Geosynthetic Strip MSE Wall Case Study at Point Defiance Marina

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ABSTRACT

An MSE Wall System has been developed using precast reinforced concrete facing panels and geosynthetic strip (GeoStrap®) soil reinforcement. At Point Defiance near Tacoma, Washington the geosynthetic strip MSE wall was proposed in a saltwater marina, an environment conducive to geosynthetic reinforcement. Consequently, a geosynthetic strip polymeric reinforcement was chosen for design and used in construction of the MSE retaining wall. The geosynthetic strip reinforcement concept is adapted from MSE wall design procedure using steel strip type reinforcement in use since the 1970’s. Keeping with this standard, geosynthetic strip technology was developed. This paper describes the history of that development in conjunction with the Point Defiance case study wall with emphasis on the geosynthetic strip design analysis related to FHWA and AASHTO recommendations and the geosynthetic strip construction method.

INTRODUCTION

This paper will focus on a geosynthetic strip MSE Wall case study using discrete geosynthetic strips with large precast facing panels (see Figure 1), an innovation of the original MSE invention.

Figure 1. Geosynthetic strip MSE Wall.

Modern day MSE Wall technology dates to the invention by Henri Vidal who first published his research in France in 1963. The Terre Armee patented system was galvanized ribbed steel soil reinforcement bolted to precast concrete facing panels. The system has evolved over the
past forty years, is regularly in use worldwide today and is recognized as one of the top engineering achievements of the 20th century. With its inception, using the typical MSE wall design methods, the maximum tensile force in the reinforcing strips is distributed at each reinforcement layer into the number of reinforcement per unit of facing surface. The reinforcement length is then checked behind the line of maximum tension with respect to the available frictional capacity.

The first recorded use of polymeric strips as reinforcement for an MSE structure was a 450m² wall located near Poitiers, France. The wall was designed by Terre Armée in 1969 and constructed in 1970 using woven polyester strips (TAI 1982). Polymeric strips were fully introduced into the European market in the mid-1970s. Instrumentation and full research followed; in 1977 a full scale and fully instrumented trial MSE wall was constructed at the Transport and Roads Research Laboratory in Berkshire, United Kingdom (UK), followed by a fully functional instrumented bridge abutment constructed in Carmarthen Southern By-pass in 1981. These two abutments were the first on a major road in the UK to utilize polymeric reinforcement. Implementation and adoption of the technology of geosynthetic strips grew rapidly thereafter in Europe and the Middle East, but was practically unknown in North America until introduction to the market in 2005.

Applications along rivers, lakes and coastal areas are common for MSE Walls. The MSE technology offers: aesthetically pleasing structure, long service life, considerable savings in both material and construction costs and flexibility to differential settlement and earthquake loading. In marine environments, an MSE Wall provides features that are desirable such as resistance to severe loading conditions from flooding, rapid drawdown, tidal fluctuations, storms, ice and overtopping in extreme wave conditions. The combination of articulated concrete facing panels and earth reinforcements forms a flexible structure which can support large loads and provide permeability to efficiently accommodate large variations in water level.

PROJECT DESCRIPTION

The project is located at 5400 North Pearl Street in Tacoma, Washington, an area exposed to harsh weather and sea conditions. The engineer proposed an MSE Wall concept with continuous geosynthetic reinforcements to be constructed at Point Defiance Peninsula to expand an existing marina (see Figure 2) as part of a $1 billion redevelopment. The project site consists of hundreds of feet of loose slag mine tailings placed in the waterfront area as part of the ASARCO Lead and Copper Smelter ore processing plant from the turn of the century, now a superfund site. The height of the wall is 5 meters and the length is 130 meters. The geometry is complex, with many bends and corners. The top of the wall includes traffic barrier and portions with coping and fence post. In one location the wall design requires an MSE abutment to carry a 7.60m span gangway extending down to the boat docks.
The MSE design had to consider geosynthetic strip orientation within the MSE backfill to accommodate multiple obstructions such as buried utilities, light poles, electrical vaults, 1.37m diameter storm drain and a geomembrane cap cover located at top of wall. The use of the geosynthetic strip (discrete reinforcement strip) proved advantageous over continuous geosynthetic reinforcement to accommodate the obstructions. The geosynthetic strip MSE Wall was selected on this project because of its technical advantages for use in sea water and other electrochemical aggressive environments. The primary characteristics the geosynthetic strip MSE system provided are as follows:

- Conventional MSE design characteristics for internal and external stability.
- High coefficient of friction between geosynthetic strips with granular backfill.
- High resistance to chemical and biological degradation.
- Not affected by marine environments.
- Reliable connection to the wall facing.

DESIGN

MSE Wall Components

The geosynthetic strip MSE Wall consists of three major components:

- Large precast concrete facing panels to provide wall facing and wave action armor.
- Geosynthetic strips manufactured with high tenacity, multifilament polyester (PET) yarns placed in tension and coated by direct extrusion with low linear density polyethylene (LLDPE). The coating provides a continuous sheathing maintaining the dimensional integrity by encasing and protecting the yarns from construction induced damage, environmental exposure and dimensional stability while the polyester yarns are the load carrying elements.
- Connection recess embedded in the facing panel is composed of smooth surface blow molded, polyolefin, omega shaped sleeve. When the geosynthetic strip is threaded through the sleeve the connection recess provides a fully synthetic integral mechanical connection.
The polymeric strip used for the structure has a nominal strength of 50kN and a nominal width of 50mm. Quality control in production of the strap will yield a 100% certainty that the values tested for the strap are higher than the nominal value used for design. Polymeric properties of PET yarns follow the requirements of AASTHO for Molecular Weight and Carboxyl End Groups. The allowable design strength of the geosynthetic strip is based on material specific testing used to derive reduction factors (AASHTO – NTPEP 2017). The long-term performance of geosynthetic reinforcement is influenced by factors such as time, temperature, load, installation conditions and environmental exposure. These factors, specific to polymer type and product, directly affect long term performance and durability and must be determined and considered in design when using geosynthetics.

RESEARCH

Andrawes et al (1978) originally defined the differences between the relative extensibility of the reinforcement inclusions. Inextensible inclusions are those that “have rupture strains which are less than the maximum tensile strains in the soil without inclusions, under the same operational conditions”; and “Extensible inclusions are those that have rupture strains larger than the maximum tensile strains in the soil without inclusions, under the same operational conditions.” This has been the basis for the separation of types of reinforcements in AASHTO.

It was determined that the pullout resistance of extensible and inextensible inclusions is mobilized differently (Segrestin and Bastick 1996). However, when compared to inextensible ribbed steel strips in pullout tests, 50mm polyester strips mobilized the dilatational frictional behavior in an analogous manner to ribbed steel strips (Lozano et al 2013). Still, as reported by Anderson (Anderson et al 2012), geosynthetic strips develop frictional resistance along the length of reinforcement quite differently from inextensible steel strip reinforcements, as evidenced by the lack of trailing end displacement on the polyester strip.

MSE Walls have been constructed with instrumentation to further understand the tensile load and pullout resistance in the reinforcement layers. Although geosynthetic strip reinforcements have been in use worldwide for at least four decades, there is limited instrumented structure data. One of the reasons for this is the complexity in attaching the right type of instrumentation directly to polyester fibers in the geosynthetic strip. Due to the two-part composition of a geosynthetic, it has proven extremely difficult to install strain gauges that can withstand the rigors of earth moving construction, without substantially altering the reinforcement geometry and stiffness properties. As such, out of the hundreds of structures constructed, there are only two relevant case histories in the literature with sufficient data in the instrumentation available: the St. Remy wall and the Christiana wall.

The structure located in St. Remy, France was designed and supplied by Freyssinet in the late 1980s and reported around 1993 by Schlosser and others (Schlosser et al 1993). It was constructed with 90mm wide strip reinforcements with a tensile strength per strip of 100kN with a heavy LLDPE sheath. These were the predecessors of the current generation of geosynthetic strip, and were nearly twice as wide and twice as strong as the most commonly used geosynthetic strips for construction of MSE structures worldwide. This wall was designed to have a trapezoidal reinforced zone with a lower zone width of 0.84H, a middle zone width of 0.95H, and an upper zone width of 1.27H. The St. Remy wall had a vertical reinforcement spacing of 0.8m typically and a horizontal reinforcement spacing of 0.5m on average resulting in a tributary area of 0.4m² per pair of geosynthetic strip. For reference, a typical MSE currently constructed in the US using
geosynthetic strips of this height would have a vertical reinforcement spacing of 0.75m and a horizontal reinforcement spacing of 0.75m resulting in a tributary area of 0.563m² per pair of soil reinforcement strips.

The most recently instrumented wall located in Christiana, Delaware, USA, for the Delaware Department of Transportation (DELDOT) was instrumented as required by DELDOT for confirmation of design parameters/methodologies. A study of the collected data was performed by D. Leshchinsky and others and presented at the 2015 TRB Conference in Washington, DC (Lou et al 2015). This wall consisted of ParaWeb™ 2D 30kN and ParaWeb™ 2D 50kN soil reinforcements with a tensile strength of 30kN and 50kN respectively. Pairs of reinforcements were placed at a vertical spacing of 0.76m and a horizontal spacing of 0.76m resulting in a tributary area of 0.578m².

These two structures are the basis for validation of the design approaches not clearly stated in AASHTO, since for the US, polymeric strip reinforcement is a relatively new development (re-introduced in 2005) requiring the suppliers of this system to provide sufficient evidence for design.

AASHTO

The MSE Wall follows AASHTO LRFD and FHWA “Simplified” design method for geosynthetics (AASHTO 2015 and NHI 2009) with supplemental data for geosynthetic strip reinforcement type regarding lateral stress coefficient (Kr/Ka) and pullout resistance factor ($f^*$) as shown in Figures 3 and 4 (Lozano et al 2017).

With geosynthetic strip tensile strength calculations, the design assumes an independent connection to the panel face with the strength of two strips per connection. The geosynthetic strip MSE Wall reinforcement is connected to the face by looping the reinforcement though the connector such that the movement of one reinforcement affects the other as in a pulley system. The tensile breakage calculated in the design assumes that the strength of the pair of strips is equal to twice the strength of the strip itself. To achieve this concentric loading all the slack is removed from the reinforcement during construction as described below.
CONSTRUCTION

Installation Method

The facing panel is cast offsite in a precast facility with in-house QC measures. A typical facing panel consists of 4 omega shaped connector inserts embedded in the panel as shown in Figure 5. The openings for the geosynthetic strip recess are covered with tape and caps to prevent concrete, dirt and water from entering the recess during precasting and storage.

Figure 5. Typical precast facing panel, connector insert and geosynthetic strip.

An unreinforced concrete levelling pad is poured to assure even panel placement. Facing panels are set at a slight batter toward the backfill. A batter of 1.5 inches over 5ft. is generally used as a starting point. Coarse backfill such as crushed stone may require less batter as was done on this project. If finer backfill such as sand is used, more batter may be required. The wall batter is monitored and adjusted according to field conditions.

The geosynthetic strip is threaded through the recess opening cast in the back of the precast facing panel after the panels are set in the wall. The opening is protected during precast operations by a removable cap. The geosynthetic strip is unrolled in the field and cut to twice the reinforced length shown in the design plus 1m to account for the length inside the recess. Each geosynthetic strip is pulled through the connection to form two parallel equal-length reinforcing strips extending into the MSE fill zone perpendicular to the facing panel (see Figure 6).

Figure 6. Geosynthetic strip pulled through facing panel into MSE fill zone.

Tensioning the geosynthetic strip is very important to maintain wall alignment. Before backfilling, the geosynthetic strip is anchored by securing the strip free end with a trench, nail, staple or soil pile.
MSE Backfill

The geosynthetic strip MSE Wall consists of compacted select granular backfill interlayered with geosynthetic reinforcing strips that are connected to facing elements. The structure relies on the interaction between the frictional soil as the geosynthetic strip resists stresses produced within the soil mass. This composite mass retains compacted random backfill beyond the reinforced zone. The properties of both the select and random backfills have a significant impact on the design of the geosynthetic strip MSE Wall. Specifications for select backfill should meet the following guidelines:

- Well drained.
- Not prone to post construction movement/settlement.
- Durable and does not break down or change its properties during construction.
- Not be aggressive to geosynthetics.

If onsite backfill does not meet these guidelines, imported select backfill may be required or modifications to the design and construction procedures may be considered after careful assessment by the Engineer and Contractor. On this project, imported select backfill conforms with the requirements shown in Table 1.

Table 1. MSE Wall backfill properties.

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gradation:</td>
<td></td>
<td>Percent Passing</td>
</tr>
<tr>
<td>Well Graded Backfill</td>
<td>AASHTO T-27</td>
<td>102mm (100)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>76mm (75-100)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No. 40 (0-60)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No. 200 (0-5) *</td>
</tr>
<tr>
<td>Plasticity Index</td>
<td>AASHTO T-90</td>
<td>Not to exceed 6</td>
</tr>
<tr>
<td>Soundness: (Magnesium Sulfate after 4 cycles)</td>
<td>AASHTO T-104</td>
<td>Less than 30 percent</td>
</tr>
<tr>
<td>pH Range</td>
<td>AASHTO T-289-911</td>
<td>4.5 – 9</td>
</tr>
<tr>
<td>Organic Content</td>
<td>AASHTO T-267</td>
<td>Not to exceed 1 percent of the total sample</td>
</tr>
</tbody>
</table>

* The typical AASHTO standard for passing the No. 200 Sieve is 15 percent maximum. This project limited fines to only 5 percent following WSDOT Gravel Borrow specification.

Using the low fines aggregate backfill allowed MSE wall construction in the rain. Installation of the MSE wall began during late Fall of 2017. Battling constant rainfall during construction became a normal occurrence on the project. Furthermore, tidal influence was expected. At the time of setting the bottom row of panels the water level reached the top of the levelling pad. Backfill placement followed conventional MSE wall construction allowing rubber tired vehicles to operate directly on the exposed geosynthetic strips. An example of backfill placed on top of the geosynthetic strip is shown in Figure 7.
The first geosynthetic strip reinforced MSE wall with integrated connections of this type was put in service in 2005 in Morzine, France. Since then over 400 geosynthetic strip MSE Walls have been constructed in 33 countries. The geosynthetic strip MSE Wall has applications in all environments, especially those aggressive to galvanized steel reinforcement. In the US, a tall 14m high geosynthetic strip MSE Wall was constructed for a dam raising at the Los Vaqueros Reservoir in northern California (Hardianto et al 2013). Geosynthetic strip MSE Wall was specified by the owner to avoid the potential for metal loss by-products to leach from backfill into the reservoir.

The Florida DOT has implemented restrictions related to MSE Wall location and nearby marine environments. With this standard in place, the geosynthetic strip MSE Wall satisfies the restriction and allows MSE Walls to continue to be constructed where steel reinforcements would not be feasible. The DOT has embraced this technology and continues to take advantage of the architectural possibilities available with the precast facing panels available with the geosynthetic strip MSE Wall system.

Polymeric strip reinforcement has been utilized in Port of Miami infrastructure supporting tunnels, in Virginia for light rail applications, several projects for highway applications in the midwest, and internationally in extremely tall walls (>30m) for supporting the infrastructure needed for crushers, dumps and roll off/roll on ramps in mines, 27m tiered walls for a highway in Croatia, a 10m mixed abutment in Fort Carson Colorado, support walls for the ring foundations in Marrero Louisiana and the list of applications in challenging conditions grows every day.
CONCLUSION

Linear geosynthetic reinforcing strips were used on the Point Defiance project to enhance the MSE Wall design to meet the challenge of a salt water marine environment. The results of research and monitored MSE Walls has led to a design basis using AASHTO design models for this type of discrete reinforcement. As with any geosynthetic, tensioning the geosynthetic strip in construction is important to maintain the wall alignment. Geosynthetic strip allowed for reinforcement to easily splay around obstructions in the MSE wall such as light poles, electric conduits and drainage media, an advantage over other traditional geosynthetic reinforcements. Geosynthetic strip is a relatively new development in the U.S. but well-known and commonly used with over 40 years of experience worldwide. It can be used in confidence in projects where due to environmental conditions or restrictions on backfills the use of metallic reinforcement may be difficult.

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REFERENCES