Geotechnical Engineering Journal of SEAGS & AGSSEA

https://ph01.tci-thaijo.org/index.php/seags_agssea_journal

Village Protection during Flooding by Wrap-Faced Embankment at Netrokona, Bangladesh

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ABSTRACT: In this paper, a case study is presented for a wrap-faced embankment. This type of embankment is found to be more efficient than a traditional embankment in case of stability and dynamic wave action under flooding. In the deltaic region, where soft soil exists below an embankment, it may suffer relatively more damage. Under this situation, a wrap-faced embankment may be a relatively better solution. The example presented here is based on a real-life wrap-faced embankment on a soft soil area located at Nowagoan Alga Hati village under Mohanganj upazila, Netrokona, Bangladesh. This study also discusses the application of soft soil improvement via jet grouting in some parts of the site. Jet grouting has improved soil stability and soil settling after being applied to the soil. Soil strength before and after jet grouting were 0.005 MPa and 0.94 MPa, respectively. The soil gains 186.8 times the strength of soil before applying jet grouting, which was very impressive. Jet grouting also improved the settlement of soil to a great extent. The areas without soil improvement by jet grouting showed more settlement than those with jet grouting. After flooding, the settlement of the wrap-faced embankment without jet grouting area was found to be 112 mm. On the other hand, settlement of wrap faced embankment (after flooding) in the jet grouting area was only 19 mm. This research output is significant for the design and implementation of the future flood-resilient embankment in the Deltaic region.

KEYWORDS: Wrap Faced Embankment, Water Wave, Resilient, and Jet Grouting.

1. INTRODUCTION

Embankments in soft soil areas tend to be less stable and less durable. Traditional embankments need more land and money than wrap-faced embankments. Wrap-faced embankment is easily accessible all over the world as it consumes less space, is more economical, and is less affected by dynamic loading.

Embankments are the core of the land mass in the transportation industry. They are needed to raise the height of current areas of low elevation to levels that are usable for roads and rail lines. Due to a scarcity of suitable land for infrastructure and additional developments, embankments are increasingly being constructed over soft, unstable terrain. Construction of an embankment on a very soft subsoil with little shear strength and significant compressibility requires skilled engineering to ensure the stability of the embankment against potential slope failure and to minimize subsurface deforming or settling to within reasonable limits (Abhishek & Madhav, 2013).

Most people on Earth are currently located 100 km or less from a shoreline. The rise in sea levels and changes in climate, both of which are caused by global warming, have recently increased the threats to coastal areas. Therefore, alternative beach barrier systems that integrate the use of a geotextile solution are desirable for the replacement of traditional resources and frameworks, including ones made of stone or block formed from concrete, particularly for sandy coasts. A geotextile wrap-around revetment (GWR) construction is one viable remedy. They are beneficial for providing shelter from waves and currents, can be built directly upon, and often have less expensive overall construction and maintenance charges than rigid frameworks (Yasuhara & Recio-Molina, 2007).

It is seen worldwide that, under seismic pressure, earthen-reinforced walls exhibit adaptability and noteworthy displacement. (Edgar et al., 1989; Collin et al., 1992; Ho & Rowe, 1996; White, 1996; Tatsuoka et al., 1995 and 1997; Ling et al., 2001). When subjected to seismic load, traditional retaining walls fail to perform and so do reinforce soil walls (Nova-Roessig & Sitar, 1998). Another benefit is that building a reinforced soil wall is cheaper than building a traditional retaining wall, as stated by Latha and Krishna (2006).

The Public Works Department of Malaysia (PWD) has been engaged with several highway and building initiatives on soft soil as a result of the country's recent fast growth. Out of 252 forensic scenarios since 2010, 182 include a ground settlement component, while the other scenarios are created by different issues, including vibration, erosion, foundation problems, and so on. Hence, it is unquestionably obvious that the basic engineering challenge related to soft ground construction is the problem of ground settling (Mohamad et al., 2016).

Floods are regularly experienced in Bangladesh's deltaic plains. It is unavoidable that the disruption of business activities caused by the flooding would have a negative effect on GDP. A nation like Bangladesh cannot continue to afford the burden of such ongoing

https://doi.org/10.14456/seagj.2025.1 Published on 11 April 2025

massive devastation and unimaginable human suffering. Although the people of Bangladesh have adapted their lifestyle to the flood phenomenon, during each monsoon season, damage still occurs from flooding, riverbank erosion, river structure breaches, etc., in various places. They often suffer from terrible consequences, including severe destruction of infrastructure, significant property loss, human suffering, and impoverishment of poor people. Since the vast majority of people live in rural areas, they are either directly or indirectly dependent on the land for their livelihood. As a result, flooding puts people's lives and means of livelihood at great risk (Mahdi et al., 2014).

If comparing disaster metrics for two different time periods, it is seen that the disaster numbers, the number of impacted people, and the economic loss all rise alarmingly over time. Bangladesh ranks first globally for population exposure and third globally for economic exposure. Floods have caused the most destruction compared to other disasters. The river's discharge is heavily influenced by the enormous upstream flow from outside the country. When 50 years of rainfall and flood data are assessed, it turns out that in more than 85% of occasions, Bangladesh's flood anomaly corresponds with the territorial rainfall anomaly (Ali et al., 2012).

Multiple studies in this field made specific recommendations for available strategies and techniques for managing floods in Bangladesh, which include collaboration between regions and basin-scale handling with neighboring nations, gathering live information from runoff points, ensuring local involvement, particularly for women, in managing floodplain resources, and co-management in bringing the flood action plan into practice. Other sources emphasized the importance of monitoring and evaluating the efficacy of current processes and activities of administering authorities in depth for flood management, as well as the process of doing so (Hossen et al., 2022).

Generally applied to ground improvement, jet grouting is an emerging technology that offers effective solutions to a variety of geotechnical and geoenvironmental issues. For it to create hard, impermeable columns, panels, or wings, jet grouting requires displacing and rapidly mixing the subsoil with cement grout. In this procedure, a stabilizer is directly mixed in place with the ground with an upper-pressure injection. Throughout the application of the jet grouting process, the subsoil's mechanical characteristics are improved, which raises its bearing capacity and elastic modulus. The main purpose of jet grout columns is to increase the bearing capacity and decrease the settlement of foundations on soft soils when static loading is applied (Guler & Secilen, 2021).

Shake table tests were performed on a wrap-faced geotextile prototype wall with nine unique dynamic motions, four bases accelerated motions, and three distinct surcharge loads. This was carried out with a predetermined relative Kobe earthquake density. The strains in the upper layer were the greatest, and in the bottom layer, the least noticeable, which showed that the seismic stability was enhanced by the placement of geotextiles there. Standard displacements were rather high at higher base accelerations, in which the displacement reaction against surcharge change was inversely proportional to all heights (Hore et al., 2023).

In this study, a wrap-faced embankment is built in a flood-prone area of Bangladesh. The major purpose of the study is as follows:

a) To build a pilot wrap-faced embankment in flood conditions.

b) To observe the condition of the wrap-faced embankment in flood conditions.

c) To scrutinize effectively soil improvement technique like Jet grouting.

d) To develop a sustainable wave-resilient novel wrap-faced embankment.

2. GEOLOGY OF BANGLADESH

Bangladesh is the biggest delta in the world (Akter, 2016). There is plenty of sedimentation opened on the surface. Deposited Sediment is not evenly distributed throughout the country. The nation has over 250 both small and big rivers. The river system has left behind the sediment that was born in the river. On the other hand, Bangladesh is divided into three tectonic zones from north to south namely: (a) Stable platform or Indian platform (consisting of Himalayan foredeep, Rangpur Saddle, Dinajpur Shield, Bangura platform and Hinge zone); (b) Bengal Basin (consisting of Faridpur Trough, Hatiya Trough, Barisal Trough, Surma Basin); and (c) the Chittagong Hill tract. A map showing the geology of Bangladesh can be seen in Figure 1. This map shows three different kinds of soils.

Bangladesh's map of soft soil thickness is shown in Figure 2. SPT values under 5 are seen as an indication of soft soil. Soft soils can be described as very small-grained soils having a higher amount of water and low shear strength. They are generally thought of as difficult to build geotechnical constructions for. Soft soils can strongly affect the magnitude, frequency, and amount of time it takes for ground motion to get to the foundations during earthquakes and, as a result, the expected dynamic reaction of the structure. The primary concerns that typically occur in structures built over soft soils include large and differential settling (Garala & Madabhushi, 2019).

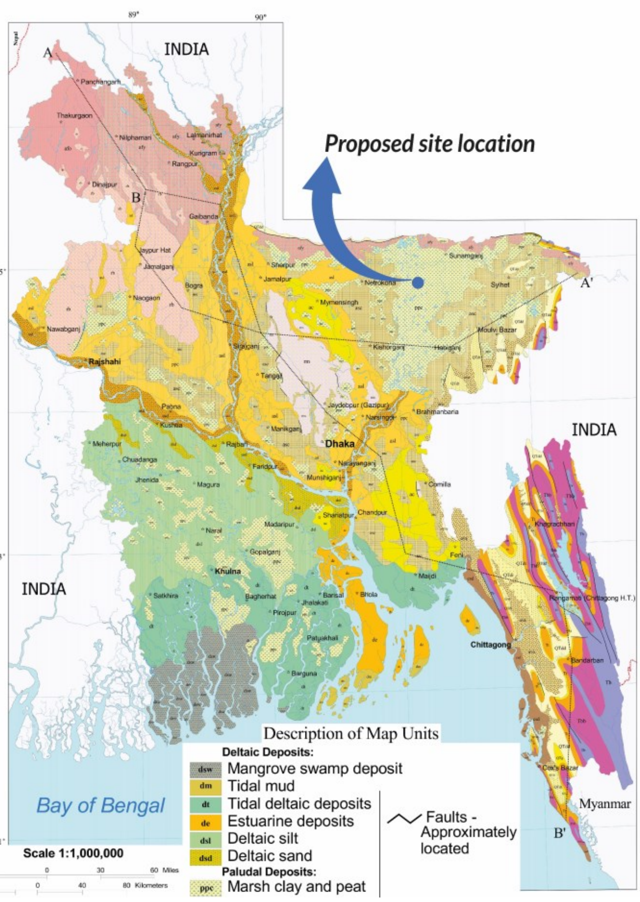


Figure 1 Geological map of Bangladesh (After GSB, 1991)

Heavy rains that led to the 2017 flash flood in the northeast region damaged portions of embankments and caused a significant destruction of belongings and loss of money for Haor residents. The flood also significantly damaged farming, particularly the Boro rice and fish produced that the Haor residents depend on to earn their living. This premature flooding directly affects the economy, water supply, livelihoods, particularly food security, and agricultural production (Mondal et al., 2019).

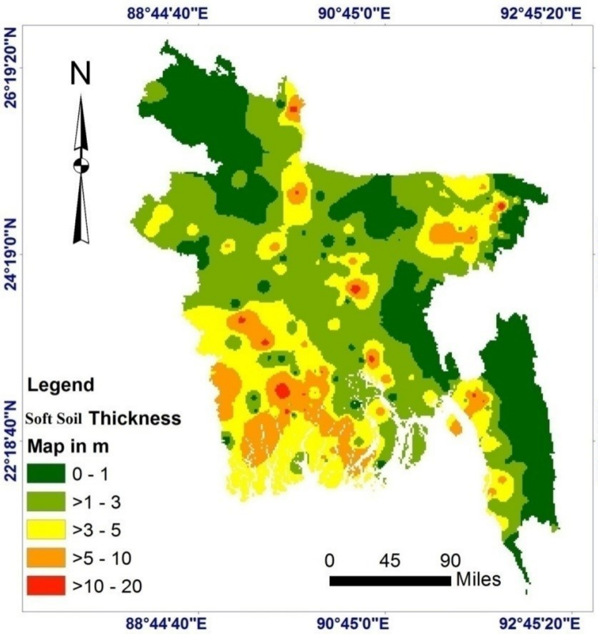


Figure 2 Thickness map for soft soil (After Hore *et al.*, 2019)

The selected location is a village in Bangladesh as our case study for its geological diversity.

3. PROJECT DESCRIPTION & LOCATION

The project site is located at Alga Hati village under Mohanganj upazila of District Netrokona in Bangladesh. The project's estimated cost is 22,392 USD. It has been executed under a project of LGED named HILIP (Haor Infrastructure and Livelihood Improvement Project) with funding of IFAD (The International Fund for Agricultural Development). Before and after photos of the site are shown in Figures 3 and 4.

Figure 3 Photo of the site before embankment construction

The coordinates of the site are 24.83487 N, 91.080720 E. Figure 1 depicts the geographic location of the site and Figure 5 illustrates the cross-section plan for the embankment. The objective of this work was to build sustainable, earthquake-resilient & stable embankments for the soft soil area of Alga Hati village, saving them from floods. A 200-m length of wrap-faced embankment is constructed for this project, and a subsoil of 16 m has been treated with jet grouting for increased stability and durability.

Figure 4 Photo of site after embankment construction

4. GEOLOGY OF THE SITE

The project site's geology consists of Paludal Deposits (ppc) and Tidal Deltaic Deposits (dt). The location has a mix of tidal deltaic deposits, comprising crevasse splays, lenses of very fine to fine sand, weathering yellowish grey silt, and clayey silt along active and abandoned stream channels. Some deposits from brackish water can be seen here. Large portions of the land are submerged during spring tides; the area is crisscrossed by several tidal creeks. Soft marsh clay, peat-grey or blue-grey clay, black herbaceous peat, and yellowish-grey silt are also found on this site (Chakraborty et al., 2017).

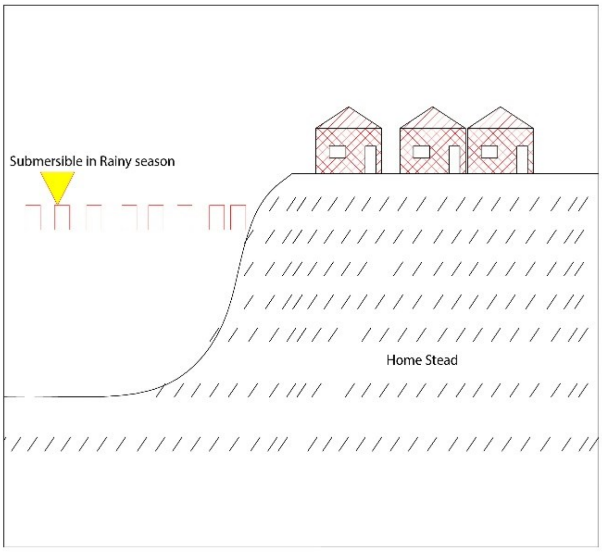
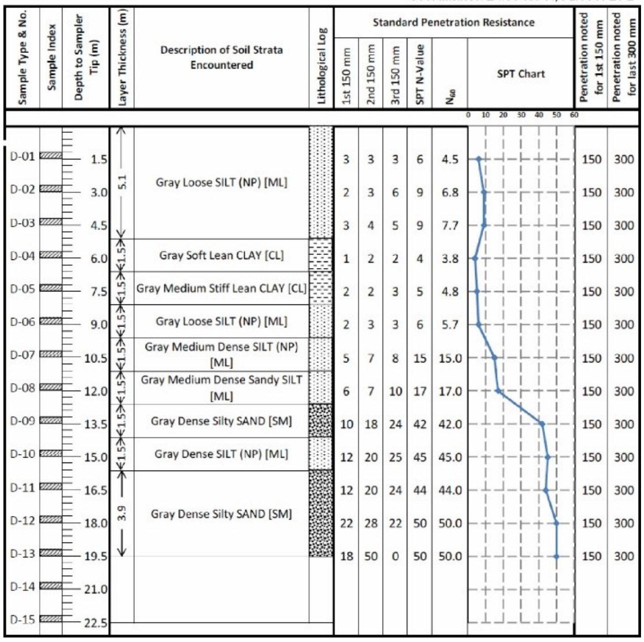


Figure 5 Plan of cross-section for the wrap-faced embankment

5. SUB-SOIL INVESTIGATION

The soil investigation report was created based on a contract involving the Local Government Engineering Department (LGED) at Mohanganj, Netrokona, and the Smart Development Engineering (SDE) Limited, a sub-soil examining company in Dhaka. The report shows at 1.5 m depth, the liquid limit of the soil was found to be 42%, and the plastic limit was 27% & plasticity index was 15%. At 4.5 m, the liquid limit was 53%, the plastic limit was 26% & plasticity index was 27%. At 6.0 m, the liquid limit was 45%, the plastic limit was 28% & plasticity index was 17%. The amount of moisture of the soil can be seen in Figure 6. Moisture content in the soil varies from 30% to 40% in dry conditions.


Coordinates: 24.83487 N, 91.080720 E

Sample Type & No.	Depth to Sampler Tip (m)	Layer Thickness (m)	Description of Soil Strata Encountered	1st 150 mm	2nd 150 mm	3rd 150 mm	SPT N-Value	N_{60}	Penetration noted for 1st 150 mm	Penetration noted for last 300 mm
D-01	1.5	5.1	Gray Loose SILT (NP) [ML]	3	3	3	6	4.5	150	300
D-02	3.0			2	3	6	9	6.8	150	300
D-03	4.5			3	4	5	9	7.7	150	300
D-04	6.0	1.5	Gray Soft Lean CLAY [CL]	1	2	2	4	3.8	150	300
D-05	7.5	1.5	Gray Medium Stiff Lean CLAY [CL]	2	2	3	5	4.8	150	300
D-06	9.0	1.5	Gray Loose SILT (NP) [ML]	2	3	3	6	5.7	150	300
D-07	10.5	1.5	Gray Medium Dense SILT (NP) [ML]	5	7	8	15	15.0	150	300
D-08	12.0	1.5	Gray Medium Dense Sandy SILT [ML]	6	7	10	17	17.0	150	300
D-09	13.5	1.5	Gray Dense Silty SAND [SM]	10	18	24	42	42.0	150	300
D-10	15.0	1.5	Gray Dense SILT (NP) [ML]	12	20	25	45	45.0	150	300
D-11	16.5	3.9	Gray Dense Silty SAND [SM]	12	20	24	44	44.0	150	300
D-12	18.0			22	28	22	50	50.0	150	300
D-13	19.5			18	50	0	50	50.0	150	300
D-14	21.0									
D-15	22.5									

Figure 6 Bore log of subsoil of the site

6. SOIL IMPROVEMENT METHODOLOGY

Jet grouting was done to 16 m of subsoil to improve the stability and settlement of the wrap-faced embankment. Embankment itself is a wrap-faced embankment, which increases its stability and makes it earthquake-resilient. Figure 7 shows a schematic diagram of the jet grouting method.

An engineer should have a variety of solutions while dealing with problematic soil conditions at the project site. Preloading, lightweight fill, geosynthetic reinforcement, over-excavation and substitution, upright drains, stiff piles, and injection are some methods that can be used to improve compressible soils that are frequently used on-site. Enhancing density, raising shear strength, and lowering compressibility are approaches to promote stability. On the contrary, increased consolidation rates by permeability alteration also result in a decrease in groundwater flow. Even if current methods may reduce stability issues, it is still essential to take into consideration selection criteria involving sustainability, cost, and construction time. All of them are now the focus of argument among scholars (Mamat et al., 2019).

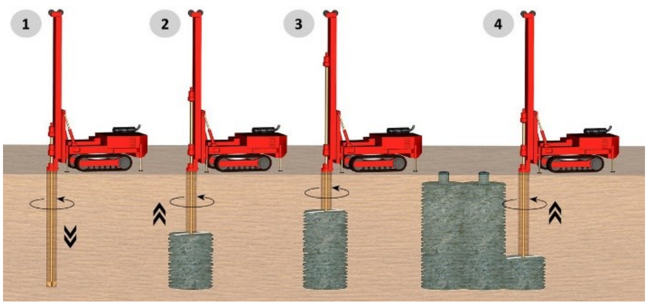


Figure 7 Schematic diagram of jet grouting method

7. EMBANKMENT CONSTRUCTION

Jet grouting was done to improve soil condition. At the toe part of the embankment, subsoil was treated with jet grouting to enhance the stability and decrease settlement of the wrap-faced embankment. The length of the embankment was a total of 200 m. The subsoil of 16 m length was improved by jet grouting. The remaining 184 m length of the embankment was not improved. The total length of the embankment underneath the soil was not improved to determine how the soil reacts with and without jet grouting. The depth of ground improvement using jet grouting is 8 m. The layout plan of jet grouting is shown in Figure 8.

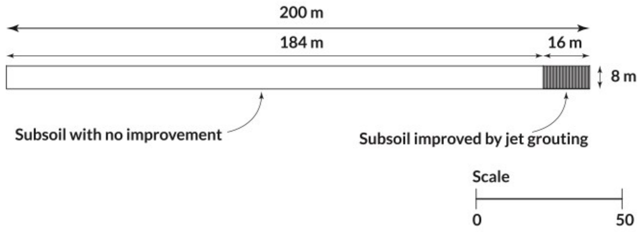


Figure 8a General site layout plan

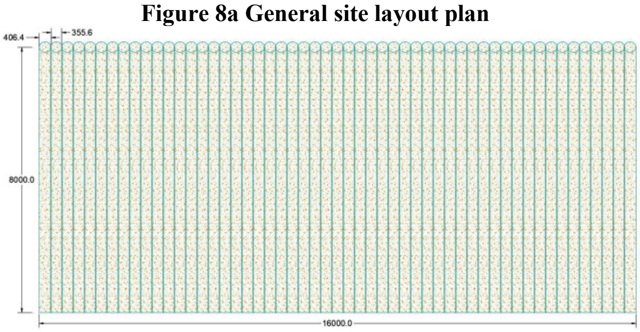


Figure 8b Layout plan of Jet Grouting

A four-layer GWR framework was constructed inside a wave flume for a study during which it was exposed to varied regular waves. Dimensions of the GWR structure were 0.45 m at the base, 0.48 m at the top, and 0.40 m at the bottom, as shown in Figure 9. The inclination of the slope was 60 degrees from the horizontal, and the wrap-around length' was 0.12 m from the border. The wave heights and periods used during the model experiments ranged from 0.18 to 0.22 m and 2 to 4 s, respectively. These trials had a scale of 1:8. To reduce scale impacts, fine sand (D50 ¼ 0:175 mm) and geosynthetics (4 kN/m for the nonwoven geotextile) with low tensile strengths were employed (Yasuhara & Recio-Molina, 2007).

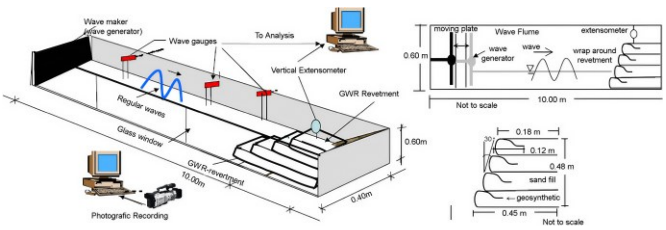


Figure 9 Dimensions of the GWR structure (Yasuhara & Recio-Molina, 2007)

The wrap-faced embankment studied in this research was vertical and had no slope. The sand of minimum FM 0.8, which is free from dust, earth, other vegetable growth, foreign materials, etc., was used in the construction of the embankment. The best quality geotextile of 2 mm thickness was used to wrap the sand filling. Machine-seamed joints (with 100% polypropylene or nylon thread) were used for the geotextile wrap sealing. The sand used in the grout mixture was fine up to 2 mm in grain size. The sand:cement weight ratio is 2:1. A hole with 18" dia, depth of 3 m was filled with grouting materials. Design specifications were maintained by following the drawings in Figure 10.

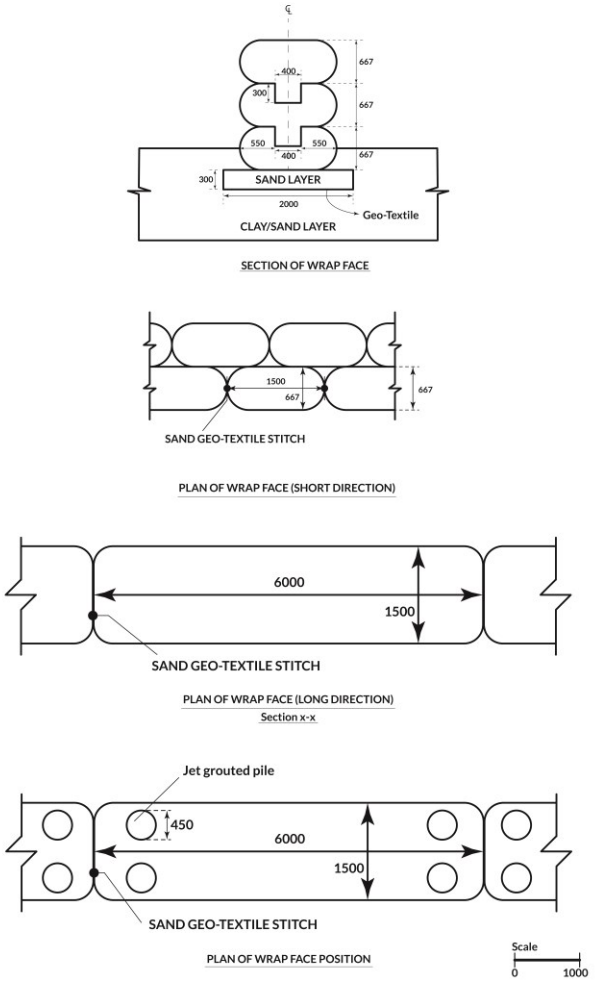


Figure 10 Wrap faced embankment sections

For constructing the wrap-faced embankment, at first, ground was dug, and a 2 mm geotextile layer was laid on the ground. Then a 300 mm layer of sand was laid while compacting it. Then another layer of geotextile was laid, and sand filling was done. Then, the wrapped face was stitched accordingly. The sand was filled in the geotextile wrap while compacting it in three layers manually (layers of 222 mm, 222 mm, and 223 mm each). The height of each wrapped face was 667 mm. For interlocking the wrap-faced together, the center part (200 mm to both sides of the centerline; total of 400 mm) of the wrap faces were lowered by 300 mm. Three layers of wrapped faces were used to build the embankment. The upper part of the top layer was not lowered as it had no wrapped faces above it.

The geotextile can be damaged by cattle or by boats. A measure was taken for this issue for 50 m length with the total embankment being 200 m of length. The vulnerability of the geotextile was minimized by layering the inner side of the geotextile with a thin layer of cement before wrapping the sand filling.

There are several approaches for constructing stable embankments over soft soil. The final decision on the adoption of an appropriate solution is determined by the actual circumstances, embankment geometry, time limitations, and potential future advantages (Abhishek & Madhav, 2013).

It has been seen that geotextile wraparound revetments (GWR) react remarkably well to differential settling and scour erosion. Customized design charts have been made easier to create with the knowledge gained from model tests run with geotextile wraparound revetments (GWR). These devices can effectively prevent tsunamis, sea level rise, and storm surges. Analysis indicates that there are still a lot of uncertainties around these structures, but geosynthetic structures shouldn't be considered as a replacement for other shore construction techniques. However, they are a better answer to a number of coastal issues. Revetments have the potential to be employed largely in a variety of coastal conditions thanks to modern advances in geotextile wrapping (Yasuhara & Recio-Molina, 2007).

Before the 18th century, grouting methods were in use, and they continued to advance through the 19th century. Some techniques consisted of injecting a grouting suspension into joints beneath dams, which contained a tiny bit of lime or cement to decrease leakage. For more than 150 years in Europe and more than 100 years in the United States, Portland cement was first used as a grout. Grouting is the process of injecting materials into soil or rock formations in order to minimize the soil's hydraulic conductivity while improving its mechanical rigidity, according to the geotechnical division of the American Society of Civil Engineers (Al-Khadaar, & Ahmed, 2023). The drilling rig used to perform the jet grouting process had the specifications mentioned in Tables 1 and 2.

Table 1 Details of jet grouting rig

Plus-Pressure Speed (m/min)	2.5, 15, 18
Stroke of Power Head (mm)	1,800
Electromotor Power (kW)	22+1.5
Working Dimension (L×W×H)	3,045 × 1,370 × 3,210 (mm × mm × mm)
Transport Dimension (L×W×H)	3,160 × 930 × 1,410 (mm × mm × mm)
Weight (kg)	1,800
Mounting Type	Bulk Type, Integral Type

Table 2 Details of jet grouting at this site

Grouting Diameter (mm)	400
Drilling Depth (m)	8
Angle of Grouting	90 (shallow depth)
Hole Diameter (mm)	100
Output Torque (Nm)	3500
Output Speed (r/min)	30
Lifting Force Power Head (kN)	40
Feeding force Power Head (kN)	25
Lifting Speed (m/min)	0.2

8. DISCUSSIONS

In recent years, new threats to riverside areas have emerged as a result of climate change and sea-level rise induced by global warming. Therefore, alternative solutions to protect the riverbank by geotextile solutions are of interest to replace more traditional materials and systems, such as those constructed from rock or concrete blocks. One of these alternative solutions is a geotextile wrap faced embankment, which will be cost effective and resist the wave action. Figure 11 shows the typical embankment failure in Bangladesh.

Figure 11 Typical embankment failure in Bangladesh

During pre-monsoon and monsoon in, Haors basin receives surface runoff water from rainwater, upstream springs, and rivers to become vast stretches creating turbulent water. Moreover, Haor water is being gained sufficient wave through wind pressure and moves towards the embankment or homestead. As a result, erosion occurs continuously in Haor villages and comes out of environmental, social, and economic impact. So, environment-friendly, wave protected along with low-cost protection (wrap face) is required to minimize erosion of embankments or homestead in Haor areas.

There are various advantages of the invented wrap-faced embankment:

Government land acquisition expenses in Bangladesh have dropped significantly. For example, if a 2:1 or 1:1 slope is provided, they would need to purchase substantial agricultural land on both sides of the embankment in order to build a traditional embankment. When constructing a wrap-faced wall, we will need less horizontal space, which will allow us to build conventional embankments in Bangladesh for less money. The embankment method, which was shown in a study to be suitable for Bangladesh's soft soil, may be made 70 cheaper than the standard embankment method since it allows for the construction of embankments on 60–70% less area.

It helps maintain a lot of agricultural land. In this area, agricultural productivity has increased.

There are numerous earthquakes in Bangladesh. It has experience with massive earthquakes, such as the Great Indian Earthquake of 1897 (magnitude 8.7), Bengal Earthquake of 1885 (magnitude 7.0) which harm both road embankments and building infrastructure. This newly created embankment offers superior protection against mighty earthquakes.

We know about Bangladesh's reasonable susceptibility to climate change. The water level of rivers is increasing day by day during the rainy season as a result of climate change. Thus, it is difficult to defend the riverbank at this time. The wrap-faced embankment that results in vertical reinforcement offers a fresh hope to withstand the wave action for the first time in Bangladesh.

Figure 12 shows the condition of the embankment before flooding. During flooding, the embankment looks like the one depicted in Figure 13. The condition of the embankment after flooding is depicted in Figures 14(a) and 14(b).

Figure 12 Wrap-faced wall before flooding

The study showed that wrap-faced embankments performed far better than traditional embankments. They were more stable, earthquake—and flood-resistant, and showed great resistance to recent floods in Bangladesh in August and September of 2023. Due to seepage, the area where soil was not improved by jet grouting was slightly deformed compared to the area with jet grouting.

Figure 13 Wrap-faced wall during flooding

Figure 14 (a) Wrap-faced wall after flooding

Figure 14 (b) Wrap-faced wall after flooding

Soil strength before jet grouting was 0.5 kPa (0.005 MPa). However, the strength changes drastically after improving the soil with jet grouting. Soil strength after jet grouting was seen to be 934 kPa (0.934 MPa). The soil gains 186.8 times the strength of soil before applying jet grouting, which was very impressive. Jet grouting also improved the settlement of soil to a great extent. The areas without soil improvement by jet grouting showed more settlement than the areas with jet grouting. Settlement was calculated using a theodolite and a sensor (The steel bar being the analog sensor). Figure 14 shows the sensor placement. After flooding, the settlement of the wrap-faced embankment without jet grouting area was found to be 112 mm. On the other hand, the settlement of the wrap-face (after flooding) in the jet grouting area was only 19 mm.

Figure 14 Steel bar used to measure settlement of the embankment

9. CONCLUSIONS

The response of a wrap-faced embankment constructed on soft clay soil has been studied in this research by piloting it at Netrokona in Bangladesh. Two different approaches have been implemented at the two parts of the same site: one where soil improvement has been implemented via jet-grouting and another part where soil improvement has been carried out. During the pilot research, different soil tests, such as the boring log, liquid limit, water content, and compaction test, were performed. In this research, it has been found that due to consolidation and seepage, the part of the site where the soil has not been improved by jet grouting, a slight settlement of the ground below the embankment has taken place. This research output will be helpful in showcasing the successful implementation of a wrap-faced embankment under flooding situations.

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