Use of Segmental Wall System by Minnesota Department of Transportation

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Alternative wall systems are being used effectively as replacements for conventional cast-in-place concrete retaining walls. Combinations of concrete block and geogrids, and precast concrete items with cast-in-place concrete footings, have been constructed in recent years. However, guidelines for their design and construction are necessary to minimize problems and obtain an aesthetically pleasing wall. Keeping the alignment of the wall straight using sound construction practices is essential. A competitively bid geogrid wall with its design and construction requirements is presented. A proprietary wall facing unit, Diamond Block, is discussed in terms of design and construction requirements. As an experimental project, the design and economy of this system was compared with the design and economy of cast-in-place concrete retaining walls. Results of the installation are given in the conclusion to aid designers in using the different wall systems. Recommendations are given that will lead to concise bid documents and a better final product with fewer construction problems.

Recent years have seen the use of new alternative retaining wall systems that use concrete segmental retaining wall (SRW) units. With the advent of these dry-cast segmental concrete products, new design and construction methodologies for retaining earth fills have been developed.

The wall system discussed is a mechanically stabilized earth (MSE) wall for a Minnesota Department of Transportation (MnDOT) project. Although this type of wall system has been in use elsewhere, it is new as an option on highway projects in Minnesota. The purpose of this paper is to present the design, specific materials used, and construction details of this wall system as used on this state highway project in Minnesota.

MSE walls are gravity mass walls consisting of three primary components: soil, soil reinforcing elements (steel or geosynthetic), and a facing system, as shown in Figure 1. The soil reinforcing elements and the reinforced backfill soils interact in a stable mass that is resistant to sliding and overturning (*1*). The soil used as reinforced backfill must drain adequately in wet conditions. Global stability of the retaining system must be satisfied. The connection strength of the geosynthetic reinforcement grid to the SRW unit is another important design consideration. The SRW interlock between vertically adjacent units must also withstand shearing forces as soil layers are placed.

When installed correctly, the wall soil fill and geogrids form a mass of material that retains the backfill behind it. In Minnesota, the bottom wall facing blocks are required to be placed at least 3 ft 6 in. below exposed grade to minimize frost and sliding problems.

One of the areas of concern is creep of the geosynthetic reinforcement in the soil over time [Geosynthetic Research Institute (GRI) Standard of Practice GG4a]. Long-term creep testing is required to define creep limit state and serviceability state values per Task Force 27 guidelines (*1*).

MnDOT stipulates that testing of connections between the geogrid and the wall facing unit be performed by an independent laboratory before acceptance for use on MnDOT projects. MnDOT also requires geosynthetic reinforcement pullout tests in soil to ensure geosynthetic interlock. Finally, the concrete SRW units must have a minimum strength of 3,000 psi and be resistant to chemical attack.

The design life of MSE walls is the same as cast-in-place concrete retaining walls, which is 50 years minimum for MnDOT projects. Thus each component of the MSE wall must be thoroughly tested by an independent testing laboratory to meet standards prior to acceptance. Once conformance to these standards (*1,2*) is achieved, an MSE wall may be allowed as an alternative.

MSE WALL ON I-94 IN ST. PAUL

On Interstate 94 in St. Paul, a MSE wall was constructed in 1991. Located just southwest of the Western Avenue bridge, this wall was the first geogrid-reinforced, SRW unit–faced MSE wall constructed by MnDOT. It was monitored by MnDOT construction inspectors for fill material, compaction techniques, tautness of geogrid, placement, and straightness.

The wall is approximately 180 m long with a maximum height of 4.25 m. It is parallel to the freeway at about 2 m from the ramp curb line. At this location it will be subject to deicing chemicals resulting from sprays from passing vehicles.

Slopes retained by this wall were at about 2.5 horizontal to 1 vertical, which added to the design requirement for geogrid lengths. A special circular curve at one end of the wall had overlapping geogrid systems. (See Figure 2 for a typical cross section of the wall.)

DESIGN OF SOIL REINFORCEMENT ELEMENTS

The wall system supplier specified the Tensar UX1400 geogrid, which is a high-density polyethylene grid structure with a mass per unit area of about 509 g/m^2. Creep tests of at least 10,000 hr at ambient and elevated temperatures were used to

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determine the load-strain relationship for this geogrid (2). A time-load-strain relationship is shown in Figure 3 for the geogrid used on the wall system. Design with the geogrid reinforcement is based on AASHTO-Associated General Contractors (AGC)-American Road and Transportation Builders Association (ARTBA) Task Force 27 guidelines (3). Overall stability analysis begins with the sizing of the minimum soil mass (length = 70 percent of wall height) per Task Force 27 guidelines. Reinforcing grid lengths of 70 percent of wall height were checked for sufficiency against external sliding, bearing, and overturning failures. Computed soil reinforcement lengths were then checked for internal stability.

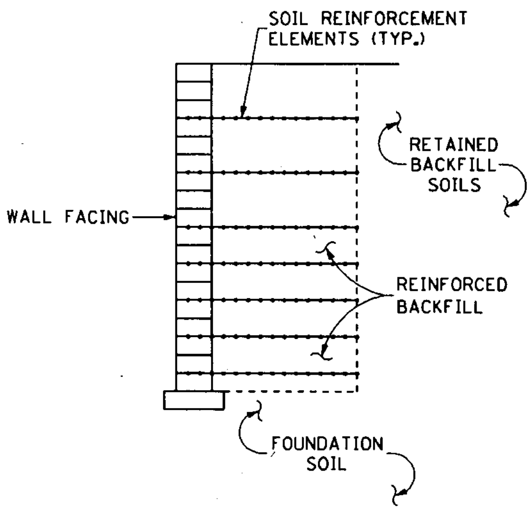

FIGURE 1 MSE wall.

A tie-back wedge analysis procedure was used to determine the internal stability of the wall. For the geosynthetic reinforcement elements it is assumed that active lateral earth pressures are developed. An active Rankine earth pressure and a one-part wedge are assumed for each geogrid element. The earth pressures are resisted by geogrid tensile forces. Potential external and compound failures were also analyzed for this project with a modified Bishop's slope stability analysis.

The design resulted in geogrid lengths of approximately 80 percent of the wall height. The minimum vertical geogrid spacing was 15 cm at the bottom of the taller wall sections. A maximum vertical spacing of 61 cm was used in the upper portion of the walls. This spacing was based on the temporary stability of facing blocks during construction. The geogrid layout for the various wall heights is given in Table 1, and a typical cross section of the wall is presented in Figure 2.

For long-term design life, several factors must be considered (4):

- Creep testing,
- Creep data extrapolation,
- Limit state creep,
- Serviceability state creep,
- Construction damage,
- Chemical degradation,
- Junction strength, and
- Connection joints.

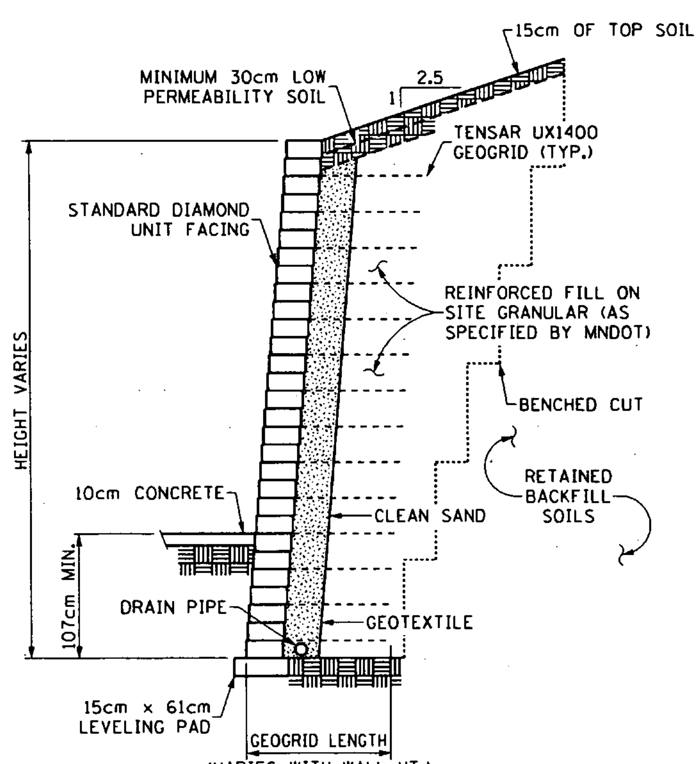

FIGURE 2 Cross section of wall system.

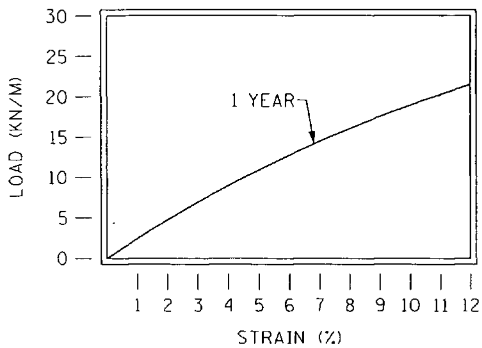

FIGURE 3 Time-load-strain relationship of geogrid reinforcement.

Equations used in computing an allowable geogrid tensile strength are from Task Force 27 guidelines. The equations address both limit and serviceability states.

Limit state:

$$t_{AL} = \frac{T_L}{FD \times FC \times FS \times FS_{JCT} \times FS_{CONN}}$$

Serviceability state:

$$T_{AS} = \frac{T_W}{FC \times FD \times FS_{JCT} \times FS_{CONN}}$$

where

T_L = allowable limit state tensile strength at maximum of 10 percent strain (kg/m);
T_W = allowable serviceability state tensile strength at strain of 5 percent (kg/m);
FC = factor for construction installation damage (dimensionless);
FD = factor for chemical and biological degradation (dimensionless);
FS_{JCT} = partial factor of safety for geogrid junction strength (dimensionless);
FS_{CONN} = partial factor of safety for facing unit to reinforcement connection (dimensionless); and
FS = overall safety factor applied to limit state analyses (dimensionless).

The values of these factors for the Tensar UX1400 geogrid used in this design were

- T_L = 2084 kg/m;
- T_W = 1325 kg/m;
- FC = 1.15 for limit state with sand soils, and 1.0 for serviceability state with sand soils;
- FD = 1.0 recommended by manufacturer, but minimum value of 1.1 used per Task Force 27 guidelines;
- FS_{JCT} = 1.0; and
- FS = 1.5.

The values for T_L and T_S are from the isochronous creep curve, shown in Figure 2. Values of FC are different for serviceability and limit states because construction damage is quantified with short-term tensile strength tests. Construction damage decreases the ultimate, or limit state, tensile load but does not significantly affect the load capacity at a serviceability strain of 5 percent.

The allowable reinforcement tension, T_a, is taken as the lesser of the T_{al} and T_{as} values. The computed values for the Tensar UX1400 geogrid, without consideration of connection strength, are

Limit state:

$$T_{al} = \frac{2084 \text{ kg/m}}{1.1 \times 1.15 \times 1.5 \times 1.0} = 1098 \text{ kg/m}$$

Serviceability state:

$$T_{as} = \frac{1325 \text{ kg/m}}{1.0 \times 1.1 \times 1.0} = 1204 \text{ kg/gm}$$

Therefore T_a is equal to the lesser value, 1098 kg/m.

TABLE 1 Geogrid Soil Reinforcement Layout

WALL HEIGHT (m)	GEOGRID LENGTH (m)	LOCATION OF GEOGRID (meters from top wall)
4.27	3.51	46, 1.09, 1.68, 2.29, 2.90, 3.35, 3.81, 4.11
4.11	3.51	46, 1.07, 1.68, 2.29, 2.90, 3.35, 3.66, 3.96
3.96	3.20	.61, 1.22, 1.83, 2.44, 3.05, 3.35, 3.81
3.81	3.20	.61, 1.22, 1.83, 2.44, 3.05, 3.35, 3.66
3.66	2.90	.61, 1.22, 1.83, 2.44, 3.05, 3.35
3.51	2.90	.61, 1.22, 1.52, 1.98, 2.44, 3.05, 3.35
3.51	2.59	.30, .91, 1.52, 2.13, 2.59, 2.90, 3.20
3.35	2.59	.30, .91, 1.52, 2.13, 2.59, 2.90, 3.20
3.20	2.59	.46, 1.07, 1.68, 2.29, 2.74, 3.20
3.05	2.43	.46, 1.07, 1.68, 2.29, 2.74
2.90	2.43	.30, .91, 1.37, 1.98, 2.59
2.74	2.43	.30, .91, 1.37, 1.98, 2.59
2.74	1.98	.46, 1.07, 1.52, 2.13, 2.44
2.59	1.98	.61, 1.22, 1.68, 2.29
2.43	1.98	.61, 1.22, 1.68, 2.29
2.29	1.83	.30, .91, 1.52, 1.98
2.13	1.83	.46, 1.07, 1.68, 1.98

CONNECTION DESIGN

The Task Force 27 guidelines were written specifically for retaining walls faced with precast concrete panels, but they can also be applied to walls faced with concrete blocks. The guidelines require that the proposed connection must be tested and capable of carrying 100 percent of the maximum design tensile load of the geosynthetic reinforcement. Thus the reinforcement design load may not be greater than the connection strength. Reinforcement load used in stability analyses is based on a maximum computed T_a but can be limited to lower values by connection strength.

The connection between the Diamond concrete block facing unit and the Tensar geogrid has been tested at the University of Wisconsin at Platteville (*5*). Connection strength tests were conducted at varying normal pressure, with the geogrid pulled at a displacement rate of 13 mm/min. A summary of test results from their work is given in the following table:

Normal Pressure (kg/m^2)	*Connection Tensile Strength (kg/m)*
1318	580
2344	997
3516	1310

These relationships were used in design to factor the allowable strength of geogrids, as applicable. Typically, the connection strength does not control except for geogrid locations near the top of the wall. Full allowable strength, T_a, of the geogrid can be mobilized by the connection 1.37 m below top of wall, assuming a vertical faced wall.

WALL FACING BLOCKS

The wall facing blocks were Diamond Block units shaped as shown in Figure 4. The facing of each unit was colored tan and had a broken-block appearance as specified by MnDOT. The interlock of each unit to the geogrid was through the 2.5-cm^2 lug at the back of the block. The interlock strength was tested by the University of Wisconsin at Platteville (*5*).

MnDOT also had the block tested for compressive strength before the wall was accepted. Initial compressive tests did not measure the required strength of 24 100 kPa. Cored samples taken from the blocks for these tests had microfractures that led to the low measured strengths.

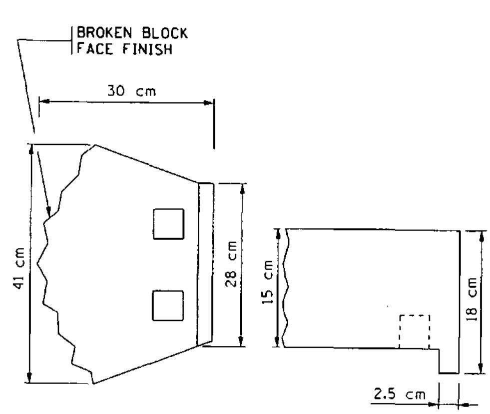

FIGURE 4 Diamond block facing unit: *left*, bottom view; *right*, side view.

Full-size block units were then tested in accordance with ASTM C90. Compressive strengths on these block units averaged 29 600 kPa. Blocks were then accepted for construction. MnDOT, however, will specify minimum compressive strengths of 20 700 kPa and 7 percent maximum water absorption on future projects.

The geometry of the Diamond wall units result in a 5-cm horizontal setback per vertical foot. This batter was conservatively ignored in the lateral earth pressure computation.

SOILS USED IN CONSTRUCTION

Because of limited knowledge of soils at the site, the materials found at the site were not entirely acceptable. Asphalt, cobblestone, brick, and other materials were found at the site and were excavated and replaced. Select granular soils were then used in the reinforced backfill zone. This MnDOT granular borrow classification requires that all material pass a 2.5-cm sieve but no more than 20 percent by weight pass a No. 200 sieve.

WALL CONSTRUCTION

Construction of the wall started in August 1991. Weather conditions over the first month included above-normal amounts of rain, which affected progress of the project because only a limited amount of excavation and placement of below-grade block, grid, and fill soil was performed when weather permitted. Normally a segmental wall contractor lays out the entire length of base blocks, starting from the lowest point and working upward.

Base blocks on this project were placed in 15.25-m chord sections because of the rain. A granular soil leveling pad was placed first, and the blocks were laid directly on top. Base blocks were laid in an inverted position (see Figure 4) so that the lip was on top and at the front. Horizontal alignment was controlled with the back of the base block lip as a reference. Subsequent block courses were laid in the normal position, with the lip down. Horizontal alignment on subsequent courses was checked along the back machine-formed face of the blocks.

The blocks have a 5 cm/30 cm batter from the overhang of the trailing lips. The top of the wall at the tallest section of 4.27 m was therefore set back 71 cm from base course alignment. This batter increased stability of the wall but was not accounted for in the wall design. This setback did not create any problems on the project, but specifying agencies and designers should be aware that setbacks vary for each segmental block type and that this factor should be considered when specifying and designing a wall.

The segmental blocks were leveled along the wall with a carpenter level as the blocks were laid and checked intermittently with survey points. Some problems occurred with holding the blocks in alignment and perpendicular to the base line. A 3.66-m section of the wall bowed outward when the wall was constructed to a 3.05-m height. The bow was eliminated by removing the facing block, clean sand, and geotextile materials down to the base and reerecting them with adjustments to the alignment. The remaining soil mass, geogrids, and soil fill stood vertically for 2 days without any problems as this reconstruction was completed.

The cause of this bowing problem was not conclusively established. Possible causes were the wet construction, the facing block's being erected slightly off level (not perpendicular to wall alignment), and the bowing's not being noticeable until a height of 3.05 m was reached. Erection procedures of fill placement, geogrid tension, and soil compaction may also have been causes, even though these procedures were held fairly constant. The wall drain detail was also a possible problem. A 37-cm width of pearock was placed behind the blocks, with a MnDOT Type 2 geotexile separating the rock from the wall fill soil. This rock was rounded and uniform and provided only a relatively small amount of shear resistance to hold the blocks in place. Finally, the wall was built in sections rather than continuously, which did not allow good alignment procedures.

MnDOT paid for reconstruction of the portion of wall that bulged outward, as tolerances were not set forth in the specifications. Acceptable tolerances were then set for the remaining wall erection, and the use of the pearock material was discontinued. The geotexile was placed directly against the segmental block face and a cleaner sand (less than 8 percent passing No. 200 sieve) placed for a 37-cm vertical width behind the geotextile. The changes helped achieve a uniform wall alignment, but three subsequent wall sections still had to be rebuilt.

The wall and grading subcontractors and prime contractor disagreed over who was responsible for placing the sloped portion of the soil fill section and to what compaction standards it needed to be constructed. The designer raised concerns that the sloped soil section on top of the reinforced mass was a necessary part of the wall system used in the stability analyses. The problem was resolved, and a 3:1 sloped fill section was constructed in accordance with wall fill compaction requirements.

Some soil spilled over the top of wall and was deposited on exposed horizontal portions of the segmental blocks during construction. The suppliers and contractors agreed to clean the face of the wall, after sodding and seeding was completed above the wall, even though this was not strictly required by specifications.

CONCLUSIONS

On the basis of experiences with this alternative retaining wall, the following conclusions are recommended for future MnDOT projects:

- Soil borings should be performed along the proposed wall alignment to determine the type of soils, water level, and such. These borings should be given on the contract plan for use by contractors and suppliers.
- Reinforced backfill soils of select granular material with less than 15 percent passing the No. 200 sieve should be used, per AASHTO recommendations.
- Wall fill zone should be defined as shown in Figure 2 to ensure proper soil masses and compaction.
- Only SRW systems approved by the contracting agency should be listed as alternatives in the contract.

Certification of facing unit and geogrid properties to meet the requirements of the designer or agency is necessary in advance of contract letting.

- Horizontal and vertical alignment tolerances need to be defined in the specifications: 1 cm in 1 m, both vertically and horizontally, is recommended.
- Specification requirements for compression and moisture absorption for wall SRW units should be set on a project basis.
- Design of segmental block walls shall be based on AASHTO Task Force 27 guidelines and AASHTO Interim Specifications for Highway Walls.
- Measurement and payment on these walls should be based on square meter of vertical wall face, yet unit cost of reinforcement and drains should be required on bid forms to provide a basis of cost change for any substantial post-award changes.
- Final acceptance criteria include provisions for cleaning the wall face, because erection procedures result in soil deposits on the SRW units.

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