Stabilization of ravines : Case study of Sabarmati river, Gujarat State, India

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ABSTRACT: The ravines along the bank of Sabarmati river have been undergoing gradual erosion thus posing threat to the adjacent structures. The primary aim of this paper is to present a suitable cost-effective solution for stabilization of these ravines. Gabion gravity walls being flexible in nature have been provided at certain locations which required immediate attention. The construction of these walls has been monitored and it is explained here in detail. It was realized that gabion gravity walls are flexible and eco-friendly solution, however they workout to be still uneconomical. Reinforced soil walls with gabions as facia and gabion mesh as reinforcement have been studied to be flexible, eco-friendly and cost-effective solution. A comparative study of the cost of both types of structures has been performed and reinforced soil walls with gabions as facia and gabion mesh as reinforcement has been suggested to be provided along the remaining stretch of ravines.

Keywords: Ravines, Gabion gravity walls, reinforced soil walls, gabion facia, gabion steel mesh

1 INTRODUCTION

The IIT Gandhinagar campus is situated on the banks of Sabarmati river. The banks of this river are in the form of deep ravines which have a depth of about 11 m and are made up of loose silty soil. The campus consists of 100 m stretch of these ravines which were observed to gradually erode over a period of time thus posing threat to the campus buildings as shown in Figure 1.

Figure 1: Eroded ravines in the campus along the bank of Sabarmati river

Different solutions were suggested for the stabilization of these ravines. The erosion of surficial soil mass was taken care of by providing grouted riprap at certain locations. However, these being rigid in nature were observed to have undergone distress as it discouraged the dissipation of pore water pressure. In order to ensure flexibility in the provided solution, rolled erosion control blankets were also provided at different locations in this 100 m stretch of ravines. These were observed to perform better than grouted rip rap and were observed to retain the integrity of the structures under two seasons of rainfall. However, rolled erosion control blankets provided on the slopes does not ensure overall stability of the structure. A toe wall is required to be provided to impart global stability to the system. Along these ravines, the height of toe wall would vary from 3 m to 7 m. These toe walls can be of different types. One of them is concrete cantilever retaining walls, which are not only rigid in nature but may also prove to be uneconomical at taller heights. As they do not allow dissipation of pore water pressures, they have been observed to undergo several brittle failures. Another solution is providing gabion gravity walls owing to the flexibility that they provide to the retaining structures and their pervious nature which discourage the development of pore water pressures. They themselves undergo distress but retain the integrity of the structures. Also, as the basic required material, i.e., stones was readily available, at various locations in the 100 m stretch of ravines, gabion walls are provided as toe wall. One of those locations is as shown in Figure 2. The contours varying from 60 m to 71.85 m are shown in this figure. Also, the position where gabion wall has been placed is marked for reference which stabilizes the soil slope elevation of 9.25 m. However, recent comparative study on gabion gravity walls and reinforced soil walls with gabions as facia has shown that reinforced soils would prove to be a cost effective solution. A detailed study on the effectiveness of this solution for the current site of ravines has been carried in this paper.

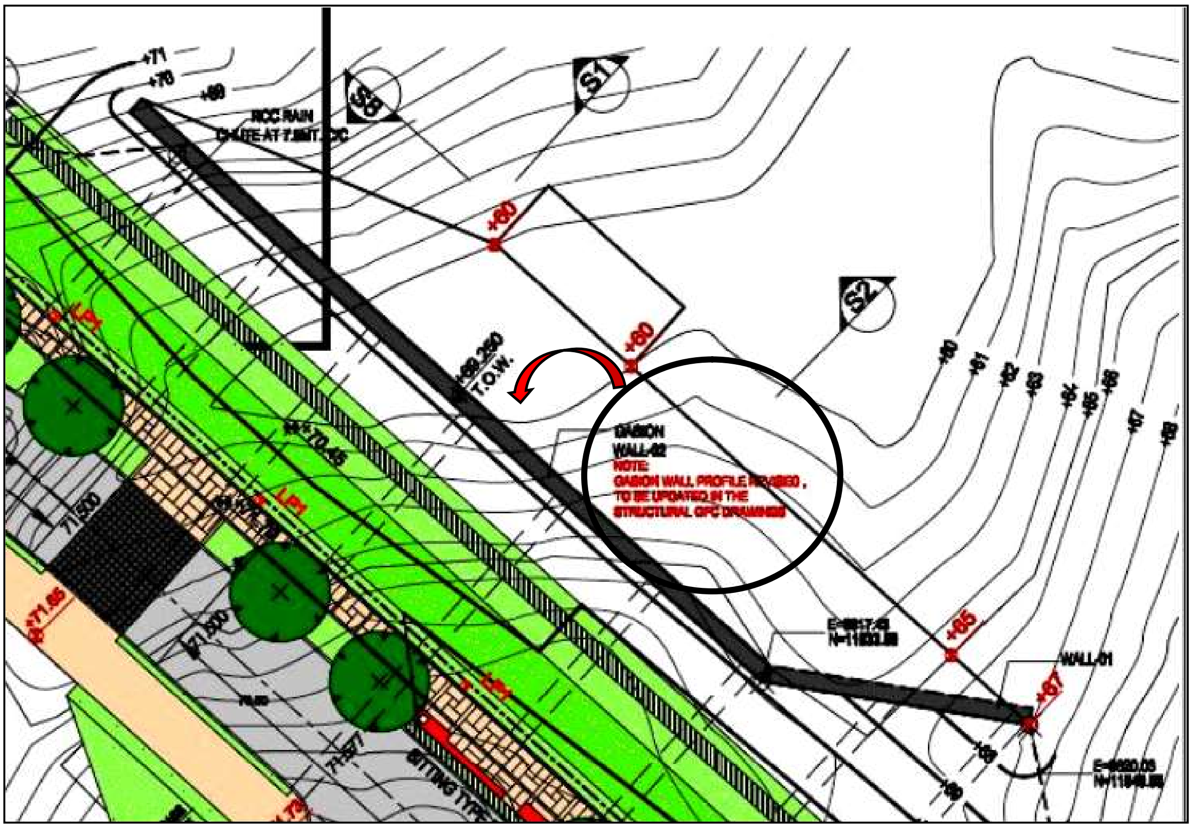

Figure 2: Plan view of the contours of reduced level and the distressed location of the gabion gravity wall has been placed

2 COMPARATIVE STUDY OF GABION GRAVITY WALLS AND REINFORCED SOIL WALLS

2.1 *Gabion gravity walls*

Gabion is a cage, cylinder or box filled with rocks, concrete, or sometimes sand and soil (IS 16014-2012). These are designed as retaining walls along hill side to protect the slope along roads and railway track and also along river banks. These prove to be cost effective, aesthetically pleasing, and environmental friendly alternative to concrete or masonry retaining walls. Permeability in the structure discourages the development of pore water pressure. Smaller stones and reduced thickness of gabions helps in erosion control when placed in the form of gabion mattress. A filter (sand, gravel or geotextile) is provided which is essentially used to prevent washing out of fine material from subgrade or backfill. Gabions are flexible enough to retain their integrity in spite of undergoing deformations. The construction of gabion walls rarely requires heavy plant or machinery and can be easily constructed in remote areas by local labours using locally available material. The design drawings showing general elevation view and various components of gabion gravity wall system of 8 m height wall is as shown in Figure 3(a) and 3(b) respectively.

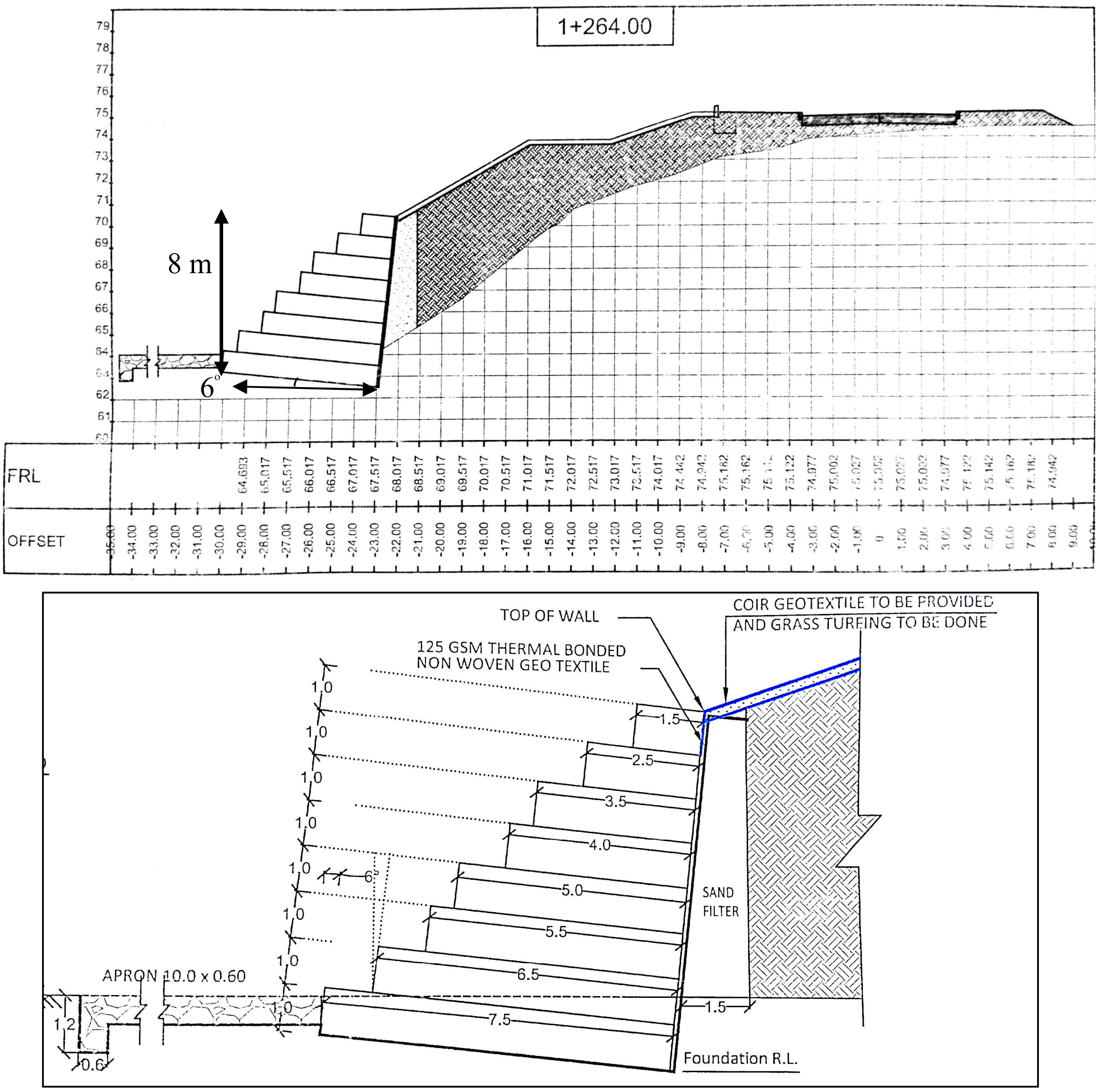

Figure 3: Elevation of gabion gravity wall (a) A general view, (b) Detailed components of gabion gravity wall system

A typical gabion gravity wall system consists of gabion boxes placed adjacent and laced to each other according to the width of the wall. The minimum width is usually considered as 0.7H. However, considering the offset of 1 m to be provided at each 1 m height and requirement of minimum 1.5 m width at the top of wall, 7.5 m was considered as the base-width of the wall. The bottom 1 m layer is embedded in the underlying soil. The wall is given a batter of 6° towards the backfill with an assumption that the human activities would cause slight outward displacements in the wall. A layer of thermally bonded non-woven geotextile layer and 1.5 m width sand layer is placed behind the wall in longitudinal direction to prevent fines from escaping the retained fill system as well as provided drainage for the water. The erosion of the top cover of retained soil is prevented by placing rolled erosion control blankets made up of coir geotextile has been provided considering it as eco-friendly solution which will degrade with time and provide suitable manure for the vegetation growth. A gabion apron is laid at the toe of wall to prevent direct contact of the river water and its scoring action at the base of wall.

The staged procedure of laying gabion gravity walls is shown as follows:

Step 1: Firstly apron in the form of gabion mattress is laid to prevent direct contact of river water currents with the gabion gravity walls as shown in Figure 4. Steel mesh of gabions reach site in the form of folded sheets as shown in Fig 4 which are opened and adjacent edges are laced together using wires of higher diameter. Depending upon the size of stones available in the vicinity, the size of the mesh required is decided. Thereafter, these boxes are filled with stones of suitable dimensions depending upon the surrounding mesh size. The availability of smaller size stones will necessitate smaller size of mesh to hold them together resulting in higher cost of the structure. But, smaller size of mesh will provide more tensile strength which may not be utilized to the fullest.

Figure 4: Placement of apron at the toe of wall and lacing of the gabion sheets

Step 2: The non-woven geotextile is thermally bonded to the gabion steel mesh from outside and stones are filled inside as shown in Fig 5. It should have sufficient resistance against installation damage and should be pervious enough to allow dissipation of pore water pressure without allowing the passage of fines through it.

Figure 5: Placing non-woven geotextile between retained fill material and gabion box

Step 3: The top cover is laced together and the other layer of gabions are laid accordingly by leaving the designed offset as shown in Fig 6. Before laying the above layer of gabions, sufficient ground preparation is done with respect to the required batter to be provided by removing the excess soil and levelling the ground where remaining offset of the gabions would rest.

Figure 6: Lacing of adjacent gabion boxes and placing them by providing required offset

Step 4: The constructed gabion gravity walls with the gabion mattress as apron is as shown in Fig 7.

Figure 7: Gabion gravity with gabion mattress after construction

2.2 *Reinforced soil walls*

The locally available silty soil can be suitably reinforced to develop a retaining structure known as reinforced soil walls. The clauses mentioned in different codes have recommended the back fill soil to be permeable and cohesionless. They do not allow fines content in soil to exceed 21%. The reinforcement in such walls are usually extruded or flexible geogrid. The soil is compacted to a minimum of 95% of MDD and OMC maintain minimum height of lift. The soil and the reinforcement behaves as a single unit and provides resistance against the lateral earth pressure due to the friction between soil and reinforcement from the retained fill and different magnitudes of upcoming surcharge as shown in Fig. 8. The facing is usually provided on the front side for the aesthetic purpose and to give support under unavoidable circumstances, if the soil and reinforcement unit undergoes any distress. Rigid facia units have led to the distress of structures at some places. This is because rigid facia does not settle with the back fill thus resulting into failure at the connections. Flexible facia units have proved to be effective in such situations. Gabion facia are flexible and most suitable for hilly areas and river banks which have enough availability of stones. The mesh size is decided on the basis of the size of available stones. Usually extensible geogrids are provided as reinforcements. Mesh wires with welded joints being inextensible can also be provided as reinforcements as they will help in reducing the costs. So, in the areas where there is minimal surcharge, steel mesh can be provided as reinforcement to utilize its complete strength. Gabion mesh is comparatively extensible because of its double-twisted joints as compared to welded mesh joints. Thus, gabion mesh can utilize its tensile strength by allowing the structure to take strain up to 10 %. Gabion mesh galvanized with zinc and coated with PVC has been used suitably on the basis of their tensile strengths. However, at the sites of heavy surcharge, still the strength can be achieved by placing one reinforcement sheet over another.

The current design methodologies do not consider the role of facia in resisting the upcoming lateral earth pressure. Usually, when the facia units are of lesser width like discrete concrete panel, it is quite insignificant to consider the effect of facia-width. However, massive gabion units when used as facia may have significant role in resisting the upcoming lateral earth pressure. Jadhav et.al.(2016) proposed a new design methodology wherein the width of wall would include the width of facia as well. For a typical 7 m height of wall, the analysis has been carried to compute cost of gabion gravity walls as well as reinforced soil wall with gabion units as facia and gabion mesh as reinforcement.

3 PREREQUISITES FOR THE COST ANALYSIS

A code was developed for the design of two types of soil retaining structures namely, gabion gravity walls and soil reinforced with gabion mesh having gabion facia. The unit weight of a gabion block is considered as 15.5 kN/m^3 in the analysis. All the walls have been designed considering back face as vertical and back fill profile as horizontal. Weight of steel wire mesh has been considered to contribute negligible impact to the computation of vertical load of wall (BS 8002-1994). The depth of embedment has been considered 1 m for both the structures. However, the upcoming passive resistance has not been considered to be conservative. The developed code can also compute the volume of stones and surface area of steel wire mesh and accordingly the total cost of the project. The specifications of the different components of wall along with their quoted rates is listed in Table 1 as obtained from local engineers.

Table 1: Specifications of the materials used

Items	Specifications		Cost (Rs)
Gabion Mesh (Galvanized with zinc and PVC coated)	Size of mesh	Tensile strength (kN/m)	
	10x12	32	180/sq.m
	8X10	42.5	192/sq.m
Stones	Supplying and filling the gabion boxes with trap rubble stones of size 150mm to 250mm inclusive of all taxes, levys, labour, transportation, scaffolding for execution at all locations, leads and lifts		1170 / cu.m
earth work	Locally available soil		381 / cu.m

Gabion gravity walls have been designed assuming wall to soil interface friction angle δ as zero. As a result, the lateral earth pressure computed for these walls is in accordance with Rankine's theory for smooth walls. The base has been assumed to be 0.75 times the height of wall and an offset of 1 m has been provided at every 1m. It has been assumed that the wall and retained fill are under drained conditions. The retained fill has been assumed to have angle of shearing resistance ϕ as 30°. The gabion gravity wall with the considered assumptions regarding dimensions is represented through Fig. 8(a). The stability of wall has been checked with respect to sliding, overturning and bearing with their corresponding critical factor of safety values considered as 1.5 and 2 respectively. However, the structure was not observed to be safe in sliding. So, the base-width was increased to 0.95H to obtain factor of safety above 1.5. The structure has been rendered safe against bearing if the eccentricity of the resultant force acts within one-sixth of base-width. It has been also ensured that the applied bearing pressure is less than the bearing capacity of soil.

Reinforced soil wall has been designed following the design procedure in accordance with Jadhav et.al. (2016) including the contribution from the weight of facia in the stability of structure. The back fill soil has been considered to have same properties as retained soil mass. Thus the interface angle δ has been assumed to be equal to the angle of shearing resistance ϕ of the back fill soil. Height of lift is maintained 1 m throughout the height of structure. The gabion mesh reinforced soil retaining wall is as shown in Fig. 8(b). Ensuring external stability of structure has been given primary importance. The external stability of structure has been ensured by obtaining the factor of safety values greater than 1.5 and 2 against sliding and overturning respectively. The resultant of the forces has been ensured to lie within one-sixth of the width of base to ensure safety against bearing failure. The internal stability has been ensured by providing reinforcement of suitable tensile strength against rupture and optimum embedment length to provide enough pull-out resistance (Bs:8006-2010, IRC:SP:102-2014). In order to compute the design tensile strength for gabion mesh, the reduction factors due to creep, installation damage and durability have been chosen different from polymeric material as well steel mesh with welded joints. As the steel mesh is comparatively inextensible, the creep reduction factor has been considered as 0.9. Steel being tough material, the reduction factor against installation damage and durability has been considered as 0.95 and 0.95, respectively. The reinforcement with available higher strength has been provided if the lower reinforcements fail against rupture which is followed by rechecking the design.

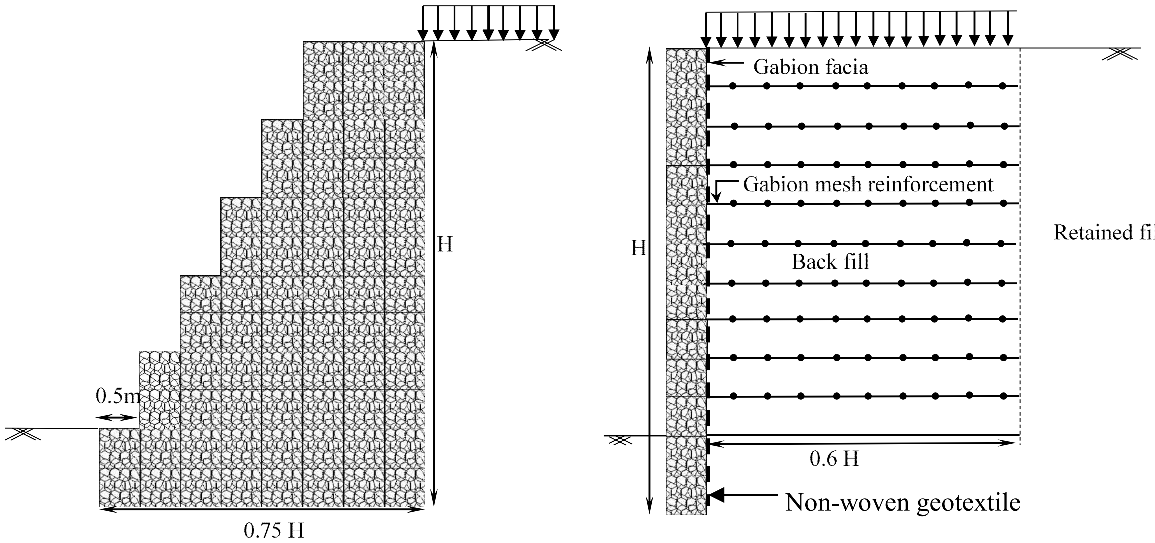

Figure 8. Schematic diagrams for (a) Gabion gravity wall (b) Soil reinforced gabion mesh with gabion facia

4 COST ANALYSIS

Jadhav et.al. (2016) suggested to perform analysis varying width of facia unit for reinforced soil walls and the optimum base-width based on the minimum cost of the project. It was observed that the cost of the project increased with increase in facia width owing to the insufficient resistance provided by 1 m width of porous facia unit, thus causing increase in the cost of earthwork required along with the reinforcement which is not required for wall with smaller facia-width where the remaining area would have been replaced by dense soil mass. The cost of project was slightly more when facia-width was not at all included as it neglected the contribution from facia blocks in the resistance of lateral pressures. Thus the optimum width of facia for the current design has been deduced as 0.5 m which is in accordance with the finding given by Jadhav et.al. (2016).

The estimated cost for 7 m height of gabion gravity wall and reinforced soil wall is given in Table 2. The cost for 100 m length for gabion gravity wall has been calculated as Rs 4600k whereas for reinforced soil walls with gabions as facia and gabion mesh as reinforcement, the estimated cost of the project is Rs 2700k. The cost incurred for gabion gravity walls would be 70% more than reinforced soil walls with gabions as facia and gabion mesh as reinforcement.

Currently, out of 100 m distressed zone, 30 m has been stabilized with gabion gravity walls. However, provided reinforced soil wall in remaining 70 m stretch would significantly reduce the cost of project.

Table 2: Cost comparison for gabion gravity wall and reinforced soil wall

	Gabion Gravity wall	Soil Reinforced with Gabion mesh and gabion facia
Depth of embedment, m	1	1
Size of mesh	100X120	100X120 and 80X100
Volume of stones, m^3	2555	350
Volume of earth work,m^3	0	3125
Cost of earthwork, Rs	0	1190575
Cost of stones, Rs	2989350	409500
Surface area of mesh, m^2	9056	4928
Cost of mesh, Rs	1629999	1053171
Total cost of project, Rs	4619349	2653247

5 COMMENTS ON FUNCTIONALITY

Gabion gravity walls as well as reinforced soil walls are flexible and eco-friendly structures which would impart global stability to the unstable slopes. For sites like ravines, the locally available soil can be sufficiently compacted and reinforced by gabion mesh thus providing enough required enough vertical reaction which would have been provided by heavy gabion blocks in gabion gravity walls. Also, between facia and reinforced soil, non-woven geotextile can be placed as provided for gabion gravity walls to prevent the flow of fines from backfill and allow purely the passage of water as shown in Figure 8 (b)

6 CONCLUSION

The reinforced soil wall with gabion as facia and gabion mesh as reinforcement has been deduced to be economical solution than the gabion gravity walls. The former type walls are observed to be 70% cheaper than the latter type of walls. The former type of walls tend to reinforce the locally available soil and provided enough resistance against the upcoming lateral pressure comparable to that of gabion gravity walls. So, reinforced soil walls with gabions as facia and gabion mesh has been proposed to be placed at the other distressed locations along the bank of Sabarmati river.

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