MSE walls in Trinidad use innovative geosynthetic soil reinforcement

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ABSTRACT
This paper provides a case study of the design and construction of 9 highway ramp walls using innovative geosynthetic soil reinforcement for MSE walls. At the time of construction in 2008 it was just the second time in the Americas that this technique had been used. The paper illustrates some design features of the fully synthetic sleeve connection in combination with the high tenacity polyester fibre strip system. The use of the geosynthetic strip was driven by the contractor's desire to use some of the local backfill which had electrochemical properties aggressive to galvanized steel soil reinforcement. The 9 walls totalled and area of about 2700m2. The MSE wall technique used was the GeoMega strip system by the Reinforced Earth Company.

RÉSUMÉ
Cet article fournit une étude de cas pour la conception et la construction de 9 murs de bretelles d'autoroute utilisant un sol de renforcement géosynthétique innovateur pour les murs TSM. Au moment de la construction en 2008, il était seulement la deuxième fois dans les Amériques que cette technique a été utilisée. L'article montre quelques caractéristiques de conception de la chemise de connexion synthétique en combinaison avec le système d'armatures en fibres de polyester haute ténacité. L'utilisation de l'armature géosynthétique a été poussée par le désir de l'entrepreneur d'utiliser du remblai local dont les propriétés électrochimiques sont agressives à l'acier galvanisé dans le sol. La surface totale des 9 murs était environ 2700 m2. La technique utilisée pour le mur TSM était le système des armatures GeoMega par la Société Terre Armée.

1 BACKGROUND

Since 1998 and up until November 2006, a preliminary conceptual design for a tri-level interchange on the outer limits of Port of Spain, Trinidad West Indies was in development. In July 2007, The Government of Trinidad and Tobago decided to tender the work to have the Interchange built and relieve traffic congestion at the intersection of Churchill-Roosevelt/Uriah-Butler Highways. (Figure 1) The Churchill-Roosevelt Highway is the major east-west highway in Trinidad and Tobago. It runs for 24km from Barataria in the west to Wallerfield in the east where it ends in the former US army base on Fort Reid. It crosses the north-south Uriah-Butler Highway at Valsayn.

On this €48-million project, the contractor was responsible for the design and construction of the CRH/UBH highway interchange and related structures that connects east-west and north-south highways. The proposed construction method of the interchange, an incrementally launched prefabricated frame, helped compress the overall construction schedule, enhance worksite safety, and maintain traffic flow from start to finish on this particularly challenging project.

1.1 The Project

Figure 1. Site Location in Trinidad

Improvement and mutual access of the CRH (Churchill Roosevelt East West Highway out of Port of Spain) and UBH (Uriah Butler North South Highway) was desperately needed since daily (135,000 vehicles/day) traffic delay up to 4 hours at the congested grade intersection. The project called for the new CRH/UBH Interchange consisting of a main 600 metre long structure and associated structures to be delivered in a short time frame without interrupting the very heavy traffic.

1.2 PROJECT TEAM

The development was managed by MOWT (Ministry of Works & Transport, Trinidad and Tobago). The contractor was Vinci Construction Grands Projets from France, who brought to the design-build project a strong team of subcontractor and suppliers of Junior Sammy Limited, Prestcon Ltd., Readymix Limited, Caroni Reber Limited, Bhagwansingh's Limite, Paramount Limited, and Reinforced Earth Company Ltd. Canada from Toronto.

Contract procurement and project/contract management was supervised by NIDCO (National Infrastructure Development Company Limited), a Special Purpose State Enterprise limited liability company that is 100% owned by the Government of the Republic of Trinidad and Tobago. Various other Canadian consultants such as Cansult JV, Shaheen & Peaker Limited, and LEA Consulting Ltd. groups also had key participation on the project.

Figure 2. Frame of Main Superstructure

Although not part of the focus of this paper, the main bridge structure was a project defining icon. The bridge structure is a curve elevated flyover, 18 metre high, and carries three lanes of traffic with full shoulders. The superstructure has a radius of 2,400 metres, a 4.6% transverse slope and a 7% slope at each end. It is the longest and highest structure in the Caribbean to-date. (Figures 2 and 3)

Figure 3. Bridge Superstructure before decking

2 MSE WALLS

The wall system used is a composite material of compacted granular soil and linear soil reinforcements. The generic name for these types of structures is commonly known as MSE, or Mechanically Stabilized Earth. MSE is designed as a coherent gravity structure made of this composite material with a facing system. It is proportioned and designed internally to resist the applied loads in accordance with well established standards. The inherent compressive and shear strength properties of the soil are improved by the tensile strength of the soil reinforcements in these structures. A positive connection design of the reinforcement with the facing of the MSE is required to prevent overstressing at the connection and to minimize post construction movement.

The author's company provided the design and layout, budget and scheduling, and pre-manufactured materials supplies pertaining to the Mechanical Stabilized Earth (MSE) retaining wall requirements.

The total surface area of the MSE structures was about 2700 m^2, ranging from heights of 6 to 9 metres. A relatively new geosynthetic earth reinforcement system known with a full geosynthetic connection was used due to the aggressive local water content and higher chemical properties of the proposed source of backfill, particularly in chloride content, for the backfill.

Although the author's company usually uses galvanised steel strips for soil reinforcement on this project the geosynthetic strips were used. The use of the geosyntheitic strip was driven by the contractor's desire to use some of the local backfill which had electrochemical properties aggressive to galvanized steel soil reinforcement. Other types of soil reinforcement commonly used in wall designs are steel grids, steel bar mats of geosynthetic grids called geogrids.

2.1 Geosynthetic Strip System

The geosynthetic strip system used on this project offers two special features distinguished from other geosynthetic MSE systems currently available in the market. Improvements were made by this system to address various common concerns such as the extensibility and durability of geosynthetic reinforcements, the protection of the reinforcement from the environmental degradation, the problem of the lack of positive connection, hydrolysis, chemical and biological influences.

2.1.1 Geosynthetic Reinforcement

This geosynthetic strip consists of high tenacity polyester fibres encased in a polyethylene sheath. The high tenacity polyester is the load bearing element, while the sheath protects the yarns from installation damage and degradation. (See Figure 4) The durability of the polyester strip has been increased by the polymerization process, achieving a minimum molecular weight and low carboxyl end group member. This geosynthetic strip is recommended for use in soil environments characterized by 3<pH<9, with no detrimental affect on the strip due to low resistivity backfill, or from backfills with high chloride or sulphate content. Ambient temperature of the retaining wall site is considered in the determination of the long term allowable reinforcement tension.

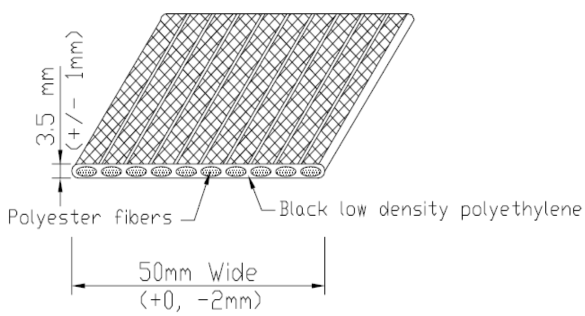

Figure 4. Geosynthetic Strip

2.1.2 The Panel Connection

The connection of the geosynthetic strip to the panel is accomplished with a unique plastic sleeve that is cast into the back face of the precast facing panel. The unique shape of this product connection considered uniform distribution of tensile loading of both the reinforcement and the connection to the facing. The connector sleeve assumes the shape of the reinforcement when it is looped into a natural anchor shape, in the configuration of the Greek letter Omega, embedded into the precast panel facing. (See Figure 5 and 6)

The smooth “Omega” configuration does not allow any acute bending or folding of the reinforcement which would weaken its strength. This shape also allows a uniform distribution of tensile stresses along the cross sections of the reinforcement.

The fully synthetic encasement of the entire sleeve and reinforcement system also provides protection from hydrolysis and other degradations and exposure of the main reinforcement to the concrete at the connection.

Figure 5. Connection Sleeve and Strip without Panel

Figure 6. Connection Sleeve and Strip Cast into Panel

2.2 Conditions for Geosynthetic Strips Application

The reasons for using the Geosynthetic strip system on these projects were:

- The tensile strength characteristics and earth pressure coefficients of the geosynthetic strips are similar to that for MSE walls reinforced with steel reinforcements,
- High apparent coefficient of friction between the strips and soil,
- High resistance to chemical and biological degradation,
- A reliable high strength connection of the reinforcements to the facing,
- Documentation of long-term reinforcement strength at various temperatures,
- Minimal construction damage during installation, and
- Standard MSE wall construction procedures

2.3 Geosynthetic Strip Design

The plastic strip designs follows similar geotechnical principles as in most accepted MSE designs and in conformance with both recognised design codes as well as material and quality control standards. Similar discreet integral cruciform shaped precast concrete facing was also used on this project therefore enabling geometries of the projects wall layout to be analysed similar to the author's routine structures. (See typical wall configurations in Figure 7)

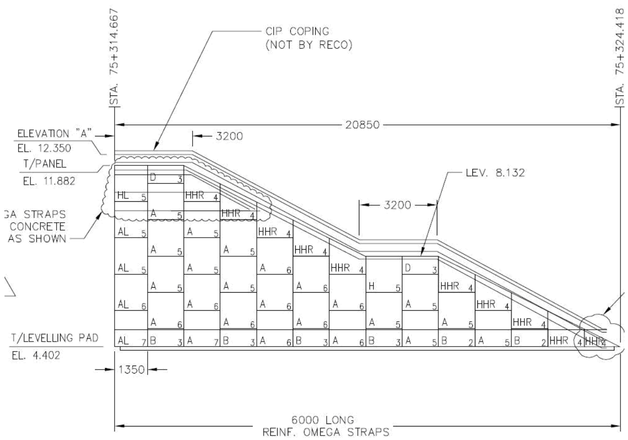

Figure 7. Typical Elevation Drawing from this Project

The durability of the geosynthetics reinforcements is influenced by environmental factors such as time, temperature, and chemical exposure. The effects of these factors on product durability are dependent upon the type of polymer used. It is noted that not all factors have significant effects on the broad range of geosynthetics products. Therefore, product specific tests were studied to evaluate the long term environmental factors.

Calculation of allowable tensile load for permanent structures follows practice codes:

$T_{al} = T_{ult} / FS * RF$

$RF = RF_{ID} * RF_{CR} * RF_{D}$

Where:

T_{al}: allowable tensile strength per unit of reinforcement width for geosynthetic reinforcements in permanent structures,

T_{ult} : ultimate tensile strength of the reinforcement,

RF: combined reduction factor to account for potential long-term degradation due to installation damage, creep, and chemical aging, (See Figure 8)

RF_{ID}: strength reduction factor to account for installation damage to the reinforcement,

RF_{CR}: strength reduction factor to prevent long-term creep of the reinforcement, (See Table 1)

RF_{D}: strength reduction factor to prevent rupture of the reinforcement due to chemical and biological degradation and, (See Table 2)

FS: safety factor which accounts for uncertainties in structure geometry, fill properties, externally applied loads, the potential for local over stresses due to load non uniformities, and uncertainties in long-term reinforcement strength.

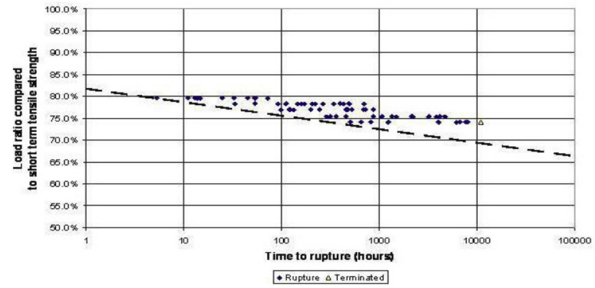

Figure 8. Time Strength Relation

Table 1. Reduction of Factors for Creep

REDUCTION FACTORS FOR CREEP

Constant design temperature (°C)	Creep rupture RF_{CR} Service life (years) 3	30	70	75	100
15	1.42	1.48	1.51	1.51	1.52
20	1.45	1.52	1.54	1.55	1.56
25	1.48	1.55	1.58	1.58	1.59
30	1.52	1.59	1.62	1.62	1.63

Table 2. Reduction Factors for Chemical and Biological Degradation

As previously noted, the choice of employing geosynthetic material on this project, for design of MSE walls is due to the aggressive backfill and water characteristics from potential sources for this site location. It is also noted that any MSE designs, regardless of material choices, should associate with prudent understanding of influencing external conditions and behaviours and predictability of the chosen composite material (soil, reinforcement and facing/connection) itself. Appropriate load factors should be incorporated in the design for all these aspects, both from the short and long term aspects during the life span of the MSE structure. Detailed wall engineering design

REDUCTION FACTORS FOR CHEMICAL AND BIOLOGICAL DEGRADATION

Design Temperature (°C)	Environmental Degradation; RF_D Design Life (years) 3	25	50	75	100
15°C	1.10	1.10	1.10	1.10	1.10
20°C	1.10	1.10	1.10	1.10	1.10
25°C	1.10	1.10	1.10	1.13	1.21
30°C	1.10	1.10	1.18	1.35	1.58

procedures for geosynthetics applications are well known and therefore not discussed herein.

The potential backfill for the MSE is a granular material but with aggressive chemical content. (See Table 3, 4 and 5) The original design was proposed in using steel reinforcing strips but was later changed to geosynthetic reinforcement due to this potential marginal backfill sources. Grain-size limits and strength characteristics of the backfill were within design parameters. (See Figure 9)

2.4 Chemical Tests

The results of the chemical tests are as follows:

Table 3. Chemical test results for Bulk 7

Test	Result	Specification requirement	Comment
pH	7.56	5-10	Acceptable
Available Sulphate	178.8 1 ppm	<200 ppm	Acceptable
Available Chloride	193.0 0 ppm	<100 ppm	High
Organic Contest	0.15%	-	-

Table 4. Chemical test results for Bulk 8

Test	Result	Specification requirement	Comment
pH	7.72	5-10	Acceptable
Available Sulphate	275.28 ppm	<200 ppm	High
Available Chloride	1213.80 ppm	<100 ppm	High
Organic Content	0.21%	-	-

2.5 Resistivity Results

The results of the resistivity tests are as follows:

Table 5. Resistivity results for Bulk 7 and Bulk 8

Sample	Minimum Resistivity (ohm.cm)	Specification Requirement	Commen t
BULK 7	2050	>3000 ohm.cm	LOW
BULK 8	277	>3000 ohm.cm	LOW

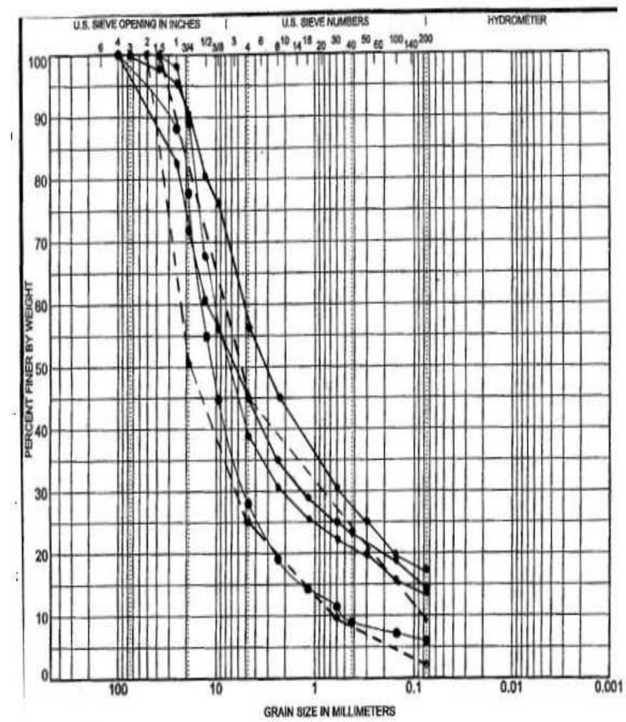

Figure 9. Grain-size Distribution of Marginal Backfill

3 CONSTRUCTION

The basic erection sequence for the geosynthetic strip system is similar to conventional MSE structures installation. Some differences and extra care in handling and securing extensible geosynthetic reinforcements should be noted.

Conventional MSE wall erection procedures can be used (with some modifications):

- Prepare the site including excavation and installation of drainage systems per design elevations and grades,
- Form and pour unreinforced concrete leveling pad,
- Install, align and secure precast facing panels, both vertically and horizontally, (Higher vertical batters may be required due to extensible reinforcement),
- Connect strips through sleeves (or uncoil strips as discussed below) and lay strips flat on the backfill, (anchor tail end of strips either by trenching, stakes or small berms),
- Spread and compact backfill in lifts up to slightly above the lowest level of the geosynthetic strips.
- Monitor the actual movement of panels during the placement and compaction of each lift of backfill; adjust the amount of batter according to field conditions.

There are two different techniques for the installation of this geosynthetic strip system. The standard technique is to receive the strips in rolls at the construction site and then feed them through the sleeves in the panel. The technique used on this project involved the strips being feed through the sleeves at the precasters after the panels were cast so that they arrive on site already inserted and coiled on the backface of the panels. This allows for a quicker site installation but does require careful monitoring of panels to ensure the panels with the correct strip length are inserted in the correct location of the wall.

The project crew consisted of inexperienced local labour under the part-time guidance of the MSE company advisor. This crew was successful in completing all MSE structures satisfactorily following the above procedures. (Refer to Figures 10 to 15 Installation sequence)

Figure 10. Casting of leveling pad

Figure 11. First row of panels sitting on leveling pad

Figure 12. Geosynthetic strips being unrolled on backfill

Figure 13. Geosynthetic strips laid flat

Figure 14. MSE Wall Installation

Figure 15. MSE Wall Installation

Figure 16. Completed project

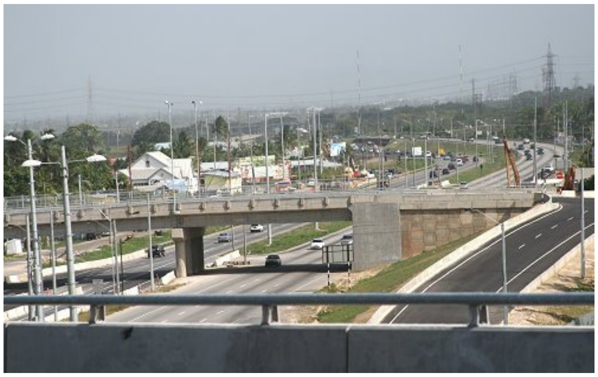

Figure 17. Completed project

Figure 18. Completed Project

4 CONCLUSION

A new MSE wall system with an innovative geosynthetic strip and panel connection system was successfully installed on this exciting Caribbean project. (See Figure 16 to 18 for completed project)

Although the author's soil reinforcement of choice for non aggressive backfills remains to be the in-extensible galvanized steel reinforcement, it is of note that for backfills aggressive to steel there is a new system utilizing a geosynthetic strip and connection system which is showing good constructability.

The use of in-extensible reinforcement however, should warrant certain caution and prudent considerations;

- Types of structure and limit of deflection,
- Environment (Aggressive applicable to any chosen reinforcement material … corrosion, UV etc.)
- Yield and Rupture behaviours,
- Aggressiveness in MSE Backfill

Main considerations in design:

- Intended function of the structures
- Tolerance of movements during and post installation of the walls,
- Connection integrity between the reinforcement and the wall facing,
- Service life
- Ease of construction
- Logistics & Cost effectiveness.

The CRH/UBH Interchange was opened on May 1, 2009.

5 ACKNOWLEDGEMENT

The writers would like to acknowledge the contribution of a number of individuals to the paper.

Vinci Construction Grands Projets team, CRH/UBH Interchange Project, Trinidad.

Design team at Freyssinet, Terre Armee, TAI Soltech, Velizy, France.

Alva Construction Nova Scotia, Canada for precasting of facing panels

Government of Trinidad and Tobago

National Infrastructure Development Company Limited

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