Construction of flood protection dyke using poor draining backfill materials on the banks of river Ganges, India

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ABSTRACT: Uttar Pradesh Jal Nigam Ltd (UPJNL), India had proposed to construct a modern Sewerage Treatment Plant (STP) of 60 million liters per day for treating the sewerage generated from the city of Allahabad. The construction site is located on the banks of River Ganges and it is extremely important to protect the STP Facility from inundation during floods. UPJNL had to build a flood protection dyke around the perimeter of the STP which eventually acts as a barrier from water intrusion during high flood water raises, which are quite common in the river bank zone of Allahabad. There are number of challenges to deal with in the project which includes scarcity of space to form a natural embankment, availability of suitable back fill materials, proximity to the river posing threat of embankment breach during peak floods. This paper effectively explains on the challenges dealt in design & engineering, quality of back fill material available and discusses challenges encountered during construction of the dyke when the peak flood occurred and submerged the dyke. This paper elaborates on the innovative approach chosen to design the 12m high & 2400m long peripheral flood protection dyke using composite geosynthetic reinforcement materials with wrap-around system, which has resulted in a sustainable engineered solution along with significant cost savings.

Keywords: Geosynthetic Flood Protection dyke, Reinforcement Composite, Back fill material

1 INTRODUCTION

Allahabad is one of the oldest cities of India, which is located 200kms South East of Lucknow, the state capital of Uttar Pradesh, India. Allahabad has a population of approx. 2.0 million with necessary infrastructure facilities. The annual population growth rate of Allahabad is about 3% and this phenomenon has resulted into increase in the demand to expand the existing infrastructure. The city authorities have taken up several measures to cope up the increasing needs of the population and this included a project to construct a new sewerage treatment plant. Uttar Pradesh Jal Nigam Ltd(UPJNL), the project authority, had initiated to construct a new Sewerage Treatment Plant(STP) of capacity 60 million liters per day to treat waste water of Allahabad city. The project authorities could allocate site to construct the STP 10 km away from city and on the banks of river Ganges. To protect the STP Facility against possible submergence during floods, UPJNL had to build a flood protection dyke around the periphery of the STP. A reinforced soil slope system using geosynthetics was chosen for construction of the dyke for its optimal usage of land space besides quicker construction over other conventional options such as earthen embankment with stone pitching, rock bunds etc. this paper focuses on the challenges in design, selection/sourcing construction materials and implementation of the project.

1.1 *Project site description and Constraints:*

As the project location chosen was in close vicinity of river Ganges (Figure 1), the authorities had a challenge to ensure the STP from getting flooded or submerged. The peak flood levels recorded were around 9m from the existing ground levels which made the authorities to propose a protection dyke of 12m height. An Earthen embankment of inclination 1H:3V with stone pitching on the slopes had been initially proposed, but this option of earthen embankment had the limitations of acquiring land and availability of quarry stones for slope and drainage arrangements made the project costs un-viable. After evaluating various options, Geosynthetic soil reinforced slope technology was chosen to build the protection dyke in 60degree slope angle for 2400m along the periphery of the STP. Conventionally, the backfill materials used for reinforced soil structures are frictional & free draining materials which provide necessary shearing resistance, allow quicker dissipation of pore water pressures and prevent lateral deformations. The standard recommendation of suitable backfill for reinforced soil structures is given below based on FHWA-NHI-00-043 code.

Recommendations for a Reinforced backfill to be used for reinforced soil slope:

1) Plasticity Index less than 20
2) % Fines passing through 75micron sieve <50%

In many cases, the fine-grained soil with poor draining properties are the only available backfill materials for reinforced soil structures. This type of soil has ability to retain high moisture content and can have adverse effects on reinforced soil structure. When these types of soils are used as backfill materials, pore water pressures can be generated and could cause high deformations to the structure. Through experiences, suitable backfill material contributes about 40% to 60% to the overall cost of the reinforced soil structures. However, significant cost savings can be achieved if soil available near the site location and be suitable for using as backfill material in reinforced soil construction. In the present case, the available fill material had fine content of 75% which is beyond the allowable standards of reinforced soil backfill specifications as per FHWA. Hence this soil is classified as "not" suitable "*backfill*" for the construction of reinforced soil slope. The grain size analysis of the backfill sample is shown in the table no 1. It may be seen that median sediment size (D_{50}) is 0.03 mm. The percentage distribution of backfill soil passing 75 microns is about 73.5%, Hence it can generally be assessed that most of the sediment to be Sandy Silt.

Table 1. Backfill Properties Grain Size analysis

Classification of Soil	D_{50} (mm)	% retained 0.075mm	% passing 0.075 mm	Uniformity coefficient
Sandy Silt	0.03	26.5	73.5	42

Figure 1. Flood Protection Dyke Plan (Google Earth)

1.2 *Solution*

The project is initially designed to build the flood protection dyke using locally available fine-grained soil to form a 1 in 3 slope embankment. However, due to scarcity of land availability on land side and limitations to extend the dyke towards river side, it was decided to build the dyke as a reinforced soil slope. The soil available at site (fine grained soil) does not comply to the specific technical requirements of the reinforced soil backfill. Though the option of using the fine-grained soil as backfill material blended with granular soil existed, the project owner/authorities soon realized that blending is often difficult to achieve consistency and is a cumbersome process for implementation besides higher associated costs. After evaluating all the available options in the market such as Geogrids, geotextiles and other forms of polymeric soil reinforcement products, the project authorities have selected the option of using a Geocomposite reinforcement material. The geocomposite material is a multi-functional product as it offers necessary tensile strength to support the internal stability of the embankment besides functioning as an effective drainage cum filter layer. Typically, this means the geocomposite will allow vertical water flow (permeability) and horizontal flow (in-plane drainage). This aspect to function as drainage cum filter layer has proved to be an excellent value for the present case by allowing the locally available backfill soil materials in the project without any requirements such as blending. The Geocomposite layer will quickly dissipate pore pressures generated within the reinforced soil mass and safe guard the stability of the embankment. Figure 2 shows the dissipation of pore water pressure versus time with soil alone (control test) and with different geosynthetic reinforcement. This test was done using a test setup with surcharge loading applied at the top by means of a hydraulic jack loader. The geosynthetics were placed at silt openings to allow drainage of water. Porewater pressure transducers were installed to measure the pressure development in the test. The results clearly indicate the dissipation of water pressure was much faster when the soil was reinforced with geocomposite compared to other geosynthetic materials. The Composite geotextile consists of a continuous fiber non-woven polypropylene sheet reinforced with a grid network of high tenacity polyester yarns. The high tenacity polyester yarns provide the required tensile strength with maximum elongation of 10% and the polypropylene base provides the high drainage capabilities for the low permeability residual soil used as backfill material, which is essential for reinforcement applications in poor draining residual soils.

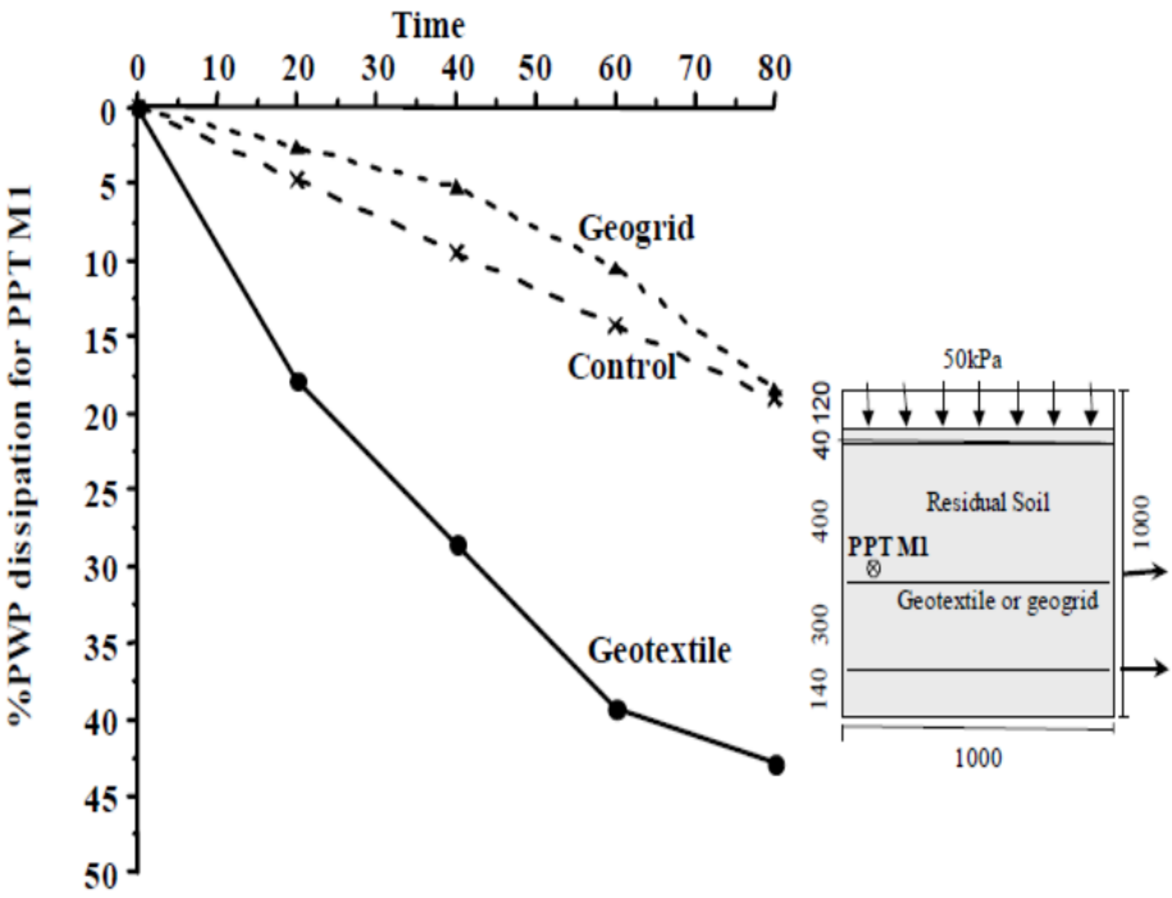

Figure 2. Dissipation of pore water pressure with time.

1.3 *Design and geometry*

The flood protection dyke, built using Reinforced soil technique, comprises of 12 m high embankment with a slope inclination of 60 degree (1in 1.8) for a length of 2400m around the periphery of the Sewage treatment plant. The design of the reinforced soil slopes is carried out in accordance with BS8006: 1995; Code of Practice for Strengthened / Reinforced soils and other fills. The method follows a limit state approach in which the disturbing forces are increased by multiplying prescribed partial load factors to obtain design loads and the resisting forces are decreased after dividing by prescribed partial material factors to obtain design strengths. The Stability checks of the Reinforced soil slope which include external and internal stability had been carried out using the ReSSA (Reinforced Earth Slope Stability Analysis) computer program version 3.0 by ADAMA Engineering INC. with the soil parameters given in table no 2. The strengths achieved through design analysis are 50kN/m and 100kN/m vertically spaced at 0.7m. the cross-section of the reinforcement dyke can be seen in figure 3.

Table 2. Soil properties considered in the design analysis

Soil Type	Friction Angle	Unit weight	Cohesion
Foundation Soil	27 degrees	16 kN/m^3	5kPa
Reinforced and Retained Soil	28 degrees	19 kN/m^3	0kPa

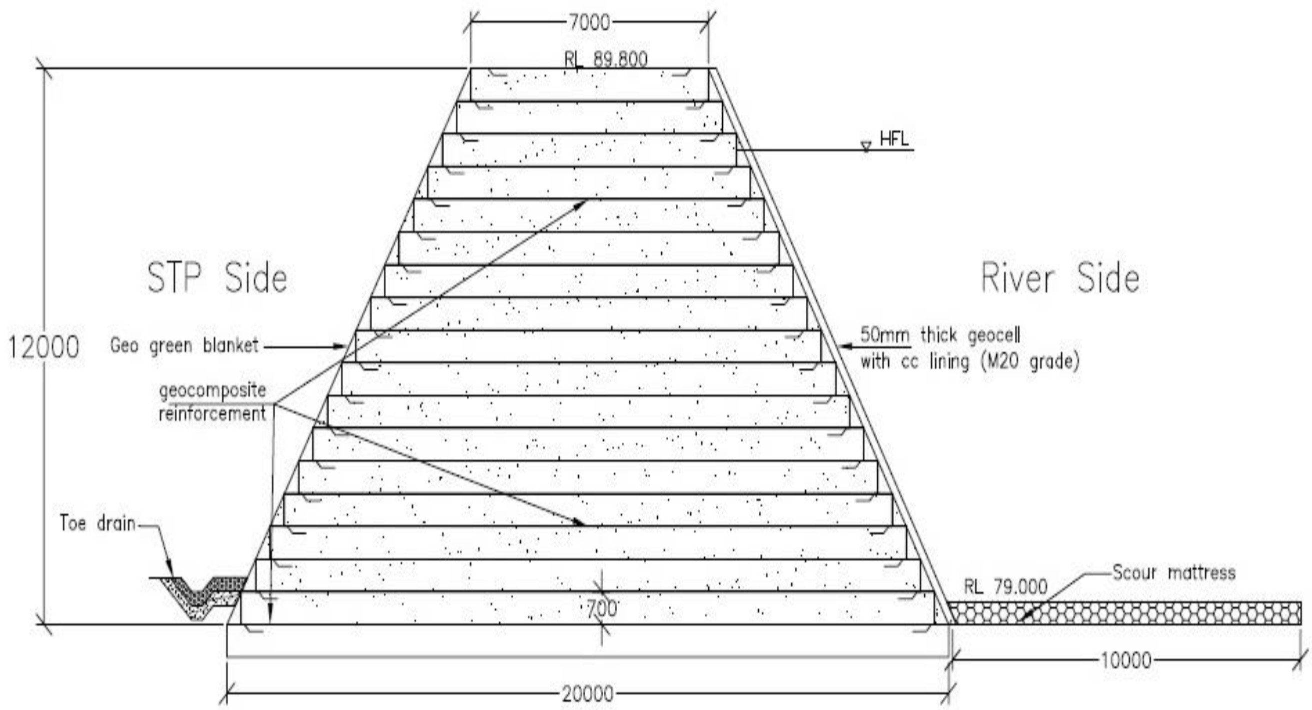

Figure 3. Typical cross-section showing Reinforcement dyke.

1.3.1 *Design analysis results*

The reinforced soil structure is analyzed for three different scenarios. In the first Scenario, the reinforcement with static conditions is considered. The second Scenario is analyzed with seismic conditions as the project lies in zone-II as per Annex E of Indian Standard 1893 (Part I): 2002. Thus, the seismic analysis is conducted using maximum ground acceleration coefficient of 0.10 and the third scenario has considered steady seepage conditions and analyzed both static and seismic cases. The summary of the stability analysis is mentioned in table no 3. The analysis with seismic conditions and seepage conditions using Geostudio International -Slope/w software is shown in figure 4.

Table 3. Stability Factors Summary

Condition	Achieved Factor of Safety with ReSSA Software	Achieved Factor of Safety with Geostudio Slope/w Software
Without reinforcement	0.63	0.67
With reinforcement -Static	1.6	1.52
With reinforcement- Seismic	1.35	1.42
With reinforcement -Static- Seepage conditions	1.41	1.36
With reinforcement- Seismic- Seepage conditions	1.26	1.19

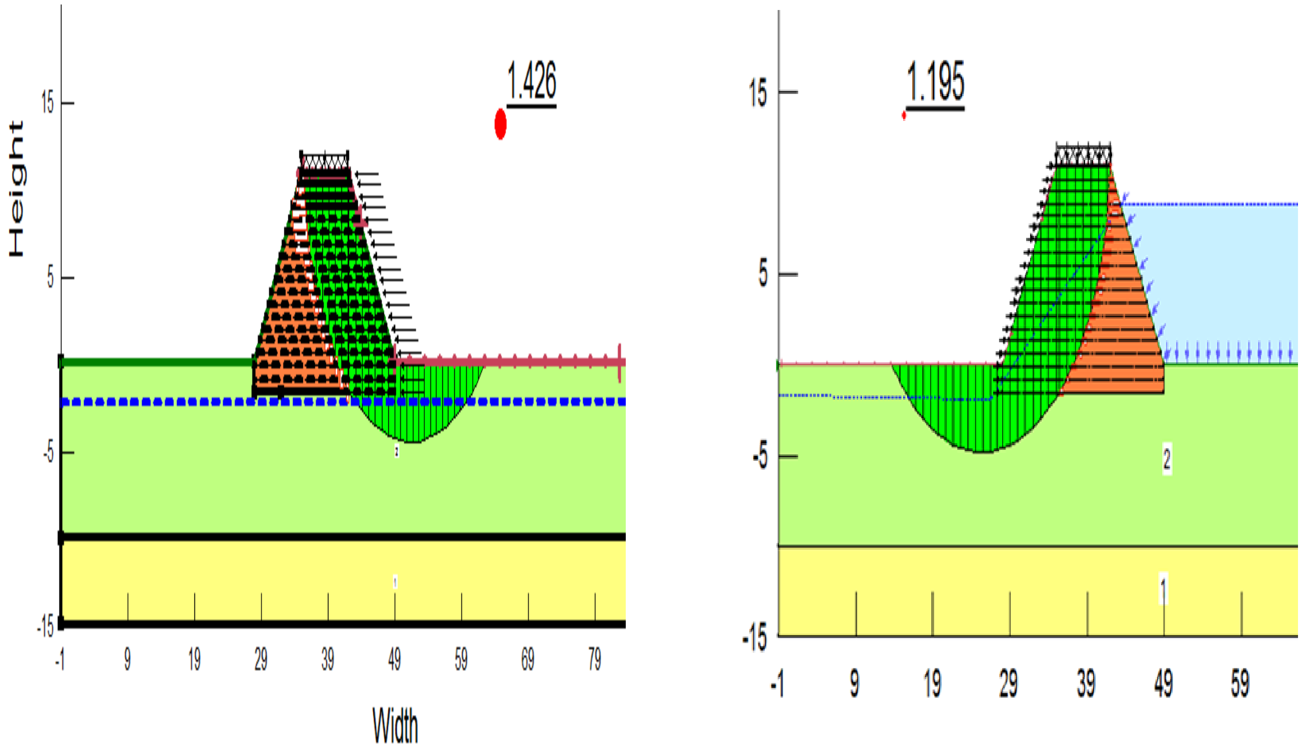

Figure 4: Static analysis and Seepage analysis with seismic conditions using GeoStudio Slope/w software.

1.3.2 *Technical specifications of geocomposite reinforcement*

The Composite geotextile consists of a continuous fiber non-woven polypropylene sheet reinforced with a grid network of high tenacity polyester yarns. The high tenacity polyester yarns provide the required tensile strength with maximum elongation of 10% and the polypropylene base provides the high drainage capabilities. Table no.4 shows the Tensile properties (Tensile Strength, elongation), allowable long-term design strength and hydraulic properties of the geocomposite used in the design of the reinforced soil structure. The design of reinforced soil slope considered a design life of 120 years.

1.3.3 *Protection works*

The Upstream side protection consisted of a scour mattress with boulder filling having 10m width and a thickness of 0.5m. The mattress is designed to act as a launching apron. The design considered typical hydraulic parameters[2] prevailing at site location such as critical velocity and scour depth. The toe drain was provided at the downstream side of the reinforced soil structure to collect seepage from the horizontal layers of geocomposite, through foundation as well as any surface water runoff on the embankment. The depth of the toe drain was about 0.40m.

Table 4. Technical Specifications of the Geocomposite

Properties of Geocomposite	Geocomposite 1	Geocomposite 2
Ultimate Tensile strength (Tu)	50kN/m	100kN/m
Tensile elongation	10%	10%
Partial factor for Long-term Creep (fcr)	1.55	1.55
Partial factor for Construction damage (fcd)	1.02	1.00
Partial factor for Environmental effects (fee)	1.1	1.1
Long term design strength Ta= Tu/(fcr x fcd x fee)	28.7kN/m	58.7kN/m
Water flow rate normal to the plane (50mm head)	65 $l/m^2/s$	65 $l/m^2/s$
Water flow rate in the plane (20 kPa)	11 l/(m.h)	11 l/(m.h)

1.4 *Flood levels*

During the design of the structure the most important considerations were the flood levels and the drainage arrangements adjacent to the reinforced soil structure. the data authorized by UPJNL is shown in table no.5. The structure was planned to be built with a provision of free board of 1.82m above High flood level. The annual flood discharge of river ganga is shown in Figure 5 which indicates discharge capacities recorded in the past 10 years.

Table 5. Flood levels at Project Site

Data	Levels
Ground Level	79.00 m
Top Level of Dyke	89.80 m
Top Width of Dyke	7.00 m
High Flood Level	87.98 m
Danger Level	84.74 m

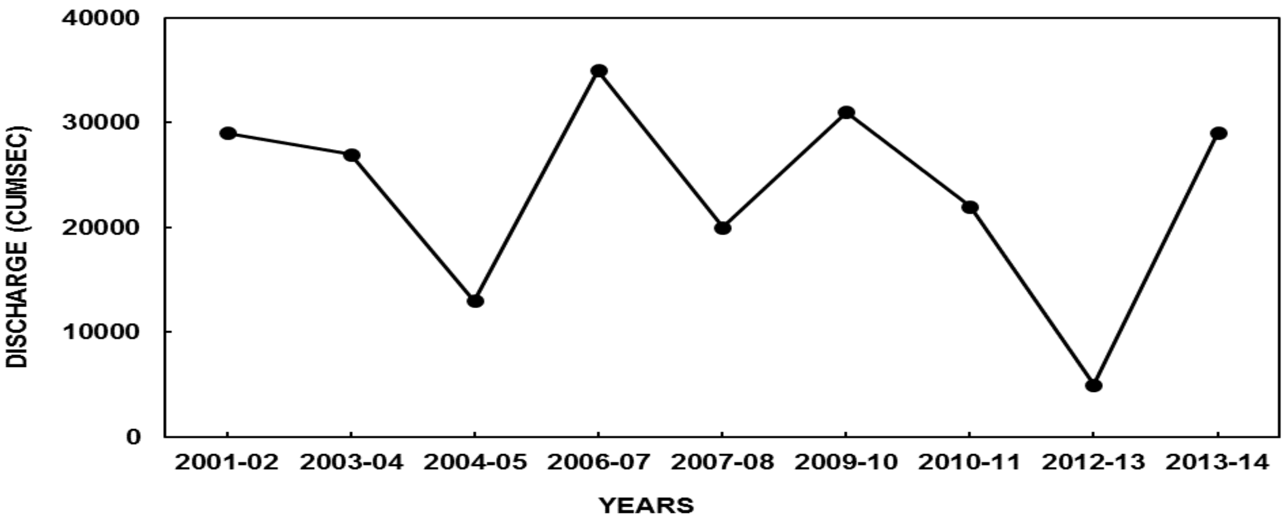

Figure 5. Annual flood peak pattern in river Ganga and its tributaries (CWC India)

2 CONSTRUCTION CHALLENGES

Standard procedures of constructing the reinforced soil slope were adhered. However, few construction challenges were countered which are listed below.

2.1 *Wrap round facing*

Wrap round facing was adopted where in fascia units of L-shaped steel frames to support continuous aluminum brace boards were erected and the first layer of reinforcement was laid (figure 6). Wooden brace boards of 20mm were originally suggested which would help in taking the stress effectively and would try to prevent the bulging in the embankment. Usage of aluminum brace boards resulted in bulging in some locations.

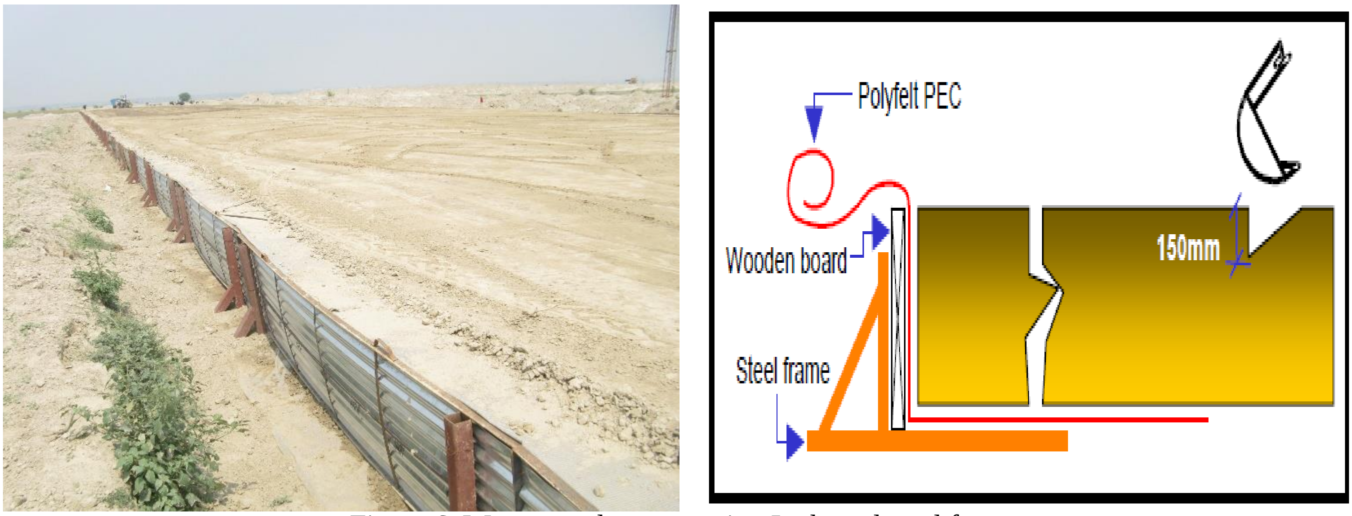

Figure 6. Wrap round system using L-shaped steel frame

2.1.1 *Compaction*

Geosynthetic reinforcement of designated lengths (end to end) were installed with a vertical spacing at 0.7m with total wrap round of 2m on both sides of the dyke. As fine-grained soil was used as backfill, the amount of water present in such type of soil mass affects the ease and quality of compaction Water ponding method was used to achieve the desired optimum dry density of 95% according to standard proctor. this method made the construction process slower.

2.1.2 *Scheduling*

The construction of the dyke began in January 2011 and completed in November 2016. Typical construction schedules in the project site are for over 7 months in a year (Jan-May, Nov-Dec). The gap of 5 months was caused mainly due to several factors ranging from un-favorable climatic conditions, construction accessibility & other operational challenges. The challenges to achieve quality in construction, timely mobilization of resources and compressed project schedules resulted in the project delay.

2.1.3 *Slope protection*

The slope configuration of the dyke is considerably steep and not suitable for conventional slope protection system such as natural vegetation and rock armor. Hence protection systems were designed in such a way that the form of protection is interconnected and sufficiently anchored to create stability. The inner side of the dyke is installed by green mat cover with an objective to protect the slope and its color blend with the surrounding greenery. The outer side facing of the dyke is designed to protect the slope against erosion caused by water currents during peak floods contacting the slope. The protection is designed using geocell filled with concrete to support stability against hydraulic uplift forces and other external destabilizing forces.

2.2 *Peak Flood Situation*

In the year 2013, peak floods occurred in three phases. First major flood had occurred during the last week of July followed by next flood in September and last flood in the 1st week of October. The partially constructed dyke of 2.5m height (RL 81.50) throughout the periphery had survived these floods. The flood level during this period was well above the danger levels (RL 84.74m), which was 9m from the ground level. The dyke was submerged for a period of 10 days and flood water receded slowly. However, a small portion of the constructed dyke had breached. The width of the breach portion was around 10m. This critical location was ascertained to be the channel of flood flow where the velocity was maximum (figure 7). this situation could have been avoided having completed the construction of the dyke on the river side first, but instead the dyke was constructed uniformly throughout the perimeter.

Figure 7. Breached portion of the dyke

Figure 8. Construction progress at site

Figure 9. Completed view of Flood protection dyke from the STP

3 CONCLUSIONS

The location to build Sewerage Treatment Plant (STP) adjacent to river Ganges is a challenging proposition as it requires to deal with issues ranging from limitation of space, availability of suitable construction materials, risks associated with floods submergence, project implementation and maintenance. The project authorities approach to deal with the issues by adopting innovative design in the form of geocomposite reinforcement has successfully addressed most of the issues. The hydraulic conductivity of the Geocomposite reinforcement (vertical flow rate and in-plane drainage) which allowed locally available backfill material has made the project viable for construction. The Geocomposite has also contributed in enhancing the safety of the dyke against any possible hydrostatic failures, thus minimizing the risk of submergence. The slope protection on the U/S of the dyke has proven to be a challenging affair considering its steeper slope configuration (> 60deg.) to install geocell filled with lean concrete. However, such slopes require more innovative solutions which are easily constructible, withstand the de-stabilizing forces & sustain over long-term. The performance of the dyke is found to be satisfactory after 2 Years of completion. However, periodical inspection & monitoring of the dyke are essential to analyze the structural behavior of the dyke in a regular manner and take up maintenance where ever necessary.

ACKNOWLEDGMENTS

We sincerely thank M/s. IVRCL Infrastructures & Projects Limited – Hyderabad, Uttar Pradesh Jal Nigam Limited – Allahabad, Ganga Pollution Control Unit – Allahabad for allowing us to have access to project site.

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