PERFORMANCE AND COST EFFECTIVENESS OF MODULAR BLOCK RETAINING WALLS

A Thesis in

Civil Engineering

by

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ABSTRACT

Modular block walls (MBWs), also known as segmental retaining walls (SRWs), continue to be a growing segment of the public retaining wall market. While MBWs have long been popular in the private sector, estimates by the Federal Highway Administration show that MBWs have had a distinct growth over the last ten years in the public sector. Still, many state Departments of Transportation do not permit the use of MBWs based on expectations of poor performance. This thesis presents information obtained from available literature including published papers and reports in regards to cost and performance of MBWs. In addition, a telephone survey was conducted of thirty-two departments of transportation to determine which states utilize modular block walls, how cost effective modular block walls have been, and how they have performed in comparison to more traditional wall types. The effectiveness of new freeze-thaw requirements was evaluated. States not currently using modular block walls revealed their current concerns that discourage these DOTs from utilizing MBWs. Based on the completed analysis and evaluation, advantages and disadvantages of MBWs are presented, and recommendations for successful implementation of MBWs are offered.
# TABLE OF CONTENTS

LIST OF FIGURES ................................................................................................................. vii

LIST OF TABLES .................................................................................................................. ix

ACKNOWLEDGEMENTS ........................................................................................................ x

Chapter 1 Introduction ........................................................................................................... 1

  Background and Current Use of Modular Block Walls .................................................. 2
  Retained & Reinforced Earth Options for State Agencies .............................................. 6
  Explanation of Survey ..................................................................................................... 7
  Survey Participation ................................................................................................ 9
  States Using Modular Block Walls ......................................................................... 10

Chapter 2 Design, Construction, and Composition of Modular Block Walls ..................... 12

  Modular Block Wall Design ............................................................................................ 12
  Modular Block Wall General Construction Sequence .................................................... 14
  Modular Block Units ....................................................................................................... 16
  Geosynthetic Reinforcement ........................................................................................... 18
  Backfill Material .............................................................................................................. 22

Chapter 3 Performance of Modular Block Walls ................................................................. 26

  Potential Performance Advantages .................................................................................. 26
    Geosynthetic Reinforcement .......................................................................................... 27
    Alignment of Facing Units ............................................................................................ 28
    Aesthetics and Adaptability ........................................................................................... 28
  Potential Performance Disadvantages ............................................................................. 29
    Aesthetic Issues ........................................................................................................... 30
    Mechanical Issues ..................................................................................................... 30
    Other Issues .............................................................................................................. 33
  Performance History ........................................................................................................ 34
    Minnesota Department of Transportation, 2001 Wall Review ................................ 34
    Wisconsin Department of Transportation, 2000 Wall Review ................................ 36
    Geosynthetic Reinforced Segmental Retaining Walls, Koerner and Soong, 2001 .. 37
    A Database and Analysis of Geosynthetic Reinforced Wall Failures ..................... 38
  Performance Related Survey Results .............................................................................. 39
    Performance Comparison of Modular Block Walls Versus Large Precast Panel MSE Walls and Cast-in-place Walls ............................................................... 39
    Maintenance Comparison of Modular Block Walls Versus Precast Panel MSE Walls and Standard Cast-in-place Walls ............................................................... 42
    Freeze-Thaw Durability ............................................................................................... 44
LIST OF FIGURES

Figure 1-1: Precast concrete paneled, mechanically stabilized earth wall on Route 22/322... 3
Figure 1-2: Typical dry cast modular block retaining wall .................................................... 5
Figure 1-3: Map of known Departments of Transportation using modular block walls. ....... 5
Figure 1-4: Departments of Transportation that participated in survey. ................................. 9
Figure 2-1: Typical modular block wall cross section (10)..................................................... 15
Figure 2-2: Left: Typical concrete (12). Right: Typical modular block unit with visible voids (12). ................................................................. 16
Figure 2-3: Some commercially available patented block (13). .............................................. 18
Figure 2-4: Various geosynthetic to modular block connection types (13). ......................... 22
Figure 2-5: Graphical representation of differing gradation requirements for MWBs. (17)... 24
Figure 3-1: Left: Multi-tiered modular block retaining wall (9). Right: Modular block wall at a ninety degree angle (15). ........................................................... 29
Figure 3-2: Above: Performance comparison to precast panel MSE walls. Below: Performance comparison to cast-in-place walls. ..................................................... 40
Figure 3-3: Above: Maintenance comparison to precast panel MSE walls. Below: Maintenance comparison to cast-in-place walls. ....................................................... 43
Figure 3-4: Above: Maintenance comparison of MBWs to precast panel MSE walls. Below: Maintenance comparison of MBWs to cast-in-place walls........................................ 44
Figure 3-5: Map showing latitude and longitude of the United States (19). ......................... 45
Figure 4-1: Left: Equipment and bracing needed for precast panel MSE walls (20). Right: Schematic for precast panel wall bracing (21). ......................................................... 49
Figure 4-2: Mean value of various categories of retaining wall costs, Koerner et al., 1998 (17)......................................................................................................................... 53
Figure 4-3: Above: Cost comparison to precast panel MSE walls. Below: cost comparison to cast-in-place walls. .............................................................. 55
Figure 4-4: Above: Maintenance cost comparison to precast panel MSE walls. Below: Maintenance cost comparison to cast-in-place walls. ..................................................... 59

Figure 4-5: Above: Modular block wall construction speed statement. Below: Modular block wall equipment use statement................................................................. 61
LIST OF TABLES

Table 1-1: Retained and reinforced earth structure types and description. ................................. 7
Table 2-1: Modular block retaining wall construction process (1). .................................................. 14
Table 2-2: Reinforced soil zone gradation requirements (17). ....................................................... 23
Table 3-1: Effects of experience on modular block wall performance. ........................................... 41
Table 3-2: Potential effect of geography on modular block wall performance. ............................... 45
Table 3-3: Comments on freeze-thaw durability after new block requirements. ............................ 46
Table 4-1: Retaining wall costs extracted from Koerner et. al., 1998 (17). ........................................ 52
Table 4-2: Adjusted Values from Koerner et. al. (1998) retaining wall data compared to survey results........................................................................................................................................ 57
Table 5-1: Table of pros and cons for modular block wall construction........................................ 64
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Chapter 1

Introduction

There are a variety of reinforced earth and retained earth structures available for use to departments of transportation. Historically, cast-in-place concrete walls were employed, as they typically lived up to their 75-100 year design life; however, oftentimes they left much to be desired when it came to price. Mechanically stabilized earth walls were later invented and rely on the mechanics of a stabilized soil mass rather than a large structure to retain soil loads. One mechanically stabilized earth option, which has gained steam in the last thirty years particularly in the private sector, is the modular block wall (also known as the segmental retaining wall). This wall type utilizes smaller concrete masonry units with geosynthetic reinforcement within a well compacted backfill. Despite a period of relative growth, a stigma still exists in the public sector concerning the cost effectiveness and performance of modular block retaining walls. In fact, many states still refuse to use this wall type for fear that they underperform. A historical database exclusively focusing on modular block walls in regards to performance and cost does not currently exist to quell the states’ concerns. Much of the stigma continues to focus on the freeze-thaw durability of the block units themselves. Research funded by the Federal Highway Administration (FHWA) has been completed on freeze-thaw durability, and new specifications to manage freeze-thaw issues have been employed by a small number of states. Again, the effectiveness of these new freeze-thaw specifications has not yet been explored.

This study explores cost and performance data from previous papers and reports while incorporating the results of a new survey. The new survey, conducted via the telephone and answered by senior engineers at state DOTs, clearly gives insight into the cost effectiveness, performance, and maintenance requirements of MBWs in the public sector. States not currently
using modular block walls revealed their continuing performance concerns that discourage their states from utilizing MBWs. Additionally, the success of new freeze-thaw specifications is explored. Incorporating all survey comments and previous research, a summary of all possible MBW advantages and disadvantages are presented along with recommendations for successful MBW implementation.

**Background and Current Use of Modular Block Walls**

Retaining walls are a vital component of highway design and construction. These earth retaining structures can be used for a variety of purposes, from retaining wall to use as headwalls, wingwalls, and bridge abutments. Historically, retaining wall structures were almost always rigid structures made of reinforced concrete. While this construction was easy and performed well over time, it proved to be less desirable when it came to cost effectiveness. Concerning performance, reinforced cast-in-place walls had difficulty dealing with differential settlement when placed in shallow foundations or when interacting with inadequate subsoil conditions (1).

The industry needed a more cost effective solution, and in the early 1960s, a French architect and engineer named Henri Vidal pioneered a new system of soil reinforcement. Henri Vidal, referencing the knowledge that soil inclusions have been used for stabilization since prehistoric times, developed a company named Reinforced Earth® which used steel strip reinforcements to aid in soil retention. Vidal’s company is still thriving today in the United States with a variety of soil stabilization and earth retaining structures. The first wall to use this technology was built in 1972 on California State Highway 39. Generally, this system utilizes large precast concrete panels (typically 20-25ft³) in conjunction with metallic reinforcement within a well compacted backfill. By placing tensile reinforcing materials in the soil, the internal shear resistance of the soil can be significantly improved, leaving the facing unit system in
essence self-supporting. Since its inception, many other similar systems have been developed and used. Overall, mechanically stabilized earth (MSE) walls have been a heavily used alternative to classic cast-in-place retaining walls. Covering more than 750 million ft$^2$ of wall facing, over 23,000 reinforced earth structures have been constructed worldwide. In the United States, over 8,000 walls have been built since 1972 (1).

Currently, mechanically stabilized earth walls are documented to have been used in every state in America. It is estimated that more than 9,000,000 ft$^2$ of retaining walls with precast panel facings are constructed each year in the United States. The majority of in-place and planned MSE walls use large precast panel facings with metallic reinforcement (2). In fact, the longest mechanically stabilized earth wall in the United States and second largest in the world was just completed in Lewistown Pennsylvania on Route 22/322.

![Figure 1-1: Precast concrete paneled, mechanically stabilized earth wall on Route 22/322.](image)

This project, seen in Figure 1-1, cost around $142 million, has a 2.5 mile long wall with a maximum height of 30ft, and utilized 41,000 metallic strips for reinforcement. Mechanically stabilized earth walls are frequently used at heights ranging greater than 40ft and can be feasible but are not often seen at heights of up to 100ft. Very few of these walls, designed for a lifespan of 75-100 years, fail completely. Yet, there is certainly a case history of these walls underperforming for their intent, which will be explored in later sections (3).
After the development of the first mechanically stabilized earth wall, the concept of using geosynthetics in MSE walls instead of metallic reinforcement soon emerged. Geosynthetic is a general term that covers all flexible reinforcement options including geotextiles, geogrids and any other polymeric material generally consisting of polypropylene, polyethylene, or polyester (4). The first geosynthetic reinforced wall was built in France in 1971, and three years later one was built in the United States. The use of geosynthetic reinforcement in large precast panel MSE walls has become more popular; however, the great majority of walls still use metallic reinforcement.

Within the last 20 to 30 years, dry cast modular block walls using geogrid reinforcement have gained acceptance in the private sector for their potential cost, construction, and performance advantages. Acceptance in the public sector has been slow, but it has been reported that around 3,000,000 ft$^2$ of modular block walls have been built yearly in the United States. This value is approximately one-third the area of large precast panel walls constructed in the United States each year. According to the Federal Highway Administration (FHWA), as of 2010 approximately 100 projects per year used modular block walls in transportation applications (2). This is a distinct growth from 2001, where it was reported that 2,000,000 ft$^2$ of modular block walls were constructed yearly with about 50 projects per year (1). A picture of a typical modular block wall can be seen below in Figure 1-2. Even though modular block walls are used substantially in the United States, there is concern by DOTs that these walls also under-perform.
While modular block wall construction has been approved for use by the Federal Highway Administration, there is no comprehensive list of states utilizing modular block walls. By researching and compiling several existing sources, a list of states utilizing MBW was created, as seen in Figure 1-3 below. As the color-coded map conveys, there are inconclusive results for the majority of state DOTs based on currently published research. The surveys completed by state DOTs for this study yielded a more accurate and comprehensive overview of MBW usage.

Figure 1-2: Typical dry cast modular block retaining wall.

Figure 1-3: Map of known Departments of Transportation using modular block walls.
In the private sector, modular block walls are used regularly for a variety of purposes. Modular block walls are most often used for landscaping purposes, and around parking lots, parks, and residential areas. Also, a modular block wall’s low cost and aesthetic appeal often make it the wall of choice around commercial centers.

Retained & Reinforced Earth Options for State Agencies

This study focuses on modular block retaining walls with geosynthetic reinforcement as compared to cast-in-place walls and precast panel walls, though many other reinforced and retained-earth options exist. In the past, traditional retaining structures such as gravity walls, cantilever walls, pile walls and anchored (tieback) walls have been used across the United States. Over time, many alternatives such as soil nailing, gabion walls, T-Walls®, double walls, and a variety of mechanically stabilized earth walls have been used by United States agencies. Table 1-1 summarizes different retained and reinforced earth structures that are typically used by state DOTs. DOTs are not limited to these wall choices; these are only the wall types most often used. It is important to understand that each wall type has distinct advantages and disadvantages. Overall, economics and site conditions are the two factors that most influence which wall type is chosen.
Table 1-1: Retained and reinforced earth structure types and description.

<table>
<thead>
<tr>
<th>Structure Type</th>
<th>Structure Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Retained Earth Structures</strong></td>
<td></td>
</tr>
<tr>
<td>Gravity Wall</td>
<td>Typically concrete, earth retaining structure that uses its own self weight to resist soil pressures.</td>
</tr>
<tr>
<td>Cantilevered Wall</td>
<td>Typically concrete, inverted T-shaped earth retaining structure that uses its own weight and configuration to resist soil pressures.</td>
</tr>
<tr>
<td>Pile Wall</td>
<td>Steel, vinyl, or wood driven into the ground to resist soil pressures. Often need tiebacks.</td>
</tr>
<tr>
<td>Anchored Wall</td>
<td>Typically used with other systems to tie back/anchor a wall.</td>
</tr>
<tr>
<td>Soil Nailing</td>
<td>A top down soil retaining system used on slopes, embankments, excavations, or retaining walls in which reinforcing bars are drilled, tensioned, and grouted to create a composite soil mass.</td>
</tr>
<tr>
<td>Gabion Wall</td>
<td>Retained earth structure made of rectangular shaped wire mesh containers filled with stone or riprap stacked upon each other. These generally act as a gravity wall.</td>
</tr>
<tr>
<td>T-Wall®</td>
<td>Reinforced concrete module system that acts as a gravity wall. The system stability is a function of the weight of units and their long concrete stems within a select backfill material.</td>
</tr>
<tr>
<td>Redi-Rock Wall®</td>
<td>Dry placed massive precast concrete blocks stacked to create a gravity wall structure. Most often do not need any type of geosynthetic reinforcement.</td>
</tr>
<tr>
<td><strong>Reinforced Earth Structures</strong></td>
<td></td>
</tr>
<tr>
<td>Segmental Precast Concrete Panel Wall</td>
<td>System utilizes large precast concrete panels (typically 20-25ft³) in conjunction with metallic or geosynthetic reinforcement within a well compacted backfill.</td>
</tr>
<tr>
<td>Modular Block Retaining Wall</td>
<td>System utilizes small dry cast blocks in conjunction with geosynthetic reinforcement within a well compacted backfill.</td>
</tr>
</tbody>
</table>

Explanation of Survey

A review of published papers and reports indicated that a current compilation of states using modular block walls does not exist. Two surveys were created to gather information on states using modular block walls and states not using modular block walls. A list of senior
geotechnical engineers at forty-one departments of transportation were gathered from the Federal Highway Administration. Most surveys were conducted via telephone, while a few were received through email. A script was followed to ensure consistency in the data collection. The script, along with a copy of an unanswered survey of both types, can be seen in Appendix A.

There were two main goals of the survey. For states not using modular block walls, the goal was to determine why the walls are not being used. For states using modular block walls, the goal was to determine the modular block walls effectiveness in cost and performance when compared to its major competitors at the same wall heights. From statistics discussed earlier, the most common wall types used in lieu of modular block walls are cast-in-place walls or precast panel MSE walls. Therefore, most of the statements used in the survey compare the use of modular block walls to cast-in-place and precast panel MSE walls. Important comments are summarized in the following chapters, with all complete comments seen in Appendix B.

When a state indicated that they currently use modular block walls, a survey with a variety of statements regarding cost and performance was conducted. In addition to comparisons of cost and performance, general questions were asked regarding the estimation of how many modular block walls have been constructed, the design specifications were used, and the typical restrictions for use of modular block walls.

When a state indicated that they currently do not use modular block walls, a separate survey was administered. The survey’s goal was to explore whether the state’s reason for not using modular block walls was cost related, performance related, or other. Additionally, each state’s current satisfaction with cast-in-place walls and precast panel MSE walls were explored.

Both surveys were comprised of a series of affirmative statements in regards to modular block retaining walls. Each statement, unless otherwise noted, could be answered on a one to ten scale. On this scale, an answer of one indicated an opinion of “strongly disagree” while an answer of ten indicated an opinion of “strongly agree”. After each answer, the survey taker had
the opportunity to add any additional comments pertaining to his/her answer. In addition to the scaled statements, there were a variety of open ended questions that were not scaled. All statements and questions can be seen in their full form in Appendix A and Appendix B.

Survey Participation

Of the forty-one states contacted by phone or email, thirty-two completed the survey. Figure 1-4 below summarizes the states that participated.

Figure 1-4: Departments of Transportation that participated in survey.
States Using Modular Block Walls

As previously discussed, information regarding what states use modular block retaining walls is currently not available. This information is very important when trying to assess why modular block walls are not being utilized and when determining if geography plays a role in this decision. Of the thirty two states that completed the survey, twenty four indicated that they use modular block retaining walls, while eight indicated that they do not. This information is summarized in Figure 1-5 below. Florida is differentiated, as they are currently in the process of constructing their first modular block demonstration wall.

![Map showing states using modular block walls](image)

**Figure 1-5**: State responses for modular block wall use.

Participating state DOT representatives were given the opportunity to keep their names or their states’ names anonymous in the survey results. Only a few state DOT representatives asked to remain anonymous, and these representatives were from states that do not use modular block
retaining walls. Therefore, to maintain anonymity, the comments of all states not using modular block walls will remain unidentified.
Chapter 2

Design, Construction, and Composition of Modular Block Walls

Modular block walls are easier to design and construct when compared to other walls that are used in similar circumstances. Modular block walls are constructed with small blocks in conjunction with geosynthetic reinforcement within a well-compacted backfill. Therefore, it is essential to explore the materials as well as the design manuals used by state agencies in the construction of these walls.

Modular Block Wall Design

Design manuals for all mechanically stabilized earth walls, including modular block retaining walls, come from a variety of sources. Historically, the most comprehensive and used design manual for mechanically stabilized earth walls has been the Standard Specifications for Highway Bridges (5) developed by the American Association of State Highway and Transportation Officials (AASHTO). The 17th edition, developed in 2002, has been used and updated regularly throughout the last decade. The Federal Highway Administration (FHWA) and the National Highway Institute (NHI) also developed a design aid. Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines (1) is a reference text for the FHWA and NHI courses on the design of mechanically stabilized earth walls and continues to reflect the current design, construction, and maintenance practices needed for mechanically stabilized earth walls.

In 2000, the FHWA and AASHTO set a transition date of October 1, 2007 to convert the design of transportation superstructures from Allowable Stress Design (ASD) to Load and Resistance Factor Design (LRFD). The substructures supporting the superstructures should be
designed using the same guidelines, so the FHWA and ASSHTO set an October 1, 2010 deadline for implementation of LRFD in all substructures, including retaining walls. Since this change to LRFD is currently in motion, most designs of mechanically stabilized earth walls in the future will be based on ASSHTO LRFD Bridge Design Specifications, 5th Edition, 2010 (6) along with ASSHTO LRFD Bridge Construction Specifications, 3rd Edition, 2010 (7). Noticing this need for change, the Federal Highway Administration developed an updated version of Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slope (2) in November of 2009 using LRFD. There are still other publications available from different sources, including the National Concrete Institute’s Design Manual for Segmental Retaining Walls, 3rd Edition (8) which is often utilized in private construction.

The introduction of LRFD brings an interesting dilemma into the situation when reviewing historical information on the cost and performance of modular block walls. A common concern is that the introduction of the LRFD system may increase both the expense and size of mechanically stabilized earth walls based on new and increased factors of safety. This may in turn allow all mechanically stabilized earth walls to perform better, but also to potentially cost more.

The design of mechanically stabilized earth walls, including modular block walls, center around external, internal, and compound or facing stability. The external stability of the wall addresses the entire reinforcement mass including sliding, overturning, bearing capacities, eccentricities and overall stability modes. The extent of the soil mass from the facing to the reinforced soil must be large enough to prevent horizontal sliding along the base and to avoid overturning of the soil block. The foundation must have sufficient bearing capacities to prevent failure from loading conditions or eccentricities, and it must also prevent excessive settlement (9).

Internal stability addresses geogrid spacing, rupture, anchorage length, interaction with reinforcing fill, and connection strength. The length of geosynthetic reinforcement must be
adequate in stopping slippage between the reinforcement and the soil in the anchorage zone
behind the assumed failure plane. The strength and layout of the reinforcement must also ensure
that the applied forces do not cause rupture or disproportionate strain on the geosynthetics. Also,
the friction between the geosynthetic and the soil must be sufficient to prevent sliding along the
soil interface (9).

Compound or facing mode failure is also possible. The system must be designed to
ensure the connection between the reinforcement and the modular blocks is secure. Also, the
blocks must have adequate shear capacity to ensure that the facings do not slide away from each
other. Extra attention to these details must be used in places with possible seismic loading (9).

**Modular Block Wall General Construction Sequence**

The construction sequence in which modular block walls are built is relatively simple.
Considering that each block is generally lightweight, the construction process occurs very quickly
as each block is hand-placed by laborers. Figure 2-1 shows a typical modular block wall cut
section. Below the figure, Table 2-1 shows a step-by-step explanation of the construction process
of a modular block retaining wall.

Table 2-1: Modular block retaining wall construction process (1).

<table>
<thead>
<tr>
<th>Step #</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Excavate the work area and appropriately prepare the subgrade.</td>
</tr>
<tr>
<td>2</td>
<td>Place the leveling pad for the erection of the first row of modular blocks. Generally only a gravel pad is needed for a modular block wall.</td>
</tr>
<tr>
<td>3</td>
<td>Erect the first row of blocks and ensure that the horizontal alignment is correct.</td>
</tr>
<tr>
<td>4</td>
<td>Place and compact the drainage backfill on the subgrade to the level of the first block. Compaction should occur every 4-8 inches or as instructed and the density should be between 95-100 percent.</td>
</tr>
</tbody>
</table>
5 Place the first layer of reinforcement material on the backfill so that they are perpendicular to the back of the facing unit.

6 Place the next layer of blocks on top of the previous block. This may also be on top of the geosynthetic reinforcement assuming a friction connection is used.

7 Repeat steps four through six until the desired height is reached.

8 Place caps on the last modular block and install traffic barriers if necessary. Construct a drainage swale or other necessary details as per the design.

Figure 2-1: Typical modular block wall cross section (10).
Modular Block Units

In the retaining wall system, the facing generally plays a minor role in the stability of the structure. The facing is used in order to keep the soil from raveling out between rows of geosynthetic reinforcement (1). Segmental retaining wall blocks are machine manufactured across America at local concrete block plants. Its constituents include water, cement (typically hydraulic, blended hydraulic, or portland), appropriate aggregates, and any other concrete additives (pozzolans, coloring agents, air entraining agents, etc) (11). Modular blocks are typically characterized by their low cement paste content and low water cement ratios that allow for a somewhat stiff consistency for compaction into molds during manufacturing. In fact, modular blocks are generally referred to as dry-mixed concrete, as the water content is considerably lower than classic concrete. Due to these attributes, the resulting blocks consistently have an arrangement of interconnected voids that are typically larger than common concrete (12). These voids are generally called “compaction voids” and can be seen below in Figure 2-2 compared to typical concrete. The material performance of modular blocks is tested in accordance with ASTM C 1372 in which dimensional characteristics, compressive strength, absorption, density, and freeze-thaw durability are tested (12).

Figure 2-2: Left: Typical concrete (12). Right: Typical modular block unit with visible voids (12).
Modular block facing units are generally small, short blocks designed to be hand-carried and placed in the field. Blocks typically range from 4 to 8 inches in height, 8 to 18 inches in exposed facing, and 8 to 24 inches in depth. The mass of the units usually range from 30 to 110 pounds, with the heavier units typically used for highway construction. Units can be solid or designed with a hollow core that is filled with aggregate during assembly. Blocks are normally dry stacked in a running bond. Dry stacking blocks is very similar to any other masonry wall construction, but no mortar is used. Connections to adjacent units are established with shear pins, lips, or keys (1). Oftentimes, connection detail also determines the back batter or the degree to which the wall vertically slopes backwards.

Modular block facing units are trademarked by many companies, including Keystone®, Versa-Lok®, and Allenblock® amongst others. Figure 2-3 below shows many different types of trademarked blocks. Again, notice the variety in shape, size, and core characteristics.
Geosynthetic Reinforcement

As mentioned before, “geosynthetic” is a general term that covers all flexible reinforcement options including geotextiles, geogrids and any other polymetric material generally consisting of polypropylene, polyethylene, or polyester (4). Geosynthetic material can possess
high tensile strengths and can nicely compliment any material that is good in compression but weak in tension. Geosynthetics are inherently useful in soils with low strength, fine grained particles and are also used with select backfill in many types of retaining structures. With modular block retaining walls, walls with four feet or less of exposure do not require reinforcement. Otherwise, reinforcement is required.

There are essentially two options available for soil reinforcement with MSE walls. Those two options are metallic reinforcement and non-metallic (geosynthetic) reinforcement. Metallic reinforcement is typically galvanized, mild steel and may be epoxy-coated. Meanwhile, non-metallic reinforcement is generally polypropylene, polyethylene, or polyester (4). Most modular block walls use geosynthetics, with polypropylene being the most widely used polymeric material (approximately 85% of the industry production) followed by polyester (approximately 12%) (13). More specifically, walls consist of high density polypropylene geogrids. This geogrid is available in six different styles with differing strengths (1).

Geogrids are available in two directional geometric options which determine the way in which the stresses are transferred. The direction of transfer can either be unidirectional (strips of reinforcement) or bidirectional (grids of reinforcement) and are generally detailed in the construction specifications (4). Bidirectional grids are most often used in modular block wall construction. The essential attribute in geogrids is the size of the opening between the transverse and longitudinal ribs, called apertures. It is critical that these openings be large enough that soil can move from one side to the other without tearing the structure (13).

The strength of geosynthetic reinforcement is greatly dependent on a number of effects in both the short and long term. In the short term, a loss of strength can be found during installation if there is any damage or abrasion to the geosynthetic. Most abrasions, notching, punching, etc. of the geosynthetics during installation occur from severe loading or from a backfill with high
angularity. It is essential to prevent construction equipment from rolling over exposed
geosynthetics and to perform compaction in the correct lift heights to avoid excessive strain (1).

In the long term, there are a number of effects that can lessen the strength of the
reinforcement. This may include creep, aging, temperature, chemical reactions, ultraviolet light, and high pH environments. Creep, or the long-term deformation of the geogrid over time, is an inevitable process that will occur over the life span of the geogrid and can be accelerated with the presence of high temperatures (normally only occurring at the facing or connection). Generally, failure of the geosynthetic is not caused by creep alone, but creep should be accounted for when determining the strength requirements of the material. Polymers are also affected by a variety of chemical processes. Polyesters are affected by hydrolysis, which occurs in alkaline areas where water is present and can dissolve fibers. Polyolefin geosynthetics can lose strength from oxidation reactions which are a function of soil porosity. Oxidation reactions can be accelerated in soil backfills with high transition metals (Fe, Cu, Mn, Co, Cr) (2). Lastly, ultraviolet light can degrade geosynthetic materials. With modular block walls, the entirety of the geosynthetic material is underground and not susceptible to UV light. Therefore, special attention should be paid to the material as it is stored on site to keep it out of direct sunlight. Polyester geogrids have a history of degradation when used in conjunction with modular blocks. By laying the geogrid in-between blocks, it is possible that the geogrid is more susceptible to high pH levels. It has been recommended that the pH levels for polyester should stay between 3 and 9 for long term degradation to not be an issue. A field FHWA field study showed that the pH levels of twenty-five MSE walls only occasionally rose above a pH of 9. Also, they concluded that this effect only occurred for the first few years, and soon after the pH level adjusted to that of the backfill (1).

When it comes to quantities, geogrid reinforcements in modular block walls usually extend to a length of 0.7 x wall height and are typically placed at vertical spacing between every other block. These are values that are typically determined during the design stage.
Lastly, the connection detail with modular block wall construction is significant. Figure 1-7 below shows the different ways in which geosynthetic reinforcement is connected to modular blocks during the construction of modular block walls. There are two distinct connection types, friction connections and mechanical connections. Friction connections, seen in Figure 1-7 b, c, and d, occur when each reinforcement layer is extended over the concrete shear key or lip to the front of the wall. The reinforcement connection is generated by friction between the geosynthetic and interlocking adjacent blocks. A combination of mechanical connections and frictional connections are developed when layers of reinforcement, placed over fiberglass shear pins at the front of each unit, are coupled with the weight of the blocks (13). This can be seen in Figure 2-4.
Backfill Material

High quality backfill material in all mechanically stabilized earth walls is essential for constructability, durability, proper drainage, and proper interaction with the reinforcement materials. There are two distinct backfill areas for modular block walls and they can be seen again in figure 2-1. These areas are the reinforced backfill zone and the retained backfill zone.

The reinforced backfill is the fill directly behind the wall where the reinforcement is placed. This backfill is the most essential part in any mechanically stabilized earth wall. In general, high quality granular backfill is used because it is free draining, easy to work with, and may require less reinforcement. The FHWA recommends the use of reinforced fill in accordance
with the Unified Soil Classification System (USCS) in ASTM D2487. Each DOT can change or limit these values as they deem necessary. Even recently, a study demonstrated that a reinforced fill with 35% passing through number 200 sieve could be adequate as a reinforced backfill (1). However, the FHWA and researchers (including Koerner and Soong) warn against the use of lower quality reinforced backfill as an increased risk of failure has been observed with more fine and plastic materials. Proper drainage of the reinforced backfill is essential to the long term success of the structure because MSE walls are typically not designed for hydrostatic loads. Seepage from the surface above the reinforced backfill zone can form perched water areas, creating unsafe hydrostatic loads and lead to internal instability. Recommendations for the gradation of the reinforced soil zone vary depending on what design manual is utilized. The NCMA, typically used for private walls, has broad requirements leaving open the option of using marginal soil in the reinforced zone. The Federal Highway Administration standards are more stringent, limiting the percent passing #200 sieve to 0-15 percent. After evaluating many wall failures caused by inadequate backfill material, research by Dr. Robert M. Koerner and Te-Yang Soong in 2001 recommended even more strict requirements. These requirements ensure that clean sand is the finest material allowed in the reinforced soil zone. Table 2-2 and figure 2-5 below summarize these three gradation requirements for the reinforced soil zone (17).

Table 2-2: Reinforced soil zone gradation requirements (17).

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Particle Size (mm)</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Koerner</td>
</tr>
<tr>
<td>-</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>No. 4</td>
<td>4.8</td>
<td>100</td>
</tr>
<tr>
<td>No. 10</td>
<td>2.0</td>
<td>90-100</td>
</tr>
<tr>
<td>No. 40</td>
<td>0.42</td>
<td>0-60</td>
</tr>
<tr>
<td>No. 100</td>
<td>0.15</td>
<td>0-5</td>
</tr>
<tr>
<td>No. 200</td>
<td>0.075</td>
<td>0</td>
</tr>
</tbody>
</table>
Even with all of this research, the use of marginal backfill in the reinforced zone has incredible cost saving implications. According to the FHWA, the cost and placement of select granular fill in a MSE wall structure can account for 30-60% of the total wall cost. This is most likely the reason marginal backfill continues to be used. If marginal backfill is used, several systems can be implemented to combat drainage concerns. First, any water around the reinforced soil zone must be collected and transported away from the reinforced soil zone. This can be done on the surface by utilizing proper grading and installing swales for transporting surface water. In addition, a geomembrane or geosynthetic clay liner can be placed at the top of the reinforced soil zone to prevent water form even entering the zone (17). Lastly, in 2009, the NCMA recommended the installation of back and base drains when using fine grained soils. These are
known as chimney drains or blanket drains, and can be installed to combat water in the reinforced zone (18).

Retained backfill is the backfill behind the stabilized reinforced backfill area. Retained backfill is generally lower-graded material placed on site or in-situ backfill from excavation. This soil is important, as it creates loading on the retained backfill area and requires quality drainage characteristics. According to the FHWA, the retained zone should extend from the reinforced backfill to a distance of 50% of the wall height. Also, the FHWA makes recommendations on the percent fines, liquid limit, plastic limit, and differential settlement and reaction between the retained backfill layer and the reinforced backfill (2).

Compaction of fill should be followed carefully. Generally, fill is placed in lifts of 6 inches or less and compacted in a variety of ways. Within 3 feet of the wall, a vibratory roller or plate compactor weighing less than 1000 pounds should be used. Compaction is done in this manner close to the wall to ensure that no modular blocks are misaligned during compaction. Farther than 3 feet away from the wall, an 8 ton smooth wheeled or rubber tired roller is acceptable. A sheepsfoot roller should not be used. Typically 3 to 5 passes are adequate to achieve the appropriate density (4). Soil layers should be compacted at, or slightly above, the level of the upcoming reinforcement layer prior to reinforcement placement.
Chapter 3

Performance of Modular Block Walls

Modular block retaining walls have been used for approximately the last three decades. In the public sector, only recently have walls been utilized by a number of DOTs. Considering modular block walls are still a relatively new earth retaining structure, a distinct case history for modular block walls is not available. Its newness also makes it difficult to determine if these walls will achieve their desired 75-100 year design life. Additionally, most DOTs do not keep a database of their walls and how they have performed; therefore, it proves challenging to grasp how well modular block walls are aging and how much maintenance is required. The following section evaluates the available performance histories and any typical performance issues that accompany a modular block wall.

Potential Performance Advantages

The most often discussed topic with modular block walls is their performance. Due to a lack of a distinct historical database and issues with early blocks, modular block walls were sometimes dismissed by a variety of organizations. Yet, many of those problems have since been remedied. Modular block retaining walls have a number of performance advantages in comparison to precast panel MSE walls and standard cast-in-place walls. The following section will explore these performance advantages.
**Geosynthetic Reinforcement**

Mostly all mechanically stabilized earth walls using large precast paneling also use metallic galvanized steel reinforcement as their primary form of soil fortification. Geosynthetic reinforcement presents a distinct advantage over metallic reinforcement. While geosynthetic reinforcement can degrade when subjected to ultra-violet light and high pH, metallic reinforcement is highly susceptible to corrosion. PVC or epoxy coatings can be used to protect against corrosion in metallic reinforcement, but they are only somewhat effective and often can be damaged during construction. Modular block walls and other MSE walls are supposed to be free draining, meaning the water should be allowed to drain through the backfill to avoid surcharge loading. This puts reinforcement in direct contact with water, and oftentimes salts found in deicing chemicals, which are known to cause increased deterioration in metallic reinforcement. Additionally, lower quality backfill materials can be used more readily with geosynthetic reinforcement as any non-drained water will not have serious effects on the geosynthetic material.

Geosynthetic reinforcement also has an advantage over metallic reinforcement as it does not need to be mechanically connected to the facing unit. Instead, geosynthetic reinforcements can save time by using frictional connections from adjacent blocks to connect reinforcement to the modular block units. While this connection type is easier and more efficient, some DOT representatives question whether this connection type is adequate.

Lastly, geosynthetic reinforcement is easier to work with than metallic reinforcement in both precast panel MSE walls and cast-in-place walls. Geosynthetic reinforcement is packaged in large rolls that can be easily rolled into place. Yet, iron workers are needed to place and shape reinforcement in cast-in-place walls and attach reinforcement in MSE walls with large precast panels.
Alignment of Facing Units

There are many alignment issues that can occur with large precast paneling that are less likely to occur when handling small modular blocks. After large precast panels are placed, they must be shored and braced while backfill material is deposited and compacted. Yet the compacted fill lifts can be up to five feet, and when the area behind the panels is compacted, the large panel will be pushed forward. This push-out effect can cause major alignment issues and can waste time in the construction process. Vertical alignment issues are less of a concern with modular block walls. With lifts between 6-12 inches in height, not enough load is created to cause push-out. If movement is induced, the modular block’s shear key may resist against misalignment. Vertical alignment is not a problem with cast-in-place retaining walls; however, this security comes at an extra cost.

Aesthetics and Adaptability

One of the greatest advantages of modular block retaining walls is their aesthetic appeal and adaptability to almost any construction situation. Aesthetically they can have a variety of finishes and colors that make them unbeatable when compared to most of their competitors. Large precast panel walls can have finishes, but oftentimes these are expensive. Concrete cast-in-place walls are typically monochromatic and very susceptible to graffiti. Additionally, modular blocks can come in an assortment of shapes and sizes and can even be placed in multi-tiers to accommodate landscaping. Figure 3-1 below shows a typical multi-tiered modular block wall.

Modular block walls are extremely adaptable when compared to other wall types. First, as discussed above, modular block walls can adapt to situations in which multi-tiers are appropriate. Modular block walls can easily navigate any curvature radius, including ninety
degree angles which can typically be an issue with large panel MSE walls. Figure 3-1 below also shows a modular block wall navigating a ninety degree angle. Modular block walls can be formed around trees, ponds, poles, buildings, or any other type of obstruction. Additionally, some DOTs use them in mountainous regions or heavily wooded areas based on the fact that blocks can be hand placed instead of using heavy machinery. Overall, modular block walls are usually more appealing to the eye and can be used in more situations than their competitors.

Figure 3-1: Left: Multi-tiered modular block retaining wall (9). Right: Modular block wall at a ninety degree angle (15).

Potential Performance Disadvantages

There are a number of potential disadvantages unique to modular block retaining walls. Again, a history of the direct causes of wall failures is limited. There are some recognized issues that can affect either the mechanical or aesthetic performance of the wall.
Aesthetic Issues

Efflorescence is an aesthetic issue that is found in modular blocks, and is also typical in other concrete materials. Efflorescence occurs when calcium hydroxide (lime) is formed during hydration with portland cement concrete (13). This byproduct is transported to the surface through capillaries in the concrete structure causing a white, cloudy look on the surface. This undesirable result can last for an extended period of time.

Vegetative growth presents another aesthetic issue that can be found in modular block retaining walls. This growth can be prevented if the walls are maintained after construction.

Poor construction practices can lead to a variety of aesthetic issues. Block placement and spacing are the most common predicaments. When executed incorrectly, the layperson may judge the work as carelessly constructed. In addition to appearing haphazard, improper placement and spacing present performance concerns.

Both an aesthetic and mechanical problem, the breakdown of modular block units from freeze-thaw cycles presents an ongoing and critical challenge. Repeated freeze-thaw cycles can cause deterioration of block units, leading to scaling issues and a compromised appearance.

Many of these aesthetic issues result in increased maintenance requirements, the cost and difficulty of which have not yet been documented. The survey results will explore these aspects of wall preservation.

Mechanical Issues

Despite the advantages discussed above, some states refuse to use modular block retaining walls based on a presumption of poor performance. While many of the performance
issues are related to poor backfill material or inadequate construction practices, DOTs still exhibit apprehension over block durability.

The major fear with modular block durability stems from the apparent effects of freeze-thaw cycles. In early use by state DOTs, specifically Minnesota and Wisconsin, blocks in cold climates with frost exposure were deteriorating, generating concern over the long term durability of modular block walls as a whole. Noticing the issue, the FHWA funded a research project headed by the University of Texas, Texas A&M, and Cornell University to determine the cause and extent of this problem and to provide information to better ensure long term durability of modular block walls. It is important to note that during their field study, it was stated that the “overwhelming majority” of segmental retaining walls visited were performing very well, no matter what the climate (12). However, some walls were performing very poorly in cold climates.

Freeze-thaw durability is always a concern area for concrete materials. The apprehension over frost damage to concrete can be linked back to the late 1940s. The above research by the FHWA, Texas, Texas A&M and Cornell has shown that there is a distinct relationship between paste content and freeze-thaw durability. Modular blocks were initially constructed with low paste contents, as it was both less expensive and less complicated. This low paste content yields a large amount of irregularly shaped voids, called “compaction voids”, which can account for up to 25% of the block by volume. Until recently, it was unclear what role paste content and compaction voids played in freeze-thaw durability. In fact, the FHWA funded research concluded that mixes with the best freeze-thaw durability were those in which the paste content was between 16 to 18 percent. Now, it has generally been agreed upon that higher compressive strengths, lower water-cement ratios, and lower absorption can decrease the effects of freeze-thaw cycling. Additionally, the research determined that increased exposure to deicing salts or fertilizing chemicals exacerbated the block durability issue. All of the damage, “without question,” was in
locations where blocks were exposed to the combination of freeze-thaw cycling coupled with deicing salts or fertilizers (12). Lastly this research discussed the difficulty in evaluating blocks, as production was often “plagued by large variations in the properties of the blocks” (12). It was found that in terms of percent loss during freeze-thaw testing, between unit variations were most limited in mixes of excellent quality or very poor quality. Therefore, DOTs which limit their block use to excellent mix designs would minimize possible freeze-thaw durability issues (12).

The conclusions of this research were vast and have since changed the specifications that DOTs supply to contractors and block manufacturers. First, it was concluded that the presence of salts in solution unequivocally increased the block damage when testing freeze-thaw durability. In fact, it took eight times more cycles to cause the same amount of damage in a water-only solution as it did in a salt solution. Secondly, the mixes with the best freeze-thaw durability were those in which the paste content was between 16 to 18 percent. Earlier research by Chan et al. agreed with the important role paste content played in freeze-thaw durability. Chan et al. stated that the following factors are considered indicators of freeze-thaw durability: paste content, total air and compaction void content, and paste to total air and compaction void ratio. Additionally, it was found that for tests in saline, the compressive strength, percent non-connected voids, and water content all had an effect on freeze-thaw durability (12).

To ensure long term freeze-thaw durability, DOTs must be vigilant in demanding that their contractors use high quality mixes in their modular block walls. Survey results discussed later will show that states not using modular block walls still have block durability concerns. The FHWA funded research shows that increased strength requirements and a certain paste content range will improve durability. Increased strength requirements and decreased percent loss during freeze-thaw testing will ensure high quality mixes, improving durability and variability between units. This, in turn, should lead to modular block units achieving their desired design life.
Other Issues

There are a few other issues that can limit the use of modular block wall construction in the public sector. First, certain block configurations and their connection details limit the batter in which the wall can be erected. This limitation can affect costs based on the amount of backfill required. Also, as previously discussed, distinct variability does exist between blocks from different manufacturers and between blocks from the same product line and manufacturer. Therefore, it is very important to understand the product being used and its intrinsic characteristics. There are several states that limit the number of products used on their projects to five or six manufacturers. This can improve quality control and limit variability from project to project.

One potential problem that exists with all earth retaining structures is the possibility of differential settlement. Differential settlement is often traced back to the engineers’ insufficient sub-surface investigation of the foundation footprint, where softer soil conditions can lead to damage (2). Contributing to the acceptance of MSE walls, the alternative option of rigid structures can only accommodate minimal differential settlement unless built in deep foundations. The flexibility of facing units gives MSE walls an advantage in this respect. However, local settlement continues to be a concern with MSE walls. Local settlement can cause excessive stress on the facing units, resulting in significant damage.

Lastly, a lack of knowledge and a resistance to change have discouraged DOTs from modular block wall construction. Modular block walls with geosynthetic reinforcement are still a relatively new construction method. From students to top professionals, using cast-in-place structures has been engrained in the minds of engineers as the only structurally sufficient option available. It has taken years to create a paradigm shift to accept mechanically stabilized earth structures, and in some places these are still not liked or trusted. The same type of shift is
happening in respect to modular block walls. In the survey, a few states specifically cited this as a reason why more walls of this type had not been built in the past.

Performance History

Minnesota Department of Transportation, 2001 Wall Review

In 2001, the Minnesota DOT, in conjunction with the University of Minnesota, conducted research in the performance history of their modular block walls in the Minneapolis/St. Paul area. A review of 104 walls built prior to 1994 was conducted in two stages. Stage one was a distress survey which focused on the type and severity of the distress; stage two focused on distress during the peak winter period. A distress manual was created to assess 19 visual wall issues, and an overall rating of 0-5 was given to each wall with a rating of 0 indicating the worst distressed walls (16).

Of the 104 walls surveyed, approximately 7% of the walls were in poor or very poor condition. 50% of the walls observed had developed some sort of distress from the following sources: freeze-thaw damage, fraying/spalling, scaling, position guide damage, vegetation growth, manufacturer flaws, efflorescence, or soil wash-through (16).

Along with these results, this research also determined that efflorescence and freeze-thaw damage were partially dependent on the age of the block and the manufacturer. This shows that much of the lack of durability of the block was dependent on poor mix designs (16). Additionally, it was determined that walls near parking lots and roadways where snow accumulates or runoff increases showed an increase in damage. These places also have an increased exposure to deicing salts, which has been linked to increased freeze-thaw damage.
Also, blocks exposed to phosphates in fertilizer runoff showed an increase in block damage similar to the effects of deicing salts (16).

After this research, Minnesota DOT was the first state to place more stringent requirements on their blocks and modular block walls as a whole. Many of these changes were to specifically combat freeze-thaw degradation. Those limitations are as follows:

- No walls should be used in critical locations, e.g. supporting roadways or bridge abutments.
- For roadways with traffic volume between 5,000-20,000 annual average daily traffic (AADT), the wall must be greater than 20 ft (6 m) beyond the outside shoulder. For roadways with traffic volumes greater than 20,000 AADT, the wall must be placed greater than 30 ft. (9.1 m) beyond the outside shoulder.
- For walls less than 4 ft tall, no offsets are required.
- The maximum allowable exposed wall height is 10 ft (3 m).
- All blocks must conform to ASTM C 1372, but with higher restrictions for certain block characteristics.
  - The minimum compressive strength for an individual unit must be 5,500 psi, and for an average of three units it must be 5,800 psi.
- All blocks must be tested for percent loss by following ASTM C 1262, with some alterations to the test.
  - When using 3% saline solution, at the end of 90 freeze thaw cycles, the percent weight loss must be less than 1% for all five blocks tested; or, four out of five blocks must be less than 1.5% weight loss after 100 cycles.
These changes to combat problems with block durability were implemented in March of 2001. It is still unclear as to the success of these implications in terms of performance or the potential cost associated with them. This will be explored later through the survey results.

**Wisconsin Department of Transportation, 2000 Wall Review**

In the summer of 2000, the Wisconsin DOT conducted a similar survey with special attention to freeze-thaw durability. Wisconsin DOT used the same distress manual that Minnesota developed, surveying 87 walls throughout the state. All walls were between 1 and 15 years old, with the majority being between 5 and 10 years old. Of the 87 walls surveyed, 18 walls (20.7%) showed freeze-thaw distress. Only 4 walls (4.6%) showed high severity of distress, with another 6 walls (11.5%) showing medium severity of distress. Overall, a lower percentage of walls in Wisconsin showed damage than those in Minnesota (12).

Wisconsin DOT also made a variety of changes to their requirements. These alterations specified that:

- Wall blocks are limited to only 6 qualified manufacturers.
- The minimum compressive strength for an individual unit must be 5,000 psi.
- Blocks must have a maximum of 6% absorption when testing with ASTM C 140.
- All blocks must be tested for percent loss by ASTM C 1262, but with some modifications:
  - When using 3% saline solution, at the end of 40 freeze thaw cycles, the percent weight loss must be less than 1% for all five blocks tested, or four out of five blocks must have less than 1.5% weight loss after 50 cycles.
• All tests must be conducted by an approved Wisconsin DOT independent testing lab (12).

Again, Wisconsin’s success with these implementations is undocumented but will be explored later in the survey results.

Geosynthetic Reinforced Segmental Retaining Walls, Koerner and Soong, 2001

In 2001, Koerner and Soong investigated twenty-six case histories of MSE walls from available literature and their own files in an attempt to understand more about MSE walls and their failures. All of these walls had either excessive deformation or had collapsed while in service. Of the twenty-six total walls investigated, nineteen were segmental retaining walls. Of the nineteen segmental walls, nine had excessive deformation and ten actually collapsed. Seven out of ten collapses were design flaws with hydrostatic pressures causing the collapse. These hydrostatic pressures were caused by using inadequate fine-grained backfill soils. Of the nine walls showing excessive deformation, six were caused by poor contractor practices (e.g. poor alignment, poor block placement, improper spacing, etc.) and three were caused by poor design (e.g. poor backfill material). It was concluded that hydrostatic pressure occurring from poor backfill material was the biggest factor in all of the collapses. Also, it was concluded that contractors’ work should be monitored and inspected during the construction process to ensure sufficient quality control. For all twenty-six cases evaluated, only one case’s degradation was caused by something other than poor drainage or poor construction practices (17).

The National Concrete Masonry Association estimates that there are around 25,000 MSE segmental retaining walls in the United States, with approximately half being geosynthetically
reinforced (17). Koerner and Soong emphasize that while these nineteen walls had a history of complications, the vast majority of walls have been successful in terms of performance.

A Database and Analysis of Geosynthetic Reinforced Wall Failures

After publishing the paper with Soong in 2001, Dr. Robert M. Koerner collaborated with George R. Koerner to develop a database of 82 MSE wall failures. These 82 walls included the 26 walls from Koerner and Soong, 2001. Again, the walls in this database had a variety of facing types, including segmental retaining walls, welded wire mesh walls, wrap-around walls, segmental concrete walls, and timber walls. Of these 82 walls, 23 cases had excessive wall deformations and 59 had collapses such that major repairs were necessary. Sixty two (76%) of the walls presented in the database were modular block walls. This by no means reflects that modular block walls are more or less adequate structures, but only that there are many walls of this type being evaluated (18).

Overall, the conclusions of this database indicated that the failure of these walls was mostly due to the following:

- Use of inadequate fine-grained soils in the reinforced soil zone.
- Poor compaction of fine-grained soils.
- Poor inspection or construction practices.
- Inadequate external drainage above the reinforced soil zone.
- Inadequate internal drainage through the reinforced soil zone.
- Design flaws incorrect factors of safety.

Again, all of these issues could have been avoided with proper care paid to the design and construction of these walls. The conclusions by Koerner and Koerner were similar to the
conclusions made by Koerner and Soong in 2001. As stated earlier, fine-grain soil use and poor drainage were identified as the main causes of potential deformation or failure (18).

Performance Related Survey Results

Survey statements in regards to MBW performance were presented to the top DOT geotechnical engineers across twenty-six states. All statements were rated by the engineers on a one to ten scale with an answer of one indicating an opinion of “strongly disagree,” and ten indicating an opinion of “strongly agree.” States had an opportunity to respond with an answer of “don’t know” in case the survey taker was uncertain. Below are the results of that survey, along with pertinent comments. All full survey results and comments can be found in Appendix B and Appendix C.

Performance Comparison of Modular Block Walls Versus Large Precast Panel MSE Walls and Cast-in-place Walls

As previously discussed, most of the survey statements compared modular block retaining walls to large precast panel MSE walls and cast-in-place walls. The reason behind this comparison is that these two wall types are the most commonly used and are often utilized in similar situations.

According to the results, states using MBWs slightly agree that MBWs have performed as well as their precast panel MSE walls (average response of 6.21). Also, states slightly agreed that MBWs have performed as well as their concrete cast-in-place walls (average response of 6.55). The results of the survey, with the frequency of each response, can be seen below in Figure 3-2. Again, as there is no available database for MBWs and how they perform, this data provides insight as to how MBWs are responding in the public sector.
Performance Statement 1
Modular block walls have performed as well as your large precast panel MSE walls

* Four states indicated an answer of "Don't know"
Average Value of 6.22

Performance Statement 2
Modular block walls have performed as well as your traditional concrete cast in place walls

* Three states indicated an answer of "Don't know"
Average Value of 6.55

Figure 3-2: Above: Performance comparison to precast panel MSE walls. Below: Performance comparison to cast-in-place walls.
When it comes to MBWs, many state engineers commented about the typical problems that they encounter. Several states remarked about quality control issues, compaction issues, and differential settlement. Freeze-thaw was also mentioned and will be explored later in this paper. Difficulties with quality control, compaction, and differential settlement can most easily be combated by using knowledgeable and experienced contractors. Additionally, providing more stringent inspection criteria during construction would limit these mistakes. This is a similar conclusion to that found in Koerner and Soong, 2001.

When looking at the effects of experience, states that have constructed approximately fifty or more walls had a higher opinion on the performance of MBWs. The effects of experience have been summarized in table 3-1 below. States that have constructed more MBWs would have a larger amount of experience with proper assemblage and maintenance, providing a more positive experience. Conversely, states that have built fewer MBWs may report a lower average of satisfaction because the experience is new and unfamiliar to them, or they have not had the time to assess their performance. A learning curve may exist with repeated construction, leading to improved wall performance.

Table 3-1: Effects of experience on modular block wall performance.

<table>
<thead>
<tr>
<th>States With Less Than 50 MBWs</th>
<th>Avg. Response For Performance Statement #1</th>
<th>Avg. Response For Performance Statement #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>States With 50 or More MBWs</td>
<td>6.38</td>
<td>6.82</td>
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</table>
The amount of maintenance required, and the costs that this incurs, are important factors for engineers. Obviously, it is every engineer’s hope that walls will achieve their desired design life while needing only limited maintenance. With this in mind, it was necessary to ask state representatives how much maintenance their MBWs have needed and whether the maintenance has been difficult in nature. As discussed previously, MBW maintenance problems could include vegetation growth, block damage, and other issues that occur during a wall’s life span.

The survey results showed that states slightly disagreed with the following two statements: MBWs need less maintenance than precast panel MSE walls (average response of 4.47), and MBWs need less maintenance than standard cast-in-place walls (average response of 4.12). The results of the survey regarding maintenance can be seen below in figure 3-3.

**Performance Statement 3**

Modular block walls need less maintenance than your precast panel MSE walls

* Eight states indicated an answer of "Don't know"

Average Value of 4.47
Overall, states indicated that MBWs need more maintenance than their counterparts. Several states commented that vegetation growth will occur, but is relatively easy to combat. Concerning vandalism, one state commented that wall cap units can be easily stolen if not glued down. Six states replied “don’t know” when asked to compare the maintenance of different walls. This potentially indicates that there may be no budget applied to maintaining MBWs in these six states. While more maintenance is needed for MBWs, their maintenance is less difficult in nature. When presented with the statement, “Maintenance of MBWs is more difficult than other wall types,” the average response was 4.73. The results of this survey statement can be seen below in figure 3-4.
Freeze-Thaw Durability

Regional results are important to understand how MBWs are performing based on geographic location. These results, based on geography, might indicate that freeze-thaw durability is still a concern among the users of MBWs. A latitude of forty was chosen to divide the states involved in this survey between colder and warmer climates. According to the results, states with a mean latitude above forty perceive their walls to perform more poorly than states below latitude forty. Although there is no indication that this is directly due to freeze-thaw durability, it would seem likely that this may be the reason. Table 3-2 below summarizes the perceived performance according to geographic location.
Table 3-2: Potential effect of geography on modular block wall performance.

<table>
<thead>
<tr>
<th></th>
<th>Avg. Response For Performance Statement #1</th>
<th>Avg. Response For Performance Statement #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>States Above Latitude 40</td>
<td>5.63</td>
<td>5.96</td>
</tr>
<tr>
<td>States Below Latitude 40</td>
<td>7.21</td>
<td>7.43</td>
</tr>
</tbody>
</table>

Figure 3-5: Map showing latitude and longitude of the United States (19).

Freeze-thaw durability is still a major concern among those states that do and do not use MBWs. According to survey results for states not using MBWs, the states are fully aware of MBW technology, but their decision not to use MBWs is performance related. Of the eight states indicated as non-users of MBWs (see figure 1-5), six of them were in northern regions. Of those six northern states, four specifically indicated freeze-thaw durability as a reason for not
using MBWs. Two states indicated facing element durability as the reason, a concern that also involves freeze-thaw durability.

Of the states that use MBWs, several admitted to having freeze-thaw issues in the past. These states include Iowa, Michigan, Minnesota, North Dakota, South Dakota, Wisconsin, and Wyoming. As discussed above, Minnesota and Wisconsin have initiated new block requirements to combat freeze-thaw issues. Many states have also followed suit after they had similar concerns over their block durability. These new requirements have only been in place for ten years or less, and currently there is no research discussing how these walls have performed since their inclusion. Through the survey, several states made comments in regards to how their walls have been performing with these new requirements. Those comments can be seen below in table 3-3.

Table 3-3: Comments on freeze-thaw durability after new block requirements.

<table>
<thead>
<tr>
<th>State</th>
<th>Important Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michigan</td>
<td>There has been a noticeable difference in performance with the new freeze-thaw specifications.</td>
</tr>
<tr>
<td>Minnesota</td>
<td>No freeze-thaw problems anymore after ten years of implementation of new requirements.</td>
</tr>
<tr>
<td>South Dakota</td>
<td>No real freeze-thaw problems. We think this is because the design mix has been better.</td>
</tr>
<tr>
<td>North Dakota</td>
<td>No freeze-thaw problems. We changed our specifications to those similar to Minnesota. New requirements were difficult to meet at first, but [manufacturers] still did. Yet, there has been a bit more efflorescence.</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>Freeze-thaw issues are better now.</td>
</tr>
</tbody>
</table>

These comments, made by state engineers who have taken a proactive approach to dealing with freeze-thaw durability, have shown that walls are performing better since the initiation of new freeze-thaw requirements. As said above, these changes normally include, but
are not limited to, the following: limiting manufacturers, increasing minimum compressive strength, decreasing maximum absorption, and testing with salt solutions.

**Limitations of Modular Block Wall Use**

Despite the relatively good performance results, many states still have limitations for the use of MBWs. As part of the survey, states were asked if they have any special provisions for their walls, or if there are any limitations to the walls’ uses. For states contemplating the use of MBWs, these engineers may want to consider the limitations of experienced states. States may have omitted some of their limitations, but several states repeated similar limitations. They include:

- Increased freeze-thaw requirements: CO, IA, MI, MN, SD, ND, WI, OR.
- Limitations on wall height: CO (20-30 ft), CT (8 ft), IA (6 ft), ID (30 ft), MN (12 ft), SD (10 ft), WY (25 ft), IL, NY, OR, SC, VI.
- Use in non-critical applications only: CT, IL
- Limited use based on surcharge or traffic loads: IA, MN, NY, VI
- Offset distance criteria: IL, MN, VI

Not included in the list above are the limitation comments made by states that were not repeated by others. All comments can be seen in Appendix B. Overall, for states looking for successful performance when constructing MBWs for the first time, they should consider limiting wall height, increasing freeze-thaw requirements if in vulnerable regions, limiting loads and criticality of use, and offsetting walls from the roadway to prevent salt spray damage.
Chapter 4

Cost Effectiveness of Modular Block Walls

While the performance of segmental retaining walls remains under question, the relative cost savings for MBWs compared to its competitors is relatively accepted. Like any project, the cost is heavily affected by the specifics of the project. Site conditions, proximity to product manufacturers and the construction crew’s familiarity with MBW erection can all greatly affect the cost. When discussing the cost effectiveness of MBWs, it is imperative to compare its expenses against other wall types used in similar circumstances in the public sector. Therefore, the cost effectiveness of MBWs was explored in comparison to its biggest competitors (particularly precast concrete panel and concrete reinforced walls).

Potential Modular Block Wall Cost Advantages

Speed of Construction

There are several factors that may increase the speed of construction of MBWs in comparison to other wall types. When analyzing cast-in-place walls and precast panel MSE walls, MBWs generally require both less equipment and time.

Precast panel MSE wall construction is a relatively fast process. Large panels are lifted into place by a small crane or other lifting equipment. A picture showing precast panel placement can be seen in Figure 4-1 below. A benefit of MBW construction is that modular blocks can be hand-placed by laborers without the use of any equipment. While the handling of many small blocks in MBW construction can be labor intensive, it is likely still a faster process. This is an economy of scale comparison. It may be true that many units of modular block can be placed at a
fast pace, but is it quicker to hand place twenty-five modular blocks or one twenty-five square foot precast panel? Initially it may seem as if a larger panel is a faster and more efficient process. Yet, there are many limitation and inefficiencies that accompany the use of equipment on a construction project. First, the placement of modular blocks is not limited by location (e.g. woods, urban settings, mountainous regions, etc.) or by weather conditions, whereas projects that require heavy equipment oftentimes are. This limitation can oftentimes create wasted work hours and delays in construction. Also, wasted work hours almost always accompany the use of equipment on a work site. The left photograph in Figure 4-1 is a perfect example of this. The use of equipment is always accompanied by one worker handling the equipment, while the rest of the crew watches and waits for the materials to be put in place. This creates an inefficient work environment. Meanwhile, MBWs can utilize the entire crew at all times, as the blocks are hand placed by each member of the work crew, limiting inefficient work hours. The opinion of states in regards to speed and efficiency are explored later in the survey.

Figure 4-1: Left: Equipment and bracing needed for precast panel MSE walls (20). Right: Schematic for precast panel wall bracing (21).

With precast panel MSE walls, the bottom foundation level must always be poured concrete. Meanwhile, MBWs need only be placed on a well compacted gravel base. When large precast panels are placed, panels must be temporarily braced with correct back batter to ensure
proper vertical alignment during and after compaction. Figure 4-1 on the previous page shows
how each panel is braced and back battered during construction. This construction detail can
cause alignment issues that can be time consuming to adjust. By comparison, placement of the
first level of MBWs can be prolonged to ensure correct vertical and horizontal alignment, but the
subsequent layers can be laid very rapidly. Push out during compaction is not as much of an
issue, as the height of compacted soil is less. Lastly, connection of reinforcement for large
precast panel MSE walls is more time consuming than the placement of geogrid reinforcement in
MBWs. All of these variables would allow MBWs to be constructed at a faster pace, resulting in
improved cost efficiency when compared to precast panel MSE walls.

The building of cast-in-place walls requires many steps that can often slow the pace of
construction. Some time can be saved when large pours are conducted, but footing setup, rebar
placement, form placement, pouring, curing, and stripping can all be very time consuming. It is
fairly well known that cast-in-place walls take longer to construct than any MSE walls.

**Labor Force**

One advantage to MBWs are the labor pool that can be utilized for construction. With
other wall types, including precast panel MSE walls, heavy equipment is needed in order to
construct a wall. When this type of equipment is present, operators and skilled workers (more
specialized and higher paid) are necessary. Additionally, metallic reinforcement with precast
panel walls and reinforcement used in cast-in-place walls both require skilled ironworkers to be
on site. With MBWs constructed with geosynthetics, no equipment is required as the blocks are
hand placed. Friction connections of geosynthetic reinforcement render ironworkers unnecessary.
These changes allow for MBW construction to utilize unskilled laborers who have been properly
trained. North Carolina DOT has even used prisoners as a construction crew. The ability to use unskilled labor for MBW construction presents additional cost savings when compared to the construction of other wall types.

**Modular Block Wall Cost History**

**Federal Highway Administrations Relative Cost Data**

According to the FHWA, MBWs are competitive in price with precast panel MSE walls and reinforced concrete walls at certain heights. The FHWA contests that MBWs are especially comparable in price with precast panel walls on small projects with less than 4000 square feet of facing. Small projects using modular blocks are an advantage, as they require less equipment costs and do not need specially made panels to fit asymmetrical or small geometries. The FHWA insists that MBWs at heights less than fifteen feet are typically less expensive than precast panel MSE walls by 10% or more (2).

MBWs are equally cost effective when compared to concrete cast-in-place walls. In fact, the FHWA asserts that the use of MSE walls can result in a savings of 25-50% or more in comparison to conventional reinforced retaining walls. While precast panel MSE walls are usually less expensive than reinforced concrete retaining walls at heights greater than 10 feet, MBWs are competitive with concrete walls at heights less than 15 feet (2).

**Geosynthetic Reinforced Segmental Retaining Walls, Koerner and Soong, 2001**

In addition to investigating wall performance, in 1998 Koerner et al. conducted a survey of wall cost data that was sent to all fifty U.S. DOTs. Forty states responded with bid cost data,
and a database was created. This survey was based on similar previous surveys which have been conducted since 1973. A table from Koerner and Soong 2001 compared several wall categories at differing heights throughout history. It was created in order to show the price effectiveness of MSE walls with geosynthetic reinforcement. The table compares the cost of four different wall types: rigid/gravity walls, prefabricated gravity walls (crib/bin walls), MSE walls with metallic reinforcement, and MSE walls with geosynthetic reinforcement. Each of these wall types has several subcategories. For MSE walls with metallic or geosynthetic reinforcement, the subcategories included precast concrete facing panels, cast-in-place facing, and segmental retaining walls (MBWs). Each of these wall categories were investigated at low wall heights (less than 15 feet), medium wall heights (between 15-30 feet), and high wall heights (greater than 30 feet). Table 4-1 below features the table found in Koerner and Soong, 2001 with prices in U.S. dollars per square meter, along with U.S. dollars per square foot in parenthesis.

Table 4-1: Retaining wall costs extracted from Koerner et. al., 1998 (17).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity</td>
<td>High</td>
<td>300 (27.9)</td>
<td>570 (53.0)</td>
<td>570 (53.0)</td>
<td>760 (70.6)</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>190 (17.7)</td>
<td>344 (32.0)</td>
<td>344 (32.0)</td>
<td>573 (53.2)</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>190 (17.7)</td>
<td>344 (32.0)</td>
<td>344 (32.0)</td>
<td>455 (42.3)</td>
</tr>
<tr>
<td>Crib/Bin Walls</td>
<td>High</td>
<td>245 (22.8)</td>
<td>377 (35.0)</td>
<td>377 (35.0)</td>
<td>I/D</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>230 (21.4)</td>
<td>280 (26.0)</td>
<td>280 (26.0)</td>
<td>390 (36.3)</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>225 (20.9)</td>
<td>183 (17.0)</td>
<td>183 (17.0)</td>
<td>272 (25.2)</td>
</tr>
<tr>
<td>MSE Walls (Metal Reinforced)</td>
<td>High</td>
<td>140 (13.0)</td>
<td>300 (27.9)</td>
<td>300 (27.9)</td>
<td>385 (35.8)</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>100 (9.3)</td>
<td>280 (26.0)</td>
<td>280 (26.0)</td>
<td>381 (35.4)</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>70 (6.5)</td>
<td>172 (16.0)</td>
<td>172 (16.0)</td>
<td>341 (31.7)</td>
</tr>
<tr>
<td>MSE Walls (Geosynthetic Reinforced)</td>
<td>High</td>
<td>N/A</td>
<td>N/A</td>
<td>250 (23.2)</td>
<td>357 (33.2)</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>N/A</td>
<td>N/A</td>
<td>180 (16.7)</td>
<td>279 (25.9)</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>N/A</td>
<td>N/A</td>
<td>130 (12.1)</td>
<td>223 (20.7)</td>
</tr>
</tbody>
</table>

*MBWs Included*

Note: Prices in U.S. dollars per square meter (U.S. Dollar per square foot). I/D, Inadequate data; N/A, not available at time of survey.
It can be seen that MSE walls with geosynthetic reinforcement are cheaper than all other wall types at all heights. Similar to the results stated by the FHWA, the biggest value can be seen at small wall heights. At low heights, MSE walls with geosynthetic reinforcement are 35% cheaper than MSE walls with metallic reinforcement (precast concrete panel walls, cast-in-place facing walls, and MBWs with metallic reinforcement). At medium heights, MSE walls with geosynthetic reinforcement are still cheaper than MSE walls with metallic reinforcement by approximately 27%. There is an inverse relationship between wall height and price when comparing MSE walls with metallic reinforcement to MSE walls with geosynthetic reinforcement. At all heights, MSE walls with geosynthetic reinforcement are significantly cheaper than concrete cast-in-place walls and are consistently 50% more cost effective at all wall heights (17). Below, Figure 4-2, created by Koerner et al. 1998 graphs the information presented in Table 4-1.

![Figure 4-2: Mean value of various categories of retaining wall costs, Koerner et al., 1998 (17).](image)
The category “MSE walls with geosynthetic reinforcement” includes several different facing types, and not MBWs exclusively; incorporated into this category were precast concrete facing panels, cast-in-place facing, and segmental retaining walls (MBWs). Because the cost of MBWs is averaged with the other facing types, it is difficult to extract the information specific to MBWs. In an email correspondence conducted for this thesis, Dr. Koerner suspected that the bid prices were mainly for masonry block walls (i.e., SRWs) (22).

This research shows that MBWs and other MSE walls using geosynthetic reinforcement are the most cost effective option at wall heights up to 36 feet, but further opinions of state agencies will be explored later to validate this assertion.

Cost Effectiveness Survey Results

A series of statements regarding MBW cost effectiveness were asked to top engineers at the twenty six states that reported using MBWs. Below are the results of that survey along with any pertinent comments. Again, all full survey results and comments can be found in Appendix A and Appendix B.

Cost Comparison of Modular Block Walls Versus Large Precast Panel MSE Walls and Cast-in-place Walls

Again, MBWs were compared to precast panel MSE walls and cast-in-place walls in terms of cost. According to the survey, states agree that MBWs are cost effective when compared to precast panel MSE walls (average response of 7.13), and MBWs are cost effective when compared to traditional cast-in-place walls (average response of 8.70). These results did not differ much from the results found in Koerner et al.’s study. MBWs were shown to be cost effective compared to MSE walls with metallic reinforcement, and even more cost effective when
compared to standard cast-in-place walls. The results of the survey can be seen below in figure 4-3. The complete survey results with comments can be seen in Appendix A and Appendix B.

![Cost Statement 1](image1)

Cost Statement 1
Modular block walls are cost effective when compared to large precast panel MSE walls

* Two states indicated an answer of "Don't know"
Average = 7.13

![Cost Statement 2](image2)

Cost Statement 2
Modular block walls are cost effective when compared to standard cast in place walls

* Zero states indicated an answer of "Don't know"
Average = 8.70

Figure 4-3: Above: Cost comparison to precast panel MSE walls. Below: cost comparison to cast-in-place walls.
Many states commented that these walls are very cost effective when compared to their competitors. Some states commented that these walls are not bid against each other specifically, but MBWs are cheaper on a unit cost basis. Additionally, states mentioned that MBWs are most cost effective in shorter wall heights. This comment matches the findings by both the FHWA and Koerner and Soong, 2001. While this seems to be true, some engineers found it difficult to compare MBWs to precast panel MSE walls because the heights of MBWs are limited in their states. All comments can be seen in Appendix A.

Several states were kind enough to give direct numbers on cost per square foot of wall. Through research, other bid cost data from the last year were retrieved online from other DOTs. It should be noted that, as discussed before, wall height, site conditions, and proximity to manufacturers will have a great effect on the cost per square foot. While there are not enough participants to make the conclusions statistically significant, the values closely resemble those found by Koerner et al.’s retaining wall results from their 1998 study. Again, costs in Koerner et al. were divided into three wall heights, whereas the new costs gathered for this survey do not differentiate between wall heights. Overall, the values indicate that MBWs with geosynthetic reinforcement are approximately 58% cheaper than precast panel MSE walls. Below, table 4-2 summarizes these results and compares them with Koerner et al.’s results, which have been adjusted for inflation.
Table 4-2: Adjusted Values from Koerner et. al. (1998) retaining wall data compared to survey results.

<table>
<thead>
<tr>
<th>State</th>
<th>MBW ($/sq. foot)</th>
<th>PPW ($/sq. foot)</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>State #1</td>
<td>$27</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>State #2</td>
<td>$33</td>
<td>$53</td>
<td>61%</td>
</tr>
<tr>
<td>State #3</td>
<td>$18</td>
<td>$45</td>
<td>150%</td>
</tr>
<tr>
<td>State #4</td>
<td>$35</td>
<td>$40</td>
<td>14.3%</td>
</tr>
<tr>
<td>State #5</td>
<td>$45</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>State #6</td>
<td>$37</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>State #7</td>
<td>$33</td>
<td>$66</td>
<td>100%</td>
</tr>
<tr>
<td>State #8</td>
<td>$30</td>
<td>$45</td>
<td>50%</td>
</tr>
<tr>
<td>State #9</td>
<td>N/A</td>
<td>$57</td>
<td>N/A</td>
</tr>
<tr>
<td>Average</td>
<td>$32.25</td>
<td>$51.00</td>
<td>58%</td>
</tr>
</tbody>
</table>

Koerner et. al 1998 adjusted values

<table>
<thead>
<tr>
<th></th>
<th>High: $42.51</th>
<th>Medium: $34.09</th>
<th>Low: $27.24</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High: $47.20</td>
<td>Medium: $46.59</td>
<td>Low: $41.72</td>
</tr>
<tr>
<td></td>
<td>High: 11%</td>
<td>Medium: 37%</td>
<td>Low: 53%</td>
</tr>
</tbody>
</table>

Note: N/A, not available at time of survey.

Other important information can also be extrapolated from the above table. Of the nine states that gave bid cost data, three of them are among the states that have implemented new freeze-thaw requirements. Most of the requirements for these states have increased minimum compressive strength, decreased maximum absorption, and decreased percent loss values during freeze-thaw testing. For states in high frost locations, it may be of interest to see if stringent block requirements have increased the cost of MBWs as a whole. The three states with more stringent freeze-thaw requirements had price per square foot values of: $18sq/ft, $27sq/ft, and $33sq/ft. The average of these values is $29.3sq/ft and is actually lower than the average value of all nine states shown in Table 4-2. Again, while there are not enough values to make specific statistical conclusions, it seems as if MBWs in locations with more stringent freeze-thaw requirements are not more expensive on a price per square foot basis.
Survey results and comments show that MBWs may require more maintenance, though the difficulty of maintenance is low. The purpose of the next cost statement was to determine whether this increase in maintenance corresponded to an increase in maintenance costs. Overall, the states slightly disagreed that MBW maintenance is more cost effective than precast panel walls and concrete cast-in-place walls. Again, it should be noted that eight states did not answer either statement. This is likely because states do not have a maintenance plan or simply do not know how they compare. Figure 4-4 below shows the maintenance cost results.

* Eight states indicated an answer of "Don't know"
* Average value of 4.68
Most comments about maintenance costs were similar to the comments made before concerning maintaining MBWs. Most maintenance costs and issues are caused by vegetation growth, freeze-thaw issues, and graffiti. Drainage issues were also commented on as a maintenance problem, but this is much more of a global performance issue not isolated to MBWs.

**Other Cost Survey Results**

Survey statements regarding the cost of facing units and speed of construction were presented to state engineers. Two of the components that heavily influence cost are price of facing elements and erection cost of the block/panels. States using MBWs slightly agree that MBW facings are more cost effective than precast panel wall facings (6.38 average). Again, this should not be much of a surprise as the casting process and typical mix design of precast concrete
panels is typically of higher quality. As shown above, modular block walls with geosynthetic reinforcement seem to be priced significantly lower than other wall types and account for 20-40% of wall construction cost. Therefore, it is possible that part of the cost savings is based on the potential savings of the facing units themselves.

Additionally, the erection of panels or blocks and the contractor profits can account for 20-30% of the cost of wall construction. The assertion that the erection of MBWs is more rapid than that of other wall types was discussed earlier. When asked, states agreed that MBWs are significantly faster to construct when compared to other retaining walls (average 7.35) and slightly agreed that the lack of equipment used during MBW construction increases construction time (average 6.5). The results of these survey statements can be seen in figure 4-5 below.

---

**Cost Statement 3**
Modular block walls are significantly faster to construct when compared to other retaining walls.

* Zero states indicated an answer of "Don't know"

Average = 7.35
Overall, many states mentioned that MBWs are slightly faster to construct. Cast-in-place walls need placement of forms, stripping of forms, reinforcement, and curing time. Large precast panel MSE walls need cranes, operators, temporary shims, bracing and battering. Most states commented that compared to this, modular blocks are still faster to construct, though a bit more labor intensive. Meanwhile, unskilled laborers can be utilized. Also, a benefit of MBWs is the ease of construction in a variety of locations. On the whole, states agreed that MBWs are faster to construct. Still, two states contest that large precast panels can be placed faster based on their large facing area. If MBWs can be placed faster, it is a logical conclusion to say that the 20-30% of cost attributed to MSE wall construction and contractor profits may be lessened by utilizing MBWs.
Chapter 5

Summary, Recommendations and Conclusions

Summary

This study investigates the performance and cost effectiveness of modular block retaining walls. The information and data gathered for the investigation were obtained from review of technical papers and reports, and by completing a telephone survey with senior geotechnical engineers at thirty-two state DOTs. The collected information and data were analyzed and evaluated to draw conclusions about MBWs.

MBWs continue to gain popularity as an earth retaining structure in the public sector. Statistics show that 3,000,000 ft$^2$ of MBWs are built yearly, but many states are still reluctant to utilize this wall type based on speculative performance issues (2). Specific performance results and databases from DOTs that construct MBWs are scarce. Past performance reviews show that, while the great majority of surveyed MSE walls with geosynthetic reinforcement are performing well, those that had failed in service were damaged by poor backfill materials, inadequate external and internal drainage, or poor construction practices. These are all avoidable issues.

Meanwhile, freeze-thaw durability continues to be the most major concern amongst states not willing to construct MBWs; six states referenced it as the main reason that MBWs are not being constructed in their state. Poor freeze-thaw performance from the Minnesota and Wisconsin wall reviews forced many states to implement new freeze-thaw specifications. These specifications can easily be applied to states with continuing freeze-thaw concerns.

There is a distinct difference in performance of MBWs when the majority of the previous research was occurring and the present performance. The inception of new freeze-thaw requirements and the implementation of more strict limitations on MBW use have increased the
performance of walls as a whole. States who implemented new freeze-thaw and general
requirements for their walls unanimously agree that they have performed markedly better. Still,
difficulties in assessing the long term performance of MBWs continue as these walls are designed
for a 75-100 year design life, but have only been in service for approximately 30 years.

Maintenance of different wall types is always a concern amongst DOTs. MBWs require
more maintenance than other wall types, with the most typical problems including vegetation
growth, efflorescence, and block damage. Also, survey results showed that maintenance costs of
MBWs are more than that of other wall types.

Available cost data have shown that site conditions, proximity to manufacturer, and
construction familiarity play an important role in the cost of any wall type. MBWs with
geosynthetic reinforcement are one of the cheapest options available for use by DOTs. The
FHWA contends that MBWs at fifteen feet or less are typically less expensive than precast panel
MSE walls by 10% or more, and that MSE walls can be 25-50% cheaper than conventional
retaining walls. At low heights (<15ft), MSE walls with geosynthetic reinforcement are 35%
more cost effective than MSE walls with metallic reinforcement. Also, these walls are cheaper
by up to 27% at medium wall heights (15-30 ft). MSE walls with geosynthetic reinforcement are
approximately 50% more economical than standard cast-in-place walls at all wall heights. States
strongly agreed that MBWs are cost effective when compared to precast panel MSE walls and
standard cast-in-place walls; in fact, many states commented that they are most cost effective at
low wall heights. States agreed that MBWs are faster to construct than other wall types, and that
without using heavy equipment during construction, assembly speed increases. Though faster
than other wall types, the construction of MBWs is more labor intensive. Generally, increased
construction speed, lack of heavy equipment, decreased material costs, and use of unskilled labor
all contribute to the cost effectiveness of MBWs.
Conclusions

The evaluation of previous papers and reports, along with a survey of state DOTs, led to a few distinct conclusions. In terms of cost, modular block walls are an economical solution at almost all wall heights. Maintenance of MBWs is arduous and can be more expensive than other wall types. However, the required labor to maintain these walls is less difficult. While the great majority of MBWs have performed well in service, many states still are reluctant to use MBWs. Freeze-thaw durability continues to be a major concern amongst states not using MBWs, but recent advances with mix designs could soon remediate this issue. While a comprehensive database on MBW performance is not yet available, the majority of senior engineers agree that they perform well for their intended purpose. There is an obvious trend among all the data collected and survey results; if costs and appearance are the focus, location is non-critical, and the wall is small to moderate in height, an MBW is a worthy contender regardless of climate.

The evaluation and synthesis of all available information can be summarized in Table 5-1 below. This table summarizes all of the advantages and disadvantages of MBWs.

Table 5-1: Table of pros and cons for modular block wall construction.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetics</td>
<td>Lack of Performance History</td>
</tr>
<tr>
<td>Adaptability</td>
<td>Potential Freeze-Thaw Issues</td>
</tr>
<tr>
<td>Potential Cost Savings</td>
<td>Block/Manufacturer Variability</td>
</tr>
<tr>
<td>Speed of Construction</td>
<td>Increased Maintenance</td>
</tr>
<tr>
<td>Lack of Equipment Needed</td>
<td>Lack of Knowledge</td>
</tr>
<tr>
<td>Use of Unskilled Labor</td>
<td>Potential Differential Settlement</td>
</tr>
<tr>
<td>Ease of Material Handling and Placement</td>
<td></td>
</tr>
</tbody>
</table>
As the majority of senior engineers agree, MBWs are a versatile, practical, attractive, and affordable candidate for a retaining structure built in the public and private sector.

Recommendations

Recommendations for Further Research

Whenever there is a new technology, a wary reception by professionals in the field is never far behind. There are still research needs in regards to modular block walls that would be helpful for prospective MBW users. The following recommendations for future research are based on comments by state DOT representatives and shortcomings discovered while assessing existing research.

- Since the inception of improved freeze-thaw specifications, more in-depth research exploring the apparent improved block durability has not been explored. Based on the continuing block durability concerns of the states not using MBWs, this type of research paper would be extremely useful.

- Some states have concerns regarding the impact on MBWs when subjected to roadway accidents. A safety research project analyzing the accident impact on a MBW would be valuable.

- A few states still have concerns over the viability and performance record of MBWs. Some states believe the FHWA has not given a clear position on the matter. A research paper or report providing a clear position on the overall performance of MBWs would be very helpful.
• Research into providing a National Highway Institute (NHI) training session on MBWs would be very useful to new users. Currently there are only courses pertaining to MSE walls, but not MBWs (SRWs) specifically.

**Recommendations for Successful Implementation**

• DOTs should utilize stricter freeze-thaw specifications in more severe climates. They should also consider limiting block manufacturers to gain familiarity with products and limit block variability.

• In heavy ADT locations, DOTs should consider applying offsets from the roadway to avoid salt spray.

• A wall's height, application, and loading conditions can all impact its performance success. DOTs should limit these factors based on the suggestions of other states.

• Proper quality control and inspection are essential to ensuring correct construction practices and long term wall success. Pay close attention to drainage details. Almost all known causes of MBW failures have shown that poor backfill material and/or inadequate internal or external drainage is at fault. DOTs should monitor the quality of backfill in the reinforced zone.

• Implementing a retaining wall asset management system can enable DOTs to make more informed and cost effective decisions. This will lead to optimizing funds and maximizing return on investment. This could also initiate increased utilization of different wall types. Ohio, Colorado, Oregon, and the FHWA are all currently implementing retaining wall asset management systems.
References


Appendix A

Survey for States Using Modular Block Walls

STATE: ________________________________

DATE: _______________

TIME: _______________

Cost Questions:

First, can you estimate the number of Modular Block Walls that your DOT has constructed?

Say: First, I will ask you questions in regards to cost savings.

1. Modular block walls are cost effective when compared to large precast panel MSE walls.

Say: Again, 1 is strongly disagree and 10 is strongly agree. If you are not sure, you can say you don’t know. Again, feel free to comment after each statement if you deem it necessary.

Strongly Disagree

Strongly Agree

1 2 3 4 5 6 7 8 9 10

Don’t know

COMMENTS:
2. Modular block walls are cost effective when compared to standard cast in place walls (i.e. gravity, reinforced cantilever).

1  2  3  4  5  6  7  8  9  10

Don’t know

COMMENTS:

3. Modular block walls are significantly faster to construct when compared to other retaining walls.

1  2  3  4  5  6  7  8  9  10

Don’t know

COMMENTS:

*Say: For the next question, I am going to give you several percentage options, each of which covers a 10% range. Please pick the one that you believe best applies.*

3a. How would you quantify the increase in speed of construction?

0-10%  10-20%  20-30%  30-40%  40-50%  50%+

Don’t know

COMMENTS:
Now we will return back to the 1-10 scale with 1 being strongly disagree and 10 being strongly agree.

4. Modular block wall facings are more cost effective than large precast panel wall facing units.

1  2  3  4  5  6  7  8  9  10

Don’t know

COMMENTS:

5. The equipment (or lack thereof) used during Modular Block Wall construction increases construction speed.

1  2  3  4  5  6  7  8  9  10

Don’t know

COMMENTS:

6. Maintenance costs of MBWs have been less than that of precast panel walls.

1  2  3  4  5  6  7  8  9  10

Don’t know

COMMENTS:
7. Maintenance costs of MBWs have been less than that of concrete cast in place walls.


Don’t know

COMMENTS:

8. After the introduction of modular block walls, the addition of this new technology has decreased the bid prices of retaining walls.


Don’t know

COMMENTS:

Performance Questions:

Say: Now, I will be reading statements in regards to performance of modular block walls. Again, we will be using the same 1-10 scale as above.

1. Modular block walls have performed as well as your large precast panel MSE walls.
2. Modular block walls have performed as well as your traditional concrete cast in place walls (i.e. gravity wall, cantilever wall).

3. Modular block walls need less maintenance than your precast panel MSE walls.

4. Modular block walls need less maintenance than your concrete cast in place walls.
5. Maintenance of modular block walls has been more difficult than that of other wall types.

Say: Now, I will be reading to you 3 general statements. Again, answer these on a 1-10 scale with 1 being strongly disagree and 10 being strongly agree.

General Questions:

1. Modular block wall construction has been a worthwhile endeavor for your DOT.

Say: Now, I will be reading to you 3 general statements. Again, answer these on a 1-10 scale with 1 being strongly disagree and 10 being strongly agree.

General Questions:

Say: Now, I will be reading to you 3 general statements. Again, answer these on a 1-10 scale with 1 being strongly disagree and 10 being strongly agree.

General Questions:
2. Modular block wall construction will be used heavily in the future in your DOT

   1 2 3 4 5 6 7 8 9 10

   Don’t know

   COMMENTS:

3. I would recommend the use of modular block walls to other DOTs that do not currently use them.

   1 2 3 4 5 6 7 8 9 10

   Don’t know

   COMMENTS:

   Say: For the last question, I would like you to respond openly with any comments that you might have.

4. What design Specs does your organization use and have you made any adjustments to them?

   Are there any other comments that you would like to make?
Would you like your comments to be anonymous?

*Say: You’ve now completed the survey. Thank you very much for your time.*
Survey for States Not Using Modular Block Walls

STATE: ________________________________
DATE: _____________
TIME: ______________

General Questions (Open-ended answers):
1. Has your organization used modular block walls in the past? If so, can you estimate how many were built?

1a. If you answered yes to #1, has your organization stopped using modular block retaining walls and why specifically did your organization stop? What was the major issue?

2. What type of earth retaining structures does your organization currently use?

Cost Questions:
Each statement, unless otherwise noted, can be answered on a 1-10 scale. On this scale, 1 indicates an opinion of strongly disagree while an answer of 10 indicates an opinion of strongly agree.

1. The reason your organization does not use modular block walls is cost related.
2. You are currently content with the cost of your large precast panel retaining wall structures

Don’t know

COMMENTS:

3. You are currently content with the cost of your conventional retaining wall structures (i.e. gravity walls, reinforced cantilever walls).

Don’t know

COMMENTS:

4. You are currently content with the rate at which construction occurs with your precast panel walls and other conventional walls.

Don’t know

COMMENTS:
**Performance Questions:**

1. The reason your organization does not use modular block walls is performance related.

   1 2 3 4 5 6 7 8 9 10

   Don’t know

   COMMENTS:

2. Your organization is currently content with the performance of your precast concrete panel walls.

   1 2 3 4 5 6 7 8 9 10

   Don’t know

   COMMENTS:

3. Your organization is currently content with the performance of your conventional retaining walls (i.e. gravity walls, reinforced cantilever walls).

   1 2 3 4 5 6 7 8 9 10

   Don’t know

   COMMENTS:
**General Questions:**

1. Your geotechnical department has a full understanding of the possibility of using modular block walls as a retaining wall structure.

   1 2 3 4 5 6 7 8 9 10

   Don’t know

   COMMENTS:

2. You/your organization have an interest in using modular block walls in the future.

   1 2 3 4 5 6 7 8 9 10

   Don’t know

   COMMENTS:

3. A comprehensive paper clearly describing the positives and negatives in regards to cost and performance of modular block walls would be helpful in deciding to use modular block walls in the future.

   1 2 3 4 5 6 7 8 9 10

   Don’t know

   COMMENTS:

If I haven’t covered it already, is there a specific reason your organization does not use modular block retaining wall structures?
Are there any additional comments you would like to make?

Would you like your comments to be kept anonymous?

You have completed the survey. Thank you very much for your time. I greatly appreciate it.
Appendix B

Survey Result Comments for States Using Modular Block Walls

Cost Survey Comments

1. Modular block walls are cost effective when compared to large precast panel MSE walls.

Connecticut: Answer=Don’t Know

- We do not bid one versus the other.
- Not a great difference in price from cost history.
- Modular block walls are normally low heights and small installs. Generally 8ft or less in non-critical locations (not under roadways).
- Precast panel walls are used for large installs.

Illinois: Answer=5

- Modular block walls have been most cost effective in shorter walls.
- The type of soil reinforcement, settlements, etc.. leads to precast panel walls to be used at higher wall heights.
- Generally use modular block walls under 10-15 feet.

Iowa: Answer= Don’t Know

- Used so little it is hard to answer.

Kansas: Answer = 8

- This answer can be different based on situation like the height of the wall.
- Generally it is of an order of 10% cheaper.
- Our values are currently $33 per square foot for modular block walls and $53 per square foot for our precast panel wall systems.

Michigan: Answer = 5

- Used mostly for landscape applications. Application is key.

Minnesota: Answer = 9

- Very cost effective.
• If durability ends up being poor, we may not get our moneys worth.
• They are not even close in bid prices. Modular block walls are 1/3 the price. Modular block walls are currently $18 per square foot and our precast panel walls are $45 per square foot for the entire system.

Mississippi: Answer = 8

• It is cost effective if you just compare materials. If you assume the backfill is the same, then yes.
• We also use soldier pile walls for similar uses, but they do not look as good.
• Panel walls can be custom for a given job.

North Dakota: Answer=8

• I would say ten but there are certain limitations.

Oregon: Answer=8

• We have recently or are in the process of opening our modular block walls up to more uses (bride abutments).

South Carolina: Answer=5

• Depends on the application.

South Dakota: Answer=5

• We don’t put in high enough (say 20 foot) modular block walls to compare it to mechanically stabilized earth precast panel walls.

Texas: Answer=7

• Depends on familiarity with the product.
• These are easier because we have rock available in most of the state.
• Precast panel walls are around $40 per square foot. Modular block wall costs are close but are also smaller. This makes it a little difficult to compare.

Virginia: Answer=8

• No direct or official data.

Wisconsin: Answer=9

• Depends on the height. With 15-20 foot or lower walls, our modular block walls are definitely cheaper.

Wyoming: Answer=9
• They aren’t bid against each other. Yet, modular block walls are cheaper on a unit cost basis.
2. Modular block walls are cost effective when compared to standard cast in place retaining walls (i.e. gravity walls, reinforced cantilever walls).

**Kentucky: Answer = 5**
- Under the current economic climate, cast in place walls are priced very low right now.

**Michigan: Answer = 7**
- Depends on the wall height.
- Modular block walls are cost effective at 10-12 feet maximum.
- the entire system.

**Mississippi: Answer = 10**
- We mostly use cast in place walls or modular block walls. Don’t really use precast panel walls.

**New York: Answer=9**
- Yes, for what you use it for.

**Oregon: Answer=8**
- Depends on application and wall height.

**South Carolina: Answer=8**
- If the design is standardized, they are more cost effective.

**South Dakota: Answer=5**
- They should be. Sometimes we pay more.

**Wisconsin: Answer=8**
- Depends on the height.

**Wyoming: Answer=10**
- We have done small cast in place walls and the modular block walls are less expensive.
3. Modular block walls are significantly faster to construct when compared to other retaining walls.

Colorado: Answer=10

- This is true if the site is suitable for modular block wall construction (bearing capacity, ground water, good weather conditions).

Connecticut: Answer=5

- Walls without reinforcement can be comparable at low heights.

Illinois: Answer=7

- Handling many small blocks can be labor intensive but it is still faster.
- It is better than cast in place, for sure. Time to cast in place, setting the footing, etc… It can depend on the size of the pour though.
- It is not necessarily better based on the size of the large precast panels.

Kansas: Answer = 10

- Forming, casting, stripping, etc.. is time consuming.
- After the first blocks are set, modular block wall construction is fast.

Kentucky: Answer=7

- Placement and compaction is quicker.

Michigan: Answer = 8

- Type of equipment needed makes it easier and faster to construct.

Minnesota: Answer = 7

- Can’t compact/spread frozen soils in the winter time. This can make modular block walls difficult in these climates.

New York: Answer=7

- Relatively inexpensive system.
- May not be faster at small heights. Modular block walls are much more attractive though.

North Dakota: Answer=8

- No formwork required.
- A larger crew can make them go up very quickly.
• Modular block walls can be $25-30 per square foot while cast in place walls are around $100 per square foot.

Oregon: Answer=8

• Site specific. Based on pre-existing conditions.

Texas: Answer=8

• Precast panel walls lifts are around 2 ½ feet.
• Precast panel walls would be a little faster than modular block walls due to their size of walls.

Virginia: Answer=8

• No direct or official data.

Wisconsin: Answer=8

• Depends on type. This is for cast in place walls. Precast panel walls are a little faster.

Wyoming: Answer=4

• Twin T walls are fastest for us.
• Base course time is fast.
3a. How would you quantify the increase in speed of construction.

**Colorado: Answer=30-40%**
- Lack of equipment makes it easier.

**Minnesota: Answer = 50%+**
- Can depend on the amount of forms, stripping, setting steel, etc… Modular block walls really pick up speed on smaller walls.

**Mississippi: Answer=20-30%**
- When compared to cast in place. Can depend on the project/contractor.

**New Mexico: Answer= 0-10%**
- More labor intensive.

**South Dakota: Answer=40-50%**
- Cast in place can be 50% or more.
- Modular block wall construction is faster because you don't have to precast for an actual site condition.

**Texas: Answer=Depends**
- It depends on the wall you are comparing to.
- Modular block wall would be %50 faster than cast in place.

**Wyoming: Answer=20-30%**
- 30% faster than cast in place.
4. Modular block wall facings are more cost effective than large precast panel wall facing units.

**Colorado: Answer=7**
- In the short term, that is true. Yet, the durability might have an effect on this.

**Idaho: Answer=7**
- We bid on systems but the whole system is cheaper.
- Speed and facings probably make up the difference.
- We even have used supervised prisoner construction.

**Illinois: Answer=3**
- In some places it could be. We bid out on a per square foot of system.

**New York: Answer=6**
- Attractive facing without much effort.

**North Dakota: Answer=8**
- Absolutely cheaper on a square foot basis. Crane, delivery, etc…

**Oregon: Answer=7**
- An equal site would yield a slight edge to modular block walls.

**Wyoming: Answer=Don’t know**
- We don’t do many precast panel walls.
- For any MSE walls, we prefer to use modular block walls.
5. The equipment (or lack thereof) used during modular block wall construction increases construction speed.

Kentucky: Answer = 8
- A little easier, more conventional and easier for laborers to understand.

Michigan: Answer = 8
- The type of laborers is an advantage.
- Not highly technical but labor intensive.
- Conventional walls need to cure.
- Precast panel walls need small cranes for placing and temporary braces. These can be slower.

Minnesota: Answer = 5.5
- Crane, operator, temporary shims for vertical alignment all take time.
- More brute force with blocks but they go in fast.
- It all probably depends most on the quality of the crew.

Mississippi: Answer = 7
- Small blocks can be placed quickly. We have built 20-30 foot walls.

New York: Answer = 4
- More hand work. Slower pace.
- On a big job, all of the equipment needed for a precast panel wall are readily available.

North Dakota: Answer = 8
- Still faster with modular block walls.
- With precast panel walls, shims, bracing, battering, and straps use instead of geogrid, there is no doubt that modular block walls are faster.

South Dakota: Answer = 8
- Still faster comparatively. Staging is easier. Easier in urban situations.

Wyoming: Answer = 4
- Twin T walls are fastest for us.
- Base course time is fast.
6. Maintenance costs of modular block walls has been less than that of precast panel walls.

Connecticut: Answer=2
- Freeze thaw problems.
- Poor quality control on 10-15 year old walls.
- Efflorescence has been an issue.
- We expect better quality with the new specifications we are using.

Illinois: Answer=5
- Have had freeze thaw issues.

Iowa: Answer=4
- Issues are definitely there but the specifications have changed.

Minnesota: Answer = 3
- Vegetation growth.

Mississippi: Answer = Don’t Know
- Not many issues on modular block walls.
- Drainage is always a main concern. Try to drain out of the bottom back base of the wall.

New York: Answer=7
- Haven’t had the walls in long enough to give a direct answer.

North Dakota: Answer=Don’t know
- Vandalism is a significant problem though. Graffiti.

Oregon: Answer=4
- Deterioration of modular block is easier than other types.

South Dakota: Answer=Don’t know
- No issues with either really.

Wyoming: Answer=Don’t know
- Had problems with precast panel walls but it may not be based on wall type. Most likely due to construction issues.
7. Maintenance costs of modular block walls has been less than that of concrete cast in place walls.

Illinois: Answer=7

- Cracking, weep hole freezing, stem rotation are all problems with the cast in place walls.
- Modular block walls have not been placed in very aggressive applications.

New York: Answer=3

- There are more potential problems with modular block walls that would make me think it wouldn’t be as good.
- The ultimate durability of dry cast system is no known.

North Dakota: Answer=Don’t know

- Not a lot of maintenance issues on either.
- Joint issues are tougher in large panels.

Wyoming: Answer=Don’t know

- No difference for either one.
8. After the introduction of modular block walls, the addition of this new technology has decreased the bid prices of retaining walls.

Colorado: Answer=10
- Many times they are bid on the same products. If we deem it suitable, it is most often chosen.

Illinois: Answer=1
- We do so few block walls that we don’t look at them to bid against each other.

Kentucky: Answer=2
- Can’t necessarily say it is. We don’t bid on alternatives against each other.
- Cast in place walls have gone down recently though.

Minnesota: Answer = 1
- They all cost what they cost. Other walls can’t price low enough to compete.

Mississippi: Answer=7
- Probably so.
- Contractor designs and bids. It has eliminated a lot of cast in place walls. If we say we want cast in place, then it doesn’t matter, they are not bid against each other.

New Mexico: Answer=Don’t know
- Not bid against each other.
- They must be cheaper for landscape purposes.
- Quality control is less stringent.

New York: Answer=Don’t know
- We don’t know but we plan on bidding them against each other.

North Dakota: Answer=8
- They are sometimes bid against each other.
- You would never value engineer out of a modular block wall.

Oregon: Answer=Don’t know
- We are expecting more use and more pre-approvals.
- We are expecting the prices to go down but have no data yet.
South Carolina: Answer=Don’t know
  • They don’t compete directly but I think it would.

South Dakota: Answer=Don’t know
  • Not bid against each other.

Texas: Answer=5
  • Typically not bid against each other.

Virginia: Answer = 8
  • From talking to others.

Wyoming: Answer=4
  • Looking at data, it doesn’t seem to be the case.
  • The can depend on location. Costs are probably higher because we often build in mountainous areas.
Performance Survey Comments

1. Modular block walls have performed as well as your large precast panel MSE walls..

Connecticut: Answer=2
- Install problems.
- Not a lot of quality control.
- Poor compaction.
- All of these things didn’t cause failure, but they are not aesthetically pleasing.
- If contractors had more knowledge, better inspection criteria, and the same attention was put in, it could be better.

Idaho: Answer=7
- No freeze thaw issues. Using ASTM standards.

Illinois: Answer=5
- We have been more careful on block walls, making sure of no differential settlement.
- With our precast panel walls, the application is more challenging and leads to more issues.

Kansas: Answer = 7
- Same issues as larger panels but we haven’t really had any problems with them.
- There are a few problems (compaction issues).

Kentucky: Answer = Don’t know
- Not enough history yet. Only approximately three years in service.

Minnesota: Answer = 9
- Have not performed quite as well. Some problems since corrected.

North Dakota: Answer=8
- No freeze thaw problems. Changed to 1500 psi, very similar to specifications from Minnesota.
- The new requirements were difficult to meet at first, but they still did it.
- There has been a bit more efflorescence since the change.

South Carolina: Answer=6
• Differential settlement issues, constructability issues.

South Dakota: Answer=8.5
• So far they have performed as well.

Texas: Answer=7
• Serviceability, maintenance issues.
• These may be more prone to problems with lack of maintenance.

Virginia: Answer= Don’t know
• The use is new. Only have 6-7 small projects so far. No problems at all yet.

Wisconsin: Answer=4
• Movement from poor compaction.
• Poor tensioning of geogrids.
2. Modular block walls have performed as well as your traditional concrete cast in place walls (i.e. gravity walls and reinforced cantilever walls).

Minnesota: Answer = 3

- We have never had a cast in place wall fail. Not as much of a headache.

North Mexico: Answer=9

- For similar applications, yes.

New York: Answer=5

- It is not anticipated.

South Dakota: Answer=8.5

- No real freeze thaw problems. We think this is because of the design mix has been better.

Virginia: Answer= Don’t know

- We know we get 100 years out of the cast in place system, but we don’t know yet about this new system.
3. Modular block walls need less maintenance than your precast panel MSE walls.

Minnesota: Answer=4

- Mostly tree growth.
- No freeze thaw problems anymore after 10 years of implementation of new requirements.

Virginia: Answer= 5

- Havent had many significant issues with our precast panel MSE walls.

4. Modular block walls need less maintenance than your standard cast in place walls.

- No Comments
5. Maintenance of modular block walls has been more difficult than that of other wall types.

**Connecticut: Answer=Don’t Know**

- No money has been put into maintaining them. Mostly they have been turned over to property owners.

**Mississippi: Answer = 5**

- One wall was backed into with a lime truck and it knocked the wall out of place.
- Vegetation growth does happen, especially in private use. Not so much for us.

**North York: Answer=4**

- This is a fairly simple system and not much maintenance has been needed.

**Texas: Answer=7**

- When you notice a problem, it is often times a bigger problem.
- If the drainage/filter materials have a problem, it is often trickier to deal with than precast panel walls.
- The determination of the problem is easier with precast panel walls.
General Survey Comments

1. Modular block wall construction has been a worthwhile endeavor for your DOT.

Connecticut: Answer=6

- In the right application, it’s the best thing there.
- $35-40 per sq/ft of wall.

Texas: Answer=8

- It has its place.

Wisconsin: Answer=9

- Offers cost and aesthetic advantages.
- Problems haven’t been few but have been reduced.
- Contractors like them, they are easy to construct.
- Freeze thaw issues are better now.
2. Modular block wall construction will be used heavily in the future by your DOT.

Illinois: Answer=2
- We should be using them more often but there is currently resistance.

Iowa: Answer=5
- If it improves we will see more use.

Minnesota: Answer=5
- We are transitioning to a lot of Redi-rock type walls. These might take over some of the market. These cost more but may be more durable.

New York: Answer=8
- They definitely have their place.

South Dakota: Answer=5.5
- No increased use will occur. Modular block walls are a viable construction entity.

Texas: Answer=8
- When constructing MSE walls, probably 70% of MSE walls are precast panel. Block walls are approximately 10%.

Virginia: Answer=6
- There are bigger restrictions initially, so they will not compete right away.

Wisconsin: Answer=9
- Offers cost and aesthetic advantages.
- Problems haven’t been few but have been reduced.
- Contractors like them, they are easy to construct.
- Freeze thaw issues are better now.
3. I would recommend the use of modular block walls to other DOT’s that do not currently use them.

**Colorado: Answer=10**

- Unless there are significant issues with the site conditions.

**Idaho: Answer=8**

- We don’t know if it will last 75 years or not. Walls have been in service for 20+ years without major issues.

**Iowa: Answer=Don’t know**

- At the Midwest conference, we don’t brag about the success we have had with these. A lot is based on the fact that we don’t use many of them.

**Michigan: Answer=7**

- Depends heavily on individual site conditions and environment.
- Follow the Minnesota freeze thaw guidelines.
- We have two different specifications for landscape walls and walls of higher heights.
- Every component has to be tested.
- Block makers have to certify blocks as passing their freeze thaw requirements.

**Minnesota: Answer=10**

- Should be something in the toolbox.
- Work beautifully in the right location.

**Mississippi: Answer=8**

- Not complicated in design or construction.
- If you want to get your money’s worth, look at the small details.
- Drainage is very important, test every 50-100 feet to know the soil types. This helps withstand settlement.

**New Mexico: Answer=3**

- We don’t have experience.

**Virginia: Answer=8**

- Yes, in selected conditions. Not on more critical applications.
Wyoming: Answer=9

- Freeze thaw issues, durability, reinforcement (rigid vs. flexible grids).
- Connections are important too.
**Additional Survey Comments**

**Colorado:**
- Overall we are happy with them. The key is to use an experienced contractor.
- They can be a cost effective solution.

**Florida:**
Note, Florida just started using MBW’s and therefore did not complete the entire survey. They did make many comments.
- Are not using them now but will be.
  - Previously they were allowed in private sector only.
  - Have only used large precast panel MSE walls in the past.
  - Were wary of differential settlement in the past. Since blocks are not individually reinforced, differential settlement will cause problems with blocks potentially breaking.
- Setting up to accept MBW’s and will build a demo wall soon.
  - Proprietary wall types allowed.
  - Depending on how this wall performs, height limitations may be induced. We would like them to be used up to heights of 20 feet.
  - Demo will show us a cost per square foot to show if this is a cheaper option. We have been told that it is.
- Will use AASHTO design
  - Mechanical connections will be the only wall connection type allowed in Florida. No friction connections. It is feared that differential settlement may occur and friction connection may be lost.
  - May use reinforcement on every block.

**Illinois:**
- Settlement and stresses on blocks is not as good. They do not handle differential settlement as well.
- Joints in precast panel walls allow them to settle independently with their ¾ inch joints.

**Iowa:**
- Freeze thaw was an issue in the past.

**Kansas:**
- Currently moving away from cast in place and using modular block walls and precast panel walls more often.
- Will probably be using modular block walls more than precast panel walls in the future.
Kentucky:

- Some people were not keen on the technology and would not try it.
- Have vandalism and freeze thaw fears in the future.

Minnesota:

- Have an advantage as Keystone started in Minnesota around 20 years ago.
- Modular block walls work and are in general cheaper if constructed correctly.
- Freeze thaw has not been a problem anymore.
- Polymer reinforcement is cheaper than steel reinforcement.
  - Labor for steel workers is expensive.
  - Modular block walls use unskilled labor.
- Polymer reinforcement is cheaper than steel reinforcement.

Mississippi:

- Really good if drained correctly and verified that foundation soils are adequate.
- Have considered Redi-rock but after 10-15 feet of wall height, they need geosynthetics. This defeats the purpose of this cost savings.
- Our recommendation for other DOT’s.
  - Use an independent tester. Using a list of HITEC walls eliminates the confusion for the contractor. The wall supplier has to give the data that they are using.
  - All of this makes dealing with new technologies easier.

New Mexico:

- Looking into it more in the future.
- Our view is that block wall systems cant handle variable soil foundation conditions as panels can. There will be more catastrophic failures in similar conditions.

New York:

- They do good work for what we ask them to do. They are another tool in the toolbox.
- They should be used for some applications.

North Dakota:

- Always use a concrete leveling pad. This ensures the first course is level and straight.
- If you drain at the bottom and behind the wall, they will perform.
- Watch out for batter on taller walls from the effects of compaction.

Oregon:
• Recommend the pre-approval procedure to make sure to set standards for design practices.
• Require the vendor to do most of the design.

South Carolina:
• They definitely have their place but you have to determine where it is.
• They are an economical and aesthetic option while being easy to construct.
• They lend themselves to be most useful in shorter walls.
• Something that would help would be an organization that brings the manufacturers together.

South Dakota:
• At a certain height, time and economics come into play. At about 15 feet, you could build a precast panel MSE wall faster.
• If it is short, urban, or aesthetics are important, it should be a modular block wall.

Texas:
• When we broke into acceptability of these walls, they have been used more and more. A shift in thinking really helped push it.
• Our early walls did have problems.
• We had one wall get hit by a car. The wall was pushed inward and some blocks broke. The wall was still usable.

Virginia:
• We are going to construct more in the future, for sure.

Wisconsin:
• All external stability checks are done by the DOT. Internal design is done by the contractor.

Wyoming:
• Inspect our walls every so often.
  • Currently in the process of fixing a modular block wall. The problem was external to the wall type.
• They fit in well with the landscape. Good color and texture.
• Have had some freeze thaw issues.
  • It is important to test blocks and accept mix designs prior to install.
Survey Result Comments for States Not Using Modular Block Walls

General Survey Comments

1. Has your organization used modular block walls in the past? If so can you estimate how many were built?

State #1:
- Very rarely used if at all.

State #2:
- In special cases they have been used (historical purposes). Very minimally.

State #3:
- Yes, at least a dozen, but not anymore.

State #4:
- Only one.

State #5:
- No.

State #6:
- We are approved but probably haven’t done any. Limited to garden walls. Landscape walls are approved.

State #7:
- Not that I am aware of. Looked at blocks in the past and they did not hold up to freeze-thaw (around 1995).
1a. If you answered yes to #1, has your organization stopped using modular block retaining walls and why specifically did your organization stop? What was the major issue?

**State #1:**
- No major reason they are not being used. Use large PPWs traditionally.

**State #3:**
- Performance issues. Most likely freeze-thaw (theorized).

**State #4:**
- Durability of blocks. Specifically freeze-thaw in a salt spray environment.
2. What type of earth retaining structures does your organization currently use?

**State #1:**

- Precast panel MSE walls, occasionally cast in place walls on smaller jobs.

**State #2:**

- Large precast panel walls, tieback/soil nail walls, cast in place walls below ten feet high, cantilever, gravity walls.

**State #3:**

- Precast concrete block gravity walls, precast modular systems, precast panel MSE walls.

**State #4:**

- Precast panel walls with metallic and geogrid reinforcement, concrete cast in place walls, redi-rock walls.

**State #5:**

- Only metallic MSE walls, double walls, t-walls, rarely use cast in place walls.

**State #6:**

- Pile lagging, soil nails, reinforced concrete cantilever, t-walls.

**State #7:**

- Large precast panel, gabion walls, cast in place gravity and cantilever, anchor walls.
Additional Survey Comments

State #1:

- Walls might not be used based on some past history.

State #2:

- Unfamiliar with new technology.
- MBWs probably won’t be used anytime soon.
- New soil mechanics methods seem unconventional to older crowd.
- Inexperience has a big part in why they aren’t used.
- There aren’t many issues with other wall type sin our state, this also why they won’t be used.

State #3:

- Facing block deterioration is a concern.
- Don’t know what the industry is offering now with MBWs.
- We are open to proprietary wall systems. Pre-approval is needed/available to vendors.

State #4:

- We are interested in using them is durability can be proven and geogrids are shown to not be an issue.

State #5:

- Service life is not as durable as precast panel MSE walls. Freeze-thaw durability is a concern. There is no proven track record.
- Facing performance and durability/elongation of geosynthetic reinforcement is a concern in regards to performance.
- Durability and performance record is not there.

State #6:

- The perception is that they are no good.
- There is a perception that they do not perform to the necessary standards.
- A clear position from the FHWA on viability and performance records would be helpful.
- An NCI course on MBWs specifically would be helpful.

State #7:

- No cost data to compare it with, only manufacturer data.
- Performance concerns are specifically related to the material (the block) itself.
# Appendix C

## Survey Results, Raw Data

### States Using MBWs, Cost Data

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