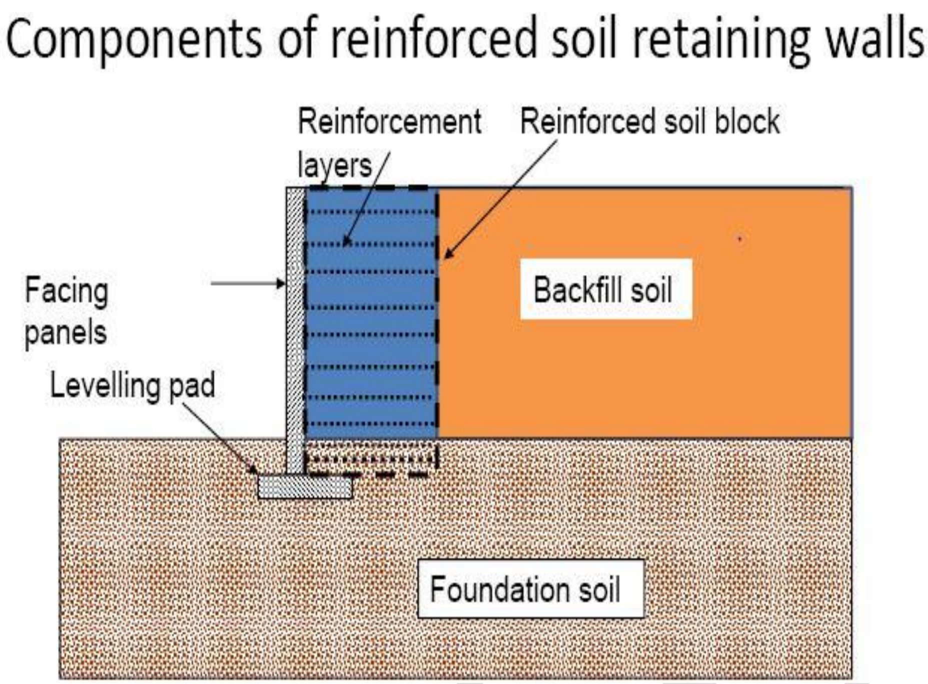


Diagram showing components of Reinforced earth retaining wall

MATERIALS AND METHODS

RCC retaining wall and reinforced earth wall of 5m, 6m, 7m, 8m and 9m height above the existing ground level have been analyzed and designed.

FHWA-NHI-00-043 guidelines are referred for the design of reinforced earth wall. Reinforced earth wall is designed by using software “Bentley Geostructural Analysis”. Geogrids and steel strips are used as reinforcement. The walls are designed and detailed out in order to estimate the cost per running meter of the walls. Conventional RCC retaining wall and reinforced earth wall are analyzed economically.

1) Design of reinforced earth wall

It includes following steps

- Defining wall geometry, loading soil and geogrid properties

- Initial Dimensioning of the Structure
  Depth of embedment
  Minimum length of reinforcement

- External stability analysis
  Check for sliding along base
  Check for overturning
  Check for bearing capacity

- Internal stability analysis
  Check for pullout resistance
  Check for tension

2) Design of concrete retaining wall
- Defining wall geometry, loading, soil properties
- Initial dimensioning of structure
- Designing base, stem, toe and heel of wall
- Check for shear
- Check against sliding

3) Estimation of cost of geogrid, steel strips reinforced earth wall and concrete retaining wall
4) Estimation of cost of geogrid reinforced earth wall by varying material
5) Economic analysis of reinforced earth wall and retaining wall

DESIGN OF REINFORCED EARTH WALL

Design, procurement and construction of Geogrid RE Wall under the project for Six Lanning of Indore- Dewas Section of NH-3.

Parameters

A) Wall height = 9.98m
B) Soil properties:
Retained backfill soils – γb = 18 kN/m³, φb =30, c =0
Reinforced backfill – γr = 22 kN/m³, φr =40, c =0
Foundation Soil – γf = 18 kN/m³, φf =40, c =0
Where, γ = unit weight of soil
φ = angle of internal friction
c = cohesion
B) External Loads:
Dead load surcharge-12.43 KN/m
Live load surcharge- 22.00 KN/m
C) Soil Geogrid Interaction Parameters:
Coefficient of interaction for pull-out – 0.85
Coefficient of interaction for directing sliding – 0.85
D) Geometry of structure:
Block height h = 0.50m
Block width b = 2.00 m
E) Inputted reduction factors:
Creep reduction factor, Cr =1.50

Durability reduction factor, RFd =1.00
Installation damage reduction factor, RFid =1.50

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.

External stability analysis

The External stability comprises of evaluation of the base width 'B' required for height 'H' of the wall.

- Factor of safety against overturning = 2
- Factor of safety against sliding = 1.5
- Factor of safety for Bearing Capacity failure = 2.5

1) Factor of safety against overturning
   FOS1 = Mro / Mo
   Mro = Resisting moment against overturning,
   Mo = Overturning moment

- Mro = V1x L/2
- Mo = F1x H/3 + F2 x H/2

- V1 = HLγ and V2= qL
- F1= $\gamma H^2 Ka/2$ and F2 = qHKa

Where, H=height of wall
q = surcharge load
Ka = active earth pressure constant
L = Length of geogrid

2) Factor of safety against sliding
   FOS2 = ΣPr/ ΣPd
   Where, Pr = Resisting force
   Pd = Driving force
   Pr =V1 Tan φ
   Pd =Fl + F2

3) Factor of safety against bearing capacity of foundation soil
   FOS3 = qult / σv
   Where, qult = Ultimate bearing capacity of foundation soil
   σv = Maximum bearing pressure.

Internal Stability analysis

In internal stability analysis, deformations are controlled by the reinforcements rather than total mass. Internal stability design consists of the determination of Geogrid size, quantity, and lengths.

Internal stability analysis includes:

- Check for Pull out resistance
- Check for Tensile strength

Calculations (FHWA-NHI-00-043):

Consider Geogrid layer vertical spacing = Sv

1) Check for tensile strength, FOS= Rt / Fx

2) Tension calculation at each Geogrid reinforcement level Fx = σh x Sv

Where, σh = horizontal stress

3) Allowable strength (Rt) = $\frac{\text{Tult x Rc}}{\text{FSun x RFd x Cr}}$

Where, FS uncertainties = 1.5

RFd = durability reduction factor = 1.5

RC = the percent coverage ratio, RC = 1

Cr = Creep reduction factor = 1.5

Tult = Ultimate strength

4) Pullout calculation at each layer

Tmax ≤ $\frac{2\ \text{Ci x}\ \gamma\text{r x Le x Rc x}\ \alpha\ \text{x}\ \tan\ \varphi}{\text{FSpo}}$

Where, FSpo = factor of safety against pullout = 1.5

Ci = Coefficient of interaction = 0.85

γr = unit weight of reinforced soil mass,

α = scale effect correction factor (α = 1.0)

di = depth below top of wall

Le = length of reinforcement in resistance zone.

Rc = % coverage of Geogrid

Table 1: Output obtained from "Bentley Geostructural analysis" software for 9 m height reinforced earth wall for type and length of geogrid at each layer.

Layer No.	Distance from bottom (m)	Rt (KN/m)	Type of Geogrid	Fx(KN/m)	Length of geogrid (m)
1	0.5	53.33	180	14.92	7
2	1	53.33	180	28.79	7
3	1.5	53.33	180	27.41	7
4	2	53.33	180	26.03	7
5	2.5	44.44	150	24.65	7
6	3	44.44	150	23.26	7
7	3.5	44.44	150	21.88	7
8	4	44.44	150	20.50	7
9	4.5	35.56	120	19.12	7
10	5	35.56	120	17.73	7
11	5.5	35.56	120	16.35	7
12	6	35.56	120	14.97	7
13	6.5	29.63	100	15.93	7
14	7	29.63	100	14.04	7
15	7.5	23.70	80	12.67	7
16	8	23.70	80	11.3	7
17	8.5	23.70	80	9.94	7
18	9	23.70	80	12.22	7

Calculations of reinforced earth wall having steel strips as reinforcement 9m height wall (FHWA-NHI-00-043):

i) Calculation of σh (horizontal stress) at this level per unit width $\sigma v = Z \times \gamma + q = 49.28$ KN/m²
$\sigma h = \sigma v \times K = 22.67$ KN/m²
Where, σv = vertical stress
ii) Tributary area $At = Sv \times 2$ panel width = 2.25 m²
iii) The maximum force on tributary area is
$T = \sigma h \times At = 51$ KN
iv) If pull out FS ≥ 1.5
Resistance = $Pr \geq \sigma h \times At \times FS = 76.5$ KN
v) The number of reinforcing strips, required to satisfy the minimum resistance
$N = Pr / (2 \times b \times F' \times Le \times \sigma v')$, Where b= 50 mm
vi) La = 0.3H = 2.7m , Le = 7 – 2.7 = 4.3 m
vii) $\sigma v' = Z \times \gamma = 27.28$ kN/m²
viii) F′ = 1.85 (Obtained by interpolation from 2.0 at Z = 0 to tan φ at 6 m)

N= 4 = Strips per tributary area
60 grade steel is used Fy = 413.7 Mpa.
Fall = 0.55(Fy) = 227.5 Mpa
xi) The tensile stress in each strip
Fs = T / (N x Ec) = 98.62 Mpa < 227.5 (OK)
Where, Fs = tensile stress (Mpa)
Ec = Thickness of reinforcement at the end of design life
Fy = Yield stress of steel (Mpa)
Table 2: Output for 9m height steel strips reinforced earth wall

D (m)	Le (m)	σv (kN/m)	K	F'	σh (kN/m)	N	Tensile Stress
0.675	4.3	49.28	0.46	1.85	22.66	4	98.62
1.425	4.3	65.78	0.45	1.85	29.60	5	66.60
2.175	4.3	82.28	0.43	1.85	35.38	4	79.60
2.925	4.3	98.78	0.41	1.85	40.49	4	91.12
3.675	4.3	115.28	0.39	1.85	44.95	4	101.15
4.425	4.3	131.78	0.38	1.85	50.07	4	112.67
5.175	4.705	148.28	0.36	1.85	53.38	5	120.10
5.925	5.155	164.78	0.34	1.85	56.02	5	126.05
6.675	5.605	181.28	0.34	1.85	61.63	5	138.67
7.425	6.055	197.78	0.34	1.85	67.24	6	151.30
8.175	6.505	214.28	0.34	1.85	72.85	6	163.92
8.925	6.955	230.78	0.34	0.67	78.46	6	176.52

Schedule of bars for 9m height counterfort retaining wall

S.NO.	Part of wall	Schedule of bars
1	STEM	12 mm φ 120 mm c/c
		12 mm φ 240 mm c/c
		12 mm φ 480 mm c/c
		12 mm φ 480 mm c/c
		12 mm φ 480 mm c/c
2	BASE SLAB	14 mm φ 80 mm c/c
		14 mm φ 160 mm c/c -
		10 mm φ 100 mm c/c
		12 mm φ 80 mm c/c
		12 mm φ 160 mm c/c
3	COUNTERFORT	18 mm φ @ 100 mm c/c
		10 mm φ @ 300 mm c/c, 4 legged
		10 mm φ @ 160 mm c/c, 4 legged
		10 mm φ @ 200 mm c/c, 2 legged

ECONOMIC ANALYSIS

Schedule of rates as per Department of Urban Administration and Development and IDA for various materials/items at the time of this study are as follows:
Concrete: Rs. 6000 /m³
Tor steel bars : Rs. 63/kg
RCC precast panels: Rs. 1224/m²
Steel strips: Rs.335/m

On the basis of these rates and outcome designs tabulated in the preceding section, the total cost per running meter of the walls with respect to the heights considered in the present study have been determined. A summary of these costs is presented below:

Cost of 9m height reinforced earth wall having geogrid as reinforcement material per meter length

Table 3: Cost calculations foe geogrid RE wall

S.No.	Description of item	Nos.	Length (m)	Breadth (m)	Height (m)	Quantity (m²)	Rate	Amount (Rs.)
1.	Total no. of geogrid layers	18						
2.	Geogrid 80	4	1	7	-	28	97.5	2750
3.	Geogrid 100	2	1	7	-	14	112.5	1575
4.	Geogrid 120	4	1	7	-	28	127.5	3570
5.	Geogrid 150	4	1	7	-	28	142.5	3990
6.	Geogrid 180	4	1	7	-	28	157.5	4410
7.	Total cost of geogrid per meter length							16275
S.No.	Description of item	Nos.	Length (m)	Breadth (m)	Height (m)	Quantity (m²)	Rate	Amount (Rs.)
8.	Cost of precast panel per meter length	-	-	-	9	9	Rs.1224	11016
9.	Cost of accessories per m length of wall 10% of total cost	-	-	-	-	-	-	2729
10.	Total cost of reinforced earth wall per meter length	-	-	-	-	-	-	30200

Hence total cost of 9m height reinforced earth wall per meter length = Rs. 30200 /-

Cost calculation of 9m height reinforced earth wall having steel strips as reinforcement material per meter length of wall

Table 4: Cost calculations steel strips Reinforced earth wall

S.No.	Description of item	Nos.	Length (m)	Breadth (m)	Height (m)	Quantity	Rate	Amount (Rs.)
1.	Steel strips	9	7	-	-	63	335	21105
2.	Precast panels	-	-	-	9	9	1224	11016
3.	Accessories per meter length (10% of total cost	-	-	-	-	-	-	3212
4.	Total cost of reinforced earth wall per meter length	-	-	-	-	-	-	35335

Hence total cost of 9m height reinforced earth wall having steel strips per meter length = Rs.35335/-

Economic analysis of 9m height reinforced earth wall by varying backfill materials and angle of internal friction of backfill material

Backfill materials used for economic analysis are: Silty gravel, gravel with fines, sand with fines, well graded sand and poor graded sand.

Cost calculation of reinforced earth wall having silty gravel as backfill material

For angle of internal friction = 30°

Calculated length of geogrid = 7.2m

No. of layers of geogrid 80 = 4

No. of layers of geogrid 100 = 2

No. of layers of geogrid 120 = 4

No. of layers of geogrid 150 = 4

No. of layers of geogrid 180 = 4

Cost of geogrid 80 = Rs. 4 x 97.5 x 7.2 = Rs. 2808

Cost of geogrid 100 = Rs. 2 x 112.5 x 7.2 = Rs. 1620

Cost of geogrid 120 = Rs. 4 x 127.5 x 7.2 = Rs. 3672

Cost of geogrid 150 = Rs. 4 x 142.5 x 7.2 = Rs. 4101

Cost of geogrid 180 = Rs. 4 x 157.5 x 7.2 = Rs. 4536

Total cost of geogrid = Rs.16740

Total cost of precast panels = 9 x 1224 = Rs.11016

Cost of accessories = 10% of total cost = 10% x 27756 = Rs.2775.6

Total cost of reinforced earth wall = Rs.30532

Table 5: Cost of Reinforced earth wall at different angle of internal friction

S.No.	Angle of internal friction	Length of geogrid (m)	Cost of Reinforced earth wall (Rs.)
1	30°	7.2	30532
2	31°	7	30020
3	32°	6.8	29284
4	33°	6.5	29172
5	34°	6.4	27960

Similarly cost of RE wall can be calculated by varying backfill materials.

Table 6: Cost of RE wall at different angle of internal friction having gravel with fines as backfill material

S.No.	Angle of internal friction	Length of geogrid (m)	Cost of Reinforced earth wall (Rs.)
1	30°	7.4	30680
2	31°	7	29674
3	32°	6.8	28950
4	33°	6.5	28205
5	34°	6.4	27960
6	35°	6.3	27270

Table 7: Cost of RE wall at different angle of internal friction having sand with fines as backfill

S.No.	Angle of internal friction	Length of geogrid (m)	Cost of Reinforced earth wall (Rs.)
1	28°	7.9	32332
2	29°	7.6	31560
3	30°	7.4	31045
4	31°	7	30020

Table 8: Cost of RE wall having poor graded sand as backfill material

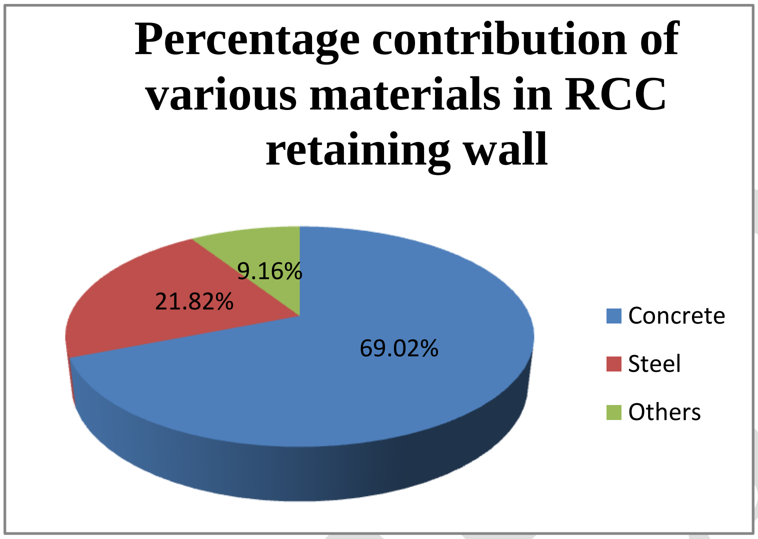
S.No.	Angle of internal friction	Length of geogrid (m)	Cost of Reinforced earth wall (Rs.)
1	32°	6.7	29255
2	33°	6.5	28635
3	34°	6.45	28081
4	35°	6.4	27960
5	36°	6.3	27710

Analysis of cost of conventional RCC retaining wall

Cost of various materials required for constructing 9m height RCC retaining wall is calculated
Total cost of 9m height per meter length of wall=Rs.73620
Cost of M-20 concrete = Rs.50816
Cost of steel reinforcement = Rs.16112
Cost of shuttering, bar bending, form work and curing etc = Rs.6692

Percentage contribution of concrete, steel, shuttering, bar bending, formwork and curing used for construction of conventional RCC retaining wall.

1) Concrete – 69.02%
2) Steel – 21.82%
3) Others – 9.16%



RESULTS

RCC retaining wall and reinforced earth wall having steel strips and geogrid as reinforcement material of 5m, 6m, 7m, 8m and 9m height above the existing ground level (EGL) have been analyzed and designed. Cost of RCC retaining wall and reinforced earth wall for various heights are tabulated below:

Table 9: Cost of various retaining walls at different heights

Height of wall	Cost of RCC retaining wall (Rs.)	Cost of Steel strips RE wall (Rs.)	Cost of Geogrid RE wall (Rs.)
5m	40250	17000	14500
6m	43952	22082	16580
7m	48780	24165	20700
8m	56605	27722	23840
9m	73620	35335	30200

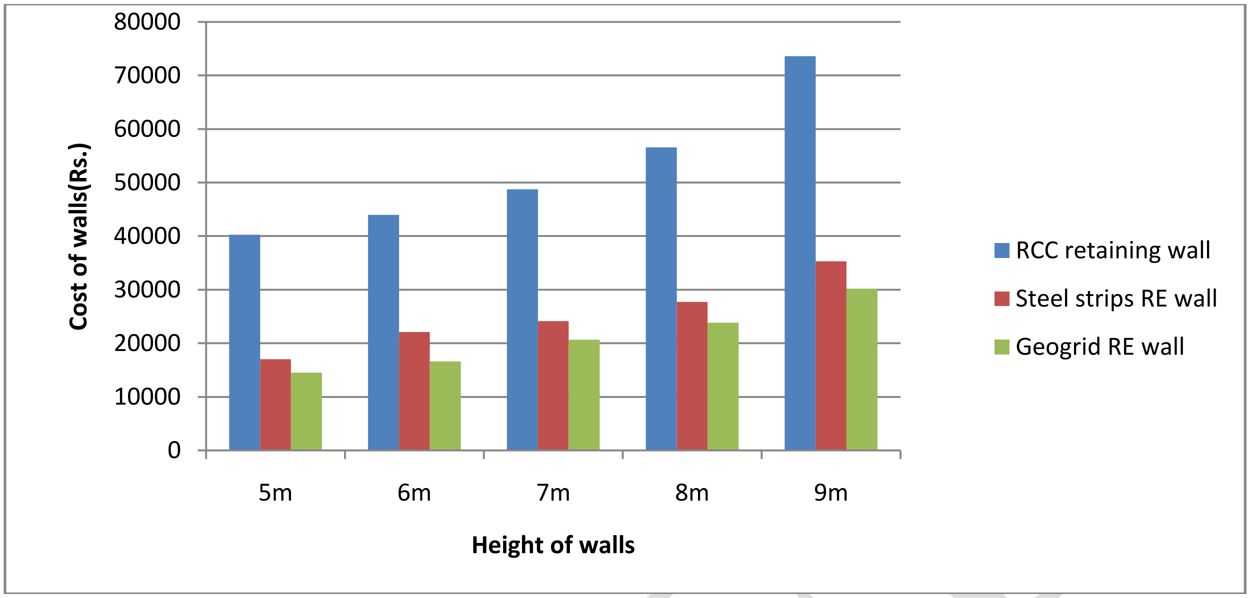


Figure 1 : Graph drawn between height of walls and cost of different walls

Table10: Percentage savings of the RE wall as compared to RCC retaining wall

Height of wall	Steel strips RE wall	Geogrid RE wall
5m	57%	63%
6m	49.75%	62%
7m	50.46%	57%
8m	51%	57.88%
9m	52%	58.9%

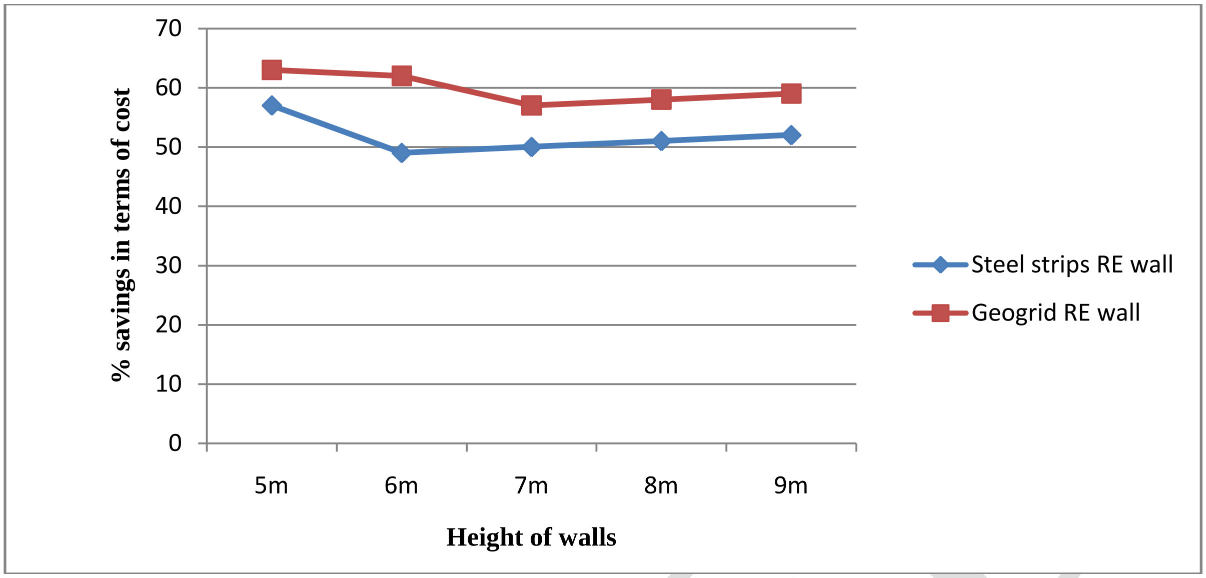


Figure 2 : Graph drawn between height of walls and percentage savings in terms of cost

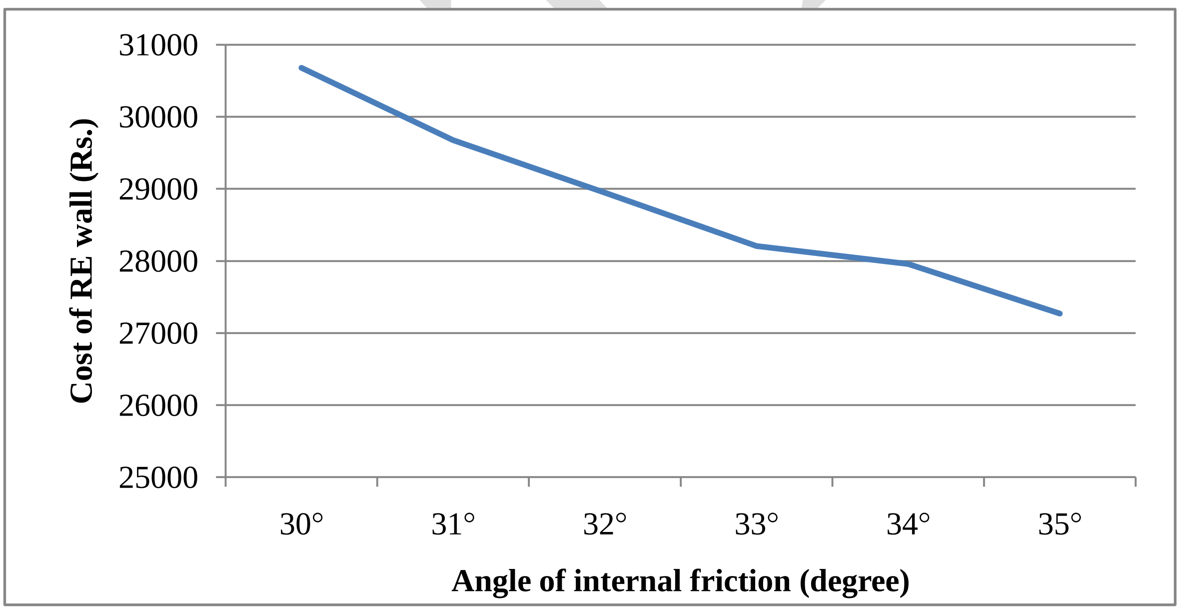


Figure 3: Graph drawn between angle of internal friction of silty gravel soil and cost of geogrid reinforced earth wall

Graphs drawn between angle of internal friction and cost of geogrid reinforced earth wall shows that

- On increasing angle of internal friction the cost of geogrid decreases for different types of reinforced backfill.

- Length of geogrid decreases on increasing angle of internal friction of backfill material.

CONCLUSIONS

RCC retaining wall and reinforced earth wall of 5m, 6m, 7m, 8m and 9m height above the existing ground level have been analyzed and designed. Following conclusions can be drawn:

• Length of geogrid required reduces on increasing angle of internal friction of reinforced soil, ultimately reduces the cost of geogrid reinforced earth wall.

• Cost contribution of concrete and steel in RCC Retaining wall of 9m height are about 67.8 % and 23.09 % respectively.
Hence the major contribution in the cost difference is attributed to the huge amount of concrete and steel bars usually required in the conventional retaining walls as compared to reinforced earth wall.

• Deployment of the reinforced earth wall by geogrid reduces the cost upto 60% and by metallic strips reduces cost up to 52.042 % as compared to conventional RCC retaining wall. Hence reinforced earth walls are significantly more economical compared to the RCC retaining wall for the given geometric and loading conditions considered in this study.

• It has been experienced that the that the construction of RE wall takes less time as compared to RCC retaining wall, since RE wall can be constructed much rapidly with the use of prefabricated concrete elements.

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