Techno-Economical Analysis of Gabion Retaining Wall Against Conventional Retaining Walls

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Abstract - *For a particular local condition selection of inappropriate conventional methods used in the construction of retaining wall proves not only time consuming but also costlier due to the transportation of required materials and its associated cost. Selecting most technically appropriate, safe and cost-effective system out of the various available types including rubble masonry gravity wall, RCC cantilever wall, RCC counterfort wall and gabion retaining wall is a rigorous task. Present work addresses a comparative techno-economical analysis of various conventional retaining walls with the Gabion wall. While performing the design procedure the input data including height, backfill, foundation strata and loading conditions are kept constant for all the four type of retaining walls. From the design output in the form of section and steel, it is observed that the retaining wall of Gabion type proves economical and effective compared to other wall considered for analysis. The locally available materials are the key elements which can be used in the construction of gabion walls makes the project time bound and cost effective.*

***Key Words*: Retaining wall, Gabion wall, Design of retaining wall, cost effectiveness.**

1. INTRODUCTION

Retaining wall is structure which restrain soil of unnatural slopes [4]. They are used to bound soils between two different elevations often in areas of terrain possessing undesirable slopes or in areas where the landscape needs to be shaped severely and engineered for more specific purposes like hillside farming or roadway overpasses [2].

Retaining walls are classified as follows of

Based on Material Used- Concrete, Brick/stone masonry, Clay/Soil Timber

Based on resisting the load-

Gravity Wall- A massive wall that resists, overturning by its own weight.

RCC Cantilever wall- Wall constructed in RCC having thin stem and base slab resist load by cantilever action. It is generally economical up to about 7m in height.

RCC Counterfort wall- When height of wall is more than 6-to 8 m Steam and base slab at regular interval tied with counterfort for economy

All the types of wall explain above have some disadvantages [14] i.e. require more cross section area, slow speed of construction work, Costly [1], may not suitable in water prone area[3] having weak foundation strata. A gabion wall is gravity wall having advantageous points as easy drainage [13], cheaper, flexible (differential settlement can be tolerate), speedy work, wastage materials can use and having no hydrostatic pressure, huge structure like landfills [12]. Above advantageous point attract the researchers to compare the Gabion wall with conventional retaining wall, to check feasibility and economy.

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2. MATERIAL AND METHOD

Gabion Wall is nothing but Boulder filled box type cage formed by Standard nets made of steel wire or polymer ropes. The netting is from mechanically double twisted hexagonal wire mesh made of Heavily Galvanized steel wire. The boxes are properly wired and laced together to form flexible, monolithic, confined building blocks, which are called as Gabion walls. Gabions in conjunction with boulders act as wall which retains water or soil as water front structures, as bridge abutment retaining structures and as slope stabilizing, erosion controlling systems, aprons and revetment construction etc. These walls are porous gravity walls, which stand by self-weight and it does not require any foundation or anchorage. Gabions can be used effectively and economically in its all applications. Gabions are classified in two categories as Metallic Gabion box & Polymer Gabion Box.

2.1 Details of Gabion box

The steel wire gabion boxes and mattresses are factory-fabricated boxes manufactured using Mechanically Woven Double Twisted Hexagonal shaped wire meshes. Mechanically woven Double twisted wire meshes are non raveling; manufactured by twisting continuous pairs of wires through three one-half turns (commonly called double-twisted) to form hexagonal shaped mesh openings which are then interconnected to adjacent wires to form hexagonal meshes. The edges of the mesh are toughened with a thicker wire called the selvedge/edge wire.

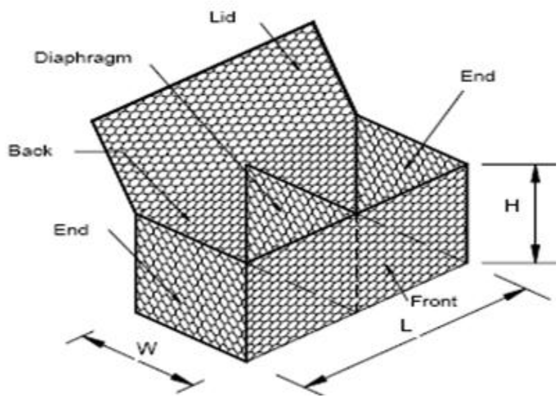

FIG 1-Metallic Gabion box [5]

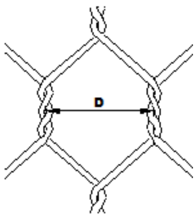

FIG 2- Double Twisted Hexagonal Wire Mesh

2.2 Specification of Metallic Gabion Box-

a) Wire Mesh- The wire used in the manufacture of mechanically woven, GI double twisted, hexagonal shaped mesh for use in gabions shall conform to the specifications shown next in Table No1.

b) Mesh Size- The mesh size is nothing but opening size of mesh is explained next in Table No 2.

c) Gabion Box sizes and Tolerances- Gabion box available in various sizes as shown in Table No 3.

d) Stone- Locally available stone are used to fill Gabion Box; its sizes are as shown in Table No 4.

Table 1- Specification for Wires for Gabion Box [6]

Parameter	Mesh wire	Selvedge / Edge wire	Lacing wire	Test Standard
Diameter (mm)	2.7	3.4	2.2	ASTM A 641 BS 1052 IS 4826 EN 10223-3 EN 10244-2
Tolerance (mm)	± 0.06	± 0.07	± 0.06	
Zinc coating (gms./sq.m)	245 Min.	265 Min.	230 Min.	
Diameter (mm)	3.0	3.9	2.2	
Tolerance (mm)	± 0.07	± 0.1	± 0.06	
Zinc coating (gms./sq.m)	270 Min.	275 Min.	230 Min.	
Diameter (mm)	3.4	4.4	2.2	
Tolerance (mm)	± 0.07	± 0.1	± 0.06	
Zinc coating (gms./sq.m)	265 Min.	290 Min.	230 Min.	
Zinc Adherence	Flaking or cracking should not be observed on rubbing with bare fingers.			EN 10244-2
Elongation (%)	10 Min			EN 10223-3

Table 2- Gabion Box Mesh Size [6]

Mesh Type	D (mm)	Tolerance for D	Mesh Wire Diameter (mm)
60 x 80	60	(+16%, -4%)	2.2, 2.7
80 x 100	80	(+16%, -4%)	2.7, 3.0
100 x 120	100	(+16%, -4%)	2.7, 3.0

Table 3- Gabion Box Sizes & Tolerance [6]

L(m)	W(m)	H(m)	Diaphragm Number	Tolerance	Test
2	1	1	1	+/- 5%	ASTM A975
3	1	1	2		
4	1	1	3		
2	1	0.5	1		
3	1	0.5	2		
4	1	0.5	3		
2	1	0.3	1		
3	1	0.3	2		
4	1	0.3	3		

Table 4- Specification for stone used in Gabion [6]

Gabion Basket or Mattress Height	Predominant Rock Size	Minimum Rock Dimension	Maximum Rock Dimension
300, 450,900 mm Basket	100 to 200 mm	100 mm	230 mm
150, 230, 300 mm mattress	75 to 150 mm	75 mm	175 mm

2.3 Tests Conducted on Gabion Box-

1) Tensile Strength- As per En 10223-3 or ASTM A641 a wire sample of sufficient length, approximately 1.2m shall be cut from either end of each coil selected for test the tensile strength. As per ASTM standards the tensile strength of the steel wire shall be in a range of 350-500 Mpa.

2) Zinc Coating- The minimum weight of the zinc coating and allowable tolerance shall meet the below mentioned requirements explain in Table No 1.

3) PVC Coating Thickness- The thickness of the PVC coating shall be determined on a randomly chosen individual piece of wire removed from the mesh. The thickness of the PVC coating is determined by stripping the PVC coating from the wire and measure the reduced diameter with a micrometer. The thickness of the coating is the difference between the diameter of steel wire before removing PVC coating and after removing PVC coating.

2.4 Construction Procedures-

Step 1: Geotechnical investigation.

Step 2: Design and Drawing.

Step 3: Foundation preparation

Step 4: Filter Cloth or Filter Stone.

Step 5: Gabion assembly

Step 6: Placing & Filling of Gabion

Step 7: Backfilling

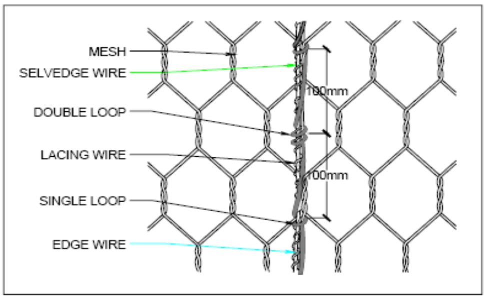

FIG 3- Gabion box connection details

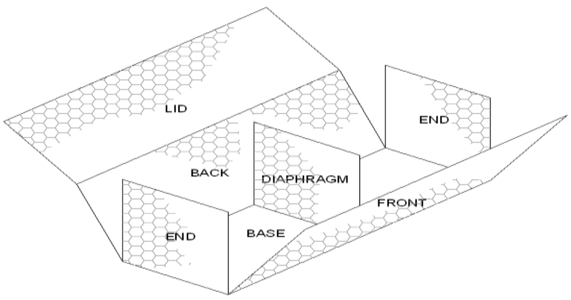

FIG 4- Gabion box assembly details

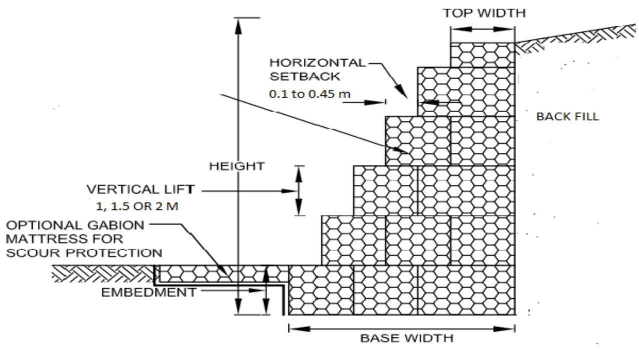

FIG 5- Typical Gabion wall cross section

FIG 6- Gabion retaining wall

FIG 7- River bank protection

3. CASE STUDY

For analysis and design of wall one site selected on bank of Mulla river (Pune ,India) near Ordinance factory at kirkee. There so much bank erosion near Compound walls between watchtowers no 16 & 17. The Erosion is so serious that started collapsing of Compound wall. Following data which is used in analysis and design are collected from site.

FIG 8- Bank erosion at Ordinance factory, Kirki, Pune

1. Length of Wall- 125 Rmt
2. Maximum RL- 99.800 (Bridge Bottom)
3. Minimum RL- 91.425
4. Maximum Height- 8.375 m
5. Detail Ground level of entire area
6. Back fill material- Black cotton Soil
7. Foundation Strata- Soft Rock

In this study most economical wall for above site is workout by comparing Gravity wall, RCC Cantilever wall ,RCC Counterfort wall and Gabion wall by analyzing and designing all above mentioned wall from data collected from site. No surcharge and horizontal backfill is considered for analysis.

3.1 Stability analyses and design method-

The design procedure of Gravity wall, RCC Cantilever wall and counterfort wall is very common and can be found in any text book [9]. Design is done as per IS Code 456-2000. Gabion wall is design similarly as Gravity wall. Stability analysis of walls includes check against sliding at the base, overturning about the toe, bearing failure of the foundation soil and overall stability failure. The notations related to Figures are described below.

γ = Unit weight of backfill, retained fill, foundation soil = 18 KN/M^3

γc = Unit weight of concrete = 25 KN/M^3

ϕ = Angle of internal friction of backfill = 30°

D = Depth of embedment of foundation = 0.90 M

H = Height of the wall from EGL to the foundation level = 9.30 M

SBC = Bearing capacity of foundation soil = 500 KN/M^2

Ka = Rankine's coefficient of active earth pressure = 1-sinϕ/1+sinϕ

Pa= Active force due to the retained fill = 0.5Ka γ

W1= Total weight of concrete (stem and base)

W2= Wt. of backfill B = Width of base of the retaining wall.

Check for overturning about toe

Overturning of the wall may occur about the toe, i.e. point A due to the lateral earth pressures shown in Figure. The Factor of Safety against such overturning can be expressed as [10]

FS (OT) = ΣMR/ΣMO>=1.55

Where, FS (OT) = Factor of Safety against overturning,

∑MR = Summation of resisting moment about point A,

∑MO = Summation of overturning moment about point A.

Check for sliding at the base

The Factor of Safety against sliding at the base may be expressed as [10]

FS (sliding) = ∑FR/∑FD > = 1.5

Where, FS (sliding) = Factor of Safety against sliding at the base; ∑FR = Summation of resisting forces against sliding; ∑FD= Summation of forces causing sliding at the base

Check for bearing capacity failure

The vertical pressure as transmitted to the soil by the base slab of the wall should be checked against bearing capacity of the soil. It should be appreciated that due to the lateral earth pressure, the bearing pressure will be maximum at the toe and minimum at the heel. The Factor of Safety against bearing capacity is then defined as [10]

FS (bearing) = qu /qmax; = 3.0

Where, FS (bearing) = Factor of Safety against bearing capacity failure; qu= Ultimate bearing capacity of the foundation soil; q max = Maximum pressure at the base of the wall

e = Eccentricity of the resultant force at the base

= B/2 - ∑MR - ∑MO/ (W1 +W2); <= B/6, no tension case.

Passive forces are neglected for safer side in design as the soil in front of the toe may get eroded with time. However, in the situations where it may be estimated with certainty that the soil in front of the toe will never erode, the contribution from the passive force may be considered in calculating the factor of safety both against overturning and sliding.

3.2 Final cross sections from analysis

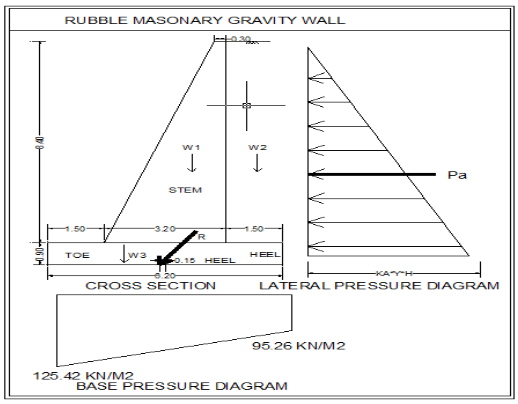

FIG 6 a- Final Cross Section of Gravity wall

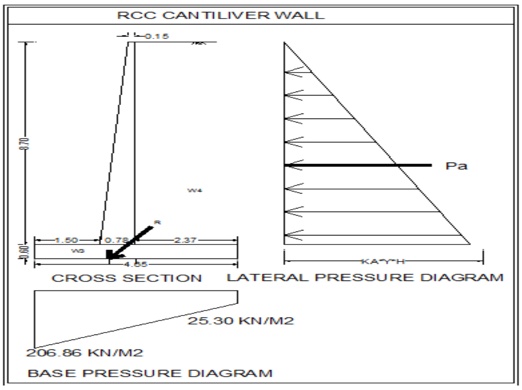

FIG 6 b- Final Cross Section of RCC Cantilever wall

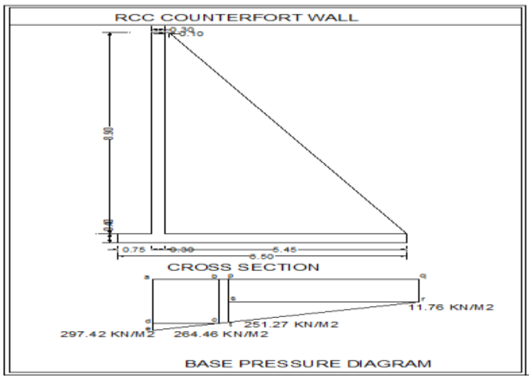

FIG 7 a- Final Cross Section of Counterfort wall

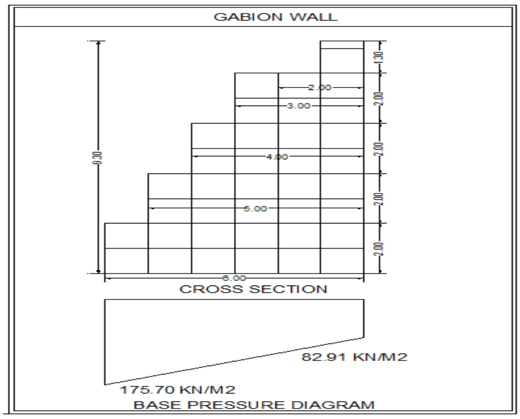

FIG 7 b- Final Cross Section of Gabion wall

4. COST COMPARISION

Estimation for various items shown table 6 are done from final sections (Fig-6,Fig-7) which are the results of analysis and design of all four walls. The rates are taken for costing are from District schedule rates, Government of India Central Public Work [8] Department. Price of Metallic box is based on its weight in Kg. Price of is about 85 Rs/Kg (7).Weight of Gabion is about 16.5 kg for box size 2X1X1 m and 24 kg for box size 3x1x1m.

Table 7- Cost per running meter length and % variation

	Stone Masonry	RCC Cantilever	RCC Counterfort	Gabion Wall
Cost per rmt	54,172	83,467	59,961	54,156
% variation	0.03	54.12	10.72	0

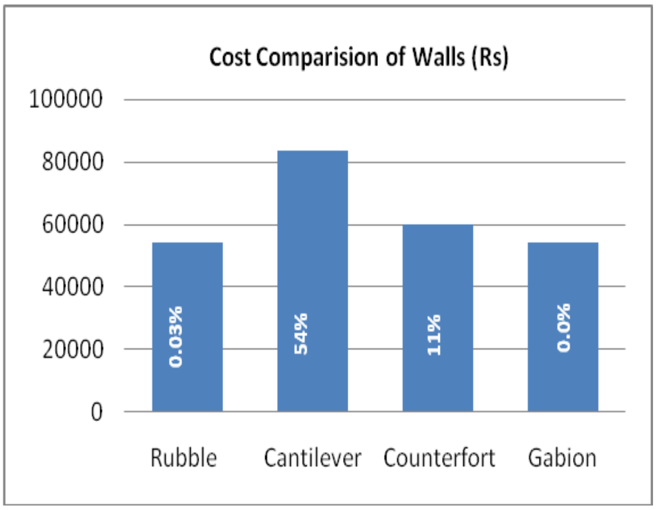

FIG 8- Histogram for cost all four walls

CONCLUSIONS-

From the entire study carried out following conclusion are drawn-

The construction cost of Gabion Wall as compare to Rubble Masonry, RCC Cantilever, RCC Counterfort, Graviloft retaining wall are 0.3%, 54.12%, 10.72% , 9.56% less respectively.

Though the construction cost variation between Rubble Masonry Gravity Wall and Gabion wall is very low (0.3%), Gabion Wall will be preferable on account of speedy (continues) work and use of locally available materials.

For speedy work Gabion Wall is best option as there is no curing period is required for it. Gabion Wall is better economical option against other conventional types of retaining wall. Gabion Wall is best suited for congested site, like Hilly area, River, nala Banks etc.

Gabion Wall is ideally suited for remote area where skill Labour, advance machinery, material is difficult to arrange.

Table 6- Estimation costing of all four walls-

Sr.No.	ITEM	UNIT	RATE	QUANTITY				AMONUT RS			
				Rubble Masonry	RCC Cantilever	RCC Counterfort	Gabion	Rubble Masonry	RCC Cantilever	RCC Counterfort	Gabion
1	Site Clearance	SQM	2.639	10,918.0	10,708.8	10,958.5	10,891.0	28,813	28,260	28,919	28,741
2	Excavation Soil	CUM	101.8	3,021.3	2,332.6	3,154.6	2,807.3	307,722	237,579	321,298	285,925
3	Excavation Soft Rock	CUM	152.6	765.0	590.6	798.8	838.0	116,739	90,129	121,889	127,872
4	Dewatreing	HP/ HR	26	738.0	198.0	324.0	198.0	19,188	5,148	8,424	5,148
5	PCC	CUM	2449	85.0	61.9	85.0	0.0	208,165	151,532	208,165	0
6	Stone Masonary-Above plinth	CUM	2384.2	1,837.5	0.0	0.0	0.0	4,380,968	0	0	0
	Stone Masonary-Below plinth		2022.7	697.5	0.0	0.0	0.0	1,410,833	0	0	0
7	Pointing	SQM	62.5	2,428.1	0.0	0.0	0.0	151,754	0	0	0
8	RCC- M20	CUM	4092.3	0.0	854.4	977.3	0.0	0	3,496,657	3,999,649	0
	M-15	CUM	3720	0.0	0.0	0.0	0.0	0	0	0	0
9	Form Work	SQM	180.4	0.0	2,325.0	4,529.0	0.0	0	419,430	817,024	0
10	Reinforcement	KG	42.7	0.0	138,164.7	41,685.0	0.0	0	5,899,634	1,779,948	0
11	Gabion box	KG	85	0.0	0.0	0.0	38,712.8	0	0	0	3,290,584
12	Gabion filling	CUM	650	0.0	0.0	0.0	4,663.4	0	0	0	3,031,210
13	Pipe-Wipe Hole	RMT	185	469.7	122.0	85.4	0.0	86,895	22,570	15,799	0
14	Refilling	CUM	32	1,890.0	2,577.4	6,063.1	0.0	60,480	82,476	194,020	0
	TOTAL COST (Rs)							6,771,556	10,433,416	7,495,136	6,769,479
	COST PER RMT (L=125M)							**54,172**	**83,467**	**59,961**	**54,156**
	% VARIATION IN COST							0.03%	54.12%	10.72%	0.00%

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