Issues Regarding Design and Specification of Segmental Block–Faced Geosynthetic Walls

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Many facing block and geosynthetic reinforcement choices are available to the designer of segmental block–faced geosynthetic walls. Because of the newness and rapid growth of this industry, technology development has lagged behind implementation, leaving the designer without the all of the tools necessary for wall design and material selection. The key issues that must be addressed to properly design and specify a segmental block–faced geosynthetic wall are discussed, including selection of block size and geometry, selection and spacing of geosynthetic reinforcement, selection of design parameters (including wall face connection strength), the effect of seismic loads on the wall system, and wall specification. Research is recommended for poorly defined aspects of segmental block–faced geosynthetic wall design.

Segmental block–faced geosynthetic walls have rapidly found a niche in the wall construction industry since their introduction in the mid-1980s, largely because of their cost-effectiveness and aesthetically pleasing appearance. Rapid growth has resulted in many companies that supply blocks of various sizes, shapes, and colors. The many options can leave a designer bewildered, since these blocks can be combined with a variety of reinforcement geosynthetics.

Are all blocks appropriate for use with all geosynthetics? What are the design issues and parameters that must be considered? What methods are appropriate for determining the design parameters? The engineer must ask such questions if a safe, cost-effective wall design is to be obtained.

Once the wall design is completed, construction specifications must be developed. Should wall facing blocks and geosynthetic reinforcement be specified generically, or must some or all of the wall components be specified from an approved list of products? What testing standards are available for specification of concrete block and geosynthetic properties? The engineer must also ask such questions to ensure that the design matches what is actually constructed.

This paper gives the designer an understanding of the key issues that must be addressed if a wall is to be properly designed and constructed; the paper is not a state-of-the-art design summary for these wall systems. Design procedures for geosynthetic walls can be found in other works (*1–4*, and the paper by Bathurst et al. in this Record). Currently, the minimum dimensions and stability of the segmental facing blocks are not specifically designed in practice because of a lack of facing design procedures (*5*).

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DESIGN ISSUES

These wall systems consist of three main components: the concrete block facing, the geosynthetic reinforcement, and the soil backfill. This discussion focuses on the manufactured components of the wall—that is, the facing and geosynthetic reinforcement. The soil is discussed only in terms of its effect on the other two main wall components.

Segmental Facing Blocks

The variables that affect facing block selection and design include block geometry, manner in which the blocks fit together, block material properties, and aesthetics. Facing stiffness, stability, and constructability are affected by these variables.

The masonry facing blocks are unreinforced concrete. They have various shapes and sizes, as shown in Figure 1. The various shapes accommodate different block and geosynthetic connection details and a variety in aesthetics. The blocks are typically 100 to 760 mm (4 to 30 in.) in height and 200 to 760 mm (8 to 30 in.) in width. Figure 1 also shows how the geosynthetic reinforcement is connected to the facing blocks.

The largest block types tend to provide the stiffest and most stable face, whereas the smaller block types tend to provide the most flexible and least stable face. The facing should not be so slender that the face bulges or buckles between reinforcement layers or topples above the top reinforcing layer. Hence, it is not desirable to use the smallest blocks available to form the facing for large walls, say, 9 to 12 m (30 to 40 ft) in height. Certainly, some large walls have been built using one of the larger facing blocks available (*6*). Such examples do not prove that smaller blocks or blocks with different geometries can also be used successfully for large walls, or that they have a desirable factor of safety for stability (i.e., maybe the factor of safety is just over 1.0).

Design procedures do not exist that allow the designer to determine directly the minimum dimensions and block geometry required to ensure facing stability between reinforcement layers. Indirectly, minimum block sizes are established to prevent geosynthetic reinforcement pullout from the facing blocks. This minimum block size may also be adequate for facing stability. The establishment of a minimum block size to ensure facing stability is recommended.

The vertical spacing of soil reinforcement, how well the blocks fit together, and the wall height (i.e., the maximum

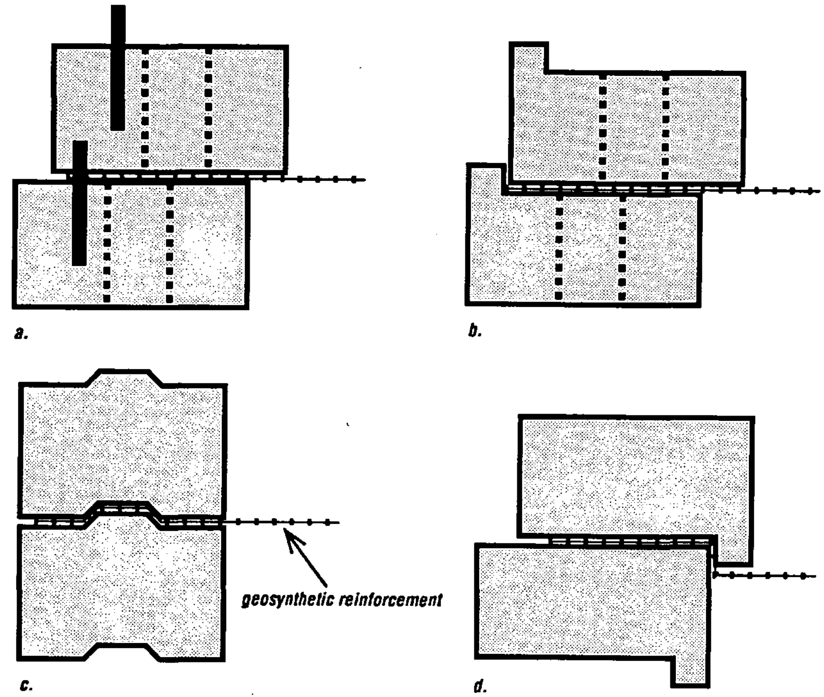

FIGURE 1 Typical facing block cross sections and connection details: (*a*) block with alignment/shear pin; (*b*) block with leading lip; (*c*) block with shear tray; (*d*) block with trailing lip.

vertical stress on the blocks) should be considered when establishing the minimum block dimensions. The shear resistance available between blocks through the use of shear lips, keys, or pins should also be considered.

An issue related to facing stability is the ability of the blocks to resist cracking. The concrete blocks are not reinforced. Therefore, block resistance to bending and shear stresses is fully dependent on the concrete strength. Vertical and bending forces on the blocks can occur because of block misalignment and irregularities in the surface on which the blocks bear. Block misalignments can also occur in the long term because of foundation soil settlement. This can be a problem especially for high walls or at rapid changes in wall geometry such as at corners (*6*). Some block cracking has occurred even in smaller walls (*7*). Cracking has so far not affected wall performance significantly (*6,7*). However, there has been some effort to repair them, indicating some concern as to the effect of those cracks (*6*). The establishment of maximum allowable wall heights and settlements may be necessary to minimize the risk of excessive block cracking as well as facing instability.

The blocks also must be durable. One key issue is the ability of the blocks to resist moisture and freeze-thaw cycles (*5*). An ASTM standard is available for concrete masonry units regarding dimensions, general properties, and moisture absorption (ASTM C90-90). This standard does not directly address the freeze-thaw resistance of the blocks, though it does mention that waterproof coatings should be used in certain instances (ASTM C90-90).

The issue of masonry block durability has not been adequately addressed. Durability standards that can be related to actual block performance regarding freezing and thawing, and possibly other mechanisms, are needed. Two ASTM standards are available for freeze-thaw testing, neither of which specifically addresses masonry. One standard, ASTM C67-91, is intended for brick and clay tile and requires 50 freeze-thaw cycles; the other, ASTM C666-90, is intended for concrete and requires 300 freeze-thaw cycles. Since the concrete in other types of walls must meet the requirements in ASTM C666-90, it is recommended that ASTM C666-90 also be applied to masonry blocks.

Backfill Reinforcement

Geosynthetic soil reinforcement variables include geosynthetic stiffness, strength, durability, and to some extent macrostructure. Wall design issues that are affected by these variables are as follows:

1. Reinforcement selection and vertical spacing requirements,
2. Long-term wall performance,
3. Wall face deformation, and
4. Reinforcement pullout requirements.

For the most part, geogrids have been used as soil reinforcement for segmental block–faced geosynthetic walls because of the perceived need for the relatively high stiffness, strength, and toughness that geogrids possess. As a result, most of the testing and evaluation of these wall systems have been performed using geogrid reinforcement. Yet even when considering in-isolation properties, there are many geotextiles available that possess comparable stiffness, strength, and toughness.

Therefore geotextile reinforcement should be considered for use with segmental block facing. The testing performed on the geogrid reinforcements for segmental block walls needs to be extended to geotextile reinforcement. Such testing includes long-term creep strength and durability characteristics and the strength of the facing connection with the reinforcement.

Reinforcement vertical spacing is determined by the long-term strength of the reinforcement both in the backfill and at the wall face. Soil properties and overall wall height affect the load applied to the geosynthetic layers and thereby affect the strength and spacing requirements. The facing stiffness and stability may also affect the maximum vertical spacing of the reinforcement allowable. Typically, reinforcement vertical spacing in segmental block–faced walls has been 200 to 760 mm (8 to 30 in.). Spacings greater than this are not recommended.

The long-term strength of the reinforcement is a function of the polymer used and the chemical and physical environment of the backfill. The most widely accepted methods for geosynthetic long-term strength determination in wall applications are in the Task Force 27 Guidelines (*3*) and the Geosynthetic Research Institute Standards of Practice (GRI GG4a, GRI GG4b). Long-term strength determination is controversial, however, due to the lack of meaningful test standards, confusing product claims, the need for basic research, and the lack of understanding of polymer durability among the civil engineering community. Some information is available on geosynthetic durability (*8,9*). A major research project, administered by FHWA, that will address many of the durability concerns is under way (*10*).

Few geosynthetic products available today have all of the test data necessary to determine the long-term product strength accounting for all degradation mechanisms, such as installation damage, creep, chemical aging, and biological degradation. Some products do have installation damage and long-term creep data available that should be used when performing wall designs. Long-term product specific reduction factors for chemical and biological degradation cannot be determined directly because of the lack of defined test protocols, though the meager data available indicate that most geosynthetics are durable except in aggressive environments (*8,9*). The author has advocated limiting the use of geosynthetic walls, regardless of the facing used, to noncritical applications and expanding such limits depending on the amount of product specific data available (*1,8*). Default reduction factors could then be used in lieu of product specific data in such applications (*1,8*).

Wall face deformation is a design issue that is usually addressed only crudely, if at all. Wall face deformation is kept within tolerable limits empirically by requiring geosynthetic products with relatively high stiffness. The approach outlined in the Task Force 27 guidelines, which requires a 5 percent strain limit at the design load, is typically used to accomplish this (*3*). Measured strains geosynthetic walls have been generally less than 1 percent (*11,12*). Even walls constructed with "extensible" nonwoven geotextiles have exhibited low deformation (*13*). These low strains are apparently the result of soil confinement and soil-geosynthetic interaction, and design methods that account for this are currently not available. It is reasonable to require stiff reinforcement materials at this time since there are no design tools or in-soil geosynthetic tensile test standards available. A design method that can predict wall face deformation on the basis of soil type, and wall reinforcement stiffness and density, is needed.

Long-term performance of the wall system may also be affected by the reinforcement macrostructure, at least when considering geogrids. It has been hypothesized that the geogrid junctions could fail within the wall design life, reducing pullout resistance or the load transfer rate between the soil and the reinforcement, resulting in increased wall deformation or failure. However, there is no evidence that it has occurred in practice, widely accepted test methods to predict junction strength effects on wall performance are not available, and the possibility of its occurrence is still controversial (*1,8*). Furthermore, there is no agreement on what impact junction failure would have on wall performance (*1,8*). Until this issue is resolved, it is recommended that the summation of the junction strengths within a 300-mm (12-in.) length of grid be equal to or greater than the ultimate strength of the grid element to which they are attached (*3*).

Information in several papers (*1–4*) can be used to calculate vertical reinforcement spacing and strength and pullout length requirements. Note that the active failure wedge location for pullout design should be based on the back rather than the front of the wall facing.

Wall Face Connection with Backfill Reinforcement

Critical to the success of a segmental block–faced geosynthetic wall are the short- and long-term strength of the connection between the facing and the reinforcement. Failed geosynthetic walls in the literature have been the result of the failure of the connection between reinforcement and facing, both in the short and the long term (*14,15*). In one case, the high pH environment created at the wall face due to the concrete appeared to contribute to the degradation of the polyester reinforcement (*16*).

The connection between the block facing and the reinforcement is made by placing the end of the reinforcement layer between the facing blocks. Pullout of the reinforcement from the blocks is resisted by friction between the geosynthetic and the block. The connection pullout resistance can be enhanced by shear keys, shear lips, or alignment pins as shown in Figure 1. The alignment pins must penetrate through the geosynthetic reinforcement.

The face-reinforcement connection can fail either by pullout or by rupture of the reinforcement. Pullout is affected by the roughness, size, and weight of the facing blocks and soil fill within the blocks. A pullout failure is more likely for small blocks, large reinforcement vertical spacings, and low confining pressure. It is likely that the strength of the geosynthetic at the connection with the facing will be less than its strength within the backfill (*7,16*). This strength reduction is the result of stress concentrations and abrasion on the geosynthetic created by irregularities and misalignments between blocks and the installation process. Shear lips or keys can severely distort the geosynthetic layers at the face, depending on how tightly the wall constructors place the blocks together. This severe distortion could cause the reinforcement to crack and rupture prematurely, especially if the geosynthetic is relatively inflexible. If high walls are constructed, the increased normal stress can increase the effect of these stress concentrations and distortions on connection strength reduction (*16*). If an alignment pin is used to enhance pullout resistance, the stress concentration in the reinforcement created by the pin could be a concern if the amount of lateral load carried by the pin is significant relative to the load carried by geosynthetic/block interface friction. Damage to the geosynthetic at the connection could occur depending on the care exercised during facing block installation.

Tests performed to evaluate connection strength must be performed for each block/geosynthetic combination anticipated. The irregularities and misalignments between blocks that are likely to occur in real walls should be modelled, requiring a minimum of two blocks side by side above and three blocks below the reinforcement for connection strength/pullout tests. The maximum vertical stress expected in the wall facing should be evaluated in the test program. Both load and deformation of the connection should be measured. Details of a proposed standard for connection strength testing are provided by Bathurst and Simac (*16*), and that method is highly recommended. Only facing block/geosynthetic systems that have been tested should be used for geosynthetic segmental block walls.

Also important is the long-term durability of the geosynthetic connection. Tests held at constant load for 1,000 hr at the in-isolation creep limit should be conducted to evaluate the creep strength of the connection. Longer tests may be needed so that creep failure occurs, as it is likely only strain at failure rather than the creep rate will be affected by the connection (*8*). Alternatively, conservative default reduction factors for creep and durability could be used to determine the long-term connection strength (*8*).

The chemical and biological durability of the geosynthetic at the facing connection should also be evaluated, as the environment at the wall face can be more severe in terms of temperature, moisture, and ion conditions than within the soil backfill. Of special concern is the potential increase in pH immediately behind the face due to the calcium in concrete, especially for polyester geosynthetics, as hydrolysis could occur (*15*). The environment behind existing concrete block–faced walls could be tested to assess the potential for this problem to occur. If a severe environment is indeed found, then only geosynthetics that are proven to be resistant to such an environment should be used for segmental block wall systems. Note also if an alignment pin is used to carry some of the pullout load at the connection, the durability of the pin should also be evaluated.

The strength of the geosynthetic connection to the facing blocks is one side of the connection design equation. Equally important is the determination of the load applied to the connections. Conservatively, it can be assumed that the load applied to the connections is equal to the maximum load in the reinforcement layers. Yet available data for geosynthetic walls indicates that the strain in the reinforcement at the wall face is lower than the maximum strain in the reinforcement observed in the wall backfill (*11,12*).

Deformation of and stress buildup in the wall face during construction and long-term are important issues for segmental block–faced walls, as the facing system is built as the wall is constructed. Wall facing stiffness has been observed to have a considerable influence on the load in the reinforcement at the connection with the wall face (*17*). The determination of lateral forces at the wall face in segmental block walls as influenced by facing stiffness is not clear at this time and requires additional research.

A safe approach to facing connection design is to assume that the stress in the geosynthetic at the wall face is equal to the maximum stress in the reinforcement (*3*). This approach is recommended. The reinforcement strength required can then be determined on the basis of the connection strength test results and the methods provided elsewhere (*1–4*).

Seismic Design of Segmental Block–Faced Geosynthetic Walls

Seismic behavior of geosynthetic walls is poorly understood, but their inherent flexibility probably makes them resistant to seismic loads (*1*). Of greatest concern is the seismic behavior of the wall facing. Vertical or horizontal acceleration occurring during an earthquake could cause the blocks to move relative to each other, or possibly even become dislodged if the shaking is severe, depending on the block geometry, as the blocks are not directly connected together. Vertical shaking could cause the normal force, and therefore the friction between the blocks and the reinforcement, to be reduced, causing a pullout failure of the connection and failure of the facing. The potential for this problem to occur may be reduced if alignment pins are used to connect the blocks and the reinforcement together, depending on how much the pins penetrate into the upper and lower blocks and the number of pins used.

Research on seismic issues is needed. Use of segmental block wall systems in seismically active areas should be limited in terms of wall height and their use to support other structures until the needed research is performed.

SPECIFICATION ISSUES

Specification issues include how block and reinforcement selection is accomplished, the method of materials specification (i.e., generic, approved list, or as a wall system), and the specific construction requirements for the available block options. Specification of segmental block–faced geosynthetic walls can be a formidable task if more than one block or reinforcement type must be allowed. It would be difficult, if not impossible, to specify facing blocks generically due to the wide variety of block geometries available. The block type affects the facing stability and reinforcement connection strength that can be expected. Connection strength is also affected by the geosynthetic type. The geosynthetic reinforced segmental block wall must be engineered and specified as a wall system due to these variables, regardless of whether or not they are marketed as such.

It may be possible to specify the geosynthetic reinforcement for a given facing block generically on the basis of minimum allowable geosynthetic and connection strength requirements once test standards are available. The contractor could then make appropriate selections. Since the needed test standards are not available, an approved list approach for both the facing block and geosynthetic reinforcement is currently more appropriate. It is also appropriate to specify the facing block and reinforcement as a wall system, and competitively bid the wall system with other wall systems, provided the block and geosynthetic manufacturer have a cooperative agreement to do this.

Properties and test results for the facing, geosynthetic, and the connection between the two must be obtained for products placed on an approved list or used in an approved wall system. The wall designer may also require proof of previous successful use of the facing or wall system. Each product or wall system that is found to be acceptable is added to the approved list. Until testing standards regarding facing connection strength and geosynthetic durability are available, the specifications need to list which geosynthetic products are acceptable for use with which preapproved segmental facing block.

A summary of the information needed to evaluate the acceptability of a given segmental block is as follows:

1. Block dimensions, geometry, and weight;
2. Details of how the blocks fit together;
3. Shear strength of alignment pins, shear lips, and the like;
4. Compressive strength of the blocks;
5. Freeze-thaw resistance and moisture absorption characteristics of the blocks; and
6. Long-term durability test results of any alignment pins or other connectors used.

A summary of the information needed to evaluate the acceptability of the geosynthetic reinforcements proposed for use is as follows:

1. Geosynthetic macrostructure and polymer(s) used,
2. Ultimate tensile strength,
3. Product specific installation strength loss test data appropriate for the site conditions expected,
4. Product specific 10,000-hr creep test data at multiple load levels and temperatures extrapolated to the design life of the wall, and
5. Product-specific chemical and biological degradation data that can be used to estimate long-term strength losses during the wall design life for the wall environment.

Few, if any, geosynthetic manufacturers will be able to provide all of the geosynthetic information listed. Default reduction factors can be used in the interim in lieu of product specific chemical and biological durability data as discussed previously. A summary of the information needed to determine facing/geosynthetic connection strength adequacy is as follows:

1. Short-term connection load-strain relationship at the typical and highest vertical confining stresses anticipated, including percentage of load carried by friction, alignment pins, shear lips, and such, and the mode of failure (i.e., pullout or rupture);
2. Connection strength data at constant load for a minimum of 1,000 hr at the in-isolation creep limit load level for the geosynthetic, preferably carried to failure, to evaluate the potential for creep rupture at the connection; and
3. Chemical and biological durability data for the geosynthetic that considers the environment at the face connection.

Due to the lack of test protocols, the key to this approach is knowing what data to obtain for review and how to determine its acceptability. The preceding lists address the information needed. The earlier discussion on the design issues as well as the cited references should provide some of the needed insight to determine the acceptability of the information provided for each product.

Proper construction specifications and inspection are also important to the success of a segmental block–faced geosynthetic wall. A detailed discussion of this is beyond the scope of this paper. Issues that should be considered when developing specifications include

1. Wall subgrade preparation,
2. Backfill compaction,
3. Geosynthetic protection during installation, and
4. Block placement and face alignment.

Wall performance problems are often the result of not following the construction specifications, or specifications that are unclear. Quality specification and inspection will help prevent this.

CONCLUSION

Segmental block–faced geosynthetic walls are an attractive and cost-effective alternative to other wall systems that are available. The technology for these wall systems should be developed. Until then, implementation and use should begin slowly. Some issues can be addressed through the use of conservative design procedures, such as the requirement to use relatively high modulus geosynthetics to control deflection, use of default design data, or by limiting the wall size and applications where such walls could be used. There are several issues in which research is required and technology development is needed before use of segmental block walls can be expanded to the more critical applications.

REFERENCES

1. Allen, T. M., and R. D. Holtz. Design of Retaining Walls Reinforced with Geosynthetics. In *Geotechnical Special Publication 27*, Vol. 2, ASCE Geotechnical Engineering Congress, Boulder, Colo., June 1991, pp. 970–987.
2. Christopher, B. R., S. A. Gill, J.-P. Giroud, I. Juran, J. K. Mitchell, F. Schlosser, and J. Dunnicliff. *Design and Construction Guidelines for Reinforced Soil Structures*, Vol. 1. Report FHWA-RD-89-043. FHWA, U.S. Department of Transportation, 1989.
3. *Design Guidelines for the Use of Extensible Reinforcements (Geosynthetic) for Mechanically Stabilized Earth Walls in Permanent Applications*. Task Force 27, AASHTO-AGC-ARTBA Committee on Materials, AASHTO, Washington, D.C., 1989.
4. Simac, M. R., R. J. Bathurst, R. R. Berg, and S. Lothspeich. *Design Manual for Segmental Retaining Walls (Modular Concrete Block Retaining Wall Systems)*. National Concrete Masonry Association, Herndon, Va., 1993.

5. Berg, R. R. The Technique of Building Highway Retaining Walls. *Geotechnical Fabrics Report*, Vol. 9, No. 5, July–Aug. 1991, pp. 38–43.
6. Anderson, R. B., F. N. Boyd, and L. Shaw. Modular Block-Faced Polymer Geogrid Reinforced Soil Walls, U.S. Postal Service Combined Carrier Facility. *Proc., Geosynthetics '91 Conference*, Vol. 2, Atlanta, Ga., Feb. 1991, pp. 889–902.
7. Kliethermes, J. C., K. Buttry, E. McCullough, and R. Wetzel. Modular Concrete Retaining Wall and Geogrid Reinforcement Performance and Laboratory Modeling. *Proc., Geosynthetics '91 Conference*, Vol. 2, Atlanta, Ga., Feb. 1991, pp. 951–964.
8. Allen, T. M. Determination of the Long-Term Tensile Strength of Geosynthetics: A State-of-the-Art Review. *Proc., Geosynthetics '91 Conference*, Vol. 1, Atlanta, Ga., Feb. 1991, pp. 351–379.
9. Elias, V. *Durability/Corrosion of Soil Reinforced Structures*. Report FHWA-RD-89-186. FHWA, U.S. Department of Transportation, 1990.
10. Fettig, D. R. A Team Player—On the Industry's Side. *Geotechnical Fabrics Report*, April 1991, pp. 22–23.
11. Allen, T. M., B. R. Christopher, and R. D. Holtz. Performance of a 12.6 m High Geotextile Wall in Seattle, Washington. *Proc., International Symposium on Geosynthetic-Reinforced Soil Retaining Walls*, Denver, Colo., Aug. 1991.
12. Simac, M. R., B. R. Christopher, and C. Bonczkiewicz. Instrumented Field Performance of a 6 m Geogrid Soil Wall. *Proc., 4th International Conference on Geotextiles, Geomembranes, and Related Products*, The Hague, The Netherlands, 1990, pp. 53–59.
13. Bell, J. R., R. K. Barrett, and A. C. Ruckman. Geotextile Earth-Reinforced Retaining Wall Tests: Glenwood Canyon, Colorado. In *Transportation Research Record 916*, TRB, National Research Council, Washington, D.C., 1983, pp. 59–69.
14. Richardson, G. N., and L. H. Behr. Geotextile-Reinforced Wall: Failure and Remedy. *Geotechnical Fabrics Report*, Vol. 6, No. 4, 1988, pp. 14–18.
15. Leclercq, B., M. Schaeffner, P. Delmas, J. C. Blivet, and Y. Matichard. Durability of Geotextiles: Pragmatic Approach Used in France. *Proc., 4th International Conference on Geotextiles, Geomembranes, and Related Products*, The Hague, The Netherlands, 1990, pp. 679–684.
16. Bathurst, R. J., and M. R. Simac. Laboratory Testing of Modular Masonry Concrete Block-Geogrid Facing Connections. Presented at ASTM Symposium of Geosynthetic Soil Reinforcement Testing, San Antonio, Tex., Jan. 1993.
17. Nakamura, K., Y. Tamura, F. Tatsuoka, K. Iwasaki, and H. Yamauchi. Roles of Facings in Reinforcing Steep Clay Slopes with a Nonwoven Geotextile. *Proc., International Symposium on Theory and Practice of Earth Reinforcement,* Fukuoka, Japan, Oct. 1988, pp. 553–558.

Publication of this paper sponsored by Committee on Geosynthetics.