River bank protection using polymer gabions – A case study on the river Tapi in India

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ABSTRACT: Reliance Industries Limited commissioned their plant at Hazira in the year 1991. This plant is located in Choryasi Taluka in Surat District in the state of Gujarat, and is an integrated facility manufacturing different petrochemicals and polyester intermediates. A coal based captive power plant has also been planned in the same complex in order to provide an economical alternative to the facilities' power requirements.
The entire complex sits on the banks of the river Tapi. The Tapi river is a large river originating in Central India and running westwards for a length of 724 km, before discharging in to the Gulf of Khambat. The entire complex rests on a stratum of "deep black soils" which comprise mainly montmorillonitic clays. Over the course of the past 25 years, the river has slowly eroded the boundary of the entire complex for a length of almost 900 m. Almost 2.0 acres of land have been lost by the facility.
In order for the captive power plant to be constructed, it was necessary to protect the facility from the ravages of the meandering river Tapi. The risk of a breach in the bank endangering the captive power plant was too large to be ignored. The typical morphology of the site also meant that traditional solutions would not work. A bank protection with sheet piling had been taken up successfully earlier in an upstream facility. A "soft" solution using a combination of polymer gabions, geo-textile bags and PVC coated metal gabions was preferred as a technically equivalent but cost effective solution to traditional sheet piling. The solution was designed and installed successfully at a much lower cost than sheet piling. The structure has withstood two monsoons with minimal maintenance and is today a good example of a "living structure" with different flora and fauna that have beautifully intermeshed with the structure.
This paper highlights the design philosophy, structural design as well as installation aspects of the river training system

1 INTRODUCTION

The Reliance Group is India's largest private sector company with business in several core sectors of the economy, like energy, materials value chain, telecom, etc.

Reliance Industries Limited (RIL) commissioned their plant at Hazira (Figure 1) in the year 1991. This plant, which has a total capacity of 7million MT, is located in Choryasi Taluka in Surat District, State of Gujarat. This integrated facility manufactures ethylene and polypropylene through the naphtha cracking process, as well as polyester intermediates. A coal based captive power plant has been planned in the same complex in order to provide an economical alternative to the facilities' power requirements.

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2 PROBLEM DESCRIPTION

Over the course of the years, temporary protection work in the form of dumping of concrete (Figure 2) and other debris on the bank, had been taken up by the Reliance Engineering team. Although these measures had served to provide temporary protection to the facility, a permanent protection measure was needed. In order for the captive power plant to be constructed, it was necessary to protect the facility from the ravages of the meandering river Tapi. The risk of a breach in the bank endangering the captive power plant was too large to be ignored. The typical morphology of the site also meant that traditional solutions would not work.

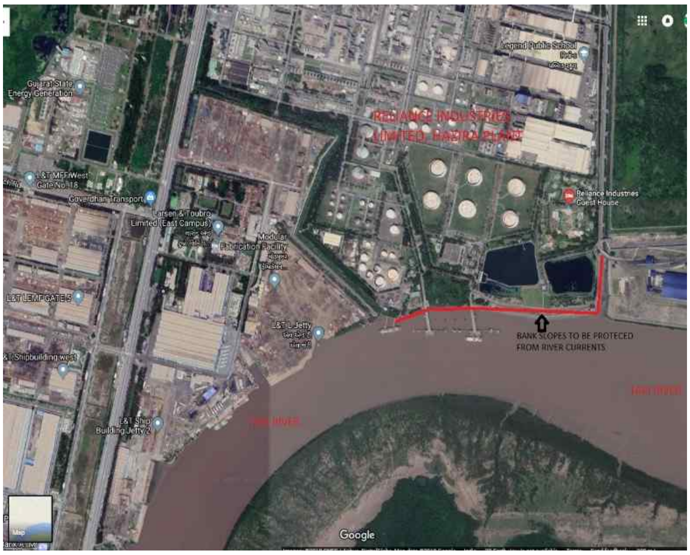

Fig 1. Google map picture showing the plan view of the RIL Hazira facility and location

3 EVALUATED OPTIONS

M/s Jacobs, an internationally renowned organization, was appointed as the Consultant for evaluation of the alternatives for the river bank protection work.
Option 1 - Geo-textile Bags with stone pitching apron
Option 2 - PVC coated metal Gabion revetment with Polymer Gabion apron
Option 3 - Sheet piling

Fig 2. Temporary bank protection measures taken up by RIL.

Options # 1 & 2 were “soft” options while Option # 3 was a traditional hard option.
The above options were assessed from the following perspectives:

- Time of implementation
- Cost
- Material availability
- Ease of installation
- Maintenance
- Aesthetics

Being a tidal zone of the river, different cases for different tide conditions were also considered for evaluation (Table 1).

Table 1. Comparative evaluation of alternatives for river bank protection works.

Alternatives	Option 1	Option 2	Option 3
Evaluation criteria	Geo-textile Bags with stone pitching apron	PVC coated metal Gabion revetment with Polymer Gabion apron	Sheet piling
Time of implementation	Since the construction of stone pitching requires properly carved stone, it can increase the time of implementation	Speedy & easy construction technique. The construction involves only Locally available boulders. This technique precludes the need for all time consuming activities like formwork, shuttering, curing and setting times	Removal of construction debris broken concrete pile, plastic etc. till the founding level of sheet pile has to be done which increases the time of implementation
Overall Cost	Since the locally available material is being used, the cost is comparatively less	Since steel gabion mattress is to be used, the overall cost will be slightly higher than option I	The presence of obstruction creates problems for installation of sheet piles. Hence the removal of entire debris adds to cost of construction
Material Availability	Availability of stones, sand and geobags etc. availability is relatively lower than sheet piles	Availability of stones etc. availability is relatively lower than sheet piles	Construction materials for sheet pile availability is higher than the option I & II
Constructability, onstruction Equipme & Site Installation	Simple Construction, can be used as single shore protection option throughout the length even under the jetties	The installation is very simple and Didn't require skilled work force. This technique precludes the need for all time consuming activities like formwork, shuttering, curing and setting times. It can be used throughout the protection length even under the captive jetties with little changes to the method adopted for rest of the length.	Cannot be driven under jetty or similar permanent structure
Maintenance	Stone riprap/pitching require routine inspection as well as repair to counter progressive failure occasioned by dislodges stones	Maintenance Free: Gabion structures are virtually maintenance free	Involves inspection and taking measures for corrosion protection of sheet piles
Aesthetic/ Environmental Aspects	Surface blends well with the surrounding landscape, vironment friendly and material can be reused non corrosive.	As Gabions promote growth of natural vegetation, it offers natural aesthetics with decorative landscaping besides maintaining the natural environment	Have aesthetic, ecologic & geomorphic drawbacks

Having zeroed in on the Option # 2 (ie) PVC coated metal gabion revetment with polymer gabion apron as the most viable Option on techno-commercial basis, the detailed designing was carried out as under:

3.1 Design analysis

Design of the Revetment: Revetment Thickness Calculation as per IRC: 89-1997

The input parameters considered

Assumed bed Level = 0.00 m, HTL/HFL = 4.79 m, Total depth of water = 4.80 m, Required free board = 1.5 m, Total height of the protection work = 6.30 m, Maximum Velocity, u = 3.0 m/sec, Unit weight of stones, $\Upsilon_g = 25$ kN/m^3, Unit weight of Water, $\Upsilon_W = 10$ kN/m^3

Considering these factors, the revetment is designed as given in the following section:

The expression given by IRC: 89-1997 for thickness of Gabion revetment is given in Eq. (1)

$$t = \frac{v^2}{2g(s_m - 1)} \qquad (1)$$

where, t = Thickness of Revetment (m), v = maximum velocity, g = ground acceleration, S_m = Specific gravity of Mattress, S_m = (Specific gravity of stone, Ss) x (1-e)
where,

$$e = \frac{0.245 + 0.0685}{d_{50}^{0.21}} \tag{2}$$

d_{50}= Mean diameter of stone filled in the gabions = 200mm, e = (0.245+0.0684) / (150)0.21 =0.11
Therefore, S_m = 2.65 x (1-0.11) = 2.35

Substituting the values,

t = 32/ (2*9.81(2.35-1)) =0.34 m

According to Section 6.1.1.1 of FHWA HEC 11, the minimum thickness of mattress is 0.3m. As per 4.3 of HEC 11 thickness should be increased by 1.50 times as the mattress is placed underwater to provide for uncertainties associated with placement.

t = 1.5x$D_{n,}$ t = 0.51 ~ 0.6 m

Hence provide revetment of thickness 0.6 m, along the slope using Zn + PVC coated Gabions of 2.7/3.7mm diameter steel wire and mesh type of 10x12.

3.2 Design of launching apron - protection of toe on riverside

To protect the toe of the embankment, a launching apron along river is designed. The size and shape of apron depends upon the size of stone, the depth of scour and the slope of launched apron. At the junction of revetment on slope with launching apron, a toe wall is provided, so that the revetment does not rest directly on the apron. Depth of Scour is given by Lacey's formula, for estimating normal scour depth in alluvial streams during floods, developed mainly on the basis of canal data, being adopted for the design of flood protection works is calculating the scour depth by using of discharge intensity per unit width using Eq. (3)

$$\text{Depth of Scour, R} = 13.5[\frac{q^2}{f}]^{\frac{1}{3}} \tag{3}$$

Where,
q = Discharge Intensity in cumecs per meter width, q = Mean velocity x Depth of the water
q = 3 x 4.8 = 14.4 m3/s / m width, f = Silt factor = 1.76√ m_r , m_r = weighted mean diameter of the bed material = 0.228 mm

f = 1.76√0.20 = 0.787, R = 1.35 (24.552/0.787)1/3 = 8.53 m

Mean Depth of Scour (below bed level, considering water depth=6m), R_m = 8.53 – 4.8 = 3.73m
Maximum anticipated scour depth = 1.5 x R_m = 1.5 x 3.73 = 5.595 m = 6.0 m
The slope stability analysis of the existing slope with revetment structure has been shown (Figure 3)
Having completed the design analysis, the designs were cross checked and vetted by hydraulic Consultants IIT Madras Coastal Engineering Department, which also posted a senior supervisor on site for providing installation guidance in the critical areas.

4 INSTALLATION

As a first step, a bathymetric survey was undertaken to establish the depth of the river bed. The overall installation methodology is as explained below. The following sequence of operations has been followed form toe to the top of the slope profile for the installation of gabion revetment works for protection of reclaimed land from erosion.

Step 1: Installation of polymer rope gabions for launching apron. In-situ Gabion Filling: In-situ filling of polymer rope gabions was done at some locations where low water level allowed in-situ installation.

Empty gabions were placed on the bed. Steel frames were used to impart a proper shape to the polymer gabions. Gabions were then filled with suitably sized boulders between 150mm -250mm.

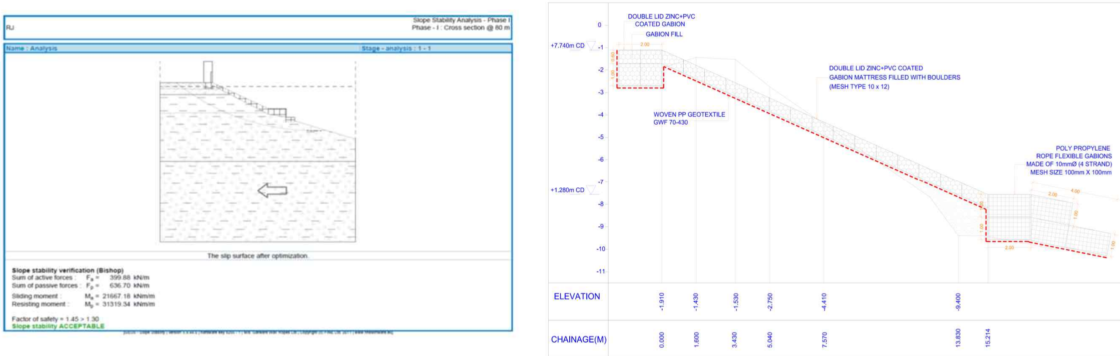

Fig 3. Slope stability analysis of river bank slopes using gabion mattresses.

Pre -filling of Gabions near site, lifting, shifting and placing in position: Where underwater installation of gabions was necessitated, the gabions were placed and filled in a yard made ready at the slope crest. Similarly, steel frames were used to impart a proper shape to the polymer gabions. These were then removed after filling the stones in the Gabions. The pre-filled Gabions were lifted with a 200 MT crane positioned near the yard, and placed at desired location. The construction plan for the above works has been detailed in Table 2.

Activity	April 2016				May 2016				June 16				July 16			
	Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	week 1	Week 2	Week 3	Week 4	week 1	week 2	week 3	week 4
Section 3 Jetty 2 to Tower towards Sheet piling section, 540 mtr																
Installation Schedule 200 mtr from Jetty 2 towards Sheet Piling area																
Survey team mobilization																
Completion of survey 200 mtr																
Completion of survey 200 mtr																
Completion of survey 140 mtr																
clearing and grubbing																
Filling of stones in Metal gabion																
Excavation of trench on top for gabion instllation																
Filing of sack Gabions	THIS ITEM IS ON HOLD DUE TO DESIGN CHANGE															
Filling of geo bags																
Laying of textile from top gabion at anchor to bottom PP gabion																
filling up of PP Rope gabions for Appron																
Postioning of bottom anchor PP Gabion																
Start laying of Gabion Mattres between top gabion and PP gabion at bottom																
Installation of anchor rods on top of Mattress installed on slope																

Table 2. Bar chart program for completion of Shore Protection Works.

Installation of gabions under water: The pre-filled gabions were placed in position under water with the help of a hydra and boats (Figure 4) of suitable boom length. The hydra hook lifted up the whole gabion with the help of rope slings attached to the gabions. The boom of the hydra was extended up to the required distance and then lowered down to place the gabion in its position under water. Trained divers were used for the purpose of guiding the crane operator for the exact location.

Step 2: Construction of metal gabion revetment. Following is a brief description of the methodology to construct the metal gabion revetment.

Dressing of slope profile: Prior to gabion installation, the slope profile was dressed to the required slope and length using excavators of suitable capacities.

1. Marking and overall alignment was done with respect to the chainage mentioned in the working drawings through suitable survey equipment.
2. Flattening and Assembling of Gabions. The folded units were taken out from the bundle and placed on a hard, flat surface. Gabions were opened, unfolded and pressed out to their original shape. Front, back and end panels were lifted to a vertical position to form an open box shape.
3. Laying & Placing of Geotextile. Upon final bed and slope preparation and acceptance by the Engineer, the geotextile was placed directly on the bed and slope at those locations shown on the drawings or as directed by the Engineer.

4. Placing of Gabion Units. The required numbers of assembled gabion units were placed side by side in the required position. The adjacent units were joined together by lacing using the single and double loop technique.

Fig 4. Installation of gabions under water using a hydra and boats.

5. Fixing of stakes. Before filling the gabion boxes, gabion boxes were anchored to the slope profile using steel stakes at regular intervals as per the approved drawing.
6. Filling of Gabion units. Stones of size 150 to 250 mm were used for filling of the gabion boxes. The range of stone sizes may allow for a variation of 5% oversize rock by number of particles, or 5% undersize rock by number of particles, or both. In all cases, undersize and oversize rock were placed within the interior of the gabions and shall not be placed on the exposed surface of the structure.
7. Closing the Lid. The lids were then stretched over the stone fill and laced down. The corners of the lids are secured first. After the gabion revetment was placed over the existing slope profile, it has to be anchored to the slope profile using specified steel rods at regular intervals as per the approved drawing.

5 CHALLENGES FACED DURING INSTALLATION

It was observed that the river bed profile was very uneven which posed the first challenge to overcome. How to place the polymer gabion boxes on a highly uneven river bed profile?
The challenge was overcome by two factors:
Factor # 1 was the highly skilled diver team that helped in the placement (Figure 5)
Factor # 2 was the flexible nature of the polymer gabion boxes that could stabilize very easily on a highly uneven surface, thus proving that the choice of this material for apron construction was appropriate.

Fig 5. Highly skilled diver's placing PP rope gabion.

Fig 6. Concrete debris incorporated into structure

The second challenge that was faced was that the concrete debris material that was dumped as a part of temporary bank protection, posed a challenge for installing the designed scheme. This challenge was overcome by:

- Removing the concrete debris wherever possible and feasible

- In most cases, the installation was done around the debris, thus incorporating the concrete debris as a part of the overall structure (Figure 6).

6 PROJECT COMPLETION

The project was completed successfully in March 2017, exactly 12 months after award of the work. The completed structure is shown here.

Figure 8. Completed structure showing the siltation over the revetment and apron.

6.1 Project maintenance

As a part of the project maintenance requirements, a pre-survey was conducted before the monsoon season in June 2017 and post survey was conducted in Feb 2018.

There was no requirement of maintenance post the crucial first year's monsoon. A recent photograph of the structure as below shows siltation (Figure 8) developing in the entire structure with the growth of typical flora and fauna associated with creeks, in the voids of the structure. This shows that the structure is stabilizing quickly and can in fact be labelled as a "bio-engineered" structure. While there was no requirement of maintenance for this structure, generally, a provision of around 3%-4% of the project cost is recommended for the first couple of years.

7 CONCLUSION

The design of the river bank protection works was novel in it's preference for a "soft" approach as compared to the traditional solution using sheet piles. This novel design was backed up with proper execution methodology to create a "bio-engineered" structure that requires very low maintenance and blends over time with it's surroundings leaving very little environmental impact. Overall, the "soft" approach using polymer gabions has proven to be a viable techno-commercial alternative to traditional solutions. This approach and design methodology could be used successfully for other similar cases as well in Asia and around the world.

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