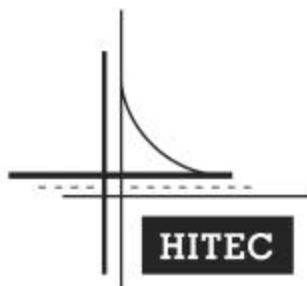


EVALUATION OF ANCHOR WALL SYSTEMS'
LANDMARK REINFORCED SOIL WALL SYSTEM
WITH T.C. MIRAFI'S MIRAGRID® & MIRATEX® Geogrid Reinforcement

FINAL REPORT



Prepared by the
Highway Innovative Technology
Evaluation Center (HITEC), a service
center of the Civil Engineering
Research Foundation (CERF)

CERF Report: #40677
March 2003

EVALUATION OF ANCHOR WALL SYSTEMS'
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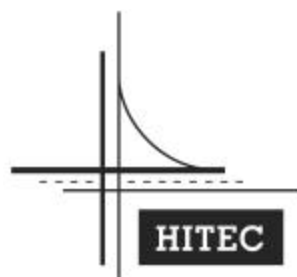
CERF through a cooperative agreement with the Federal Highway Administration (FHWA), created the Highway Innovative Technology Evaluation Center (HITEC) to expedite the introduction of innovative products into the U.S. highway and bridge markets.

HITEC evaluates products for which there are no recognized standards or specifications. By providing impartial evaluations of technologies, HITEC hopes to encourage state and local governments to implement more quickly innovative products in the highway system, thereby enhancing the incentives for private industry to invest in highway-oriented research and development. HITEC was organized not only to provide a service to specific clients, but also to serve as a clearinghouse for information useful to the highway community at large, particularly public sector officials.

To guide the overall process, HITEC assembles a unique, multi-disciplinary panel of experts for each evaluation. The panel works with the manufacturer of the innovative product or technology to devise a plan for comprehensively evaluating the performance of the product. The panelists selected to direct the evaluation include experts from county, state, and federal transportation agencies, academia, and the private sector.

The information found in this report is neither an endorsement nor an approval of a technology. Instead, the information is intended to provide the reader with accurate information and/or a credible analysis. Also, where appropriate, HITEC hopes to feed the development of national standards for innovative technologies through its published reports.

If you would like further information on HITEC, please contact us at **202-785-6420**, hitec@cerf.org, or visit www.cerf.org/hitec.



ABSTRACT

The Highway Innovative Technology Evaluation Center (HITEC), a service center of the CERF, serves as a clearinghouse for implementing highway innovation by conducting nationally focused, collaborative evaluations of new products and technologies. This report, Evaluation of Anchor Wall Systems' Landmark Reinforced Soil Wall System With T.C. Mirafi's Miragrid® & Miratex® Geogrid Reinforcement, was prepared as part of the HITEC evaluation for earth retaining systems (ERS). This evaluation was performed on the Landmark Reinforced Soil Retaining Wall System with Mirafi geogrid reinforcement (Landmark/Mirafi System), a mechanically stabilized earth (MSE) structure developed, designed, and supplied by Anchor Wall Systems, Inc.

This report describes a HITEC evaluation designed to determine the basic capabilities and limitations of the Landmark/Mirafi System for use as a technically viable precast MSE retaining wall system. The evaluation was conducted based on material, design, construction, performance, and quality assurance information outlined in the HITEC Protocol.

The Landmark/Mirafi System features modular block wall facing (MBW) and geogrid soil reinforcement.

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Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the Highway Innovative Technology Evaluation Center (HITEC) and do not necessarily reflect the view of the Federal Highway Administration.

This report is the result of an impartial, consensus-based approach to evaluating innovative highway technology in accordance with the HITEC Technical Protocol. The data presented are believed accurate and the analyses credible. The statements made and conclusions drawn regarding the product evaluated do not, however, amount to an endorsement or approval of the product in general or for any particular application.

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PREFACE

When a manufacturer is introducing a new or innovative technology to the highway community, it is often necessary to demonstrate the product to many, if not all, state highway agencies to prove that it performs as claimed. This practice is inefficient, time consuming, and often costly. To overcome these barriers, the Highway Innovative Technology Evaluation Center (HITEC) was established in 1994 in cooperation with the Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), and the Transportation Research Board (TRB). HITEC's mission is to accelerate the process of introducing technological advances to the highway community.

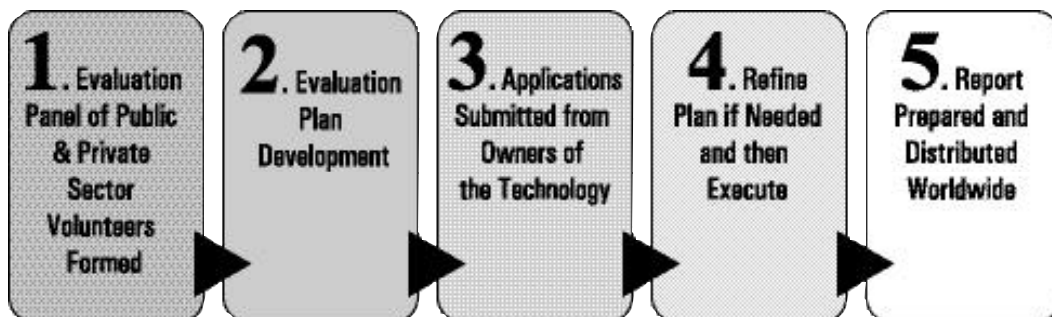
HITEC facilitates the conduct of consensus-based, nationally accepted performance evaluations of new or innovative technologies for the highway community. HITEC is available to evaluate products, systems, services, materials, equipment, or other technologies that the owners believe can be used beneficially on the nation's highways.

The HITEC earth retaining system (ERS) program was initiated at the request of federal and state highway officials and was established through a collaborative relationship with FHWA. It is an ongoing program to evaluate the performance of proprietary ERS technologies against a common evaluation plan. It is believed that the development of up-to-date evaluation criteria and performance information will help reduce the time and efforts required of suppliers and user agencies, and eliminate the inefficiency associated with the current agency-by-agency approval process. The figure below illustrates the step-by-step group evaluation process pioneered by HITEC and used for this ERS program.

The fundamental feature of this process is the formation of the Technical Evaluation Panel (Panel), a group of key representatives from the user community, academia, and the private sector. The Panel, with the cooperation and assistance of the ERS technology suppliers, identified the specific performance issues and concerns requiring resolution for these products to be adopted by the highway community. The Panel oversaw the development and execution of the evaluation plan, and ultimately, reviewed the evaluation findings.

As a result of their participation in this ERS program, many system suppliers have taken advantage of the process to modify and improve their retaining wall systems so they conform to HITEC Protocol and AASHTO design methods. Consequently, it is important to verify that the retaining wall system currently provided by a supplier is the same as that evaluated in this program.

HITEC is accepting applications for this ERS program on an ongoing basis and will publish the results of each evaluation. Evaluation reports will be developed to provide an analysis of each of the technologies participating in this program. Currently, there are several reports completed and/or scheduled for publication. Additionally, HITEC created the *Guidelines for Evaluating Earth Retaining Systems* report (#40334), which fully describes the scope and details of the program. These reports are available from ASCE at 800-548-2723 or marketing@asce.org. Copies can also be downloaded from the HITEC Web site at www.cerf.org/hitec.



ACKNOWLEDGMENTS

The Highway Innovative Technology Evaluation Center (HITEC), a service center of CERF, prepared this report and wishes to acknowledge the contributions of individuals whose efforts and suggestions have significantly influenced the content of this report. Notably, this report is based on work by members of a technical evaluation panel (Panel) who volunteered to develop the evaluation plan for this project and carry out its objectives. The HITEC Panel is composed of Chairman Terry Shike, David Evans & Associates, Inc.; Tony Allen, Washington State Department of Transportation; Randy Cannon, South Carolina Department of Transportation; Todd Dickson, New York State Department of Transportation; Jerry DiMaggio, Federal Highway Administration; Chris Dumas, Federal Highway Administration; David Dundas, Ontario Ministry of Transportation; Dov Leshchinsky, University of Delaware; and Mark McClelland, Texas Department of Transportation. Additionally, D'Appolonia served as the consultant to the Panel and was instrumental in producing this report.

CERF also wishes to thank the employees of Anchor Wall Systems, Inc. and their reinforcement supplier, TC Mirafi, Inc. for their cooperation during the evaluation process.

Among the staff who worked on this project, I wish to acknowledge the efforts of HITEC Senior Program Manager, Muhammad Amer.

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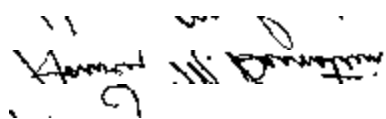
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President, Civil Engineering Research Foundation

TECHNICAL EVALUATION PANEL

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EXECUTIVE SUMMARY

This evaluation was performed on the Landmark Reinforced Soil Retaining Wall System, a mechanically stabilized earth (MSE) structure. The Landmark system was developed by Anchor Wall Systems, Inc. of Minnetonka, MN to be used in combination with a variety of reinforcement materials. It is evaluated here only in combination with Mirafi geogrid reinforcement (“Landmark/Mirafi system”).

The evaluation was conducted based on design, construction, performance, and quality assurance information provided by Anchor Wall Systems, Inc. and TC Mirafi, Inc. of Pendergrass, GA. This information was evaluated for conformance with the latest state-of-practice criteria as outlined in the HITEC Protocol (Appendix A).

As shown in Figures 1 and 2, the Landmark system features a modular concrete block facing (MBW) (a.k.a. segmental precast concrete blocks), a PVC lock bar, and layers of soil reinforcement material. In particular for the Landmark/Mirafi system, the soil reinforcement is PVC coated, woven polyester geogrid. The modular block facing units have a face area of 0.0774 m² (0.833 ft²). Each facing block unit has a receiving channel formed in the top of the block and a lock flange (i.e., shear key) formed in the bottom of the unit, which is used to connect vertically adjacent facing units. During installation of a structure, a sheet of soil reinforcement material is laid across the top of a course of facing units. A length of PVC lock bar is then laid across the soil reinforcement material and inserted into the receiving channel so as to clamp the continuous sheets of geogrid reinforcement to the facing blocks. The clamping action is not dependent upon the existence of any normal loading of the wall facing. The locations, strengths, and lengths of geogrid are designed to meet individual project requirements. The design of this type of structure is fully governed by Article 5.8 of AASHTO Standard Specifications (AASHTO, 2000).

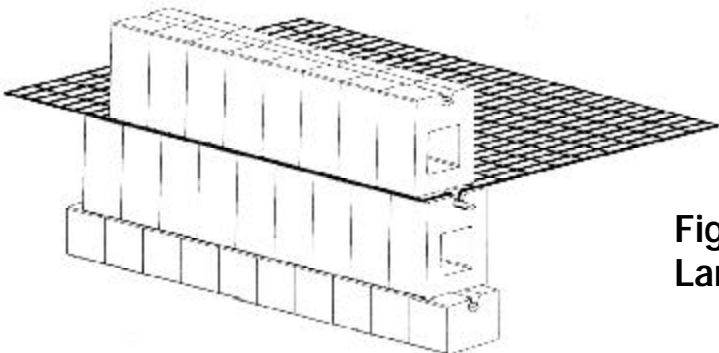
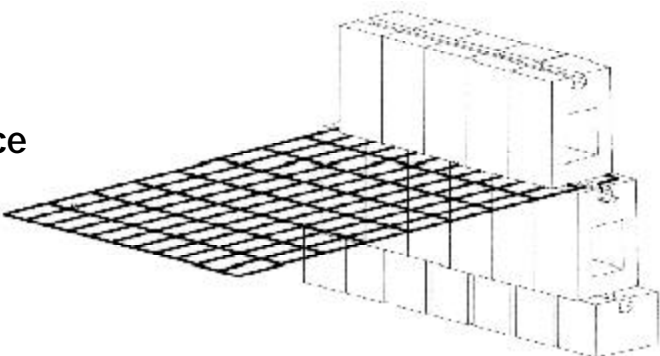


Figure 1. Isometric View of Landmark System – Front Face

Figure 2. Isometric View of Landmark System – Rear Face



The design methods submitted for external and internal stability are in accordance with the requirements in AASHTO (2000) except for the variations noted in this evaluation.

With respect to the submitted system details and design parameters, the following are noted:

- For public-sector national designs, Anchor Wall Systems, Inc., states that the AASHTO (2000) requirements as submitted for the HITEC review will be followed as required by the agency/owner. However, the standard private sector design used for the Landmark system conforms to the National Concrete Masonry Association (NCMA, 1997) requirements. It should be noted that the NCMA design criteria do not necessarily conform with the AASHTO (2000) requirements.
- The Landmark/Mirafi system uses a maximum vertical spacing of 762 mm (30 in) for its 302 to 320 mm (11.9 to 12.6 in) front to back length MBW units based on the use of mechanical connections between adjacent vertical blocks and between blocks and geosynthetic reinforcement. The use of mechanical connections to derive the connection capacity and the resistance of interlocked vertically stacked blocks to sliding and rotation, as evaluated in this review, appears to provide sufficient justification for waving the AASHTO spacing requirement of twice the width of the block, which as indicated by NHI 043 should be applied to modular block systems deriving their connection capacity by friction.
- Sufficient connection capacity testing has been performed to qualify all block and Mirafi geogrid combinations submitted for this review. The recommended connection capacity was developed by application of the AASHTO (2000) criteria based on long-term connection test results. Interpretation of the connector-testing mode of failure was made both visually and by examination of the test stress-strain relationships.
- For cases where the modular block facing is anticipated to be wet for an extended period of time, a higher durability reduction factor of 1.3 should be considered for the connection evaluation. Chapter 3 of NHI 043 recommends that PET geogrid reinforcement, as submitted for this evaluation, should not be used in an environment with pH greater than 9, such as in between submerged MBW facing elements.

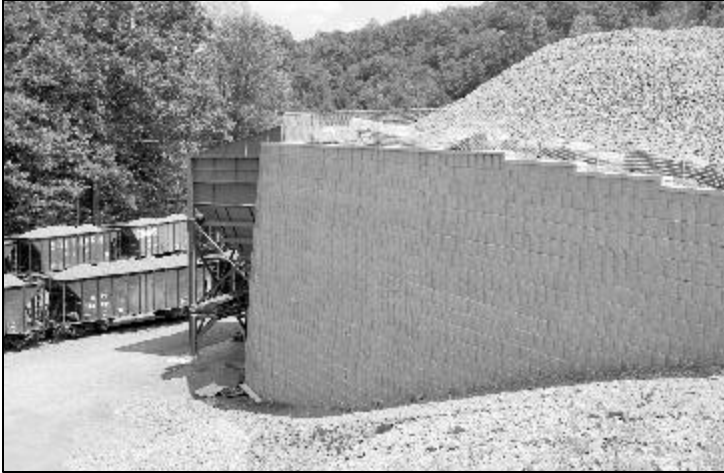
The construction materials specification submitted is in substantial agreement with current practice and AASHTO (2000).

Anchor Wall Systems, the developer and marketer of the Landmark/Mirafi system, has assembled and evaluated the design and construction guidelines, and quality control/quality assurance (QC/QA) programs for this system as reviewed in this report. While Anchor monitors its licensees and material suppliers for compliance with the Landmark/Mirafi system requirements, Anchor does not itself make or sell the Landmark facing units. Nor does Anchor itself make or sell the Mirafi geogrids that are component parts of the evaluated system. Nor does Anchor itself typically do final designs of Landmark/Mirafi structures, or itself construct Landmark/Mirafi structures. Accordingly, Anchor does not provide a warranty with respect to the combined Landmark/Mirafi system, or with respect to the performance of any particular Landmark/Mirafi structure, except to the extent noted in the Warranties and Insurance section of this report.

Independent concrete block manufacturers produce the facing units used in the Landmark system under license agreements with Anchor Wall Systems, Inc. The license agreements require the licensed Landmark manufacturers to produce facing units that, at a minimum, conform to the Landmark Product Specifications established by Anchor. The license agreements also require the licensed Landmark manufacturers to practice a QC/QA program specified by Anchor in the manufacture of the Landmark facing units. Independent plastic fabricators manufacture the PVC lock bar for the Landmark system and follow a specified QC/QA program under contract with Anchor. Anchor relies on TC Mirafi, Inc. to provide quality control of the geogrid materials in accordance with specification requirements and but does not maintain a copy of certificates of compliance. Mirafi performs in-house quality control tests on the geogrids in accordance with the Mirafi QC/QA program described herein.

The design strength of the geogrid, the long-term connection capacity and the height of the modular block, which controls the minimum vertical spacing, limit the present maximum height of the Landmark/Mirafi system. Although not analyzed as part of this evaluation, 15 m (50 ft) would appear to be the practical height limit of the Landmark/Mirafi System using the AASHTO design method. As of October 2002, over 50 retained soil structures have been constructed using the Landmark system. Of these structures, at least 15 have been constructed using the Landmark/Mirafi system evaluated in this report. The tallest Landmark/Mirafi structure completed to date is on the order of 13.6 m (44.5 ft).

The Landmark/Mirafi system appears to be a technically viable MSE retaining wall system. The in-place costs for Landmark/Mirafi system walls appear to be in the range of other MSE systems for the same design heights.



*Birdsboro Materials in Pennsylvania.
13.75 meter high wall designed to support
high loading capacity.*

INTRODUCTION

1.1 Purpose, Scope and Basis for Evaluation

This evaluation was conducted for the Landmark Reinforced Soil Retaining Wall System with Mirafi geogrid reinforcement (Landmark/Mirafi System) developed by Anchor Wall Systems, Inc. (Anchor), of Minnetonka, MN. The primary components of this mechanically stabilized earth (MSE) structure include:

- Prefabricated dry cast concrete modular block facing units (MBW) with shear key and receiving channel formed within the block.
- Continuous PVC coated, woven polyester geogrid reinforcing elements.
- CPVC and PVC “lock bar” to provide a mechanical connection between the block facing units and soil reinforcement.
- Select granular backfill.

Figures 1 and 2 in the Executive Summary show front and rear isometric views of the Landmark/Mirafi System and the locking bar connector is shown in Figure 3.

The evaluation was conducted using material, design, construction, performance, and quality assurance information provided by Anchor and their geogrid supplier, TC Mirafi, and was evaluated for conformance to the latest state-of-the-practice criteria outlined in the HITEC Protocol. The Protocol document substantially incorporates the AASHTO Standard Specifications for Highway Bridges (AASHTO, 2000) and FHWA-NHI-00-043 (an update of Demonstration Project 82 Guidelines; Elias and Christopher, 1996) (Elias, et al., 2001), referred to as NHI 043. Where no applicable criteria in the referenced documents exists, evaluations were based on state-of-the-practice guidance as indicated in the technical literature or documentation submitted by Anchor.

This evaluation is intended for readers who have a working knowledge of the design and construction specification requirements in AASHTO (2000), Article 5.8 for MSE Walls, and NHI 043 design guidelines and construction specification manual. Understanding the test methods and interpreting procedures in the Appendices of NHI 043 is essential to understanding the test data submitted by Anchor in support of product-specific design parameters. The submittal by Anchor for the Landmark/Mirafi System was evaluated relative to the Protocol developed by the HITEC Panel and the Consultant. The Protocol (see Appendix A) was further reviewed and commented on by industry in a public forum prior to being finalized.

The results of this evaluation do not constitute an approval or a rejection of the system and/or its components. Further, any recommendations for modifications and/or conformance to specific evaluation criteria should not be construed as mandatory. The potential effects are noted, and each approval agency must determine its own requirements for implementation. It is suggested that manufacturers note any deviation from their HITEC submittal when submitting their system for acceptance by an approving agency.

1.2 Documents Reviewed

The documents that support this report were initially submitted in October 2001. An initial review of these documents indicated the need for additional information to complete the submittal. This information was requested in December 2001 and received in April 2002. During the course of this evaluation additional information or clarification was requested and was subsequently submitted for the record in June and October 2002.

A complete set of the submitted data is available from HITEC, which maintains the chain-of-custody for all data reviewed and used in this evaluation, including revisions to the initial submittals.

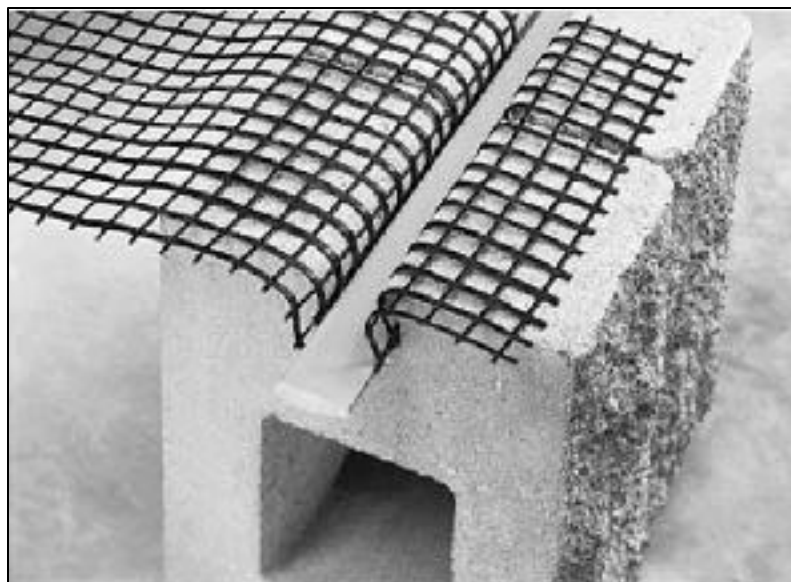


Figure 3. Channel with Grid and Lock Bar Connector in Place



*South Carolina commercial development.
4 meter high wall supporting parking and
drive areas.*

HISTORY AND SYSTEM CONCEPT

The Landmark/Mirafi System is an MSE retaining wall system comprised of dry cast modular block for a facing and extensible polymeric soil reinforcement. The design of this type of structure is therefore fully governed by applicable design and construction criteria in AASHTO (2000).

The Landmark/Mirafi System features precast modular concrete blocks identified as Landmark facing units. The Landmark facing units are 381 mm (15 in) high, 203 mm (8 in) wide, and 302 mm (11.88 in) (small block units) to 321 mm (12.62 in) (large block units) long as measured from front to back. Note: this latter dimension is the width, W_u , in AASHTO (2000). The exposed area of the facing block unit shown in Figure 1 is 0.0774 m² (0.833 ft²). The Landmark facing units have a receiving channel formed in the top of the block and a lock flange (i.e., shear key) formed in the bottom of the unit, which are used to connect vertically adjacent facing units. Other modular block units are sometimes used and include: 1) tapered units, 2) half-high units, 3) base or foundation units, 4) corner units, and 5) cap units. Cap units are manufactured without a shear key and a smooth top surface. These units are used as a coping alternative to cap the wall and to vary the face appearance for aesthetics. Base units are used for the first row of elements. Appendix C contains information regarding the dimensional features of the facing units.

The modular blocks are dry-stacked (i.e., without mortar) in a running-bond configuration (see Figures 1 and 2). The shear key or lock flange of an upper unit is placed in the receiving channel of the units directly beneath it to join vertically adjacent Landmark units as shown. Through the location of the receiving channels, the facing units incorporate a horizontal setback, which is 25 mm (1 in) for the standard 381-mm (15-in) high facing unit. This setback results in a wall face with a batter of approximately 3.8 degrees from the vertical plane. An illusion of batter is also provided by manufacturing the face texture of the standard units on an incline from the vertical plane.

The Landmark units over which geosynthetics will be placed are manufactured with a chamfer at the upper rear corner of the block to reduce shear stress that could be applied to the reinforcement due to downdrag during and after installation.

The earth reinforcing elements consist of Mirafi geogrids, which are manufactured by weaving high tenacity polyester (PET) yarns (Type 811) and coating the finished grid with polyvinyl chloride (PVC) to maintain the integrity of the geogrid during handling and placement and to protect it during construction. The geogrid reinforcements are placed with the machine direction perpendicular to the block units. Connection is achieved by securing the reinforcement in the receiving channel of the block with the patented CPVC and PVC “locking bar” to provide a mechanical connection between the block facing units and soil reinforcement. The shear key of the upper adjacent vertical unit in turn restrains the locking bar. The components are illustrated in Figure 3 and Appendix C.

The Landmark/Mirafi System is a retaining wall system marketed, designed, and serviced by Anchor. Anchor initially marketed the Landmark/Mirafi System in Minnesota and is currently expanding distribution to other North American markets thru authorized licensed producers.

The Landmark/Mirafi System is a new MSE system. The system has been commercially available since it was introduced in January 2001. However Anchor has been in the MBW market for over 10 years using a traditional frictional facing connection and has significant experience in the design and construction of modular block wall systems. The Landmark/Mirafi System was developed through recognition of the need to enhance the facing connection strength for their modular block facing system to achieve the prescribed factor of safety in a wider range of conditions. The system has been designed and prototyped for three years including laboratory testing, field trial tests and an instrumented structure prior to its introduction in its current form. The first wall using this technology was constructed in April 2000 for a commercial facility in Simpsonville, SC. As of October 2002, over 15 Landmark/Mirafi System walls have been constructed. The highest wall using this system was constructed for the Minneapolis Convention Center and is on the order of 13.6 m (44.6 ft). Additional system details, including key contacts, are provided in Appendix E.



10 meter high wall supporting the truck loading dock area of a commercial development.

DESIGN METHOD EVALUATIONS

3.1 Performance Criteria

The methodology submitted, supported by typical computations, indicates a design practice that conforms to AASHTO (2000) criteria with respect to Factors of Safety (FS) for external and internal stability, foundation embedment, bearing pressure computations, minimum reinforcement length, and vertical reinforcement spacing (Article 5.8, AASHTO, 2000). Anchor does note that their standard design used on most of their projects to date conforms with other design methods such as the National Concrete Masonry Association method (NCMA, 1997) for private-sector projects, which are not necessarily in conformance with the AASHTO (2000) requirements. However, for national designs, Anchor states that the AASHTO (2000) requirements would be followed as submitted for the HITEC review, if required by the agency/owner.

With respect to overall vertical tolerances during erection, the Landmark/Mirafi System specification by reference includes tolerances of 19 mm/3 m of wall height (0.75 in/10 ft) with a maximum rotation from vertical of 2 degrees as stated in the sample specifications submitted for this review. Post-construction measurements from a project were provided to demonstrate that the system could be erected to the specified tolerances (see Appendix E).

Regarding the facing unit(s) tolerance to differential settlement, Anchor limits the differential settlement to a maximum of 1 over 200 to prevent the deviation of horizontal joints from a horizontal plane as recommended for modular block walls in Chapter 8 of NHI 043. To demonstrate performance under significantly greater differential settlement, project data was presented from one project where the face of the wall was undermined during construction as a result of high water flow. Over 125 mm (5 in) of movement occurred within a 2.4 m (8 ft) span, 1 over 20, without significant cracking of the block.

3.2 External Stability

The submitted methodology for external stability computations under static and transient loading (dead and live load) conforms to AASHTO (2000) criteria.

As indicated in NHI 043, the project owner is responsible for providing strength parameters for the retained fill as well as allowable foundation bearing pressures, anticipated foundation settlement, and global stability determinations for each structure.

3.2.1 Global Stability

Evaluation of global stability is beyond the scope of services provided by Anchor. As stated in NHI 043, the analysis of potential compound and deep-seated failure planes should be performed by agency engineers or consultant geotechnical engineers who have experience with local geological conditions. Anchor, upon request, provides consultation regarding appropriate methods to incorporate Landmark/Mirafi System components in global stability analyses. Anchor uses the FHWA program MSEW¹ for design, which allows for an evaluation of global stability.

3.3 Internal Stability

The submitted methodology for internal stability computations under static and seismic loading conforms to AASHTO (2000) and NHI 043 requirements with respect to:

- Assumed failure surface for internal stability calculations and calculations for effective length, L_e .
- Horizontal stress computations using $K_r = K_a$ over the full height of the wall.
- Distribution of surcharge and concentrated static loads.
- Development of seismic loads and calculations to preclude pullout or rupture.
- Distribution of supplemental loads due to traffic barrier impact.

The maximum vertical reinforcement spacing used by Anchor is 0.76 m (2.5 ft), which is consistent with the AASHTO (2000) and NHI 043 requirements. Anchor justifies the use of a maximum vertical spacing that is approximately 2.5 times the front to back length (W_v) of their block based on the use of mechanical connections between adjacent vertical blocks and between blocks and geosynthetic reinforcement. Article 5.8.8.2 of AASHTO (2000) requires that the vertical spacing between reinforcement layers in segmental concrete facing block be no more than twice W_v ; however, Chapter 3 of NHI 043 further clarifies this requirement as being applicable to modular block systems deriving their connection capacity by friction. The use of mechanical connections to derive the connection capacity and the resistance of interlocked vertically stacked blocks in the Landmark/Mirafi system to shear and rotation as reviewed later in this section, appears to provide sufficient justification for waving this AASHTO (2000) vertical spacing requirement. Anchor places a layer of reinforcement at the base of the topmost Landmark unit and at the top of the lowest unit in a given wall section in compliance with AASHTO (2000) spacing requirements.

With respect to design parameters needed to determine spacing and sizing of the reinforcement to preclude pullout or rupture, the submitted data for interaction coefficients and allowable strength are described in the following sections.

¹ MSEW is a copyrighted (1998-2002) computer program developed for the FHWA by ADAMA Engineering, Inc.

3.3.1 Interaction Coefficient (F*)

The reinforcement-soil interaction coefficients used in design are not stated by Anchor, but a range of values was provided. These values were based on pullout tests performed on Mirafi geogrids by several independent laboratories in general accordance with the methods outlined in Appendix A of NHI 043. All tests were performed with the coarse sand type soil with the interaction coefficient, C_i , the normalized pullout resistance factor, F^* , and scale factor, α , used in AASHTO (2000) and NHI 043 reported, where $F^* = C_i \tan \phi$. The F^* and α values are slightly above the AASHTO (2000) and NHI 043 default values for geogrid reinforcements as follows:

Lab 1 (Mirafi XT geogrids - machine direction):

$$F^* = (0.89 \text{ to } 0.93) \tan \phi = 0.64 \text{ to } 0.87 \text{ and } \alpha = 1$$

Lab 2 (Mirafi TD3 geogrids – machine direction):

$$F^* = (0.81 \text{ to } 1.0) \tan \phi \gg 0.92 \text{ and } \alpha = 0.7 \text{ to } 0.95, \text{ or}$$

$$F^* \alpha = 0.64 \text{ to } 0.83$$

On the basis of these results, $F^* = 0.6$ and $\alpha = 1$ appear reasonable for predominantly sand reinforced fills in the absence of project specific testing. For predominately gravel reinforced fill, the default value recommended by NHI 043 of $F^* = 0.66 \tan \phi$ and $\alpha = 0.8$ should be used in the absence of specific project test data.

3.3.2 Allowable Tensile Strength of Reinforcement

Landmark/Mirafi System soil reinforcement elements are PVC coated woven high tenacity PET geogrids of various configurations and strengths, which are identified as Mirafi Miragrid™ XT and Mirafi Miratex™ TD3 geogrids.

In accordance with AASHTO (2000) criteria, the allowable geosynthetic material strength (T_{al}) is defined as the ultimate strength (T_{ult}) from wide-width tests based on minimum average roll values (MARV) for each product, divided by reduction factors to account for creep (RF_{CR}), durability (RF_D), and installation damage (RF_{ID}) that can be anticipated over a design life of either 100 or 75 years. Reduction factors are determined by laboratory or field tests in accordance with methods outlined in the NHI 043 Manual Appendices. The allowable design load (T_a) is the material strength (T_{al}) divided by $FS = 1.5$ for retaining wall design. The T_{ult} values in Table 1 were submitted for the Mirafi geogrids based on wide-width strip test method. Note that T_{ult} is defined as the mean production strength minus two standard deviations.

Table 1
 T_{ult} of Mirafi Geogrids in the Machine Direction Based on MARV

Product	T_{ult} kN/m (lb/ft)
Miragrid 3XT	40.9 (2800)
Miragrid 5XT	52.4 (3590)
Miragrid 7XT	63.5 (4350)
Miragrid 8XT	90.9 (6230)
Miragrid 10XT	121 (8300)
Miratex TD3	80.4 (5500)

The T_{ult} values submitted are less than or equal to the minimum ultimate acceptable production tensile strength values per lot specified in the manufacturer's quality control/testing and inspection manual. Production statistics from representative QC results are presented in Appendix B.

The reduction factors submitted for the Mirafi XT and TD geogrids are discussed in the following section. The factors are supported by laboratory and/or field test data developed in conformance to AASHTO (2000) criteria except as noted.

3.3.3. Installation Damage (RF_{ID}) Reduction Factors, PET Geogrids

A significant amount of test data was submitted to support recommended installation damage reduction factors submitted by Anchor. Installation damage tests on five products for several soil types were evaluated and recommendations were provided for three soil types. However, interpretation of this data was not provided to support the recommended values. In review of the test results from three independent laboratories, it was noted that tests were performed on sand and sandy gravel fills and finer grain fill soils that would support reduction factors for FHWA Type 2 sand and gravel fill (i.e., $D_{max} = 20$ mm and $D_{50} < 0.7$ mm) per NHI 043. Test results were subsequently provided on coarse gravel materials equivalent to FHWA Type 1 fill ($D_{max} = 102$ mm and $D_{50} < 30$ mm) per NHI 043 and course 25- to 76-mm (1- to 3-in) open-graded gravel. It was also noted that all tests were performed by placing the fill from the side of the test area, which is not as severe as placing and spreading with a dozer or front end loader as required in the FHWA test procedure (Elias, 2001). Test data were provided from tests on one geogrid where the fill was placed and spread with a front end loader, which indicated no influence from this placement procedure. The reduction factors in Table 2 are supported by the data and correlations submitted as shown in the summary of installation damage data in Appendix B.

Table 2
 RF_{ID} for Mirafi Geogrids

Product	Backfill Type	
	NHI 043 Type 2 Sand and Gravel $D_{max} = 20$ mm; $D_{50} \gg 0.7$ mm	NHI 043 Type 1 Gravel $D_{max} = 102$ mm; $D_{50} \gg 30$ mm
Miragrid 3XT	1.2 - 1.4	1.5 - 1.85
Miragrid 5XT	1.15 - 1.3	1.3 - 1.7
Miragrid 7XT	1.15 - 1.3	1.3 - 1.7
Miragrid 8XT	1.15 - 1.3	1.3 - 1.7
Miragrid 10XT	1.15 - 1.3	1.3 - 1.7
Miratex TD3	1.3 - 1.4	1.5 - 1.85

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The reduction factors reflect the range of data submitted for each product. The range provided for Type II sand and gravel for most cases represents material with a higher D_{50} and lower maximum particle size than the Type II sand. The range provided for Type I gravel represents test results in both NHI 043 Type I gravel and coarse 25- to 76-mm (1- to 3-in) open-graded gravel. The actual gradation and the corresponding installation damage results are summarized in Appendix B. Reduction factors should be selected with consideration of the specified project backfill characteristics and the placement procedures.

It should be noted that the coating thickness, or coating weight/product weight, can significantly affect the magnitude of RF_{ID} (Sprague, et al., 1999). Information was not provided on the coating thickness or weight for the samples tested to produce these installation damage test results. The coating used on the Mirafi geogrids is controlled by weight as measured by subtracting the geogrid weight of the uncoated product from the total weight. The target weight is 48% of the total weight of the finished product. However, coating weight is not included in the product specifications, the variability of the coating weight (e.g., the average minimum roll value) was not provided, and the evaluation of coating requirements was not included in the Mirafi QC/QA program.

3.3.4 Durability (RF_D) Reduction Factor, PET Geogrids

The durability reduction factor is primarily focused on potential strength losses due to hydrolysis of the polymer during in-ground use over the design life. The Mirafi geogrid reinforcements are manufactured with Type 811 PET yarns characterized by their high molecular weight (> 25,000 grams/mo), and low carboxyl end group number (< 30) as supported by data submitted by Mirafi. Although no direct aging studies were submitted for the Mirafi geogrids, they should offer good resistance to hydrolysis when used within the AASHTO non aggressive reinforced fills with pH of 5 to 9 based on: 1) a review of the polymer literature; 2) molecular weight and carboxyl end group results from independent tests performed for Mirafi on their polymer; 3) preliminary testing developed by FHWA on the durability of geosynthetics (Elias, et al., 2001), and, 4) literature submitted by Mirafi on aging studies of PET fibers and yarns used for the manufacture of geogrids.

The submitted information supports the use of $RF_D = 1.15$ in a pH range of 5 to 8 as recommended by Anchor and in accordance with the minimum requirement specified in AASHTO (2000). However the data indicate that a higher value should be used in more aggressive environments. For more aggressive environments with a pH of 8 to 9 or in a pH range of 3 to 5, $RF_D = 1.3$ is recommended by NHI 043. A FHWA-sponsored field study to examine pH conditions within MBW units showed that the pH occasionally increased above 9 and then only for the first few years. For cases where the modular block facing is anticipated to be wet for an extended period of time, the higher reduction factor should be considered for connection evaluation. Certain natural soil conditions (e.g., some limestone backfills) may also require the use of the higher reduction factor. As recommended in Chapter 3 of NHI 043, PET geogrid reinforcement should not be used in an environment with a pH > 9 (e.g., lime stabilized soils and in between submerged MBW facing units) or pH < 3 (e.g., some industrial waste construction materials).

3.3.5 Creep (RF_{CR}) Reduction Factor, PET Geogrids

Laboratory data from several independent laboratories were submitted in support of the determination of a creep limiting long-term strength reduction factor, however interpretation of the data in compliance with the HITEC Protocol was not presented. In review of the data, it was noted that conventional stress rupture data for the Mirafi geogrid series was not submitted in accordance with the NHI 043 requirements. Although a significant amount of stepped isothermal method (SIM) data was submitted along with long-term creep strain data to support these results, stress rupture data must be available for correlation and confirmation of the SEM results. Until such data are made available, the creep reduction values should be conservatively determined based on: 1) the assumption that the limited conventional creep strain data points supplied by Mirafi are at or near rupture; and 2) that the conventional rupture envelope is parallel to the SIM rupture envelope. The conventional data point is then extrapolated to the performance period (e.g., 75-year rupture line) and time extrapolation factors applied as shown in Appendix B.

Extrapolation of the data to 75 and 100 years, respectively, indicates a RF_{CR} based on creep-rupture of 1.9 for Miragrid XT geogrids and 2.4 for the Miratex TD3 geogrid. These reduction factors are valid for in-ground use where the temperature is no greater than 20° C (68° F).

3.3.6 Long-Term Allowable Design Strength (T_a), PET Geogrids

The long-term allowable design strength, T_a , used for Mirafi PET geogrid design depends on:

- Design life desired
- Specific geogrid used
- Predominant backfill size
- FS = 1.5

For Miragrid XT5 – XT10 geogrids and a 75 year performance period using a FHWA Type 2 (NHI 043) sandy gravel reinforced fill, T_a is expressed by:

$$T_a = T_{ult}/(RF \times FS) = T_{ult}/(1.9)(1.3)(1.15)(1.5) = T_{ult}/4.3$$

For Miragrid XT3 geogrid and a 75 year performance period using a FHWA Type 2 (NHI 043) sandy gravel reinforced fill, T_a is expressed by:

$$T_a = T_{ult}/(RF \times FS) = T_{ult}/(1.9)(1.4)(1.15)(1.5) = T_{ult}/4.6$$

For Miratex TD3 geogrid and a 75 year performance period using a FHWA Type 2 (NHI 043) sandy gravel reinforced fill, T_a is expressed by:

$$T_a = T_{ult}/(RF \times FS) = T_{ult}/(2.4)(1.3)(1.15)(1.5) = T_{ult}/5.4$$

The total reduction factor should be appropriately increased for longer performance periods, coarse FHWA Type 1 (NHI 043) gravel fill and/or more aggressive soil conditions as indicated in the previous sections.

3.3.7 Connection Capacity

The connection detail for the Landmark/Mirafi System is based on a polymer lock bar that secures the geogrid in a receiving channel on the top of the block. The clamping action is directly from the locking bar and is not dependent upon the normal loading of the block facing, as indicated by the test results discussed later in this section. Details for connector placement are included in Appendix C. The Landmark/Mirafi connection thus relies on both shear from the mechanical polymer connection to fasten the geogrid to the block and friction to prevent the geogrid from sliding out of the attachment. Considering that both the geosynthetic component and the connector are polymeric materials, long-term creep of the connection is a principal design issue. Both short- and long-term connection strength data were submitted from an independent laboratory following the procedures outlined in NHI 043 and in general accordance with the NCMA Test Method SRWU-1, as required by AASHTO (2000) to support the connection capacity. Connection capacity was determined through short-term testing for most combinations of blocks and geogrids including the three standard block configurations with the Miragrid and Miratex TD3 geogrids. Representative block and geogrid combinations have been evaluated in long-term tests to confirm creep response of the connection. Representative short-term and long-term connection test data are provided in Appendix B. Table 3 provides a summary of the short-term and long-term connection strength results.

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With respect to the design connection capacity of the Landmark/Mirafi system, application of the NHI 043 connection design criteria and by reference AASHTO (2000) requires that the capacity be the lesser of the:

- maximum allowable design strength of the geogrid; or
- connection strength developed by friction or structural means based on long term connection capacity testing reduced for long term environmental aging and $FS = 1.5$.

The test data submitted indicate that a breakage failure of the geogrid occurred except for the higher strength geogrids where, in some short-term test cases, the concrete key failed. Article 8.31 requires that the connection test develop “the strength of reinforcement without damage to the concrete used as anchorage.” Using working stress concepts, this requirement is met when the test capacity, in accordance with Article 8.15 (AASHTO, 2000a), does not exceed the allowable stress in the concrete with respect to the maximum design load carried by the reinforcement. Further, AASHTO (2000a) requires that the bearing stress must also be limited in accordance with the provisions of Article 8.15.2.1.3 (AASHTO, 2000a). Considering that concrete breakage occurred in some of the tests, calculations for the allowable stress in the concrete using both the allowable stress and load factor design methods (Article 8.15 and 8.16, AASHTO, 2000a, respectively) were provided (see Appendix B). The calculations indicate that the allowable strength of the concrete does not control the pullout capacity, at least for walls less than about 15 m (50 ft) in height. Higher walls may require higher strength block than the 4,000 psi standard required by AASHTO. Therefore, the allowable connection capacity can be calculated using the creep reduction and durability factors used for either the connector or the geogrid.

Table 3 Landmark/Mirafi Connection Capacity Summary

Product	Normal Load kN/m (lb/ft)	Geogrid Lot Specific Tensile Strength T_{lot} kN/m (lb/ft)	Average Short-term Connection Strength $T_{ultconn}$ kN/m (lb/ft)	Long-term (75 Year) Test Load T_{crc} kN/m (lb/ft)
Miragrid 3XT with Straight Block	14.6 (1000) 21.9 (1500) 29.2 (2000)	45.5 (3116) 45.5 (3116) 45.5 (3116)	42.2 (2890) 41.1 (2816) 40.1 (2746)	Not available at time of publishing
Miragrid 3XT with Tapered Block	14.6 (1000) 21.9 (1500) 29.2 (2000)	45.5 (3116) 45.5 (3116) 45.5 (3116)	32.1 (2201) 29.3 (2006) 26.5 (1812)	Not available at time of publishing
Miragrid 5XT with Straight Block	14.6 (1000) 21.9 (1500) 29.2 (2000)	56.1 (3844) 56.1 (3844) 56.1 (3844)	40.9 (2805) 41.4 (2835) 40.0 (2743)	27.6 (1890) 29.2 (2000) 25.8 (1766)
Miragrid 5XT with Tapered Block	14.6 (1000) 21.9 (1500) 29.2 (2000)	56.1 (3844) 56.1 (3844) 56.1 (3844)	39.6 (2714) 38.7 (2653) 37.8 (2591)	Not available at time of publishing
Miragrid 7XT with Straight Block	14.6 (1000) 21.9 (1500) 29.2 (2000)	70.3 (4815) 70.3 (4815) 70.3 (4815)	46.6 (3191) 45.8 (3138) 45.0 (2449)	Not available at time of publishing
Miragrid 7XT with Tapered Block	14.6 (1000) 21.9 (1500) 29.2 (2000)	70.3 (4815) 70.3 (4815) 70.3 (4815)	36.0 (2467) 35.9 (2458) 35.8 (2449)	Not available at time of publishing
Miragrid 8XT with Straight Block	7.66 (525) 30.3 (2074) 58.4 (4000)	95.8 (6564) 95.8 (6564) 95.8 (6564)	71.7 (4911) 73.7 (5046) 76.1 (5215)	47.6 (3261) 53.0 (3631) 53.7 (3612)
Miragrid 8XT with Tapered Block	14.6 (1000) 36.5 (2500) 73 (5000)	95.8 (6564) 95.8 (6564) 95.8 (6564)	60.8 (4163) 58.9 (4031) 55.7 (3812)	Not available at time of publishing
Miragrid 10XT with Straight Block	14.6 (1000) 36.5 (2500) 73 (5000)	138 (9456) 138 (9456) 138 (9456)	61.8 (4235) 68.1 (4665) 78.6 (5382)	In Progress In Progress In Progress
Miragrid 10XT with Tapered Block	14.6 (1000) 36.5 (2500) 73 (5000)	138 (9456) 138 (9456) 138 (9456)	63.5 (4347) 76.1 (5213) 79.4 (5437)	Not available at time of publishing
Miratex TD3 with Straight Block	8.03 (550) 16.1 (1100) 29.2 (2000)	85.2 (5836) 85.2 (5836) 85.2 (5836)	69.5 (4757) 67.7 (4635) 64.8 (4436)	57.3 (3922) 57.1 (3910) 55.6 (3813)
Miratex TD3 with Tapered Block	14.6 (1000) 21.9 (1500) 29.2 (2000)	85.2 (5836) 85.2 (5836) 85.2 (5836)	56.4 (3862) 54.3 (3719) 52.2 (3575)	Not available at time of publishing

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Representative calculations of connection capacities for several combinations of geogrid and block type are provided in Appendix B. The maximum allowable design strength of the geogrid, T_a , appears to control the connection capacity for the cases evaluated. Whether or not T_a controls on a specific project will depend on the magnitude of RF_{ID} (smaller values of RF_{ID} increase T_a making it possible for T_{ac} to control the design). On the basis of the long-term connection test results, $RF_{CR} = 1.55$ could be applied to the short-term connection strength results (i.e., $T_{ultconn}$ provided in Table 3 and in Appendix B) to determine the connection capacity for a 75-year performance period. This 1.55 connection creep reduction factor is consistent with the recommendations of the test laboratory that obtained the long-term connection strength results. This connection creep reduction factor value could be applied to the short-term connection strength $T_{ultconn}$ and used in combination with F_{RD} and FS to determine design connection strength, T_{ac} , for the combination of block and reinforcement shown in Table 3, or to interpolate between the combinations of block and reinforcement shown in Table 3, in accordance with AASHTO (2000) and NHI 043 requirements. Caution should be exercised when attempting to extrapolate these connection strength results to lighter weight or heavier weight grids than shown in Table 3.

Under seismic loading, the allowable connection capacity is the lesser of the geogrid seismic allowable load or the product obtained by dividing $T_{ultconn}$ by the reduced FS (i.e., 1.1 instead of 1.5) times RF_D .

No specific durability data were submitted in support of a design life of 75 to 100 years. However, the aging resistance of the connector should be consistent with the resistance of the PVC in other geotechnical applications such as liners for landfill cap and cover systems.

3.3.8 Block Shear Capacity

The interface shear capacities of both the Landmark straight and tapered units, with and without reinforcement, were also evaluated in accordance with the NCMA Test Method SRWU-2 “Determination of Shear Strength Between Segmental Concrete Units” (NCMA, 1997). It should be noted that the shear capacity measured is the sum of friction and/or shear developed between the blocks and the shear strength of the shear key. Data were submitted for the three standard block configurations in combination with two of the Mirafi geogrids as well as without geogrids. The lower-bound design envelope developed for the interface shear, with or without reinforcement, with respect to normal stress is:

$$V_u = 19.2 \text{ kN/m} + N \tan 38^\circ = (1313 \text{ lb/ft} + N \tan 38^\circ)$$

where:

$$V_u = \text{interface shear capacity in kN/m (lb/ft), and}$$
$$N = \text{normal stress in kN/m (lb/ft)}$$

3.3.9 Block Facing Unit Rotation

Rotation of the block facing units is prevented primarily by the running bond configuration used for the face assembly, mechanical attachment via shear keys, inter-block friction, equilibrium of soil pressures behind the units, and connection to soil reinforcement elements. This HITEC evaluation indicates that these factors should be adequate to prevent rotation of the blocks. Data were submitted from an independent study on the resistance to overturning of individual units which supports this evaluation.

3.3.10 Backfill in Reinforced Zone

Select granular fill in accordance with the grain size and soundness requirements in AASHTO Division II (AASHTO, 2000) is specified with no deviation in the Landmark/Mirafi System construction specifications evaluated for this review. The electrochemical requirements for minimum resistivity, maximum chloride, and sulfate content in AASHTO (2000) should be waived because they are applicable to metallic reinforcement only. The pH requirements should remain applicable.

The Landmark/Mirafi system uses hollow blocks with no exposed core, which are butted such that no infill in or between the blocks is required. However, the installation of free-draining aggregate, which readily compacts to within 95 percent of standard Proctor density in accordance with AASHTO T99 (AASHTO, 2001a) or ASTM 698 (ASTM 2001), is recommended for the zone within 300 mm (12 in) of the back of the block. The zone of aggregate behind the face is considered to be part of the drainage system and is tied into the weep hole outlet system at the base of the wall. The material used in this zone is required to meet the gradation criteria in NHI 043 specifications for unit fill and drainage aggregate for MBW systems. Where the reinforced fill is free draining, this zone is not required and a nonwoven geotextile filter layer meeting the requirements of AASHTO M288 (AASHTO, 2001b) is placed against the back of the blocks to prevent migration of fines through the face and staining of the face.

3.4 Design Computations

The submitted design computations for four typical cases (i.e., horizontal backfill, infinite backslope, broken backslope and bridge abutment), plus special conditions of both traffic loading and concentrated dead loads for the horizontal backfill case, were checked and found to be in compliance to AASHTO (2000) criteria. External and internal stability calculations for static and seismic design are in compliance with respect to methodology for the typical cases submitted.

Typical computations for the transfer of supplemental loads, horizontal and/or vertical, are consistent with AASHTO methodology. The computer program MSEW, developed by the FHWA, is used for the design of the Landmark/Mirafi System. The computer program yielded the same answers as the hand calculations. Typical computations for the horizontal backfill case are presented in Appendix B.

3.4.1 Coverage Ratios

Continuous geogrid reinforcement is used for the Landmark/Mirafi System, therefore the coverage ratio is 100%. Less than 100% coverage was not evaluated as part of this report.

3.5 Limitations

The following AASHTO (2000) limitations should be observed with respect to the use of Landmark/Mirafi System, which include:

- Placement of utilities within the select fill volume
- Reinforcements exposed to runoff or industrial pollution characterized by low pH or high pH
- Unpredictable erosion or uncontrollable scour depth below the reinforced fill zone

As previously indicated in Section 3.3.4, PET geogrid reinforcement should not be used in an environment with a pH > 9 (e.g., lime stabilized soils and below water applications with modular block wall systems) or pH < 3 (e.g., some industrial waste construction materials) as recommended in Chapter 3 of NHI 043.

For environments where de-icing salts are used, the wall face should be periodically coated with a sealer specifically designed for use with dry cast concrete products.

3.6 Design Details

3.6.1 Facing Units

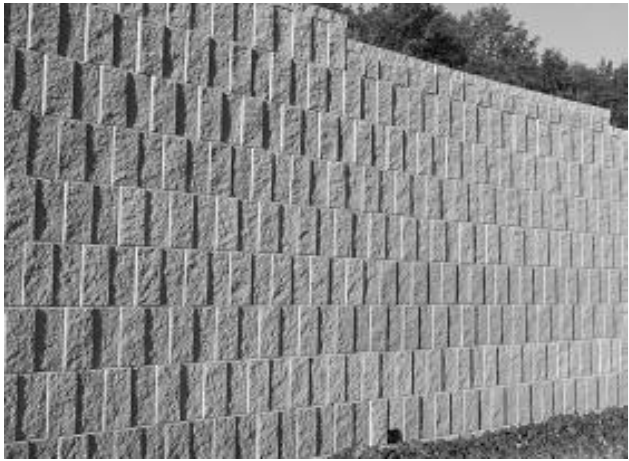
Structural design of facing units, according to NHI 043, is based only on the ability of facing blocks to resist compression and shear stresses imposed on the face of the wall. Minimum compressive strength and water absorption should be specified to ensure durable units in accordance with AASHTO (2000). The Landmark/Mirafi System facing units are designed to have a minimum compressive strength of 28 MPa (4,000 psi) at 28 days and a water absorption limit of 5 percent, as sampled and tested in accordance with ASTM C 140 (2001b), which are in compliance with Article 7.3.1.4 of AASHTO (2000). The dimensions of the modular block facing units are shown in Appendix C.

Additional freeze-thaw restrictions should be required where site conditions warrant them. Freeze-thaw durability of modular units is governed by the AASHTO (2000), Article 7.3.1.4, which has been modified by NHI 043, Section 8.10, and has been adopted by AASHTO (2002). The applicable test method is ASTM C 1262 (ASTM, 2001b) as required in NHI 043. The current specification requires that specimens comply with either of the following:

- The weight loss of four out of five specimens at the conclusion of 150 cycles shall not exceed 1% of its initial weight when tested in water.
- The weight loss of each of four of the five test specimens at the conclusion of 50 cycles shall not exceed 1.5% of its initial mass when tested in a 3% saline solution.

As stated in NHI 043, the agency may require that either or both acceptance criteria be met depending on the severity of the project location. Test results were submitted from both an independent laboratory and Anchor's internal laboratory to demonstrate the ability of licensed Landmark block producers to meet both of these requirements. Representative results are included in Appendix B.

Available color of Landmark/Mirafi System facing units will vary between individual producers. Typically available colors include tan, buff, gray or charcoal, and red. The standard facing texture is obtained by splitting the individual facing units from a precast, two unit "slug" after it has cured. Another face texturing option is Anchor's Rough Face™ process, in which the face texture is applied to the facing units during the molding process, rather than after curing. A third option includes manufacturing the facing units with a smooth face, which can be painted. The facing units are also manufactured with the front face panel slightly inclined from vertical (tipped backward slightly) to enhance the visual appearance of batter. In addition, units are manufactured with a 19-mm (0.75-in) offset split or textured face. By mating units with a different base width, a "staggered" in and out effect to the finished wall face can be achieved in either a regular or random pattern as shown in Figure 4.



a.)



b.)

Figure 4. Staggered Wall Face Patterns Showing: a) Regular and b) Random Patterns

Anchor indicates that coating type graffiti treatment is available for the Landmark/Mirafi System facing units and provided information from several manufacturers.

Details showing standard modular block facing units, wall capping units, and traffic barriers are provided in Appendix C. Details are also provided for abutment of the Landmark/Mirafi system to a cast-in-place wall or other similar structure. Corner face units are available where outside corners are required as shown in Appendix C.

Where required, slip joints are constructed by saw cutting every other vertically adjacent facing unit along a vertical axis. A non-woven geotextile filter meeting the AASHTO M288 (AASHTO, 2001b) criteria is placed behind the facing units at the joint to prevent movement of fill through the joint. At the time of this review, no provision for a façade over the slip joint to improve aesthetics (should differential movement occur) was available.

3.6.2 Leveling Pad

A non-reinforced cast-in-place concrete leveling pad, as presented in NHI 043, is preferred by Anchor for public-sector projects. A minimum compressive strength of 21 MPa (3000 psi) is recommended. A precast concrete board or plank, placed on a properly prepared aggregate leveling pad, is also acceptable for the Landmark/Mirafi system. An alternative gravel pad is permitted by Anchor for commercial applications and when requested by public agencies. Gravel leveling pads may be more vulnerable than concrete leveling pads should scour remove soil at the wall base. Uncontrolled drainage behind the wall crest may also cause erosion of the gravel pad and precipitate excessive settlement. Horizontal control to preclude uneven horizontal joints is also more difficult with a gravel pad.

3.6.3 Wall Drainage

In general, drainage of water from the reinforced soil zone is primarily through weep holes placed slightly above the finished grade elevation and joints between facing units. To prevent excess water from flowing through the wall face, the drainage system includes a slotted PVC or HDPE pipe behind the weep holes.

To facilitate movement of water to the face (and facilitate compaction behind the face), drainage aggregate, noted as “unit fill” in NHI 043, is placed immediately behind the facing unit for a distance of 300 mm (1 ft), extending

down and tied into the slotted pipe system. The material specified by Anchor unit fill and drainage aggregate conforms with the concrete modular block specification requirements in Section 8.10 of NHI 043 as shown in Table 4.

Table 4
Gradation of Face Unit Drainage Aggregate

Sieve Size	Percent Passing
25 mm (1 in)	100
19 mm (0.75 in)	50 - 75
4.74 mm (No. 4)	0 - 60
425 mm (No. 40)	0 - 50
75 mm (No. 200)	0 - 5

Anchor recommends that a design check be made of grain size compatibility between the unit fill and reinforced fill using standard geotechnical filter criteria as provided in the submittal document.

Anchor notes that additional drainage provisions can be provided at the base of the reinforced mass if water infiltration is of major concern. The drainage layer would consist of free draining material (e.g., crushed rock) placed below the reinforced mass with perforated drainpipes installed to drain the water. Anchor also notes that if groundwater is present in the retained zone behind the reinforced mass, then a drainage layer of free-draining material can be placed between the reinforced mass and retained embankment to drain groundwater around the reinforced mass. A geotextile filter would be placed between the retained soils and drainage layer to maintain free drainage in the drainage layer. Design details and example plan sheets were provided for these options. A drainage geocomposite is recognized as an alternate for the chimney drain constructed behind the reinforced fill.

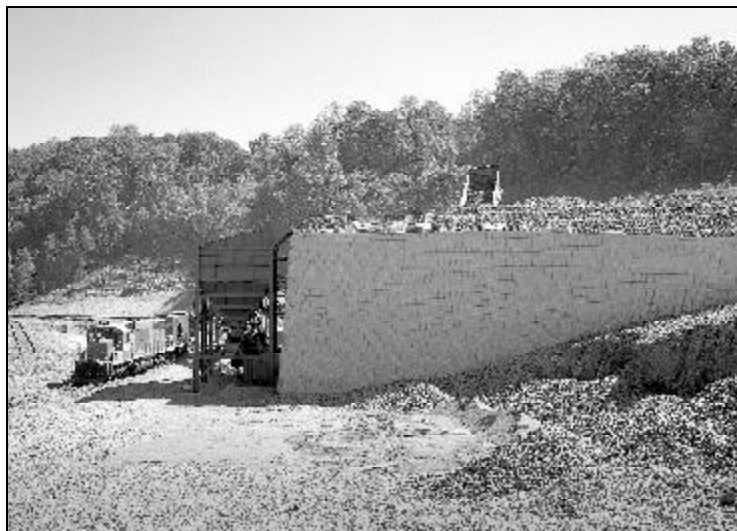
3.6.4 Copings and Barriers

Cap units are available for the Landmark/Mirafi system and are typically attached to the top block using a synthetic resin and rubber adhesive. However, Anchor has not demonstrated the longevity of this application sufficiently to satisfy the criteria established in Section 8.10.3.6 of NHI 043. Therefore, for public-sector projects, Anchor recommends using mortar to secure the cap units to the upper course of facing blocks. They note that the channel formed into the top of the units easily facilitates this connection. Cast-in-place copings or barriers may also be used with closely spaced joints on the order of 3 m (10 ft) to limit uncontrolled cracking of the coping system; however, details were not provided.

Traffic and pedestrian barrier details have been developed and are also presented in Appendix C. The overturning leg dimension must be designed on a project-specific basis. Although feasible in principle, the performance of traffic barriers under the AASHTO impact traffic loads has not been demonstrated. Note that the expansion joint material is a critical element in the jersey and traffic barrier details to avoid wearing of the block during normal traffic loading.

3.6.5 Obstruction Avoidance Details

Major obstructions to the normal placement of geogrid soil reinforcement are designed individually, with typical details shown in Appendix C. Calculations of a typical design were submitted to support these details. The submittals provided sufficient design and plan detail to evaluate conformance with the AASHTO requirements regarding this item.



Demonstration of Anchor Landmark system ability to support heavy loads.

CONSTRUCTION SPECIFICATIONS

The Landmark/Mirafi System submittal for materials and construction specifications indicates general conformance with the applicable provisions of the specifications for MSE Walls with Segmental Concrete Precast Facings, Sections 8.9, 8.10 and 8.11 from NHI 043. For agencies using NHI 043 specifications, the following section includes editorial and technical revisions to Section 8.9 that would be necessary to produce an appropriate specification for Landmark/Mirafi System.

4.1 Description

Editorial changes to reflect the use of geogrid reinforcement and modular facings.

4.2 Materials

- (MBW) Facing and Drainage Fill: delete “Reinforced Concrete Facing Panels” and substitute Section 8.10, “Concrete Modular Block.”
- Under “Soil Reinforcing and Attachment Devices,” delete Subsections 1, through 5 and substitute the following:
 - (1) The geogrids shall consist of Mirafi Miragrid 3XT, 5XT, 7XT, 8XT, 10XT and Mirafi Miratex TD3 manufactured by weaving high tenacity polyester (PET) yarns (Type 811) and coating the finished grid with 48% by weight of polyvinyl chloride (PVC), having aperture geometry, rib, and cross-section sufficient to allow significant interlock to permit mechanical interlock with the backfill soil. No substitution allowed.

The geogrid shall be stored in conditions above -20° F (-29° C) and not greater than 122° F (50° C) and in such a manner to prevent contamination from mud, wet cement, epoxy, and like materials. Geogrid rolls may be laid flat or stood on end for storage.

Chapter 4

(2) Subsection 3.0 from Section 8.11. Table 1 should contain the applicable information as outlined in this evaluation for Mirafi Miragrid 3XT, 5XT, 7XT, 8XT, 10XT and Mirafi Miratex TD3.

(3) Subsection 4.0 from Section 8.11.

(4) Subsections 5.0 and 6.0 from Section 8.11.

(5) Connectors – The Landmark lock bar connector as supplied by Anchor shall be manufactured from CPVC and/or PVC to the dimensions shown on the plans. The contractor shall submit a manufacturer's certification verifying the connector supplied meets the index criteria set when approved by the agency.

- Delete Joint Materials

- Select Granular Material

(1) Use 20 mm (0.79 in) as maximum size, unless design has considered the higher RF_{ID} factors.

(2) Eliminate electrochemical requirements except for pH, where the limits are greater than 5 and less than 8. (A pH up to 9 is allowed if the design has considered the higher RF_d factors.)

- Add drainpipe: All drain pipe shall meet the requirements of AASHTO Standard Specifications M278 or M304 as shown on the plans.

- Add geotextile filter: Geotextile filter material shall meet the requirements of AASHTO Standard Specification M288 meeting the following requirements: (*Specify class and index properties for filtration based on adjacent backfill aggregate to be filtered.*)

4.3 Construction

Wall erection. Delete 2nd paragraph and add the following:

- Facing units shall be placed in successive horizontal lifts in the sequence shown on the plans as backfill proceeds as follows.

- Foundation units shall be placed on the leveling pad. Units shall be checked for horizontal alignment with a string line placed at the back of the units and vertical alignment front to back and side to side with a level. The top of all units in the base course shall be at the same elevation. A 25 mm (1 in) gap between the foundation units is allowed, provided a geotextile filter meeting the requirements in the Materials Section is placed behind the foundation units. The foundation course of modular units shall be backfilled and compacted, front and back, then checked for level and alignment prior to placing the next course of wall units.

- Perforated drainpipe shall be installed at the lowest elevation possible to maintain gravity flow of water to outside of the reinforced zone at the locations shown on the plans.

- Remove all excess fill from top of units and from the locking bar channel in the top of the units and install the next course.

- Subsequent courses of modular units shall be placed side by side for the full length of wall alignment with a maximum gap of 3.2 mm (0.125 in) between units. Alignment should be checked by using a string line at the back of the units and units adjusted as necessary to maintain horizontal alignment within these specification requirements.

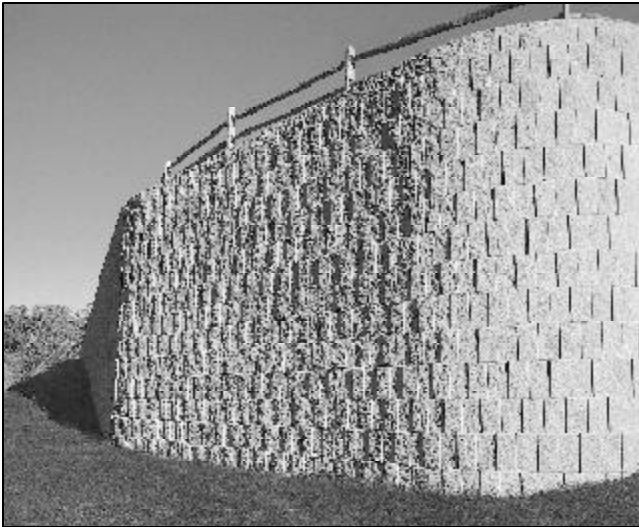
- If required as shown on the plans, a minimum of 300 mm (12 in) of unit fill shall be placed behind the row of modular units.

- Place drainage aggregate and backfill and compact in accordance with the following Backfill Placement section of this specification to the top level of the in place facing units. At each level of soil reinforcement, the backfill material shall be roughly leveled to an elevation approximately 30 mm (0.1 ft) above the level of the facing unit before placing the soil reinforcement.

- Install each succeeding course. Backfill as each course is completed and prior to placement of the next course. Remove all excess fill from top of units and from the lock bar channel in the top of the units prior to placing the next row of facing units. Pull the units forward until the locating surface of the unit contacts the locating surface of the units in the preceding course. Check unit horizontal alignment with a string line and vertical alignment with a level on each course, adjusting units as necessary with shims made from geosynthetic reinforcement to maintain proper alignment and set-back control.

- Install geosynthetic reinforcement over the surface of facing units and backfill at the locations and elevations indicated on the plans. All excess material shall be swept from the top of the units and the lock bar channel prior to installing the geosynthetic reinforcement. Reinforcing geogrids shall be placed with the highest strength axis normal to the wall face and connected with the Landmark connectors. Prior to the placement of any backfill, the reinforcing geogrids shall be pulled taut perpendicular to the orientation of the geogrid with enough force to remove slack and staked into position. Construction equipment shall not operate directly on the geogrid.

- Landmark lock bar connectors shall be installed at each geosynthetic elevation. Gaps between adjacent section of locking bar shall be no greater than 75 mm (3 in). The lock bar shall be placed flat side up, with the angled side to the back of the unit, as shown on the construction drawings. The reinforcement must be maintained within 25 mm (1 in) of the face of the smaller Landmark units below. Facing vertical tolerances and horizontal alignment tolerances shall not exceed 13 mm (0.75 in) when measured with a 3 m (10 ft) straight edge. The completed wall shall have overall tolerances (top to bottom) not exceeding 13 mm per 3 m (10 ft) from the plan dimensions. The maximum rotation of the wall face during construction from the established wall plan batter is 2.0 degrees.



Example of the unique vertical appearance of the Anchor Landmark system.

QUALITY CONTROL/QUALITY ASSURANCE (QA/QC) SYSTEMS

QC/QA programs have been developed for the manufacture of all supplied materials, design, and construction. A copy of the QC/QA submittal for each element is included in Appendix D. Each plan was separately reviewed as discussed in the following subsections.

5.1 Modular Block Facing Units

Quality Control Procedures for Production of Anchor Landmark Modular Units dated December 15, 2000 was submitted by Anchor. Licensed Landmark block producers are required by contract to follow these QC/QA procedures and supply test results to Anchor for review. The QC/QA procedures provide for raw materials, blending and measuring of materials, mixing, manufacturing and testing during production, personnel qualifications, and documentation and establishes the minimum level of quality assurance acceptable to Anchor. Anchor has their own in-house testing facility through a sister company, Anchor Block Company, for performance of quality control tests. Anchor and, occasionally, their licensees use the services of American Engineering Testing, Inc. (AET) to provide certification-related services. The submitted QC/QA Block program includes information related to AET's QC/QA program.

5.2 Geosynthetic Reinforcement

Anchor relies on Mirafi to provide quality control of the Mirafi reinforcement that is a component of the system evaluated here. Quality Control/Quality Assurance Procedures for Mirafi Geogrids dated August 23, 2001 was submitted and identifies all of Mirafi's required testing and acceptance limits. Mirafi primarily performs wide-width strip testing in accordance with ASTM D 4595 (ASTM, 2001c) for their tensile strength quality control test on their geogrids and has established the minimum average roll value for each product on that basis. As indicated in the Installation Damage section of this report, the QC/QA program did not include an evaluation of the geogrid coating including the requirements for minimum thickness or weight. Manufacturer certification of product deliv-

ered is based on meeting all of the requirements and within the tolerances specified in this document and summarized in the production specification and process control data sheets enclosed in Appendix D. Anchor does not perform audits of this process or maintain geosynthetic certification records.

5.3 Connector Manufacturing

The Anchor Landmark Lock Bar Production Quality Control Document dated September 30, 2002 as performed by Anchor and their producers is included in Appendix D. To date, the lock bar has been manufactured from industrial recycled CPVC and PVC obtained from a manufacturer of prefabricated window moldings, the excess from which is trimmed and reground for processing. Virgin polymers are also suitable. The resins used to manufacture the lock bar currently consist of 84 to 100% CPVC, 0 to 14% Flexible PVC and 0 to 14% PVC capstock or 100% PVC. Data sheets indicating polymer composition and properties of each of the components were submitted. No plasticizers are used in the CPVC, with 20 to 30% used in the FPVC, and to a lesser extent in the PVC. Plasticizers can leach over time and create embrittlement.

The lock bar connectors are fabricated by several US producers (e.g., Intek Plastics, Inc., Hastings, MN) who produce lock bars to the surface texture, dimensional tolerances and strength/modulus properties specified by Anchor. The submitted Quality Control program indicates the minimum requirements and testing frequency for evaluating conformance of each of these characteristics. In the past, these plastic fabricators have submitted samples of lock bar to Anchor on specified intervals, and Anchor had the samples tested at an independent lab to confirm that the lock bar is in compliance with Anchor's specification. In the future, the lock bar fabricators will be required to submit samples directly to a qualified test lab at specified intervals, and to forward the lab reports to Anchor.

5.4 Design QA/QC

Anchor has a staff of five registered professional engineers and provides "preliminary" engineering design during the pre-bid stage for licensed Landmark block producers, as well as final drawings and calculations for some agency projects. When final design is performed by Anchor, it is responsible for system design for external stability (sliding and overturning) and internal stability (size, length, and spacing of geosynthetic grids). Anchor's QC/QA Procedure for Preliminary and Final Design Services dated April 11, 2002 was submitted for review and is enclosed in Appendix D. Final construction drawings and the project file are peer-reviewed by a designated senior engineer. A registered Professional Engineer licensed in the project state seals all drawings and calculations.

Typically, the owner or owner's consultant perform design of the Landmark/Mirafi system with technical support provided by the Anchor engineering staff. If requested, Anchor will work with local licensed manufacturers and experienced wall design consultants to provide final design services. Anchor periodically reviews the designers used by their licensed producers along with representative project designs.

5.5 Construction and Quality Control Manual (Erection Manual)

An undated erection manual was submitted and reviewed. The Anchor Landmark Technical Performance Manual contains specifications for installation, which are in general compliance with Sections 8.9, 8.10 and 8.11 in the NHI 043 manual, and sound construction practice. The specification contains a quality control section that clearly delineates the responsibility for quality between the contractor, owner and engineer. A Construction and Quality Assurance Manual is also included in the Landmark Technical Performance Manual. The construction section contains installation photos of routine wall construction as well as special construction features such as corners, guardrails, terraced walls and water applications. A separate, special addition of the construction manual has been developed for AASHTO and DOT projects, the standard construction section of which is included in Appendix D.

Chapter 5

A Segmental Retaining Wall (SRW) Quality Assurance Inspection Guide and Post Construction Monitoring Program was also provided for construction and is included in Appendix D. The guideline provides information on the minimum level of inspection required prior to and during construction, although it lacks documentation requirements for the contractor. The owner is responsible for providing construction observation, inspection and quality assurance during construction of the walls.

5.6 Warranties and Insurance

Anchor does not itself make or sell the Landmark facing units. Nor does Anchor itself make or sell the Mirafi geogrids that are component parts of the evaluated system. Nor does Anchor itself typically do final designs of Landmark/Mirafi structures, or itself construct Landmark/Mirafi structures. Accordingly, Anchor does not provide a warranty with respect to the combined Landmark/Mirafi system, or with respect to the performance of any particular Landmark/Mirafi structure, except to the extent noted below. Anchor does provide a limited 5-year written warranty that blocks manufactured by its licensed block producers comply with ASTM standards for segmental retaining wall blocks. Substitute blocks for defective blocks will be provided free of charge, but exclude the cost for removal and installation. Under the terms of their license agreements with Anchor, licensed producers must honor this warranty agreement.

With respect to the lock bar stock that is manufactured for Anchor under a private label arrangement, and resold by Anchor, Anchor is responsible for the performance of that item. Anchor does not currently publish any written warranty with respect to the lock bar, and thus is subject to those warranties that apply by operation of law to the lock bar. This situation may change, as new lock bar fabricators are qualified and are permitted to sell lock bar stock direct, rather than through Anchor.

Mirafi is responsible for the soil reinforcement geogrids. Mirafi in their Technical Data Sheet warrants that their products are free of defects in material and workmanship when delivered to TC Mirafi's customers and that their products meet their published specifications as reported herein. Claims must be reported before installation.

Anchor supplied the following evidence of insurance in force as of August 2002:

Anchor Professional Liability (Errors and Omissions) Insurance.

Amount: \$2,000,000 claims made, each claim
Insurer: Admiral Insurance Company
Renewal: Annual

Anchor General and Product Liability Insurance.

Amount: \$2,000,000 Product/Completed Operations Aggregate
\$20,000,000 Excess Liability/Each Occurrence - Aggregate
Insurer: St. Paul Fire & Marine Ins. Co.
Renewal: Annual

Mirafi General and Product Liability Insurance.

Amount: \$3,000,000 Product/Completed Operations Aggregate
Insurer: Zurich American Insurance Company
Renewal: Annual

Licensed Landmark block producers must demonstrate evidence of insurance (annually) as a requirement of their Anchor Landmark license agreement. The license agreements require the licensed Landmark manufacturers to carry at least \$5,000,000 of commercial liability insurance.



Land bridge under construction. Finished wall will be approximately 20 meters high.

PERFORMANCE REVIEW

Since 1999, Landmark/Mirafi System has been used for the construction of projects with a total wall face area of approximately 10,000 m² (100,000 ft²) of walls. The highest wall constructed, as of July 2002, is 13.6 m (44.5 ft) in height. Project information was provided for four walls. Project information and contact personnel are included in Appendix E.

Due to the recent introduction of the Landmark/Mirafi System, no long-term performance data are available for the total system; however, one structure completed in 2001 is instrumented with inclinometers. A case history for that project was submitted along with construction reports and instrumentation results during and after construction (see Appendix E). The data demonstrate the ability to construct the system to within project requirements. Several other projects have also been constructed to Minnesota Department of Transportation SRW block quality requirements with no reported problems.

Anchor indicated that no major or unusual problems have been reported for the Landmark/Mirafi System with the exception of one project where problems with undermining due to erosion occurred during construction. The undermining occurred because of high overland water flow, which breached a berm placed to protect the wall and flowed through the drainage rock behind the wall face. The high flow created an erosion gully beneath the wall. Even with this breach of the wall, the wall face did not collapse and significant cracking of the blocks did not occur. The section of the wall was rebuilt and construction of the wall was completed.

Finite element analysis was performed by SEB Corp. of Eagan, MN, to evaluate the load capacity of the lock bar. The reports from their analysis were submitted for review.

6.1 Costs

Anchor's project experience indicates a typical private sector installed material cost of \$136/m² to \$178/m² (\$12.60/ft² to \$16.50/ft²) excluding reinforced fill and one project indicating a cost of \$261/m² (\$24.30/ft²) including reinforced fill. Cost information is included with the in the project information and contact personnel information for the four projects listed in Appendix E.

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APPENDICES

Appendix A

Submittal Protocol Check List

Appendix B

MARV Production Statistics

Pullout Coefficients

Geogrid Creep Data Summaries

Installation Damage Summaries

Connection Test and Representative Results

Connection Capacity – Allowable Concrete Strength Calculations

Connection Capacity Calculations

Interblock Shear Capacity Data

Typical Wall Design Computations

Freeze-Thaw Test Results

Appendix C

Available Modular Block Configurations

Cap Details

Corner Units

Corner Details

Connector Details

Drainage Details

Leveling Pad Detail

Pedestrian Sidewalk and Fence Details

Traffic Barrier Details

Obstruction Avoidance Details

Connection to Abutting Structures

Appendix D

Modular Block Quality Control

Locking Bar Connector Quality Control

Geosynthetic Manufacturing Quality Control

Design Quality Control

Construction Manual

Construction Quality Control Guide

Appendix E

List of Contractors

Users List with Cost Data

Case History

Verification of Alignment Tolerances

Insurance Certificate

Warranty



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