Reinforced earth® MSE wall with high adherence GeoStrap® for the approach of bridge over Shitalakshya river at Kanchpur near Dhaka, Bangladesh

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ABSTRACT: Reinforced Earth® retaining structures, also known as Mechanically Stabilized Earth (MSE) structures, are an alternative to conventional earth retaining structures. This technology is based on the concept of resisting earth pressure exerted by the retained soil by means of either Steel or geosynthetic reinforcing elements. Reinforced Earth® technology was invented in the 1960's by the French engineer and architect Sir Henri Vidal, who first published results of his research in 1963. In 1967, Sir Henri Vidal received patents for this technology. The new, patented technology was so versatile and cost effective that its use spread rapidly in the early 1970s to more than 30 countries throughout the world. The application of an axial load on dense granular material induces lateral expansion. Because of dilation, the resulting lateral strain is more than one-half the axial strain. However, if inextensible/extensible horizontal reinforcing elements are introduced within the soil mass, the lateral strain can be resisted through frictional interaction between the granular material and the reinforcing elements. This is the fundamental principal on which Reinforced Earth® technology works. This paper presents the case study of a completed project in which the Reinforced Earth®Wall with High Adherence GeoStrap® was adopted for construction of the approaches of Kanchpur 2nd Bridge in Bangladesh. With the objective of contributing to sustainable economic growth of Bangladesh, This JICA funded project was undertaken to enhance the capacity and efficiency of transport in Bangladesh by rehabilitating and constructing Kanchpur, Meghna, and Gumti bridges on National Highway No. 1 between Dhaka and Chittagong. The total length of these 3 four lane carriageway bridges with is around 2.7 Kms. The superstructure is comprised of continuous steel narrow box girder while the substructure is comprised of T type inverted abutment and columnar pier resting on RCC bored pile. Cruciform shaped concrete panels were used as facing element of the bridge approach MSE walls. Technical details pertaining to the bridge approach design and construction are presented in this paper.

1 INTRODUCTION

Reinforced Earth® Technology was invented in 1960's by the French engineer and architect Sir. Henri Vidal, who first published results of his research in 1963.In 1967, Sir. Henri Vidal received patents for this technology, and he started his company called "Terre Armee Internationale" and the first significant structures were constructed in Europe.

The new patented technology was so versatile and cost effective that its use spread rapidly in the early 1970s to more than 30 countries throughout the world.

Reinforced Earth® retaining wall system is a fast and cost effective solution for the construction of earth stabilized vertical walls for bridge and approaches for various underpasses. The facing system offers a natural aesthetic appearance and can be casted in various shapes. Reinforced Earth® retaining walls utilizes discrete concrete panels with joints provided between panels in order to enable the structure to accommodate differential settlement and dynamic loads. The Reinforced Earth® system adopted in this project was composed of High Adherence GeoStrap® which were connected to the facing panel by means of patented connectors, which were embedded inside the panels during panel casting. The high adherence reinforcing straps have high adherence edges to provide passive resistance.

Design and construction of Reinforced Earth® includes all dead and live loads and its combinations including seismic load. The connectors between the straps and the facing have been designed to provide high durability and easy installation. The structure has to be designed for a service life of 100 years.

Before execution of works it is necessary to conduct requisite tests of the founding soil for checking the Safe Bearing Capacity in terms of overall stability and safety of the structure.

The MSE walls are also very much earthquake resistance due to their flexibility and has resisted ground acceleration of 0.91g (Sankey, J.E. and Segrestin, P. 2001. “Evaluation of seismic performance in MSE structures.”Landmarks in Earth Reinforcement, Volume 1.Proceedings of the International Symposium on Earth Reinforcement, Kyushu, Japan. pp 449-452) with minimum damage.

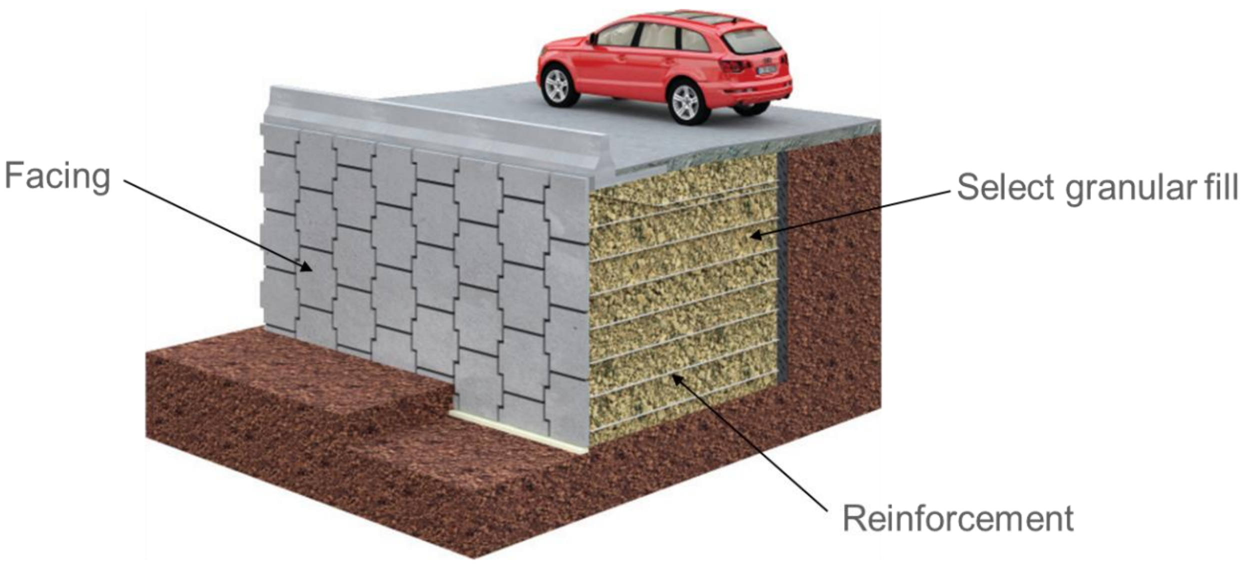

Figure 1. 3D View of a Reinforced Earth® Structure.

2 PROJECT BRIEF

The Road Transport and Highway Department of Bangladesh intended to build the prestigious Kanchpur 2nd Bridge over Shitalakshya River with the following major challenges:

- The project had to be completed within a short duration.
- The adopted system had to be economical and faster to construct as compared to conventional earth retention systems like RCC retaining walls.
- The project site is adjoining to Dhaka-Chittagong road with a huge traffic movement all through the day, so movement of heavy piling rigs and concrete batch mixers are very difficult for the construction of convention concrete retaining wall.

2.1 *Location of the Project*

Figure 2. Location of the project in Google Map.

2.2 *Salient Feature of the Bridge Approach*

The objective of the bridge is to strengthen the capacity and to enhance the efficiency of transport in Bangladesh by rehabilitating and constructing Kanchpur, Meghna, and Gumti Bridges on National Highway No. 1 between Dhaka and Chittagong, thereby contributing to sustainable economic growth of Bangladesh.

- Length of the approach at the interchange – 400m both sides
- Maximum Height of retaining structure – 10m (from existing ground level near abutment)
- Carriageway Width – 12.85 m
- Application – Road
- Traffic surcharge at top – 24 kPa
- Seismic Coefficient – 0.20g.

2.3 *Backfill Soil Properties*

- Fill Density of Reinforced fill – 20 kN/m^3
- Fill Density of Retained fill – 20 kN/m^3
- Angle of Shear resistance of reinforced fill – 34 degrees
- Angle of Shear resistance of retained fill – 34 degrees

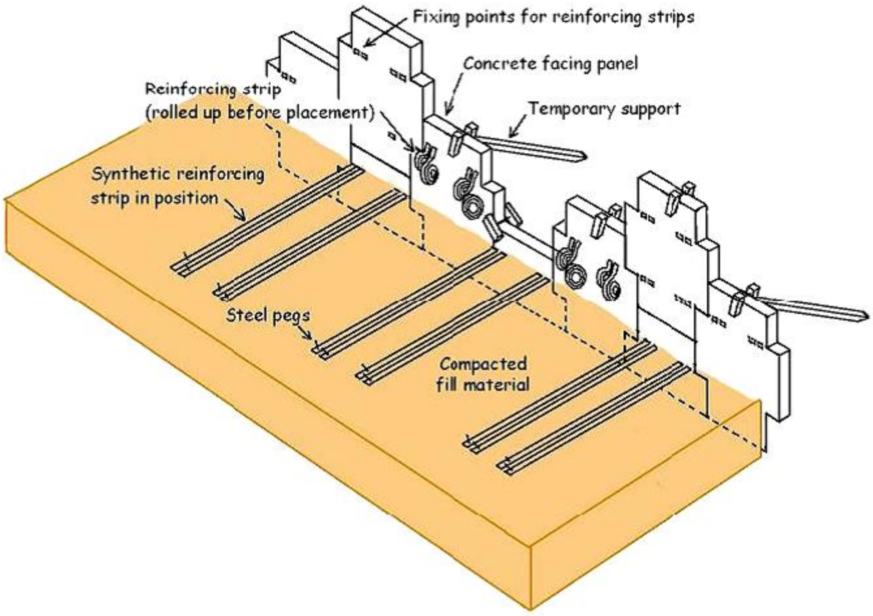

Figure 3. 3D view of reinforced earth system.

Figure 4. Aerial view of the structure (taken during construction).

3 DESIGN CRITERIA

3.1 *Principle of Reinforced Soil Engineering*

A simple model helps to explain the principle on which the reinforced soil techniques are based. Let us consider a soil element which is part of an infinite mass of soil: the application of a vertical stress σ_v produces a deformation in the element and the consequent horizontal stress σ_h, generated by the lateral compression suffered by the adjacent soil. Horizontally, the soil element undergoes a "tensile deformation" e_h, which is one of the main causes of local failures.

When a reinforcing element is put into the soil, the application of a vertical stress is followed by the deformation of the soil element and the extension of the reinforcement. This extension then generates a tensile strength F in the reinforcement, which in turn produces a horizontal stress σ_h*. This stress, which also provides a confinement action of the soil granules, greatly contributes to resist the horizontal forces and to reduce the horizontal deformations. Therefore, the inclusion of a soil reinforcement into the soil mass reduces the stresses and strains applied to the soil; on the other hand, the vertical stress σ_v applied to the soil mass can be increased, compared to the unreinforced soil, at equal deformations.

3.2 *Properties of the Soil Reinforcement*

- Friction behavior of the polymeric strap is defined by the pullout resistance which is defined by the ultimate tensile load required to generate outward sliding of the reinforcement through the reinforced soil mass.
- Ultimate tensile strength of Polymeric strap is defined as force required to rupture the reinforcement. The ranges of Polymeric strap available have ultimate tensile strengths varying from wide ranges however 25 kN to 50 kN is used in this project.
- Creep behavior
- Installation damage
- Long term durability

The summary of all reduction factors are as follows:
LTDS = $Tult \times (RF_{CR} \times RF_{ID} \times RF_D)/FS_R$
RF_{CR} = 0.69 (Reduction factor for creep)
RF_{ID} = 0.95 (Reduction factor for Installation Damage)
RF_D = 0.87 (Reduction factor for Durability)

The apparent coefficient of friction μ^*, between the fill and the high adherence polymeric strap reinforcement can be conservatively considered as 1.5 at top and linearly varying to tanΦ at a depth of 6m from top and down. For the reinforced earth fill specification used on this project (ϕ' = 34^{0}Coefficient of Uniformity $C_U \geq 2$), μ^* varies from a value of 1.500 at a depth of 0.0m to 0.675 at depth of 6m or greater.

3.3 *Backfill Requirement*

The design of high embankment is based on the following criteria of fill soil:

- The fill in the structure or slope shall be wholly frictional.
- The fill for reinforced soil structures shall be well graded selected material as specified and available within reasonable lead distance. The fill must allow dissipation of pore pressure by designing the same with free draining characteristics and by providing vertical and horizontal drainage provisions in the reinforced soil volume. The association of drainage bay or interface drains shall be connected properly to the gradient required and shall be maintained during compaction in layers.

Table 1. Mechanical requirements of RE Fill.

Sieve size	Percent passing
80 mm (gravel)	100%
4.75mm (coarse sand)	more than 75%
75 micron (silt)	less than 15%

- Acceptance limits for materials with more than 15% passing 75 micron are related to the percentage of particles smaller than 15 microns as follows.

– Materials with more than 15% passing 75 micron sieve and more than 20% of particles smaller than 15 microns are inadequate and shall not be used except.
– Materials with more than 15% passing 75 micron sieve and 10% of particles smaller than 15 microns are acceptable provided that the internal friction angle is not smaller than 32° and the fill shall be non-plastic.

3.4 *Basis of Design for the Project*

The design is based upon the principles in BS8006: 2010 'Code of Practice for Strengthened/reinforced soils and other fills' published by the British Standards Institution. In common with other codes for the design of civil engineering structures, this code of practice adopts limit state principles. These principles involve the application of partial material and load factors for various structure types; design lives and load combinations to ensure sufficient safety margins.

The design of reinforced soil structures is considered in two parts. The first part is the external stability. First, the lateral earth pressure acting on the back of the reinforced soil structure is derived using the active earth pressure coefficient, ka. Passive earth pressures on the foot of the wall are always ignored when considering any stabilizing forces. The reinforced soil structure is considered to behave as a mass gravity structure and is designed to prevent the external failure modes like sliding, overturning and rotational failures from occurring:

The second part of the design is the internal stability. This aspect of the design is used to determine the amount of soil reinforcement required to maintain the structural integrity of the reinforced soil mass. For Reinforced Earth® structures, the internal stability of the structure is designed using the Coherent Gravity Method as described in 6.6.4 of BS8006: 2010. Sufficient reinforcement is provided to ensure the following internal failure modes do not occur:

– Tensile rupture at any point along the length of the reinforcement.
– Tensile/shear failure at the connection between the reinforcement and the facing element.
– Loss of frictional bond (adherence) between the reinforcement and the soil fill.

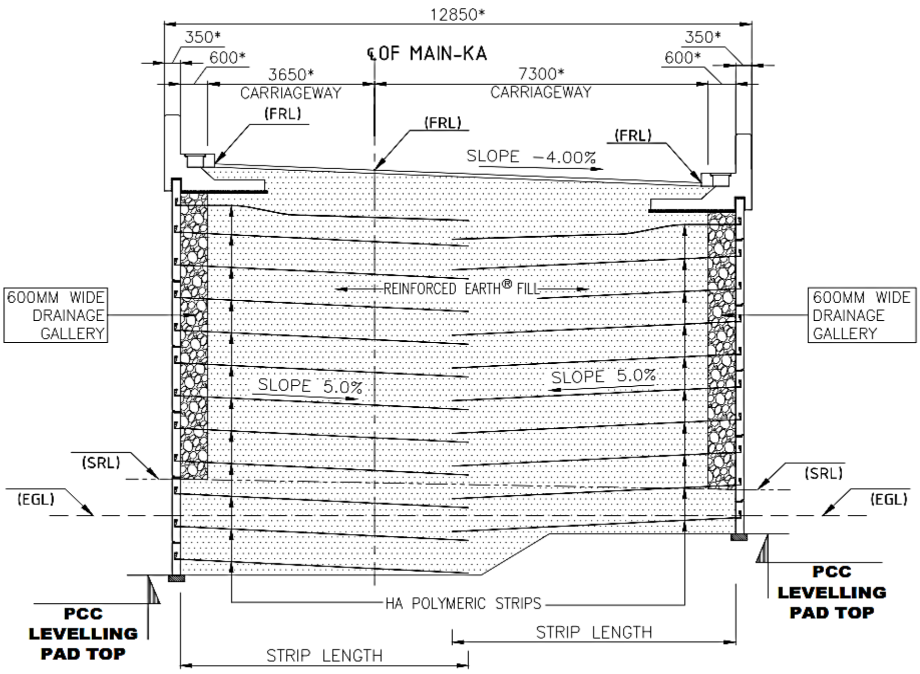

Figure 5. Typical cross-section of reinforced Earth® structure.

3.5 *GeoMega® Mechanical Connection System*

The purpose of the connector which was used is to provide a fully synthetic connection that gives mechanical and chemical protection to the geosynthetic straps, as well as a smooth surface for installation of the strap on site. The patented mechanical connection between the facing panels and the soil reinforcements consists of a loop shaped like the Greek letter **Ω**, which is partially cast into the precast concrete facing panel. This loop contains a recess through which polymeric strap is threaded into and thus, fitted to the facing panel on the jobsite."

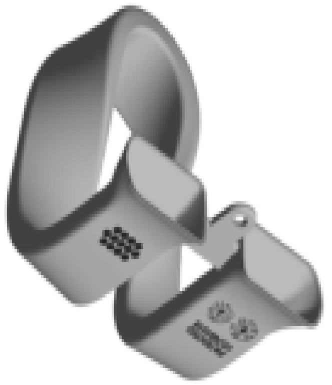

Figure 6. Mechanical GeoMega connector.

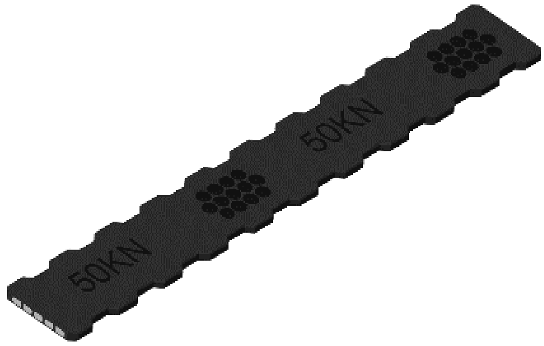

Figure 7. High Adherence GeoStrap®

3.6 *High Adherence (HA) GeoStrap® as Soil Reinforcing Structural Elements*

The High adherence (HA) polymeric strap is 50mm wide and has got rib(lateral teeth) on both side of the strap to enhance the adherence capacity of soil. The strap consists of discrete channels of closely packed high tenacity polyester fibers respectively encased in a LLDPE sheath. While polyester (PET: Polyethelene Terrapthalate) is the load bearing element maintaining minimal deformation, the polyethylene sheathing maintains both the integrity of the product and encases the yarns, protecting them from harsh installation conditions. Polymeric strap have been tested independently in accordance to published standards and will conform to the property values considered in the design. All the values are Minimum Average Roll Values (MARV) unless otherwise noted. Polyester straps have been used as reinforcing elements for designing Reinforced Soil Walls.

3.7 *Facing Panels*

The facing to the structures is formed from reinforced concrete precast panels. As specified in Table 9 of BS8006, the facing panels are designed to comply with BS5400: Part 4: 1990: '*Code of practice for design of concrete bridges*'. The panels are modelled as slabs and are designed to resist the imposed soil pressures acting on the rear face of the panel. Reinforcing steel to the panel is detailed to withstand the resultant load effects under ultimate limit state (ULS) and serviceability limit state (SLS) conditions. In this project cruciform shaped panels are used. The panels are casted with M35 grade of concrete.

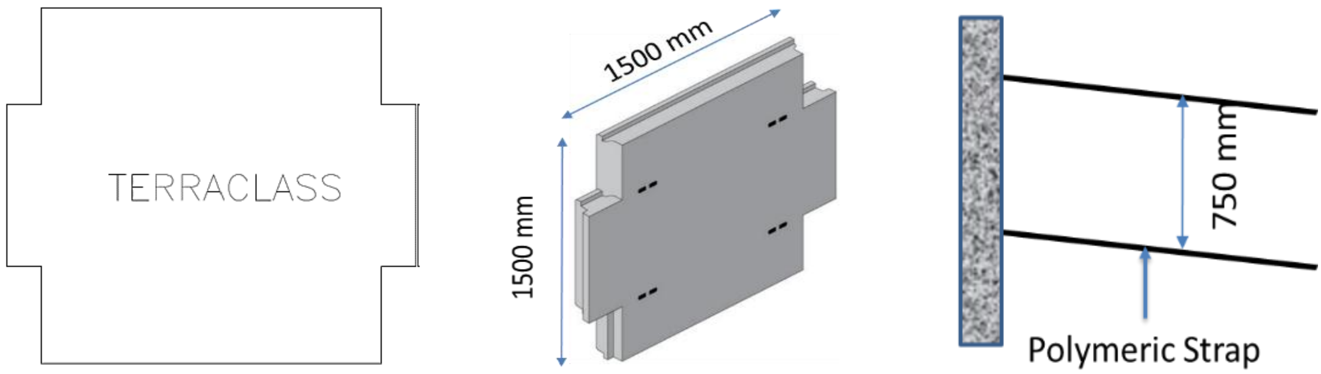

Figure 8. Cruciform panels used in this project.

3.8 *Seismic Analysis*

Horizontal seismic acceleration coefficient, A_o represents the maximum horizontal ground acceleration for a particular area. Recognizing the conservative nature of pseudo static analysis, FHWA recommends using design seismic acceleration, Am, which is half the maximum value (see Geotechnical Engineering Circular No. 3, Design Guidance: Geotechnical Earthquake Engineering for Highways, Vol. I & II, May 1997, Publication No.FHWA-SA-97-077).Also, reference can be made to Page 241 of FHWA-NHI-10-025 for design seismic acceleration. It may also be noted that many Reinforced Earth® structures have been designed to this standard and subjected to significant seismic events such as the devastating earthquake, which struck Turkey in August 1999. This 45-second earthquake, measuring 7.4 on the Richter scale, caused widespread damage to buildings and significant loss of life. Whilst several highway structures suffered irreparable damage, the Reinforced

Earth® structures remained largely serviceable. This confirms the stability of such flexible structures against earthquake.

The value of maximum ground acceleration (α_o) largely depends on which of the classified zones of the country the structure is located within. The design seismic acceleration considered is 0.2g as per BNBC code 2015. This has been interpreted as a horizontal bedrock acceleration of 0.2g. It has been assumed that the seismic design case is to be considered as an accidental load case and that the effect of traffic surcharge is reduced to 50% during the seismic event. The long term design strength for High adherence GeoStrap® reinforcement do not require a creep reduction factor for the seismic loading condition. The dynamic component of load for seismic design is a transient load and does not cause strength loss due to creep as per section 7.1.2.a of FHWA-NHI-10

3.9 *Drainage System*

The reinforced backfill is considered a self-draining media, having sufficient permeability to eliminate any destabilising lateral forces due to hydrostatic pressure and ground water seepage. This is in line with figure 78, Section 9 of BS 8006: 2010, requirements of drainage for RE walls. A600-mm wide drainage bay is provided behind the precast panel due to construction reasons.

4 CONSTRUCTION METHOD

Construction of Reinforced Earth® wall is a simple and repetitive method which is mostly labor oriented and have lesser usage of machineries or construction equipments. The construction steps are:

- The panel precasting and curing was done in a casting yard and then the casted panels are shifted to site as per erection requirements.
- The first row of panels is installed and aligned properly on a well-leveled PCC leveling pad casted on a compacted technical fill with requisite inward batter / slope for construction reasons. Proper barricade has to be implemented to ensure the safety.
- The first row of panel is braced directly to the ground to prevent movement during placement, after that first layer of HA GeoStrap® is laid by fixing with the connectors in the panel and compaction of selected backfill in layers is done over it.
- The succeeding panel courses are installed as the geotextile backing, backfill, drainage gallery at the fascia and GeoStrap® (soil reinforcing elements) are placed. Once installed, each layer of GeoStrap® is vertically spaced 750 mm apart, which corresponds to a multiple of the backfill layer thickness.
- The backfill is placed and compacted using vibratory rollers, except near the fascia. The 1.5m width from the fascia should be compacted by means of plate compactor or a 1Ton baby roller.

The above methods were followed in sequence to reach at top followed by pavement works and road furniture and fixtures.

Figure 9. Precast moulds used for casting.

Figure 10. Casting of panels in progress.

Figure 11. Curing of precast.

Figure 12. Panels transport to site.

Figure 13. PCC leveling pad casting.

Figure 14. Safety barricade.

Figure 15. Erection of first layer.

Figure 16. Strap laying and backfilling.

(a) (b)

Figure 17. Erection in progress.

(a) (b)

Figure 18. Completed structure.

5 FIELD TESTING

After the construction, a field pull out test was performed in the High Adherence GeoStrap® to corroborate the frictional coefficient value considered in the design to the frictional coefficient actually obtained in site. After testing it was observed that the test results are well inside the limits as considered in the design & was clear that the High adherence GeoStrap® can generate more friction than other materials of same nature.

Figure 19. Pull-Out test.

6 CONCLUSIONS

Recognized as a major innovation in the field of civil engineering, the Reinforced Earth® wall technique provides numerous structural solutions for owners and contractors ranging from retaining walls to bridge abutments and have following significant advantages:

- As in the MSE wall the load transfer mechanism is by friction so the reinforcing element should be such that the frictional factor should be higher. Keeping this is mind High Adherence GeoStrap® is used in this project. The mobilization of friction is higher in case of HA GeoStrap® as their outer surface is tooth shaped.
- Lower global cost: the possibility to build steeper slopes reduces the quantity of fill material needed for an embankment;
- Use of more natural resources and relatively less quantity of manufactured product and hence less emulsion of carbon dioxide (CO_2) and less impact on global warming;
- Relatively less use of equipment for construction and hence again less impact on global warming, besides saving in direct cost
- Improved stability: the reinforcement allows to increase the factor of safety;

- Reinforced soil structure is inherently flexible, it is possible to build directly on a foundation soil with low bearing capacity; a reinforcement at the base allows to build on soft soils, which would usually require a preliminary consolidation and great caution during construction.
- High resistance against earthquake load due to flexible in nature.
- Use of special facing units will give an even face for good appearance
- For heavy traffic areas no onsite casting is required thereby prevents traffic blockage and accidents.

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