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"Comparative Design and Cost Analysis of Reinforced Soil (MSE) walls and RCC Cantilever Retaining walls"

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ABSTRACT:

This research presents a comparative analysis between Reinforced Cement Concrete (RCC) cantilever retaining walls and Reinforced Soil (RS) walls, also known as Mechanically Stabilized Earth (MSE) walls. The objectives are to analyse the design, cost estimation, and environmental impact of both walls. Retaining walls were designed for various heights (3.2 m to 6.4 m) using Limit State Design principles as per IS 456:2000 for RCC and BS 8006:2010 for RS walls. In RS walls, geogrids were used as a reinforcing element with segmental panel facings, whereas RCC walls required considerable quantity of cement and steel content, as well as shuttering and curing. According to the cost comparison, RS walls are 40.80% more cost-effective than RCC walls. In additionally, RS walls offer better performance in seismic zones, require less construction time, and are environmentally sustainable. This study concludes that RS walls are a cost-effective, durable, and environmentally sustainable. alternative to conventional RCC retaining walls, especially for infrastructure and highway projects.

Key words: Retaining wall, Reinforced soil, Geogrid, External Stability, Internal Stability.

Introduction:

Retaining walls play a crucial role in geotechnical and civil engineering by providing lateral support to vertical or near-vertical grade changes. They are widely used to prevent soil erosion, stabilize slopes, and create level surfaces on sloping ground, making them essential in both urban development and transportation infrastructure. The concept of reinforced soil, first proposed by Henri Vidal in 1969, served as the foundation for the constructions, demonstrating that the use of soil in conjunction with tensile reinforcing materials greatly improves stability and load-carrying capability (Vidal, 1969). Traditionally, Reinforced Cement Concrete (RCC) cantilever walls have been the preferred choice due to their high strength and reliability in withstanding lateral earth pressures. But there are several disadvantages to RCC walls. Their construction requires substantial quantities of high-energy materials such as cement and steel, which not only increases project costs but also contributes to a higher environmental footprint. Nowadays conventional retaining walls are replaced with Reinforced soil walls, also known as Mechanically Stabilized Earth (MSE) walls. These systems consist of compacted granular backfill reinforced with layers of geosynthetics, such as geogrids or geotextiles, to provide a stable mass that can effectively resist lateral earth pressures and durability while reducing the embodied energy and environmental footprint of retaining structures (Pisini et al., 2020). Reinforced Soil Retaining Walls have received an extensive amount of attention for their cost-effectiveness, versatility, and structural efficiency. The application of geosynthetics or metallic reinforcements in MSE walls provides enhanced stability and allows for design flexibility. Studies have shown that such systems perform well under various loading conditions, including seismic and differential settlements (Sarkar & Biswas, 2021). For rehabilitating and reconstructing the embankments of the study road, reinforced concrete and reinforced earth retaining walls were evaluated. After detailed design, cost, and time analysis, the reinforced earth retaining wall was found to be the most suitable and economical for road projects in Jordan. Geosynthetic walls are especially effective for high vertical cuts and have shown long-term stability in existing projects in Amman, with no visible damage or settlement (Al Rawi & Al Abade, 2017).

This research aims to provide a comprehensive comparison between Reinforced soil (MSE) walls and RCC cantilever retaining walls by evaluating their design approaches, material requirements, cost analysis, and overall structural behavior to assess which type of wall offers the most suitable solution for modern infrastructure requirements.

Methodology:

The main objectives of this research methodology are to design RS walls and RCC walls based on relevant design codes and to conduct a comprehensive cost estimation.

Design details:

The design of both Reinforced Soil walls and RCC cantilever retaining walls was carried out using Limit State Design principles, ensuring safety against both external and internal failure modes as per BS 8006:2010 for Reinforced soil walls and IS 456:2000 for RCC walls for design heights of 3.2 meter to 6.4 meter for the following parameters.
Soil Parameters

Table 1 Soil Parameters

Soil Data	**Cohesion (C) (kPa)**	**Unit Weight (ϒ) (kN/m^3)**	**Angle of internal friction (Ø)**
Reinforced fill Soil	**0**	**18**	**32o**
Retained Soil	**0**	**20**	**32o**
Foundation Soil	**0**	**18**	**30o**

External Loading,

- Dead Load Surcharge DL = 13.20 kN/m^2
- Traffic Surcharge LL = 22 kN/m^2
- Frictional Slab Load SL = 8 kN/m^2
- (assumed width of Frictional Slab is 1.60 m)

Seismic Parameters,

- Seismic Zone = II
- Max. Ground acceleration coefficient = 0.08
- Max. wall acceleration = 0.11

Design of Reinforced Soil Wall Namaste

- Design for External Stability: The effects of dead loads and other loads and forces acting on the structure should be considered when assessing external stability. To ensure external stability of a retaining wall, the design must satisfy three key criteria with their respective partial factor of safety (FS) of 1.5 against overturning, 1.4 against sliding, and 1.20 for bearing capacity failure:

- Overturning ($Mr\ /\ Mo \geq 1.5$)
- Mr = Resisting moment, Mo = Overturning moment.
- Sliding ($(Rv \tan Ø)/Rh \geq 1.4$)
- Rv = Vertical Load, Rh = Horizontal Load.
- Bearing Capacity Failure ($q_{allow}/q_{req} \geq 1.2$)
- q_{allow} = Ult. Bearing Capacity of foundation soil, q_{req} = Req. Ultimate Bearing Capacity of soil.

Table 2. Factor of safety with respect to wall height for load combination A

Sr. No	**Height of wall H (m)**	**Trial Length of Reinforcement B (m)**	$\frac{Mr}{Mo}$	q_{allow}	$\frac{Rv \tan Ø}{Rh}$	**Provided length of reinforcement B (m)**
1	**3.2**	**3.0**	**5.43**	**3.519**	**3.146**	**3.5**
2	**4.0**	**3.3**	**5.22**	**3.216**	**3.030**	**4.10**
3	**4.8**	**3.8**	**5.33**	**3.074**	**3.023**	**4.8**
4	**5.6**	**4.4**	**4.87**	**2.762**	**2.863**	**5.20**
5	**6.4**	**4.9**	**4.86**	**2.639**	**2.839**	**5.8**

Table 3. Factor of safety with respect to wall height for load combination B

Sr. No	**Height of wall H (m)**	**Trial Length of Reinforcement B (m)**	$\frac{Mr}{Mo}$	q_{allow}	$\frac{Rv \tan Ø}{Rh}$	**Provided length of reinforcement B (m)**
1	**3.2**	**3.0**	**3.62**	**5.575**	**1.649**	**3.5**
2	**4.0**	**3.3**	**3.48**	**4.806**	**1.645**	**4.10**

3	**4.8**	**3.8**	**3.55**	**4.479**	**1.684**	**4.8**
4	**5.6**	**4.4**	**3.25**	**3.806**	**1.628**	**5.20**
5	**6.4**	**4.9**	**3.25**	**3.567**	**1.641**	**5.8**

Table 4. Factor of safety with respect to wall height for load combination C

Sr. No	**Height of wall H (m)**	**Trial Length of Reinforcement B (m)**	[illegible]	q_{allow}	[illegible]	**Provided length of reinforcement B (m)**
1	**3.2**	**3.0**	**14.39**	**10.810**	**5.702**	**3.5**
2	**4.0**	**3.3**	**12.11**	**9.520**	**5.019**	**4.10**
3	**4.8**	**3.8**	**11.20**	**8.781**	**4.689**	**4.8**
4	**5.6**	**4.4**	**9.47**	**7.780**	**4.224**	**5.20**
5	**6.4**	**4.9**	**8.88**	**7.275**	**4.026**	**5.8**

(Minimum Trial Length = Greater of 0.7H & 3.0m, as per BS 8006:2010)

Design for Internal Stability: Internal stability checks ensure that the reinforcement layers within the Reinforcement soil zone are capable of resisting all imposed forces without failure. As per BS 8006:2010, internal stability is evaluated through two modes.

Tensile Rupture Check: This check ensures that the tensile force produced in each reinforcement layer due to earth pressure and surcharge loads does not exceed the long-term design strength of the geogrid.

Rupture check = $Td.Rc/fn \geq Tj$

$Td = Tult/fm$ = Design strength of Reinforcement.

Rc = Coverage ratio for geogrid (assumed Rc = 0.5)

Fn = ramification factor = 1.10,

Fm = Partial material factor = 1.714

Tensile force $(Tj) = Tpj + Tsj$

Tpj = Tensile force due to vertical loads,

Tsj = Tensile force due to strip/concentrated load.

i) **Pullout Resistance Check**: Pullout checks ensure that the embedded length of reinforcement is sufficient to resist pullout under the applied tensile loads.

Pullout check $= Pj(\mu.Lej.(ffs.\gamma.Zj + ffs.DL)/(fp.fn)) \geq Tj$

Pullout Strength $= Pj(\mu.Lej.(ffs.\gamma.Zj + ffs.DL)/(fp.fn))$

Pj = Available total horizontal width of the top and bottom faces of reinforcement (geogrid),

μ = Coefficient of friction between fill & reinforcement element (0.50),

$Lej = (L - (H - hj) \times \tan(45 - \varphi/2))$,

ffs = Partial factor for load combination as per BS 8006:2010,

fp = Partial factor for soil reinforcement.

Notes:

- The spacing ((Sv) provided for the uppermost layer and lowermost layer is 0.4 m, and for the intermediate layer is 0.8 m. (IRC: SP: 102–2014).
- Reinforcement layer is sequenced from bottom to top; layer no. 1 is the bottom layer.
- Zj is the height of the jth layer measured from top of levelling pad.
- T_{ult} is the short-term peak tensile strength of the geogrid.
- TD is the long-term design strength of the geogrid.

Table 5 Output for 6.4 m Wall for Reinforcement (Geogrid) Details at Each Layer

Layer from bottom	zj **(m)**	hj **(m)**	**Length of Reinf. (m)**	$Tult$ (kN/m)	**Td**	**Type of Geogrid**	**No. of Connection**
1	**0.40**	**6.00**	**5.80**	**250**	**145.86**	**SGU 250**	**2**
2	**1.20**	**5.20**	**4.90**	**250**	**145.86**	**SGU 250**	**2**
3	**2.00**	**4.40**	**4.90**	**200**	**116.68**	**SGU 200**	**2**
4	**2.80**	**3.60**	**4.90**	**180**	**109.13**	**SGU 180**	**2**
5	**3.60**	**2.80**	**4.90**	**150**	**90.95**	**SGU 150**	**2**

6	**4.40**	**2.00**	**4.90**	**120**	**72.76**	**SGU 120**	**2**
7	**5.20**	**1.20**	**4.90**	**100**	**60.63**	**SGU 100**	**2**
8	**6.00**	**0.40**	**5.30**	**80**	**48.50**	**SGU 80**	**2**

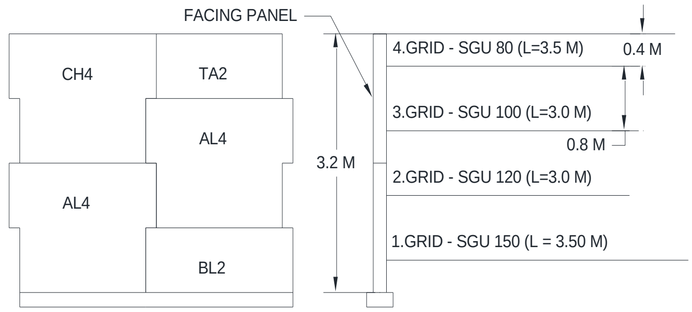


Figure 1: Design detail of RS wall for height 3.2 M

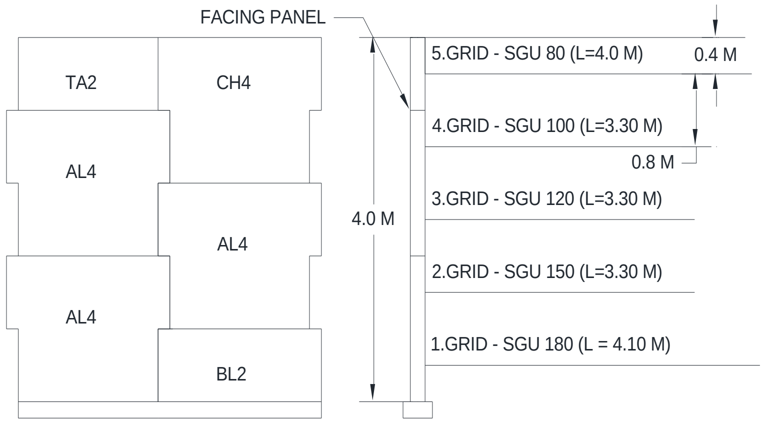


Figure 2: Design detail of RS wall for height 4.0 M

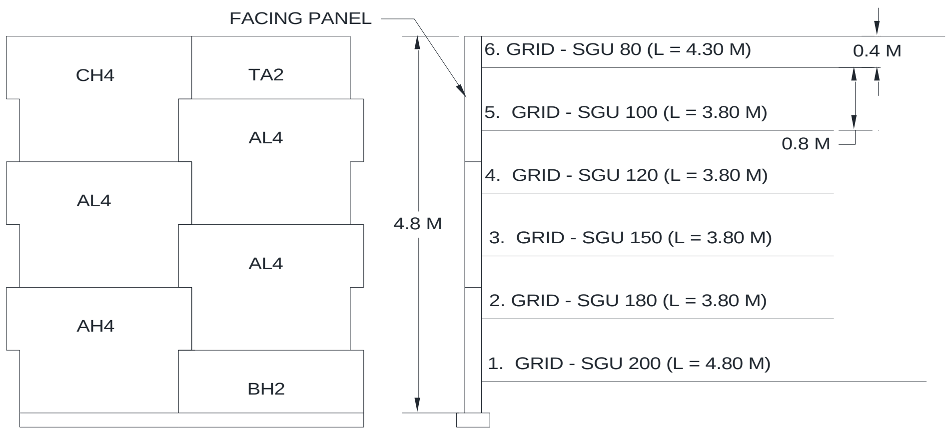


Figure 3: Design detail of RS wall for height 4.8 M

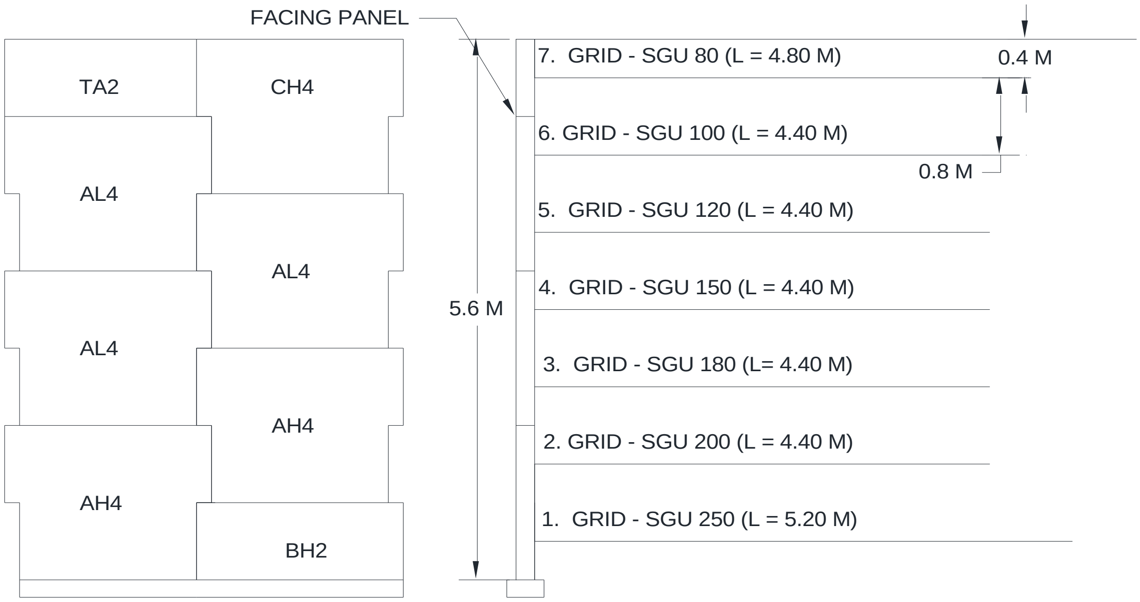


Figure 4: Design detail of RS wall for height 5.6 M

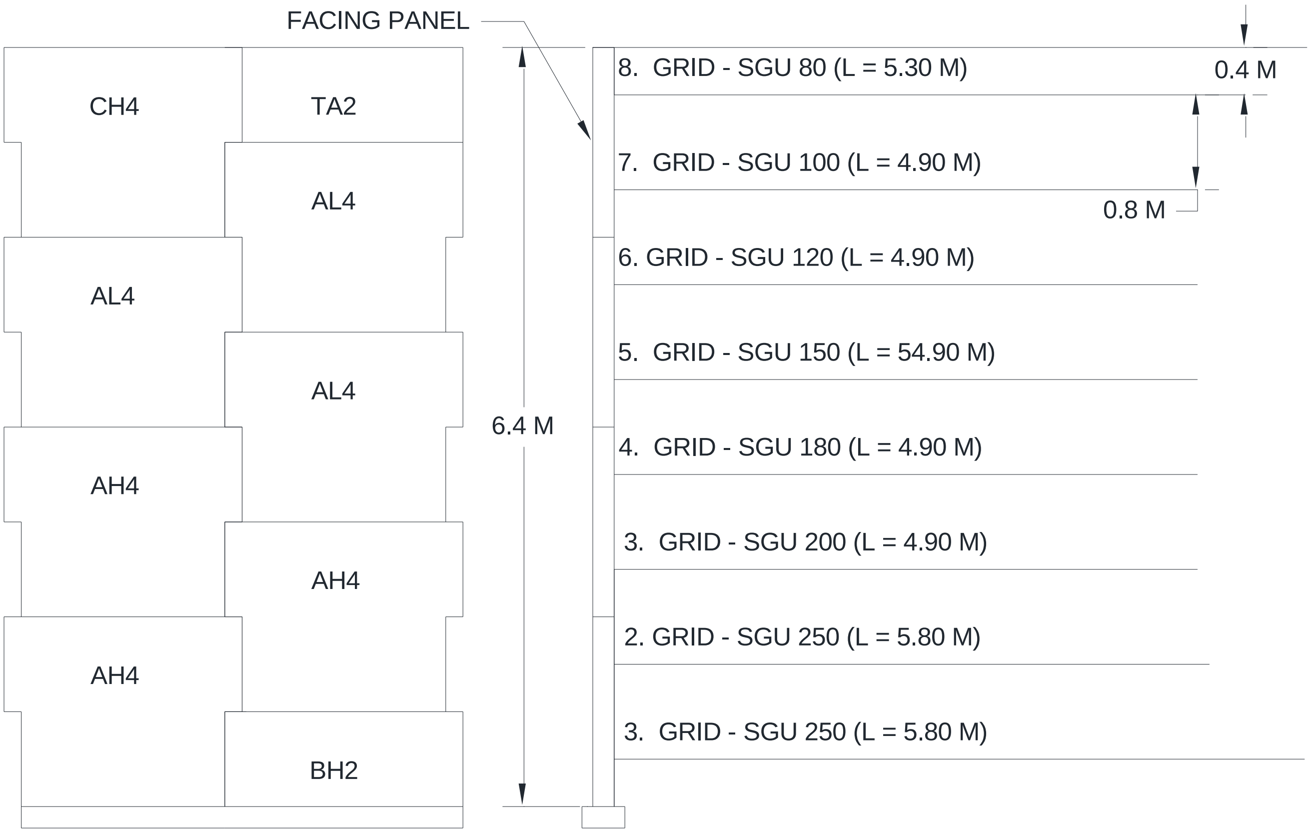


Figure 5: Design detail of RS wall for height 6.4 M

- **Design of R.C.C. cantilever wall** with uniform surcharge by using limit state method as per IS 456:2000 for Materials M20 concrete and Fe415 steel.

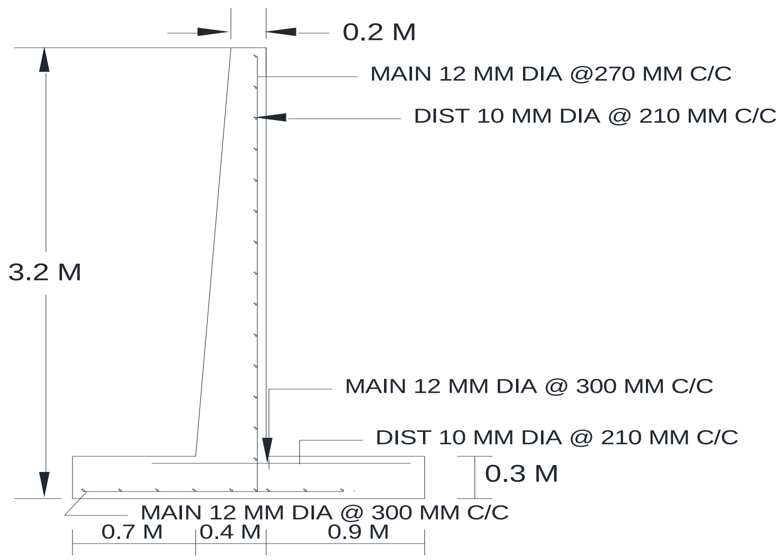


Figure 6: Design detail of RCC wall for height 3.2 M

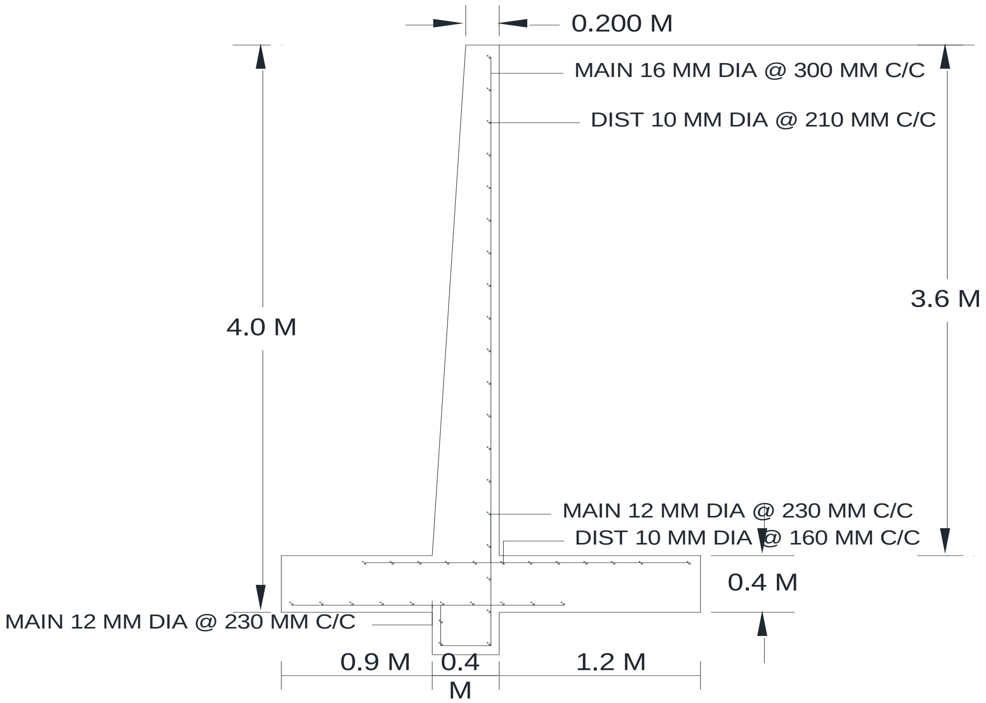


Figure 7: Design detail of RCC wall for height 4.0 M

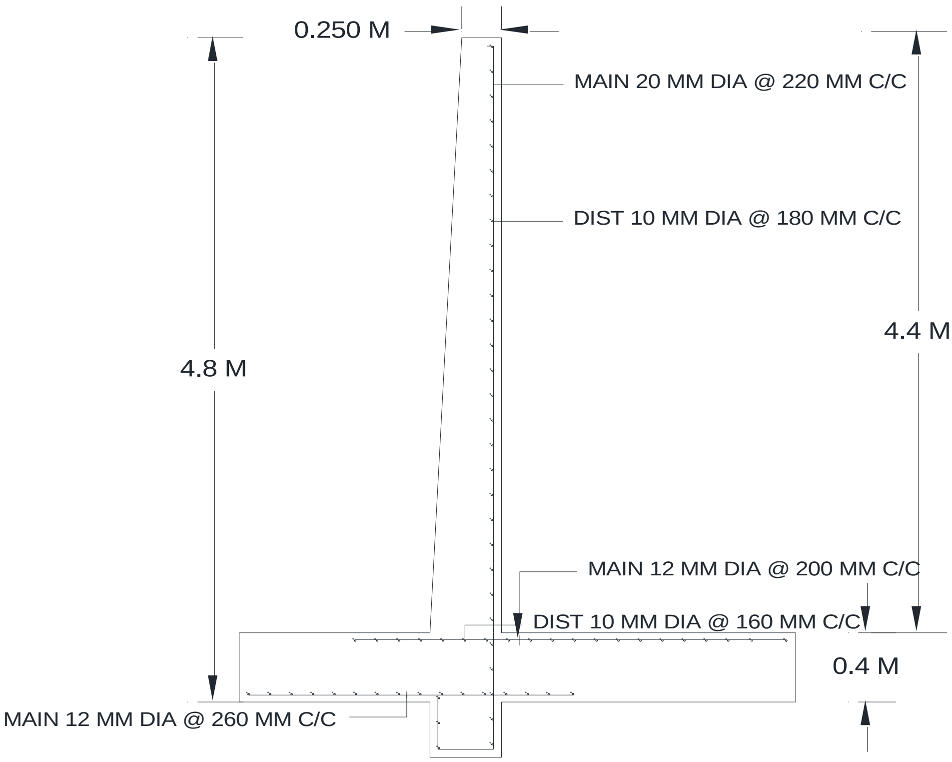


Figure 8: Design detail of RCC wall for height 4.8 M

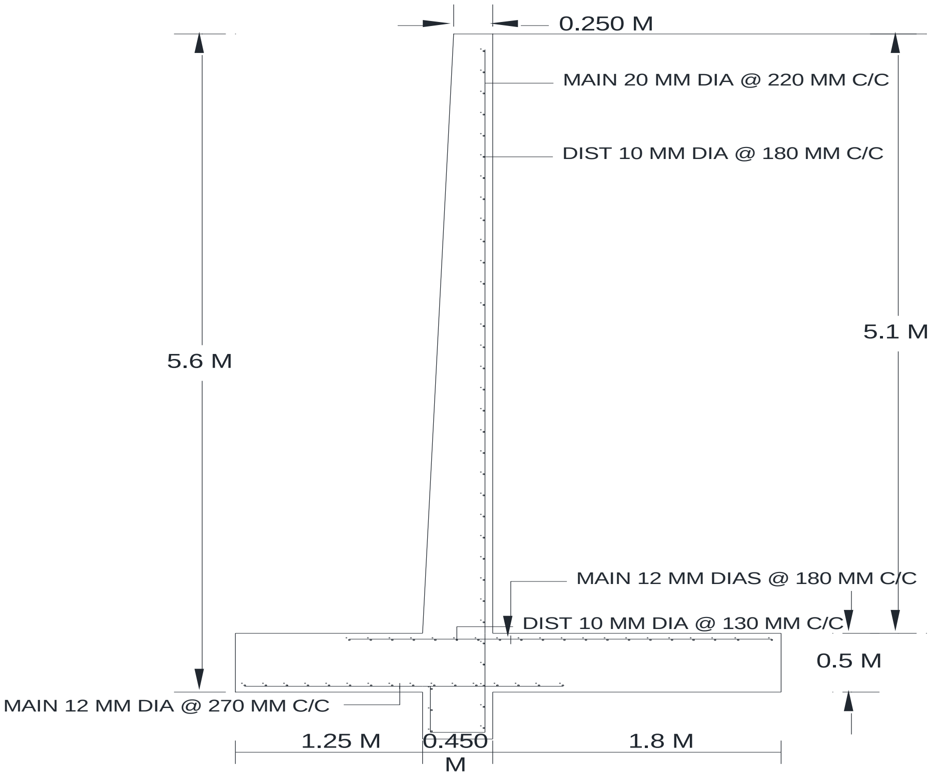


Figure 9: Design detail of RCC wall for height 5.6 M

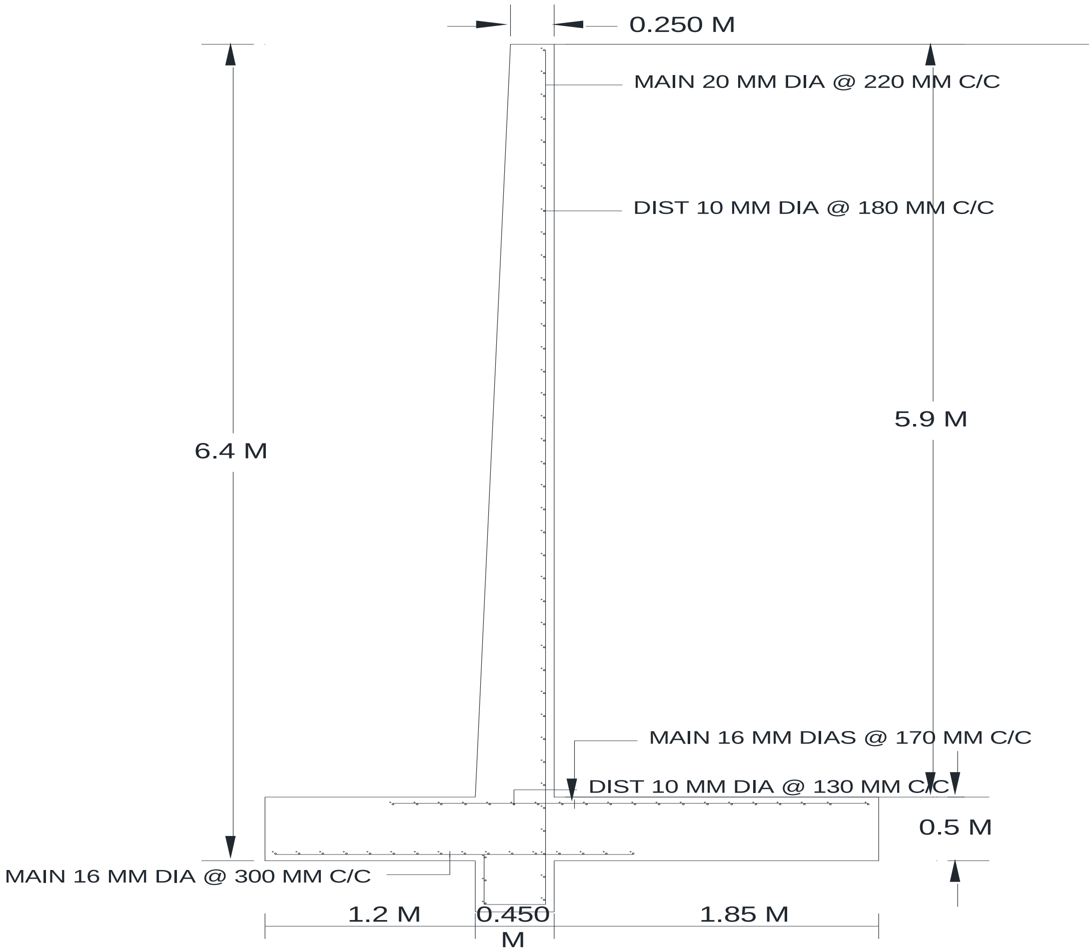


Figure 10: Design detail of RCC wall for height 6.4

Cost Comparison of Reinforced soil (MSE) wall and RCC cantilever Retaining wall: To compare cost estimation of Reinforced soil wall and RCC cantilever wall, Wall height of 6.4 m is selected.

Cost Estimation of Reinforced Soil wall for height 6.4 M.

Table 6 Geogrid consumption

Grade	Length In M	bs	R_c	Connection	Consumption in (M^3)	Rate	Cost
SGU 250	**5.8**	**0.25**	**0.5**	**2**	**2.9**	**114.7**	**332.63**
SGU 250	**4.9**	**0.25**	**0.5**	**2**	**2.45**	**114.7**	**281.015**
SGU 200	**4.9**	**0.25**	**0.5**	**2**	**2.45**	**101.2**	**247.94**
SGU 180	**4.9**	**0.25**	**0.5**	**2**	**2.45**	**91.5**	**224.175**
SGU 150	**4.9**	**0.25**	**0.5**	**2**	**2.45**	**81.6**	**199.92**
SGU 120	**4.9**	**0.25**	**0.5**	**2**	**2.45**	**71.6**	**175.42**
SGU 100	**4.9**	**0.25**	**0.5**	**2**	**2.45**	**64.1**	**157.045**
SGU 80	**5.3**	**0.25**	**0.5**	**2**	**2.65**	**55.3**	**146.545**
TOTAL CONSUMTION =					**20.25**		**0**
PER M^2 CONSUMTION =					**3.164**		**1764.69/-**

Table 7 Consumptions of Concrete and Steel for Facing panel

2. PANEL TYPE	AREA IN (M^2)	CONCRETE IN (M^3)	WEIGHT OF STEEL IN (kg)	REMARK
TA2	1.486	0.26748	5.69	As per Panel referred by RSE INFRA PVT.
AL4	3.2	0.576	15.433	
AL4	3.2	0.576	15.433	
AH4	3.2	0.576	24.109	
BH2	1.732	0.31176	13.122	
TOTAL	12.818	2.3072	73.787	
PER METER CONSUMPTIOM	6.409	1.15362	36.89	

Table 8. Abstracting

SR. NO	DESCRIPTION	GRADE	UNIT	CONSUMPTION	RATE PER UNIT	TOTAL AMOUNT	REMARK
1	CONCRETE	M35	M^3	1.15	7300	8421.43	RATE AS PER MARKET PRICING
2	STEEL	FE500	kg	36.89	72	2656.33	
3	GEOGRID	AS PER DESIGN	M^2	20.25	1764.69	1764.69	
CUMULATIVE RATE PER 1 MTR LENGTH 6.4 MTR HEIGHT OF RE WALL						12842.45/-	
4	ADD 5% FOR CONTIMGENCIES & WORK CHARGED ESTABLISHMENT					642.12/-	
GRAND TOTAL						13484.57/-	

Cost Estimation of RCC cantilever retaining wall for height 6.4 M.

Table 9 Steel Consumption

SR. NO	BAR	DIA	SPACING IN MM	NUMERS	LENGTH IN M	TOTAL LENGTH IN (M)	WEIGHT IN (KG)	REMARK
1	STEM							WEIGHT= $\left(\frac{\Psi^2}{162}\right) \times TOTAL\ LENGTH$
	MAIN	20	130	8	6.4	51.2	126.42	
	DIST	10	180	36	1	36	22.22	
2	HEEL SLAB							
	MAIN	16	170	6	2.3	13.8	21.8	
	DIST	10	130	18	1	18	11.11	
3	TOE SLAB							
	MAIN	16	300	4	1.65	6.6	10.43	
	DIST	10	130	13	1	13	8.02	
4	SHEAR KEY							
	MAIN	16	170	6	1.45	8.7	13.75	
	DIST	10	130	11	1	11	6.79	
TOTAL STEEL CONSUMPTION IN kg =							220.55	

Table 10 Concrete Consumption

SR.NO	PARTICULARS OF ITEM	NO	LENGTH IN M	BREATH IN M	HEIGHT IN M	QUNTITY IN M^3	REMARK
	R.C.C WORK 1:2:4						
							STEM LENGTH=

1	STEM	1	1	0.35	5.9	2.065	6.4-0.5
2	BASE SLAB	1	1	3.5	0.5	1.75	
3	SHEAR KEY	1	1	0.45	0.4	0.18	
TOTAL CONTITY IN M^3 =						3.995	

Table 11 Abstracting

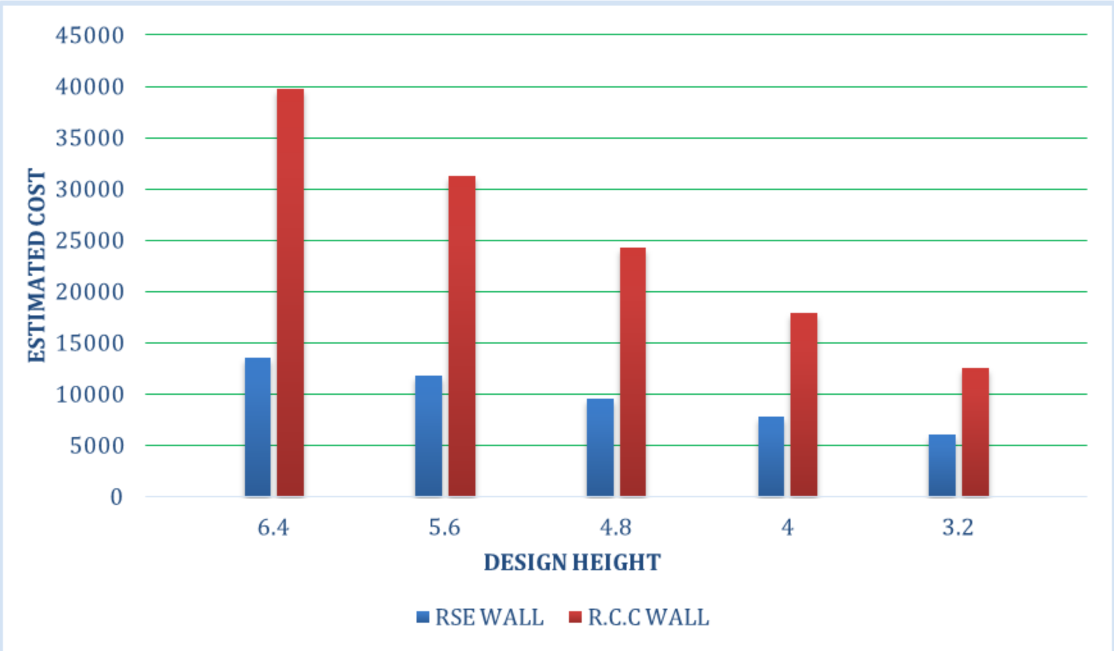
SR. NO	PARTICULARS OF ITEM	GRADE	UNIT	QUANTITY	RATE PER UNIT	TOTAL AMOUNT	REMARK
1	CONCRETE	M20	M^3	3.995	5500	21972.5	AS PER MARKET RATES
2	STEEL	FE415	kg	220.553	72	15879.8	
CUMULATIVE RATE PER 1 MTR LENGTH						37852.32/-	
3	ADD 5% FOR CONTIMGENCIES & WORK CHARGED ESTABLISHMENT					1892.62/-	
GRAND TOTAL =						39744.94/-	

Result and Discussion:

Cost Comparison between R.C.C. Cantilever Retaining Wall and Reinforced Soil (MSE) Wall for per 1 Meter Length.

Table 12 Cost Analysis

COST COMPARISON					
SR.NO	1	2	3	4	5
DESIGN HEIGHT IN MTR	3.2	4	4.8	5.6	6.4
RSE WALL	6008.7/-	7799/-	9508.7/-	11806/-	13485/-
R.C.C WALL	12543/-	17924/-	24301/-	31314/-	39745/-
% COST DIFFERENCE	48%	44%	40%	38%	34%
AVERAGE	40.80%				



Graph 1: Cost Analysis between RSE Wall and RCC Wall

According to cost analysis, the construction cost of a Reinforced soil (MSE) wall is **40.80%** less than that of R.C.C cantilever retaining wall. Because of this, the geosynthetic reinforced soil wall is more economical and cost-effective for large-scale infrastructure projects.

Conclusion:

According to cost analysis, the construction cost of a Reinforced Soil (MSE) wall is approximately 40.8% lower than that of a conventional RCC cantilever retaining wall. RS walls offer environmental benefits through reduced carbon emissions and material use, and their flexibility makes them ideal for seismic zones and uneven terrains. Because of this, the geosynthetic reinforced soil wall is more economical and cost-effective for large-scale infrastructure projects.

This study concludes that RS walls are a cost-effective, environmentally sustainable, and construction-friendly alternative to RCC retaining walls. Their adoption should be encouraged in infrastructure projects where applicable, without compromising safety, durability, or performance standards.

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