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Study of Cost Economics of Retaining Wall over Reinforced Earth Wall

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***Abstract*— In this paper the analysis for the retaining wall and reinforced earth walls have been designed by keeping the same design data (at same location) and then calculating quantities and cost accordingly for the height of 6m and 9m. The cost estimation has been done with Schedule Of Rates 2014 issued by MP PWD for road and bridges. From this analysis this has been proved that the reinforced earth wall is more economical then the retaining wall and with the increase in height the cost effectiveness of Reinforced Earth Wall over retaining wall increases.**

***Keywords* — Retaining wall, Reinforced Earth wall, cost effectiveness.**

I. INTRODUCTION

Retaining wall/ Reinforced earth walls play a critical role in the development of modern infrastructure due to safety, environmental, and economic reasons. Planning, design and construction techniques are revised and refined to satisfy several parameters including feasibility, ease of construction, safety, maintainability, and economy of the better soil retention system. There has been a significant increase in the traffic and congestion across urban areas that has created a demand for a better, efficient and economical soil retention system for bridges, underpasses, flyover and any other type of grade separator.

Over the time, classical gravity retaining walls transitioned into reinforced concrete types, some with buttresses and counterforts. A paradigm shift occurred in the 1960s with the advent of mechanically stabilized earth (MSE) masses, i.e., reinforced layers of soil allowing for modular construction, which was clearly recognized as being advantageous in most situations. The reinforcement was initially steel straps, and subsequently welded wire mesh provided an alternative. Wall facings varied from metallic-to-reinforced concrete-to-segmental units of a variety of types and shapes.

By the 1980s this mechanically stabilized earth technology was advanced by the methods of polymeric reinforcement using geo-grids, geotextiles and polymer straps.

Thus, at the present time these are still followed. There are number of reasons of using the mechanical stabilized earth reinforced earth wall among which are construction for the use of blocks, ease of placement using manual labor, ease of geo-synthetic connection to the facing, conformance to essentially any variation in line and grade, good tolerance for irregularities, and (perhaps most importantly) outstanding aesthetics.

No longer confined to low and medium heights, MSE walls with geo-synthetic reinforcement now compete with other wall types in all height categories. Twelve meter high walls, and above, exists at the present time. The largest wall is located in Taiwan which is approximately 38m high. Soil retaining technique has several applications like simple retaining walls, abutment for bridges, high embankment, Slope stabilization etc. It basically involves incorporating reinforcement in earth/ fills to provide steeper slopes than would otherwise be possible. It involves use of a range of reinforcements; such as metallic strips, bars, grids, meshes, sheets, etc embedded in the well compacted fill behind. The grids or meshes are either anchored in facia panels or wrap around, the latter especially in case of polymeric reinforcement. The reinforcement improves the behavior of the fill both at service condition and at the failure stage.

II. NEED FOR THE STUDY

Retaining structures are essential elements of every highway design. Retaining structures are used not only for bridge abutments and wing walls but also for slope stabilization and to minimize right of way for embankment.

For many years, retaining structures were almost exclusively made of reinforced concrete and were designed as gravity or cantilever walls that are essentially rigid structures and cannot accommodate significant differential settlements unless founded on deep foundations. With increasing height of soil to be retained and poor subsoil conditions, the cost of reinforced concrete retaining walls increased rapidly.

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Whereas, on the other hand Mechanically Stabilized Earth Wall (MSEW) is cost-effective soil-retaining structures that can tolerate much larger settlements than reinforced concrete walls. By placing tensile reinforcing elements (inclusions) in the soil, the strength of the soil can be improved significantly such that the vertical face of the soil/reinforcement system is essentially self-supporting.

Use of a facing system to prevent soil raveling between the reinforcing elements allows very steep slopes and vertical walls to be constructed safely. In some cases, the inclusions can also withstand bending from shear stresses, providing additional stability to the system. Inclusions have been used since prehistoric times to improve soil. The use of straw to improve the quality of adobe bricks dates back to earliest human history. Many primitive people used sticks and branches to reinforce mud dwellings during, the 17th and 18th centuries, French settlers along the Bay of Fundy in Canada used sticks to reinforce muddikes.

III. Types Of Retaining Wall

Retaining walls may be classified into two groups, externally stabilizes walls and internally stabilized walls. The examples of the externally stabilizes walls are gravity walls, reinforced concrete cantilever and reinforced concrete counterfort walls. These walls are essentially characterized by the concept that the lateral earth pressures due to self-weight of the retained fill and accompanied surcharge loads are carried by the structural wall. This necessitates a large volume of concrete and steel to be used in such walls. The construction sequence of these walls involves casting of base and stem followed by backfilling with specified material. This requires considerable amount of time as concrete has to be adequately cured and sufficient time spacing has to be allowed for concrete of previous lift to gain strength before the next lift is cast.

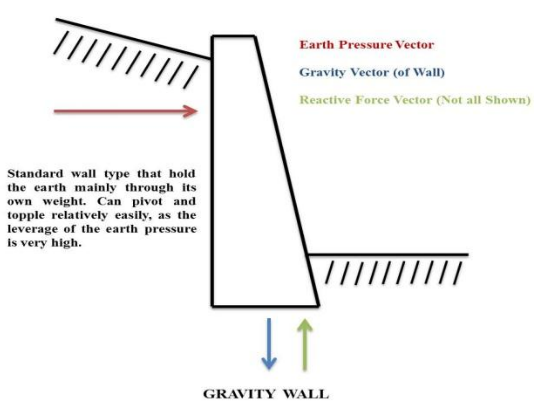

Fig.1Gravity Wall

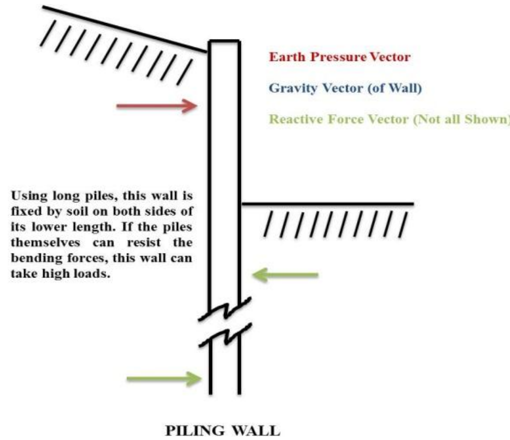

Fig.2 Piling Wall

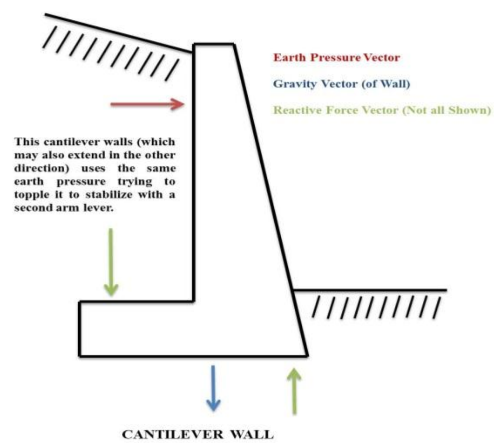

Fig.3 Cantilever Wall

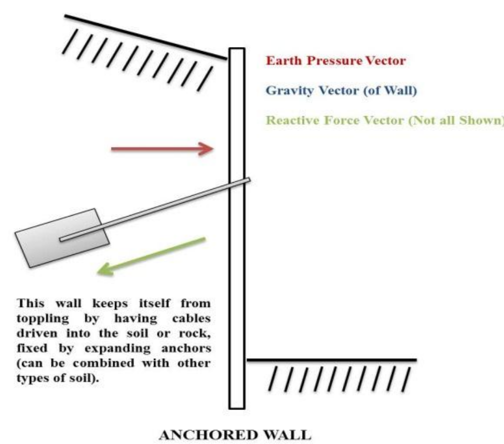

Fig.4 Anchored Wall

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IV. Types Of Reinforced Earth Wall

The internally stabilized walls include metal strip walls; geotextile reinforced walls and anchored earth walls. These walls comprise of horizontally laid reinforcements which carry most or all of the lateral earth pressure via soil-reinforcement interaction or via passive resistance from the anchor block. If the reinforcements are spaced closely enough, the stiffness of the soil-reinforcement system may be so high that practically very insignificant lateral thrust will have to be carried by the wall facing elements. This reduces the volume of concrete and steel reinforcement in the wall significantly. An additional feature of the internally stabilized walls is their relatively fast speed of construction. This is firstly because of less volume of concrete and steel fabrication work, and secondly because the placing of wall panels, lying of reinforcements and compaction of reinforced fill are carried out simultaneously. A retaining wall is a structure that retains holds back any material usually earth and prevents it from sliding or eroding away. It is designed so as to resist the material pressure of the material that it is holding back.

These walls are generally soil constructed with artificial reinforcing via layered horizontal mats (geo-synthetics) fixed at their ends. These mats provide added internal shear resistance beyond that of simple gravity wall structures. Other options include steel straps, also layered. This type of soil strengthening usually needs outer facing walls to affix the layers to and vice versa.

The wall face is often of precast concrete units that can tolerate some differential movement. The reinforced soil's mass, along with the facing, then acts as an improved gravity wall. The reinforced mass must be built large enough to retain the pressures from the soil behind it. Gravity walls usually must be a minimum of 50 to 60 percent as deep or thick as the height of the wall, and may have to be larger if there is a slope or surcharge on the wall.

Mechanically Stabilized Earth walls (MSE) have many advantages compared with conventional reinforced concrete retaining walls. They are summarized as follows:

- Use simple and rapid construction procedures and do not require large construction equipment.
- Do not require experienced craftsmen with special skills for construction.
- Require less site preparation than other alternatives.
- Need less space in front of the structure for construction operations (facia panels)
- Reduce the requirement of space.
- Do not need rigid, unyielding foundation support because MSE structures are tolerant to deformations.
- Cost effective.
- Technically feasible to heights in excess of 25 m (80 ft)

One of the greatest advantages of MSE walls is their flexibility and capability to absorb deformations due to poor subsoil conditions in the foundations. Also, based on observations in seismically active zones, these structures have demonstrated a higher resistance to seismic loading than have rigid concrete structures. Precast concrete facing elements for MSE walls can be made with various shapes and textures (with little extra cost) for aesthetic considerations. Masonry units, timber, and gabions also can be used with advantage to blend in the environment.

V. Design Of Retaining Wall

Model Calculations Data For Retaining Wall/ Reinforced Earth Wall

Grade of concrete = 30 MPa
S.B.C. of soil = 140 kN/Sqm
Density of soil = 20 kN /cum
Grade of steel = 500 MPa
Density of Concrete = 25 kN /m
Friction Coefficient = 0.5
Active earth Pressure = 0.33
Angle of wall friction = 20Deg 0.3491 radians
Angle of internal friction = 30Deg 0.5236 radians

The values for Grade of concrete, S.B.C. of soil, Density of soil, Grade of steel, Density of Concrete, Friction Coefficient, Active earth Pressure, Angle of wall friction, Angle of internal friction shall be kept same for the designing of Cantilever Retaining Wall/ Counterfort Retaining Wall and Reinforced Earth walls.

A. R.C.C. RETAINING WALL for Height of 6.0 m

Height of embankment above GL = 6.0 m

Dimensions of Retaining Wall

Provide minimum Depth of Foundation= 1.0 m
Height of wall above ground level = 6.0 m
Overall depth of Wall (H) = 7.0 m
Base Width (b) = 3.5 m
Toe Projection = 1.05 m
Thickness of Base Slab = 0.585 m
Thickness of Stem at top = 0.2 m
Thickness of Stem at bottom = 0.583 m
Heel Projection = 1.867 m

Design Of Stem

Height of Stem = 6.4 m
Horizontal Pressure at Stem = 163.33 kN m
Overturning Moment (Mo) = 190.55 kN m

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Total weight of structure = 353.43 kN
Stability moment (Ms) = 793.52 kN.m
Area of steel r/f = 2477.88 mm^2
Provide 16 mm dia bars at a spacing of 80 mm c/c

Distribution reinforcement

Average thickness of wall = 391.67 mm
Area of steel (0.12%bd) = 470 mm
Steel to be provided in each face = 235 mm
Provide 10 mm dia bars at a spacing 330 mm c/c

Stability against Overturning

Factor of Safety (FOS) = (0.9*Ms) / Mo
FOS = 3.74 > 1.4
Hence Safe

Stability against sliding

Factor of Safety (FOS) = (0.5*Total horizontal pressure) / total weight of structure
FOS = 0.974 <1.4
Hence Shear Key is required

Check for maximum pressure at toe

Net bending moment = Ms-Mo
x = Net Bending Moment/ Total weight of structure
Eccentricity = (Base width/2)-x
Eccentricity < b/6
Hence Safe

Maximum pressure at toe

Pmax = 108.58 KN/m^2
Pmax < SBC
Hence Safe

Design of Toe Slab

Maximum bending pressure (Mu) = 50.14 kNm
Depth = $\sqrt{(Mu/ (0.138*fck*b)}$
= 134.79 < 450 mm
Hence safe
Area Of Steel = 390.06 mm^2
Provide 12 mm dia bars at a spacing 280 mm c/c

Distribution reinforcement

Area of steel (0.12%bd) = 470 mm
Provide 12 mm dia bars at a spacing 180 mm c/c

Design of Heel Slab

Net bending moment = Bending moment due to downward moment – bending moment due to upward pressure
Factored moment (mu) =1.5* net Bending moment
Mu = 243.52 kNm
Area of steel r/f = 1308.03 mm^2

Distribution reinforcement

Area of steel (0.12%bd) = 600 mm
Provide 12 mm dia bars at a spacing 180 mm c/c

Design of Shear Key

Coefficent of earth passive earth pressure (kp) = 1/ 0.33
0.9*mu*total weight + (kp*vertical earth pressure)/v = 1.4
Provide a 200 mm deep shear Key

B. R.C.C. Counterfort Retaining Wall For Height of 9.0 m

Height of embankment above GL = 9.0 m

Dimensions of Retaining Wall

Provide minimum Depth of Foundation= 1.0 m
Height of wall above ground level = 9.0 m
Overall depth of Foundation (H) = 10.0 m
Base Width (b) = 7.1 m
Thickness of base slab = 500 mm
Toe Projection = 1.90 m
Clear height of Stem = 8.5 m
Thickness of stem = 0.30 m
Heel Projection = 4.9 m
Total Horizontal pressure = 270 kNm
Bending moment (Mo) = 202.5 kNm
Factored moment (Mu) = 303.75 kNm
Overall Depth = 320 mm
Effective depth = 272 mm
Area of steel r/f = 1934.84 mm^2
Provide 16 mm dia bars at a Spacing of 100 mm c/c

Design of Stem

Bending moment = 42.5 KNm
Factored moment = 63.75 KNm
Depth of stem = 175 mm
Effective depth = 127 mm
Distribution reinforcement
Area of steel (0.12%bd) = 915.81 mm^2
Provide 10 mm dia bars at Spacing of 380 mm c/c

Overturning Moment $(1/2*\gamma*H^3/3)$(mo)= 810.00 kNm
Total Moment (Mr) = 4319 kN.m
Total weight of structure = 985.80 kN

Stability against Overturning

FOS (Mr/Mo) = 5.35 > 2.0
Hence Safe

Stability against sliding

FOS = 1.84 > 1.5
Hence Safe

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Check for maximum pressure at toe

Net bending Moment = Mr-Mo
= 3509.20 kNm
Pmax = 138 KN/m^2 < SBC

Hence Safe

Design of Toe slab

Overall Depth = 450 mm
Effective depth = 402 mm
Area of steel r/f = 231.53 mm^2
Provide spacing as 480 mm c/c

Design of Heel Slab

Over all depth = 450 mm
Effective Depth = 402 mm
Area of steel r/f = 471.39 mm^2
Assume Spacing as 400 mm c/c

Distribution of Steel R/F

Area of steel = 540 mm
Assume spacing to be provided = 140 mm c/c

Design of Counter fort

Effective Depth = 0.66 m
Length of Counter fort = 5.19 m

VI. DESIGN OF REINFORCED EARTH WALL

Model Calculations For Reinforced Wall

A. Design for reinforced RE Wall with metallic strips for Height of 6.0 m

Height of embankment above GL = 6.0 m

Dimensions of Wall

Provide minimum Depth of Foundation= 1.0 m
Height of wall above ground level = 6.0 m
Overall depth of Foundation (H) = 7.0 m
Base Width = 4.2 m
Lateral earth Pressure = 33.33 KNm
Horizontal Pressure = 147.00 KN/m

Assume horizontal and vertical spacing of strips 1.0m
Width of strips = 0.1 m
Density of material to be used in filling = 18 Kn/m^2
Yield strength in steel = 250 N/m^2
Height of strips to be considered for RE wall

Considering clear cover from foundation = 0.5 m
Considering clear cover from top = 0.5 m
Height in which reinforcement is to be provided = 6.0 m
No of reinforcements = 6.0 m
Force at reinforcement = 51 Kn
Provide thickness as 15.0 m

Stability against sliding: Safe

Stability against Overturning: Safe

Bearing Pressure: Safe

B. Design for reinforced RE Wall with metallic strips for Height of 9.0 m

Height of embankment above GL = 9.0 m

Dimensions of Wall

Provide minimum Depth of Foundation= 1.0 m
Height of wall above ground level = 9.0 m
Overall depth of Foundation (H) = 10.0 m
Base Width = 6.3 m
Lateral earth Pressure = 60 KNm
Horizontal Pressure = 270.00 KN/m
Assume horizontal and vertical spacing of strips 1.0m
Width of strips = 0.1 m
Density of material to be used in filling = 18 Kn/m^2
Yield strength in steel = 250 N/m^2
Height of strips to be considered for RE wall
Considering clear cover from foundation= 0.5 m
Considering clear cover from top = 0.5 m
Height in which reinforcement is to be provided = 9.0 m
No of reinforcements = 9.0 m
Force at reinforcement = 120 Kn
Provide thickness as 20.0 m

Stability against sliding: Safe

Stability against Overturning: Safe

Bearing Pressure: Safe

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VII. QUANTITIES AND COST CALCULATION OF RETAINING WALL AND REINFORCED WALL

A. Quantities And Cost Of Retaining Wall At Height Of 6.0m & 9.0m

Sl. No.	Description of works	Unit	Length (m)	Width (m)	Height (m)	Qty (cum)	Total Quantity
A	Earth work in Excavation						
		cum	10.000	4.000	1.000	40.000	
				TOTAL Earth work		40.000	40.000
B	PCC M-15 Grade Concrete						
	M-15 G. Con.	cum	10.000	3.500	0.150	5.250	
				TOTAL M-15		5.250	5.250
C	RCC M-30 Grade Concrete						
i	M-30 .G. con Raft	cum	10.000	3.500	0.600	21.000	
v	M-30 WALL	cum	10.000	0.583	5.400	31.482	
				TOTAL M-30		52.482	52.482
D	TOTAL Quantity of Steel	MT					4.62

Fig.5 Quantity of Retaining Wall at Height of 6.0m

Item No as per SOR 2014	Description	Unit	Rate (Rs./Unit)	Quantity	Amount (Rs.)
3.2	Earth work in Excavation Excavation in ordinary rock by Manual Means Excavation in ordinary rock including loading in a truck and carrying of excavated material to embankment site with all lifts and leads	cum	226.00	40.00	9,040
9.1	PCC M-15 in Foundation Plain cement concrete M-15 mix with crushed stone aggregate 40 mm nominal size mechanically mixed, placed in foundation and compacted by vibration including curing for 14 days.	cum	4,209.00	5.25	22,097
13.6	Plain/Reinforced cement concrete in sub-structure complete as per drawing and technical specifications.	cum	6,588.00	52.48	345,751
13.7	TMT / HYSD Reinforcement: in Retaining walls as per Technical Specification Clause 1600.	MT	75,415.00	4.62	348,298
	Total Amount				Rs. 725,187

Fig.6 Cost of Retaining Wall at Height of 6.0m

Sl. No.	Description of works	Unit	Length (m)	Width (m)	Height (m)	Qty (cum)	Total Quantity
A	Earth work in Excavation						
		cum	10.000	7.500	1.000	75.000	
				TOTAL Earth work		75.000	75.000
B	PCC M-15 Grade Concrete						
	M-15 G. Con.	cum	10.000	7.100	0.150	10.650	
				TOTAL M-15		10.650	10.650
C	RCC M-30 Grade Concrete						
i	M-30 .G. con Raft	cum	10.000	7.100	0.500	35.500	
ii	M-30 WALL	cum	10.000	0.500	8.500	42.500	
iii	M-30 Counterfort	cum	3.300	0.300	5.19	5.138	
				TOTAL M-30		83.138	83.1381
D	TOTAL Quantity of Steel	MT					7.32

Fig.7 Quantity of Retaining Wall at Height of 9.0m

Item No as per SOR 2014	Description	Unit	Rate (Rs./Unit)	Quantity	Amount (Rs.)
3.2	Earth work in Excavation Excavation in ordinary rock by Manual Means Excavation in ordinary rock including loading in a truck and carrying of excavated material to embankment site with all lifts and leads	Cum	226.00	75.00	16,950
9.1	PCC M-15 in Foundation Plain cement concrete M-15 mix with crushed stone aggregate 40 mm nominal size mechanically mixed, placed in foundation and compacted by vibration including curing for 14 days.	Cum	4,209.00	10.65	44,826
13.6	Plain/Reinforced cement concrete in sub-structure complete as per drawing and technical specifications.	Cum	6,588.00	83.14	547,714
13.7	TMT / HYSD Reinforcement: in Retaining walls as per Technical Specification Clause 1600.	MT	75,415.00	7.32	551,748
	Total Amount				Rs.1,161,237

Fig.8 Cost of Retaining Wall at Height of 9.0m

B. Quantities And Cost Of Reinforced Wall At Height Of 6.0m & 9.0m

Sl. No.	Description of works	Unit	Length (m)	Width (m)	Height/ Depth (m)	Qty	Total Quantity
A	Earth work in Excavation						
		cum	10.000	4.700	1.000	47.000	
				TOTAL Earth work		47.000	47.000
B	GSB Below Leveling PAD						
	GSB Below Leveling PAD	cum	10.000	4.700	0.150	7.050	
				TOTAL GSB		7.050	7.050
C	PCC M-15 Grade Concrete						
	M-15 G. Con. Leveling Pad	cum	10.000	0.450	0.150	0.675	
				TOTAL M-15		0.675	0.675
C	RE wall Fill And Geo Grid						
i	RE wall Fill	cum	10.000	4.200	7.000	294.000	
ii	RE wall facia panel	Sqm	10.000	1.000	7.000	70.000	
iii	Geo Grid	cum	10.000	4.200	7.000	294.000	
						658	658

Fig.9 Quantity of Reinforced Wall at Height of 6.0m

Item No as per SOR 2014	Description	Unit	Rate (Rs./Unit)	Quantity	Amount (Rs.)
3.4	Earth Work Excavation	cum	55	47.000	2,585
4.1	GSB Below Leveling Pad	cum	943	7.050	6,648
12.8 A	Leveling Pad (M 15 Grade Concrete)	cum	5,080	0.675	3,429
7.5 I	RE Wall WITH FACIA PANNEL	sqm	1,330	60.000	79,800
4.1	Selected Filling In Reinforced Zone	cum	943	294.000	277,242
7.5	Aluminum Strip	M	284	294.000	83,496
	Total				Rs.453,200

Fig.10 Cost of Reinforced Wall at Height of 6.0m

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Sl. No.	Description of works	Unit	Length (m)	Width (m)	Height/ Depth (m)	Qty	Total Quantity
A	Earth work in Excavation						
		cum	10.000	6.900	1.000	69.000	
				TOTAL Earth work		69.000	69.000
B	GSB Below Leveling PAD						
	GSB Below Leveling PAD	cum	10.000	6.900	0.150	10.350	
				TOTAL GSB		10.350	10.350
C	PCC M-15 Grade Concrete						
	M-15 G. Con. Leveling Pad	cum	10.000	0.450	0.150	0.675	
				TOTAL M-15		0.675	0.675
C	RE wall Fill And Geo Grid						
i	RE wall Fill	cum	10.000	6.300	10.000	630.000	
ii	RE wall facia panel	Sqm	10.000	1.000	10.000	100.000	
iii	Geo Grid	cum	10.000	6.300	10.000	630.000	
						1360	1360

Fig.11 Quantity of Reinforced Wall at Height of 9.0m

Item No as per SOR 2014	Description	Unit	Rate	Quantity	Amount (Rs.)
3.4	Earth Work Excavation	cum	55	69.000	3,795
4.1	GSB Below Levelling Pad	cum	943	10.350	9,760
12.8 A	Levelling Pad (M 15 Grade Concrete)	cum	5,080	0.675	3,429
7.5 I	Re Wall With Facia Pannel	sqm	1,330	100.000	133,000
4.1	Selected Filling In Reinforced Zone	cum	943	630.000	594,090
7.5	Aluminium Strip	M	284	630.000	178,920
	Total				Rs.922,994

Fig.12 Cost of Reinforced Wall at Height of 9.0m

VIII. CONCLUSIONS

To study the cost effectiveness of the Retaining wall and reinforced earth walls the Retaining wall has been designed for a height of 6 and 9 m. As it is a well-known fact that the retaining wall tend to fail after a certain height. To stabilize the Retaining walls, counter forts are added to the retaining wall. Similarly the Reinforced Earth walls also known as RE walls have been designed for the heights of 6 and 9 m.

The major contribution in the cost difference is attributed to the huge amount of concrete and steel bars usually required in the retaining walls as compared to its RE walls due to the basic design difference. The retaining wall is designed on the basis that the earth is retained behind the wall and major loading is on the wall whereas, in its counterpart (Reinforced Earth Wall) the friction between the earth and the reinforcement shares the load which is then transferred to the ground. The reinforcement thus develops tension and the earth behaves as if it has cohesion.

The economic benefit achieved from the Reinforced Earth Wall increases with the increase in the height of the wall. The per cent savings of the internally stabilized walls may range from 40 to 65%.

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