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.
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 mudlakes.

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.
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

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

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
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 kN/m
Depth                    =  $\sqrt{\left(Mu / (0.138*fck*b)\right)}$
                        =  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 kN.m
Area of steel r/f    =  1308.03 mm$^2$

**Design of Shear Key**

Coefficient 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*γ*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
Check for maximum pressure at toe

Net bending Moment = Mr-Mo
= 3509.20 kNm

$P_{\text{max}} = 138 \text{ KN/m}$

Hence Safe

**Design of Toe slab**

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

**Design of Heel Slab**

- Overall depth = 450 mm
- Effective Depth = 402 mm
- Area of steel $\ell/f$ = 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
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

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

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Description of works</th>
<th>Unit</th>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Height (m)</th>
<th>Qty (cum)</th>
<th>Total Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Earth work in Excavation</td>
<td>cum</td>
<td>10.000</td>
<td>4.000</td>
<td>1.000</td>
<td>40.000</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>PCC M-15 Grade Concrete</td>
<td>cum</td>
<td>10.000</td>
<td>3.500</td>
<td>0.150</td>
<td>5.250</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>RCC M-30 Grade Concrete</td>
<td>cum</td>
<td>10.000</td>
<td>3.500</td>
<td>0.500</td>
<td>21.000</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>TOTAL Quantity</td>
<td>MT</td>
<td></td>
<td></td>
<td></td>
<td>52.482</td>
<td>52.482</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Description of works</th>
<th>Unit</th>
<th>Rate (Rs./Unit)</th>
<th>Quantity</th>
<th>Amount (Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2</td>
<td>Earth work in Excavation</td>
<td>cum</td>
<td>226.00</td>
<td>40.00</td>
<td>9,040</td>
</tr>
<tr>
<td>9.1</td>
<td>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 cutting for 14 days.</td>
<td>cum</td>
<td>4,209.00</td>
<td>5.25</td>
<td>22,097</td>
</tr>
<tr>
<td>13.6</td>
<td>Plain/Reinforced concrete in sub-structure complete as per drawing and technical specifications.</td>
<td>cum</td>
<td>6,588.00</td>
<td>52.48</td>
<td>345,751</td>
</tr>
<tr>
<td>13.7</td>
<td>TMT / HSYD Reinforcement in Retaining walls as per Technical Specifications Clause 1600.</td>
<td>MT</td>
<td>75,415.00</td>
<td>4.62</td>
<td>348,298</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Description of works</th>
<th>Unit</th>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Height (m)</th>
<th>Qty (cum)</th>
<th>Total Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Earth work in Excavation</td>
<td>cum</td>
<td>10.000</td>
<td>6.700</td>
<td>1.000</td>
<td>47.000</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>GSB Below Leveling PAD</td>
<td>cum</td>
<td>10.000</td>
<td>4.700</td>
<td>0.150</td>
<td>7.050</td>
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<tr>
<td>C</td>
<td>PCC M-15 Grade Concrete</td>
<td>cum</td>
<td>10.000</td>
<td>0.450</td>
<td>0.150</td>
<td>0.675</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>TOTAL Quantity</td>
<td>MT</td>
<td></td>
<td></td>
<td></td>
<td>75,415.00</td>
<td>4.62</td>
</tr>
</tbody>
</table>

B. Quantities and Cost of Reinforced Wall at Height of 6.0m & 9.0m

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

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Description of works</th>
<th>Unit</th>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Height (m)</th>
<th>Qty (cum)</th>
<th>Total Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Earth work in Excavation</td>
<td>cum</td>
<td>10.000</td>
<td>7.500</td>
<td>1.000</td>
<td>75.000</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>PCC M-15 Grade Concrete</td>
<td>cum</td>
<td>10.000</td>
<td>7.100</td>
<td>0.150</td>
<td>10.650</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>RCC M-30 Grade Concrete</td>
<td>cum</td>
<td>10.000</td>
<td>3.500</td>
<td>0.500</td>
<td>35.500</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>TOTAL Quantity</td>
<td>MT</td>
<td></td>
<td></td>
<td></td>
<td>83.138</td>
<td>83.138</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Description of works</th>
<th>Unit</th>
<th>Rate (Rs./Unit)</th>
<th>Quantity</th>
<th>Amount (Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.4</td>
<td>Earth Work Excavation</td>
<td>cum</td>
<td>55</td>
<td>47.000</td>
<td>2,585</td>
</tr>
<tr>
<td>4.1</td>
<td>GSB Below Leveling Pad</td>
<td>cum</td>
<td>943</td>
<td>70.59</td>
<td>6,648</td>
</tr>
<tr>
<td>13.8 A</td>
<td>Leveling Pad (M 15 Grade Concrete)</td>
<td>cum</td>
<td>5,080</td>
<td>0.675</td>
<td>3,429</td>
</tr>
<tr>
<td>7.5</td>
<td>Aluminum Strip</td>
<td>M</td>
<td>284</td>
<td>294.000</td>
<td>83,496</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Description of works</th>
<th>Unit</th>
<th>Rate (Rs./Unit)</th>
<th>Quantity</th>
<th>Amount (Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.4</td>
<td>Earth Work Excavation</td>
<td>cum</td>
<td>55</td>
<td>47.000</td>
<td>2,585</td>
</tr>
<tr>
<td>4.1</td>
<td>GSB Below Leveling Pad</td>
<td>cum</td>
<td>943</td>
<td>70.59</td>
<td>6,648</td>
</tr>
<tr>
<td>13.8 A</td>
<td>Leveling Pad (M 15 Grade Concrete)</td>
<td>cum</td>
<td>5,080</td>
<td>0.675</td>
<td>3,429</td>
</tr>
<tr>
<td>7.5</td>
<td>Aluminum Strip</td>
<td>M</td>
<td>284</td>
<td>294.000</td>
<td>83,496</td>
</tr>
</tbody>
</table>

Total Rs: 853,200
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%.

REFERENCES