December 2009

CONCRETE MASONRY DESIGNS

Skyline Ridge

Global Stability and Segmental Retaining Walls

SRWs Carry the Weight in Indianapolis Water Park

Load and Resistance Factor Design Method

AIA Continuing Education Learning Program

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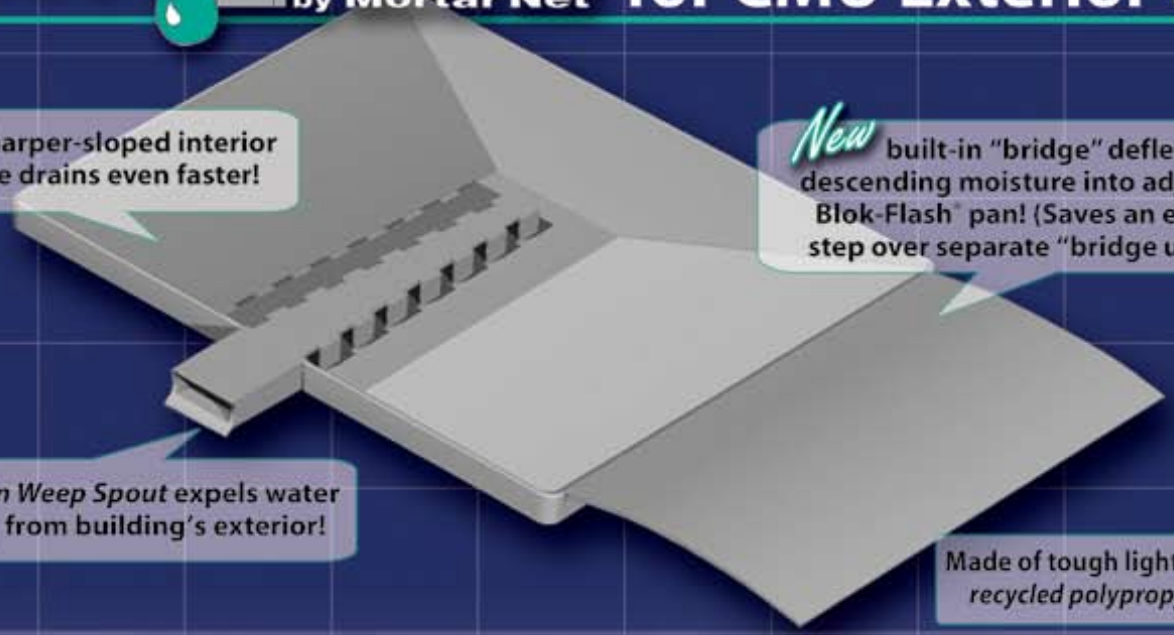

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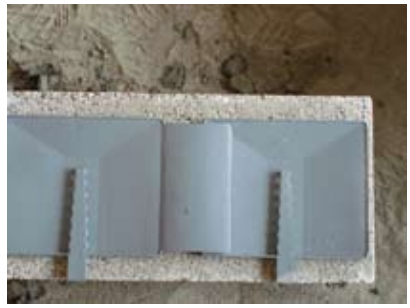
More Benefits.



Blok-Flash has been shown to maintain a 10 times stronger bond than thru-wall flashing. It's easy to install on reinforced block, too--simply snap the Bridge Unit off one of the pans and lay it next to the re-bar...then go right on "dealing the cards"!

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CONCRETE MASONRY DESIGNS

Hardscape Issue **December 2009**

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Global stability is a critical geotechnical assessment to be made for projects involving SRWs. The stability analysis should include the influence of all site geometry, soil and rock properties, existing and proposed loading, groundwater conditions, and existing or proposed slopes above and below the retaining wall.

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Skyline RIDGE

The Skyline Ridge development is a large residential community with 90 luxury condominiums overlooking the Manhattan skyline. The original site was very hilly and provided no quality space for building. The solution was a set of large segmental retaining walls (SRWs) built to form a construction plateau. The project has 17 retaining walls consisting of more than 75,000 SRW units and a maximum grade change of 70 ft (21.3 m).

A project as large and complex as Skyline Ridge takes careful planning and coordination from the beginning. The site civil firm, Casey and Keller, started with the basic need for a large flat area to build the condominiums. They could have chosen to build one tall wall around the site, but the Owner, Garden Homes of Short Hills, New Jersey, chose to break the height into shorter terraces with accenting landscaping on each level. The walls not only provide the necessary grade change, but also support the parking lots and recreational areas and in some areas support the condos themselves. By allowing adequate time to plan the site, Casey and Keller, Inc. was able to plan for the building footings above the reinforced soil mass and for the required utilities and their placement locations and produce a detailed water management plan for the site.

Most of the utilities were brought to the site under the single access road leading in and out of the property. This was done in part to avoid potential interference with the reinforced soil masses of the wall structures. The site drainage is handled with many drop structures (catch basins), all draining to a large detention basin near the lowest part of the project. Most of the drop structures were built outside the reinforced soil mass, but one needed to drop down through the mass and out the face of the wall. By having an early plan, Casey and Keller was able to highlight this drop structure for the wall designer to incorporate in the wall construction details.

Porcello Engineering was contracted to design the walls because of their familiarity with SRW design and construction. They had designed many SRWs, but these were different, as they were very tall and they supported the buildings directly on top of them.

Before starting the design, Porcello coordinated the building loads with the designer and did a thorough review of the geotechnical report to determine the quality of the site soils. The buildings were supported on spread footings which would be applied to the wall's designs as dead load, and the site soils were very high quality gravels and sands which could be reused as backfill. In tall wall construction it is very important to use high quality compactable soil with a low plasticity index (PI) to minimize the potential for future settlement. Because of the requirement for high quality material and high levels of compaction Porcello and the owners called for an on-site soils engineer to monitor the soil compaction and wall construction.

Porcello used SRW software for their initial design of the walls and ReSSA (www.geoprograms.com) to model the walls for global stability. It is important when designing any wall, but especially for tall walls, to consider global stability. For this site, the global model dictated the lengths of the geogrids in the lower walls. Once the grid strength and length were set in ReSSA, these final values were entered back into the original SRW software. Then the program was rerun for wall safety factors and quantities. The power of the SRW design programs give engineers like Porcello the tools to model walls of virtually any size.

Pillari, LLC was contracted to build the walls. They worked directly with Porcello for the wall construction, but because of the integration of the walls into the building plans, coordination with all disciplines was mandatory. The project owners and designers held a preconstruction meeting to get the project started in the right direction and held weekly site meetings to ensure the project coordination went smoothly and stayed on schedule.

During the beginning of the project the focus was on building as much wall as possible and getting the utilities in place. The lower walls were between 10 and 20 ft (3 and 6.1 m) tall. Under normal conditions, it would have grid lengths between 60 and 80 % of the wall height, however these were the base for a terraced structure reaching a height of 70 ft (21.3 m) so the extremely long grid lengths posed a challenge to Pillari. Pillari was careful to install the grid correctly by first connecting it to the facing and then pulling it back and staking it tight. They were also careful when placing the infill material; they always started at the facing and filled back towards the tail of the grid layer. This way, the natural placement and compaction of this material would act to pull the grid and facing tight into the soil mass. If an installer places the infill material starting at the tail of the grid and then works towards the facing, slack will appear in the grid layer at the facing.

As they reached the top of the plateau, the building construction started and the wall progress slowed to accommodate more detailed installation such as stairs, railing and planters. Many of the smaller walls above were directly incorporated into the building's esthetic design, so Pillari had to stage their work around the building's construction.

One of the more interesting aspects of the wall construction, as it related to the building construction, was the incorporation of an air ventilation system for the underground parking garage. The design called for a 4 ft (1.2 m) round air duct with a concrete headwall build into the wall. The installers built the walls up to either side of the duct to help form the sides of the headwall, then the bottom and sides of the headwall were formed and cast. The SRW unit walls were then built up to a point level with where the top of the headwall would be. A last headwall pour was cast to bring the headwall up level with the top SRW course. Pillari used the same building technique they would if the duct had been a large drain pipe of culvert.

No matter what the size of a project, planning ahead and taking a methodical approach to design and construction is the key to building a quality structure with a lifetime of service. CMD

PROJECT
Skyline Ridge, Springfield, New Jersey
PROJECT SIZE
75,000 AB Units, 70.0 ft (21.3 m) total height
ENGINEER
Fred Porcello, P.E., Porcello Engineering
Pine Brook, New Jersey
WALL BUILDER
Pillari, LLC, Howell, New Jersey
SITE CIVIL
Casey and Keller, Inc., Millburn, New Jersey
SRW MANUFACTURER
Clayton Block, Edison, New Jersey
SRW LICENSOR
Allan Block

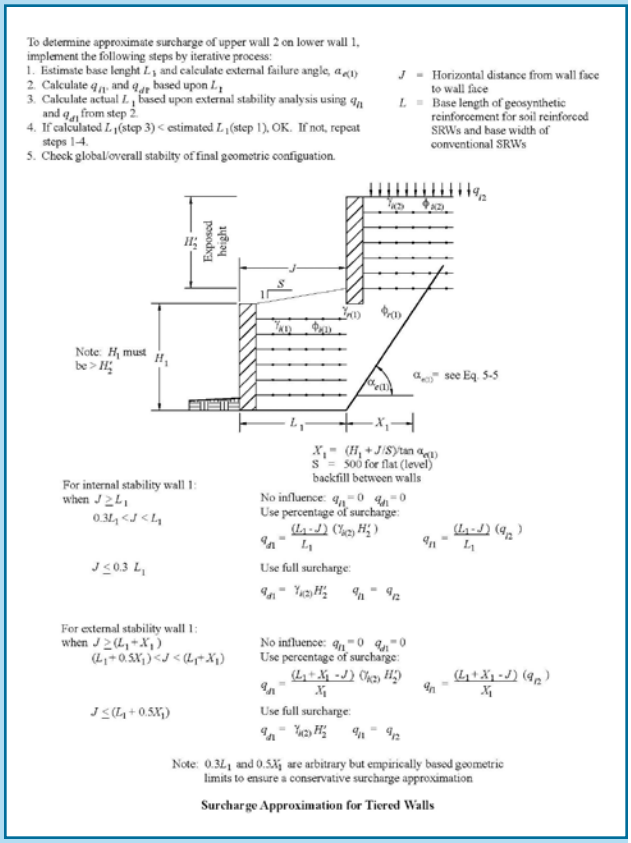
DESIGN CONSIDERATIONS FOR TERRACED OR TIERED WALLS

Tiered walls often require more complex analysis than provided by standard wall stability design methods. Some simpler cases, however, may be conservatively modeled by the following method.

The effect of the upper tier walls is to act as a uniformly distributed load on the underlying tiers. Generally, if a tiered retaining wall is placed within a horizontal distance (wall face to wall face) less than twice the height of the underlying wall, a load will be applied to the lower wall. This 2:1 rule assumes that there are no slopes below, between or above the tiered structures and that there are reasonably competent soils. The figure below may be used to estimate the equivalent uniformly distributed surcharge loading applied to a lower wall by the upper wall for both internal and external stability analyses of a tiered reinforced soil SRW system. If the upper tier is set back past the reinforced zone of the lower wall, however, it may behave more like a live load than a dead load because the vertical load of the upper wall is not contributing to stabilizing forces in the lower wall.

This method does not, however, account accurately for the effects of slope around or between tiered walls. The only way to accurately model tiers and adjacent slopes is to use conventional slope/global stability analysis methods.

The retaining wall designer and the site geotechnical engineer must work together to ensure that all modes of failure are investigated for these complex structures. The same approach as shown in the figure is suggested for conventional gravity SRWs except that the dimension L_1 in the figure is restricted to the base width of the SRW units (W_u). In both instances, the lower wall height H_1, must be greater than the exposed height H_2 of the upper wall to use the approximation in the figure. The approximation is also applicable to triple and quadruple tiered wall systems by starting the analysis at the lowermost wall. The information that is required to analyze the effects of tiered SRWs is the geometric location of one tier with respect to the other (i.e., H_1, L_1, and J from the figure at right).



Source: *Design Manual for Segmental Retaining Walls* 3rd Edition, NCMA.

GLOBAL STABILITY AND SEGMENTAL RETAINING WALLS

A critical geotechnical assessment to be made for projects involving SRWs is the long-term slope stability (i.e.,global stability) around the SRWs. The stability analysis should include the influence of all site geometry, soil and rock properties, existing and proposed loading, groundwater conditions, and existing or proposed slopes above and below the retaining wall. A global stability failure involving an SRW is defined as the general mass movement of the structure and adjacent soil mass. Global stability concerns may result from changes in grade, weak soil layers, increase in groundwater elevation, and/or the additional gravitational forces imposed on the site soils as a result of construction. While the ultimate responsibility of each design profession is determined by their contract with the owner, it is recommended that the geotechnical engineer be responsible for the evaluation of the global stability of soil masses in and around SRWs as a required part of a geotechnical analysis just as it is for other types of structures.

A detailed presentation of slope stability methods can be found in many geotechnical engineering text books. The analytical derivation for the equation defining factor of safety (FSglobal) is based on force and moment equilibrium. Commercially available slope software that uses Bishop's method or other slope stability analysis methods is the typical means for evaluating global failure surfaces around retaining walls. The minimum design factor of safety against global instability recommended in the *NCMA SRW Design Manual* is 1.3.

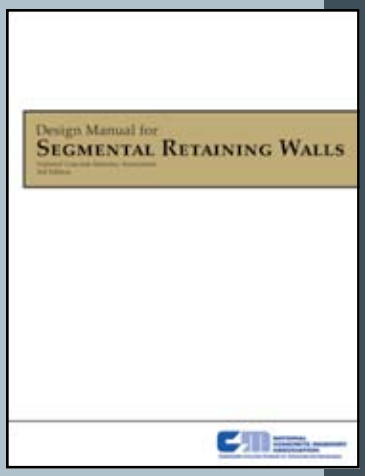
Because SRW structures consist mostly of geogrid-reinforced soil, critical global failure surfaces may sometimes pass through a portion of an SRW. To analyze such failure surfaces accurately, the global analysis method and software should have the means to account for the SRW unit properties and the geogrid reinforcement layers. As a simplification, the SRW units are sometimes modeled as a soil zone having equivalent shear strength properties and horizontal width as the units. Methods for accounting for the geogrid reinforcement vary with global analysis methods and software. A global stability evaluation could account for geogrids in a method similar to the Internal Compound Stability (ICS) analysis. ICS accounts for the geogrid as a resisting force, however this possible similarity of ICS methods to global analysis methods should not be mistaken to indicate ICS is a global analysis. ICS, as defined in the *NCMA SRW Design Manual*, is much more limited than a global analysis and is not a substitute for a complete geotechnical global stability review which is outside the scope of the NCMA SRW design manual and software.

ENSURING ALL CRITICAL FAILURE SURFACES ARE EVALUATED

Projects involving retaining walls can have complex site grading and geometry, so an important factor in a proper geotechnical evaluation is taking particular care to ensure that all potential global stability failure surfaces are analyzed and addressed in the vicinity of an SRW. The figure summarizes common potential failure surfaces in and around a single height SRW. The failure surfaces that

NCMA DESIGN MANUAL FOR SEGMENTAL RETAINING WALLS, 3RD EDITION

Essential guide to aid designers. Incorporated into the 3rd edition are two previously separate SRW manuals, Segmental Retaining Walls-Seismic Design Manual and Segmental Retaining Wall Drainage Manual. Now for one low price, all the technical information you need for your SRW design project is now available in a single manual. 206 pages (2009).



Retail: $198 (Note: Prices discounted if you have already purchased SRWall Version 4.0. Go to Product Code TR127B*. Software registration number is required.)

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occur in the top slope independent of the wall (Surface A) or pass behind and below the SRW structure (Surfaces F, G) are labeled as global failure surfaces. It is recommended that these be analyzed by the geotechnical engineer per an acceptable slope stability analysis method.

In addition to global failure surfaces that pass behind and below the wall system, there are possible failure surfaces that start behind the wall system but then pass through some part of the wall system, sometimes referred to as compound failure surfaces. These failure surfaces should not be neglected in the global analysis, as they may be the most critical failure surfaces for some conditions. A failure surface that starts directly behind an SRW and exits out the face of the SRW, for a limited region behind the SRW (Surfaces B, C, D, E figure page 30), is labeled an "internal compound" failure in this manual. This Internal Compound Stability (ICS) analysis is part of the recommended wall design methodology. See Detail of the Month, page 30. So some compound failure surfaces may be addressed by the SRW engineer as a part of their wall design.

The geotechnical engineer should be aware that an ICS analysis done by the SRW engineer ends a short distance behind the wall and only reviews surfaces that exit out the wall's face. Thus, a geotechnical engineer performing a global analysis around an SRW should not neglect evaluating possible failure surfaces that either exit out the wall face but start well behind the wall or that pass through part of the reinforced soil zone but not through the wall face.

Both these stated cases involve compound failure surfaces that ICS analysis does not address. The designer can, however, use the results of ICS to evaluate whether a global stability problem exists. As mentioned in Section 5.3.4 of the NCMA manual, if all critical failure surfaces begin at the back limit of the design envelope, a comprehensive global stability analysis must be performed by the geotechnical engineer. In addition, tiered or stacked walls can introduce many other possible compound and global failure surfaces.

Commercially available global stability software that allows for accurate representation of these complex geometries and accounts for the wall face and geogrid reinforcements is the typical means of evaluating compound and global failure surfaces for tiered walls.

The number of possible failure surfaces shown in the figure and the further complexities with tiered walls demonstrate the need for close coordination between the geotechnical engineer and the SRW engineer to ensure proper global stability analysis around SRWs. For this reason, this manual suggests in Section 3.3 that the geotechnical engineer be contracted by the owner to have clear, ultimate responsibility for global stability analyses for the project site, including in the vicinity of the SRW. As such, the duties that the geotechnical engineers are recommended to be contracted for should include: determining where and when global analysis is needed, ensuring that all critical failure surfaces are analyzed, and ensuring the proper soils and groundwater properties are used in these analyses. CMD

SRWs Carry the Weight in Indianapolis Water Park

The goal was to create an outdoor water park for Carmel Clay Parks & Recreation. The objective of this water park is to enhance the neighborhoods of the City and Township, build a sense of community and positive image, and encourage citizens to view Carmel Clay Parks & Recreation as a valued investment.

The retaining walls were designed for heavy surcharges and water applications. Backfill, geogrid reinforcement, and drainage were all necessary design goals on this project. To achieve this while maintaining the beauty of the landscape, a multi-piece system was utilized.

This project had multiple issues that needed to be addressed. The installation contractor paid close attention to the specific needs on this project and close consideration was given to the compaction of material behind the walls.

The retaining walls were designed for heavy surcharges, water applications, and slope reinforcement. Specific select backfill with geogrid reinforcement was utilized to address these unique circumstances. An outside geotechnical firm was hired to test compaction on a per lift basis, which resulted in multiple tests per day. A multi-sized SRW system ensured that the project added to the beauty of the original landscape.

The system utilized with this project creates a natural stone appearance with easy-to-install options from Anchor Wall Systems. The Anchor Highland Stone® retaining wall system combines earthen tones, rich textures, varied contours and all the advantages of the structurally sound rear-lip locating system, making it a reliable and easy-to-install alternative to natural stone walls.

This 10-acre (4-hectare) outdoor aqua park is a major component of the 161-acre (65-hectare) Carmel Central Park. The Outdoor Aqua Park features:

- Zero-depth activity pool with a beach-like entrance, interactive water features, water play structure and shade structures
- Lap pool with six, 25-yard (22.9-meter) lanes
- Lazy river
- Two water slides
- Kiddie pool with zero-depth entry, interactive water feature, tot slide and sand playground
- Deep pool with plunge slide and one-meter diving board
- Concession stands with deck and rental lawns

PROJECT
The Manon Center, Carmel, Indiana
ENGINEER
Level 5 Engineering, Indianapolis, Indiana
MASONRY CONTRACTOR
Roudebush Improvement Corporation, Westfield, Indiana
BLOCK PRODUCER
Rogers Block, Indianapolis, Indiana

Load and Resistance Factor Design Method

Most designers are familiar with the traditional Allowable Stress Design (ASD) method to design structures, but only a few are familiar with the Load and Resistance Factor Design (LRFD) method. Yet, most designs for publicly funded projects have been officially transitioning to this method since 2000 and Mechanically Stabilized Earth (MSE) Walls will be have to be completely transitioned by October 2010 following AASHTO recommendations. Since most states follow the AAHSTO specifications, LRFD will be the common design method in the public sector. This article presents a brief summary of the similarities and differences in between ASD and LRFD methods for MSEs and their impact on the design for the public projects.

The Load and Resistance Factor Design (LRFD) procedure has been introduced for Mechanically Stabilized Earth (MSE) walls in the new FHWA/NHI design manual. The LRFD procedure harmonizes with the AASHTO 2007 recommendations and replaces the Allowable Stress Design (ASD) procedures. The basic principle remains, the load effects have to be less or equal to the Resistance and the difference is how uncertainty is incorporated in the design (see table 1). Basically, LRFD Method increases the loads on the system and decreases the resistance of the elements to find an efficient design where the supply (resistance) is larger than the demand (load).

The core analytical method for MSE walls such as external and internal stability evaluation remained unchanged. The assumption of a coherent gravity mass, the shape of internal failure planes, and treatment of reinforcement as discreet elements haven't changed. The primary modification is the way the loads and resistances are compared and how uncertainty is incorporated into the design process. While the ASD method accounted for uncertainties in loads and resistance on a combined safety factor (FS), LRFD procedures allow for individual uncertainty factors for loads (y) and resistance (ø). Some of the common uncertainties to consider are shown in Table 2.

The LRFD procedure uses reliability (probability) theory to quantify the uncertainty in loads (Q), and resistances (R) and determines the appropriate values of load (y) and resistance (ø) factors. The various factors can be found in the AASHTO manual including the increase in lateral earth pressure for external stability, increase on vertical pressure for internal stability, increase in dead and

TABLE 1. ASD VS. LRFD PROCEDURES

ASD procedure	LRFD Procedure
Load effects ≤ Resistance	Load effects ≤ Resistance
$FS = \frac{\text{Ultimate Resistance}}{\text{Applied Load}} = \frac{R_n}{Q}$ $\sum Q \le \frac{R_n}{FS}$	$\sum y_i Q_i \le øR_n$ Load Factor: $y \ge 1.0$ Resistance Factor: $ø \le 1.0$

*Load and resistance factors (y and ø) shouldn't be confused with unit weight and shear strength angle of the soils. The loads and resistances are called factored if y and ø have been applied, or nominal if they are the original value.

Photos provided by Allan Block

live loads, etc. In the LRFD procedure, once the factors have been established, the factored loads and resistances are combined to create the worst possible case (maximum load effect with lowest resistance). Then the efficiency of the system is evaluated through the Capacity to Demand Ratio (CDR) that is the ratio between the factored resistance and factored load that has to be equal or bigger than one (see Eq. 1). The closer the CDR is to one the more efficient the design is.

$$CDR = \frac{\sum y_i Q_i}{\phi R_n} \geq 1 \quad (Eq.1)$$

LRFD factors (y and ϕ) are currently calibrated to ASD (Allowable Stress Design) results. Therefore, LRFD designs should not significantly vary from past ASD designs. Any existing design method could be applied to LRFD as long as the load and resistance factors are adequately calibrated using statistical data. It is expected that in the upcoming years research will allow the MSE industry to change the Load and Resistance factors to refine the design towards more efficient structures with known levels of reliability.

It is good to remember that there isn't an LRFD method for the slope stability analysis, so if necessary the designer will have to run a global analysis with the known ASD method.

The LRFD methodology as currently calibrated should give designs really close to ASD (Allowable Stress Design) results. It is expected that in the upcoming years, research will refine the Load and Resistance factors for MSE design towards more efficient structures and certainty in levels of failure.

Designers need to be aware of the changes and modification coming to keep up with this sector of the industry. CMD

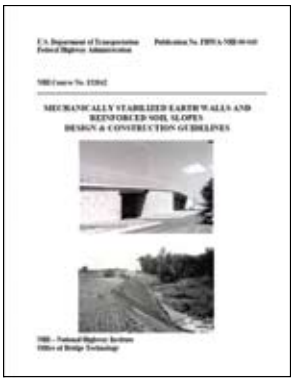
TABLE 2. UNCERTAINTIES FOR LOAD AND RESISTANCE FOR MSE WALL DESIGN

Loads	Resistances
Magnitude	Soils variability
Direction	Prediction model
Location	Construction QC
Frequency	Extent of exploration
Combinations	Failure consequences

FHWA NHI manual on *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes*

The revised version of the FHWA NHI manual on "Mechanically Stabilized Earth Walls and Reinforced Soil Slopes", will be released late 2009/ early 2010. The new version of the manual will be updated to incorporate the Load and Resistance Factor Design (LRFD) approach.

Copies can be obtained from the FHWA NHI bookstore (www.fhwa.dot.gov) when the manual is released.



NATIONAL CONCRETE MASONRY ASSOCIATION
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GUIDE TO SEGMENTAL RETAINING WALLS

TEK 15-8A
Structural (2009)

INTRODUCTION

Segmental retaining walls are modular block retaining walls used for vertical grade change applications. The walls are designed and constructed as either gravity retaining walls (conventional) or reinforced soil retaining walls. The system consists of dry-cast concrete units that are placed without mortar (dry stacked) and rely on their unit to unit interface and mass to resist overturning and sliding. Unit to unit interfaces include friction, shear elements, and interlock. The systems may also employ soil reinforcement that extends into the backfill and allows for the construction of walls with significant height (e.g. in excess of 50 ft (15.24 m)) that could not be accomplished with the units alone.

Segmental retaining walls are considered flexible structures, so the footing does not need to be placed below the frost line provided there is sufficient foundation bearing capacity. SRW units are manufactured in conformance with industry standards and specifications to assure that units delivered to a project are uniform in weight, dimensional tolerances, strength, and durability—features not necessarily provided in site cast materials.

SYSTEM ADVANTAGES

Segmental retaining walls afford many advantages; among which are design flexibility, aesthetics, economics, ease of installation, performance and durability.

Design flexibility: The size and weight of SRW units make it possible to construct walls on difficult topography or on limited access sites. Curves and other unique layouts can be easily accommodated. Segmental retaining walls have the ability to function equally well in large-scale applications (highway walls, bridge abutments, erosion control, parking area supports, etc.) as well as smaller residential landscape projects.

Aesthetics: Since SRW units are available in a variety of sizes, shapes, textures and colors, segmental retaining walls provide designers and owners with both an attractive and a structurally sound wall system.

Economics: SRWs provide an attractive, cost-effective alternative to other retaining walls. Savings are gained because most on-site soils can usually be used eliminating costs associated with importing fill and/or removing excavated materials, and because there is no need for extensive formwork or heavy construction equipment.

Ease of installation: Most SRW units are small enough to allow placement by a single person. The dry stack method of laying units without mortar allows erection of the wall to proceed rapidly.

Performance: Unlike rigid retaining wall structures, the flexible nature of segmental retaining walls allows them to move and adjust relative to one another. Segmental retaining walls can readily accommodate differential settlements on the order of 1/200.

Durability: Segmental units are manufactured of high compressive strength, low absorption concrete, which helps make them resistant to spalling, scour, abrasion, the effects of freeze-thaw cycles, rot, and insect damage.

Related TEK:
2-4B, 15-4A, 15-5A, 15-9

Keywords: retaining walls, segmental retaining walls

WALL TYPES

Segmental retaining walls can be designed as either conventional or as reinforced soil, as illustrated in Figure 1. The structural capacity of the SRW system will vary with the SRW unit size, shape, batter, etc. Manufacturer's recommendations should be followed regarding the capacity of their particular system for the soil loads under consideration.

Conventional

Conventional SRWs are constructed with either single or multiple depths of units. For stability, the conventional SRW structure must have sufficient mass to prevent both sliding at the base and overturning about the toe of the structure. Since the system consists of individual units dry stacked, shear capacity is an important component to assure that the units act together as a coherent mass.

Shear capacity provides a means of transferring lateral forces from each course to the succeeding one. This is provided by the frictional resistance between SRW units; and in the form of "keys", leading/trailing lips; clips, pins, or compacted columns of aggregate placed in the open cores (Figure 2).

Structural stability of the SRW can also be improved by increasing the wall batter. Batter is achieved through the setback between SRW units from one course to the next. In most cases, the batter is controlled by the location of shear pins or leading/trailing lips (Figure 2), however, some systems allow some adjustment to the batter.

Taller walls can also be achieved by using multiple depths of units, shown in Figure 1a. The multiple depths of units increase the weight of the wall system and provide a more stable base and greater resistance to soil pressures. Note that multi-depth unit SRWs should always be designed by a qualified engineer.

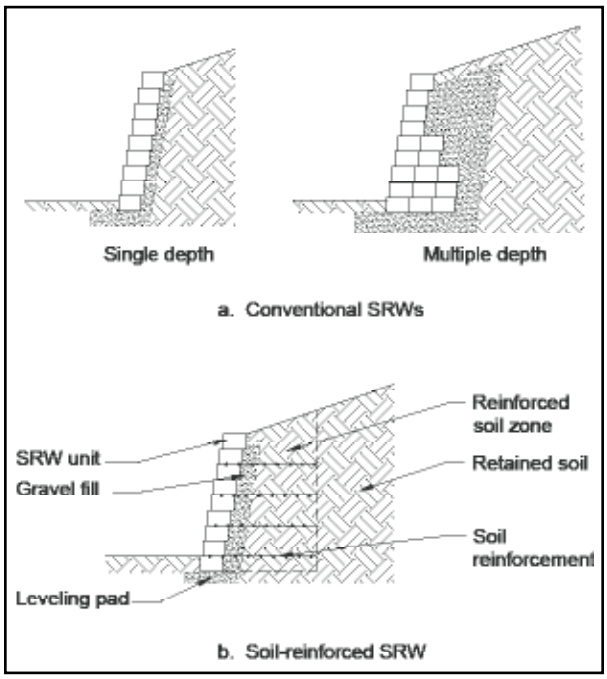

Figure 1—Segmental Retaining Wall Systems

Reinforced Soil

Reinforced soil walls should be specified when the maximum height for conventional gravity walls is exceeded or when lower structures are surcharged by sloping backfills, live loads, and/or have poor foundations. A reinforced soil SRW is designed and constructed with multiple layers of soil reinforcement placed between the SRW courses and extending back into the soil behind the wall at designated heights and lengths as shown in Figure 1b. The geosynthetic reinforcement and the soil in the reinforced zone act as a composite material, effectively increasing the size and weight of the wall system.

SYSTEM COMPONENTS

The basic elements of each segmental retaining wall system are the foundation soil, leveling pad, segmental retaining wall units, retained soil, gravel fill, and, for reinforced soil SRWs, the soil reinforcement.

Foundation soil: The foundation soil supports the leveling pad and the reinforced soil zone of a soil reinforced SRW system.

***Leveling pad*:** The leveling pad is a level surface, consisting of crushed stone or unreinforced concrete, which distributes the weight of the SRW units over a wider area and provides a working surface during construction. The leveling pad typically extends 6 in. (152 mm) from the toe and heel of the lowermost SRW unit and is at least 6 in. (152 mm) thick.

Segmental retaining wall units: Segmental retaining wall units are concrete masonry units that are used to create the mass necessary for structural stability, and to provide stability, durability, and visual enhancement at the face of the wall.

Retained soil: Retained soil is the undisturbed soil

for cut walls or the common backfill soil compacted behind infill soils.

Gravel fill: Gravel fill is free-draining granular material placed behind the facing units to facilitate the removal of incidental groundwater and minimize buildup of hydrostatic pressure, and to allow compaction to occur without large forces acting on the SRW units. In units with open cores, gravel can be used to increase the weight and shear capacity. In some cases, a geotextile filter is installed between the gravel fill and the infill to protect the gravel from clogging. The gravel fill should extend a minimum of 12 in. (305 mm) behind the SRW units regardless of the type.

Reinforced soil: Reinforced soil is compacted structural fill used behind soil-reinforced SRW units that contains horizontal soil reinforcement. A variety of geosynthetic soil reinforcement systems are available.

DESIGN CONSIDERATIONS

Typical designs and specifications for SRWs should be prepared by a designer with technical knowledge of soil and structural mechanics. Each SRW unit manufacturer can provide design information tailored to their product, which will indicate the wall heights and design conditions when an SRW should be designed by a qualified engineer. In addition, unique design conditions that may warrant special consideration include:

- structures will be subject to surcharge loads;
- walls will be subjected to live loads;
- walls will be founded on poor foundations; or
- the nature of the design conditions requires special consideration.

The following general site information should be provided:

- a wall profile, including the grade at the top and bottom of the wall, the physical elevation of the top and bottom of the structure to be retained, and the variation of the design section along the height of the wall,
- a description of the infill, foundation, and retained soils,
- a wall plan, which should include geometry for curved wall lengths and the proximity to any existing or proposed surcharges, structures, or utilities that may affect wall construction or performance. Ends of the wall should be designed with consideration of how surface water flow is directed around the wall ends to prevent erosion.

This data should be sufficiently accurate to develop an efficient, safe, and cost-effective structural design.

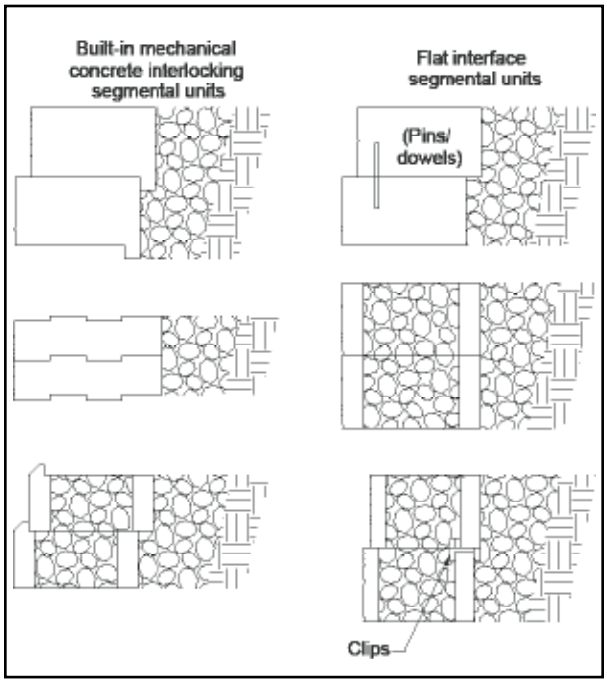

Figure 2—Shear Connectors for SRWs

GUIDE SPECIFICATIONS

A guide specification for a materials specification (product/method) for segmental retaining walls is available in standard Construction Specifications Institute (CSI) format in the *Design Manual for Segmental Retaining Walls*, (ref. 1).

The traditional product/method specification, designating materials and installation requirements, stipulates that a site-specific design be performed by the engineer. Designs should be such that specified SRW and soil reinforcement properties can be met by a number of manufacturers, and should include properties of the on-site soil. SRW and soil reinforcement properties are then specified as the minimum properties that must be met.

In addition, the specification for SRW units may be found in ASTM C 1372, *Standard Specification for Segmental Retaining Wall Units* (ref. 3).

CONSTRUCTION

The success of any segmental retaining wall installation depends on complete and accurate field information, careful planning and scheduling,

the use of specified materials, proper construction procedures, and inspection.

It is good practice to have the retaining wall location verified by the owner's representative. Existing and proposed finish grades shown on the drawings should be verified to ensure the planned design heights are in agreement with the topographic information from the project grading plan. The contractor should coordinate the delivery and storage of materials at the site to ensure unobstructed access to the work area and availability of materials. Materials delivered to the site should be accompanied by the manufacturer's certification that the materials meet or exceed the specified minimum requirements.

Construction occurs in the following sequence:

1. excavation and leveling pad construction,
2. setting and leveling the base course,
3. filling unit openings with gravel (if applicable) and placing gravel fill behind the units ,
4. backfilling from the back of the gravel fill to the end of the reinforcement (if applicable),
5. compaction of backfill to the specified density in lifts of 8 in. or less from the front of the wall to the back of the reinforcement (if applicable),
6. placement of units, backfilling and compacting in succeeding courses,
7. placement of soil reinforcement, securing with the next course of blocks and the gravel fill before tensioning, and backfilling (when required),
8. capping and finish grading.

As with any structure used to retain soil, careful attention should be paid to the compaction equipment and procedures used during construction. When compacting soil within 3 ft (0.91 m) of the front face of a wall, compaction tools should be limited to hand operated or walk-behind equipment, preferably a vibrating plate compactor with a minimum weight of 250 lb (113 kg). Reinforced soil behind the 3ft area can be compacted with self-propelled riding compaction equipment.

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3. *Standard Specification for Segmental Retaining Wall Units*, ASTM C 1372-04e2. ASTM International, 2004.

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Freeze-Thaw Durability of SRW Units

By Cesar Chan and Ken Hover, Cornell University

ASTM C1262, *Standard Test Method for Evaluating the Freeze-Thaw Durability of Dry-Cast Segmental Retaining Wall Units and Related Concrete Units*, is the test method used for evaluating durability of segmental retaining wall units when subjected to repeated freezing and thawing. First published in 1994, this standard was developed through years of research and testing at NCMA, and was originally intended to be tested using relatively inexpensive testing equipment. The method is referenced in ASTM C1372, *Standard Specification for Dry-Cast Segmental Retaining Wall Units*, as one way to determine acceptable levels of freeze-thaw durability.

The ASTM C1262 test method was originally designed to be a simple and direct means of testing freeze-thaw durability of coupons cut from SRW units and partially immersed in plastic containers with a test medium of either fresh or salt water. As cycles of freezing and thawing accumulate, frost-susceptible specimens lose more mass than durable specimens, and various specifications reference the test method and prescribe fresh or salt water and a limiting percent of mass loss (often 1% of initial specimen mass) after a given number of cycles (often 100). The test method was intended to accommodate a range of SRW unit shapes and corresponding coupon sizes, and a wide range of laboratory freezer equipment. To determine whether the flexibility in the test method contributed to variability in test results, the National Concrete Masonry Association Foundation funded a study at Cornell University to answer three questions:

1. What are the effects of variations in coupon and container size and depth of coupon immersion?
2. What difference does it make if coupons cut from the same batch of SRW's are tested in two different freezers, both meeting the temperature requirements of ASTM C1262?
3. How does the mass lost in freeze-thaw cycles relate to the physical behavior of the material?

As shown in Table 1, coupons were cut from full-size SRW units at the NCMA Laboratory and shipped to Cornell in Ithaca, NY. Coupon sizes ranged from 4x8 to 3x6 inches. All coupons met the surface area requirements in ASTM C1262 Three different containers were used, and solution depth varied from 3/8 to 5/8 inches. ASTM C1262 specifies a solution depth of ½ ± 1/16 inch. All specimens were cut to 1¼ ± 1/16 in. thickness per ASTM C1262 and all tests were conducted using 3% sodium chloride (NaCl)solution by mass (30 g NaCl and 970 g water to make 1 kg of solution). All specimens in this test set (labeled "variability" were tested in the Tenney freezer as shown in Figure 1, and coupon mass was recorded after every 10th cycle. Average performance for each test set is shown in Figure 2.

While coupon and container size do make a difference, the results are clouded by significant differences in behavior among identically sized coupons in identically sized containers. As seen in Figure 2, coupons of Set E reached 1% mass-loss at around 110 cycles, while Set

Table 1. Test Sets in Variability Test Series

Set	Size of container[a]	Dimensions of specimen, mm × mm (in. × in.)	Specimen area, mm^2 (in.2)	Aspect ratio	Solution depth, mm (in.)	Approx. solution clearance[b] mm, mm (in., in.)
A	Lg Rect	100 × 200 (4 × 8)	20,000 (32)	1:2	13 ($^1/_2$)	30 L, 30 W (1.2, 1.2)
B	Lg Rect	100 × 200 (4 × 8)	20,000 (32)	1:2	10 ($^3/_8$)	30 L, 30 W (1.2, 1.2)
C	Lg Rect	100 × 200 (4 × 8)	20,000 (32)	1:2	16 ($^5/_8$)	30 L, 30 W (1.2, 1.2)
D	Sm Rect	100 × 200 (4 × 8)	20,000 (32)	1:2	13 ($^1/_2$)	5 L, 20 W (0.2, 0.8)
E	Sm Rect	75 × 150 (3 × 6)	11,250 (18)	1:2	13 ($^1/_2$)	30 L, 33 W (1.2, 1.3)
F	Sm Rect	113 × 150 (4$^1/_2$ × 6)	16,950 (27)	1:1.3	13 ($^1/_2$)	30 L, 15 W (1.2, 0.6)
G	Sq	133 × 150 (5$^1/_3$ × 6)	20,000 (32)	1:1.1	13 ($^1/_2$)	25 L, 15 W (1.0, 0.6)

[a]Container sizes as follows (more information provided in Section 2.0):
Lg Rect: inner dimensions of 260 × 160 mm (10.4 × 6.4 in.) at base of container
Sm Rect: inner dimensions of 210 × 140 mm (8.4 × 5.6 in.) at base of container
Sq: inner dimensions of 183 × 183 mm (7.3 × 7.3 in.) at base of container
[b]L: in the long direction, W: in the wide direction

G specimens reached the same level of damage at about 150 cycles. For the SRW units sampled in this study, all combinations would have passed a 1% mass loss in 100 cycles specification, but had their quality been slightly less robust, some coupon/container combinations may have been judged to have failed the test, while others passed. Analysis of the entire data set suggests that the test is more severe when a small coupon with a high surface to volume ratio is placed in a container considerably larger than the coupon. The test is apparently less severe when a large specimen with a low surface to volume ratio is placed in a container only slightly larger than the coupon. For this reason it is recommended that the range of specimen and container sizes currently permitted in ASTM C1262 be narrowed to reduce variability in results. Of concern, however, is the fact that SRW units come in many shapes and sizes, so the ability to remove the proper size sample from many different types of units would need to be evaluated.

While the "variability" specimens were being tested, a companion set of samples were tested in a walk-in freezer. The specimens used to compare the two freezers differed by no more than 7% in compressive strength (average 37 MPa (5390 psi) for specimens in walk-in freezer vs. average 35 MPa (5030 psi) for specimens in Tenney freezer) with oven-dry density (2230 kg/m^3 (139 pcf) in walk-in vs. 2210 kg/m^3 (137 pcf) in Tenney). Average 24-hr water absorption was similar for specimens in the two freezers at 127 kg/m^3 (7.9 pcf). Of the various test sets in the "variability" series, Test Set A specimens were similar to those tested in the walk-in freezer, which comprised nominal 200 x 100 x 32 mm (8 x 4 x 1¼ in.) size SRW coupons placed in 13 mm (½ in.) deep saline solution inside plastic containers of size 310 x 210 x 108 mm (12.3 x 8.3 x 4.3 in.). (Specimens in the walk-in freezer are labeled the "PC series.") While both freezers complied with ASTM C1262 temperature-time requirements, the results show dramatically different performance of otherwise similar specimens. After 100 cycles, Test Set A specimens in the Tenney freezer exhibited mass loss of 0.4% compared to 0.2% for specimens in the walk-in freezer (factor of 2). After 200 cycles, Test Set A specimens in the Tenney freezer exhibited mass loss of 4.4% compared to 0.8% for specimens in the walk-in freezer (factor of 5.5) (Figure 4). It is interesting that 2 of the 16 specimens in the walk-in freezer behaved similarly to those in the Tenney freezer. The other 14 were very different.

Figure 1. Variability specimens loaded in the Tenney Freezer.

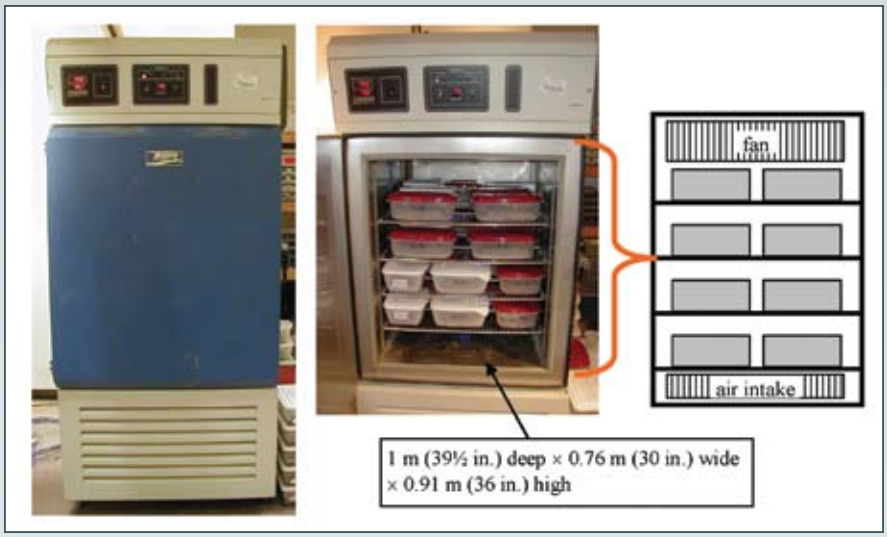
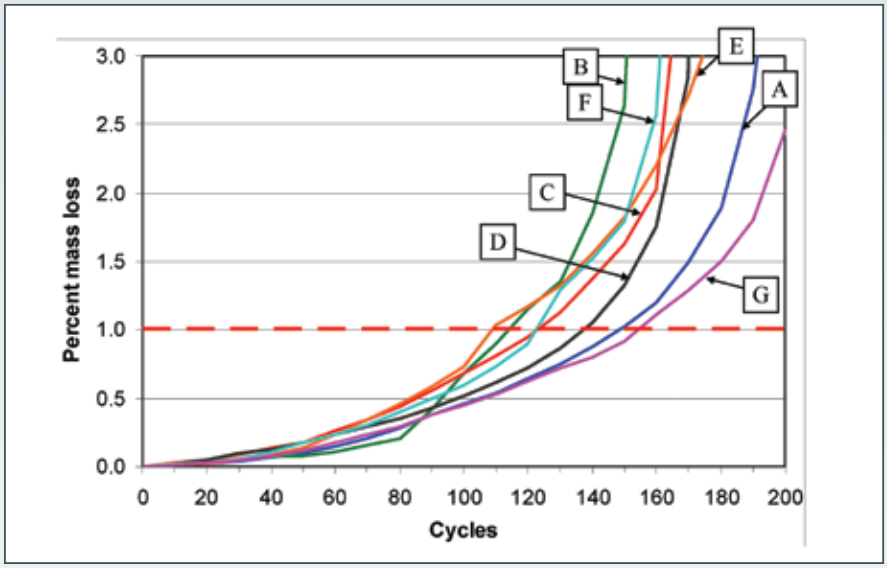


Figure 2. Average mass-loss for each set in the variability series.



Even though the environment in both freezers complied with the ASTM C1262 requirements for freezer air temperature, differences were measured in the actual rates of temperature change (cooling or warming) as follows:

- The air inside the Tenney freezer cooled about 3 times faster than the air in the walk-in freezer at the onset of ice formation in the solution surrounding the specimens. Water in the containers froze about 1.5 times faster in the Tenney freezer than in the walk-in freezer.
- The solutions reached different minimum temperatures during cold soak. In the Tenney freezer, the solution temperature reached –18°C (0°F); while in the walk-in freezer, the solution temperature reached –14°C (7°F).
- Before ice melted, the peak warming rate of freezer air was 1.5 times faster in the Tenney freezer than in the walk-in freezer. Moreover, the peak warming rate of frozen solution was 2.5 times faster in the Tenney freezer than in the walk-in freezer.

These observations suggest that to reduce variability in results the test method should also specify the complete freeze-thaw cycle including cooling rate, cold soak length and duration (with tighter temperature tolerances), warming rate and warm soak length and duration. Further research is needed to determine how each of these parts of the freeze-thaw cycle affects overall specimen performance. Some international research (referenced in the full report) suggest that a faster thawing

ASTM C 1262, Standard Test Method for Evaluating the Freeze-Thaw Durability of Manufactured Concrete Masonry Units and Related Concrete Units, was created in 1994 to specifically to evaluate the resistance to freezing and thawing damage of concrete masonry products made using a dry-cast process. Test specimens are partially submerged in water and sealed in flexible containers. Air temperatures around the containers are controlled for thaw cycles at 20°C (68°F) and for freeze cycles at 15°C (5°F). The method was written specifically to accommodate automatically cycling freeze-thaw chambers to perform up to three cycles per day as well as for conventional freezers.

For areas subject to repeated freezing and thawing under saturated conditions, durability must be demonstrated by proven field performance or testing. ASTM C1262 is the applicable standard if a test is specified. As such, the weight loss of five specimens (also cut coupons) must not exceed 1 percent over 100 cycles (or 1.5 percent over 150 cycles in four of five specimens).

Figure 3. Walk-in Freezer

rate will also increase damage to specimens since warming ice expands before it melts. Since the completion of this research, ASTM C1262 has been revised to require the use of a freeze-thaw chamber with characteristics of a "Tenney-type" chamber. Walk-in chambers are no longer permitted.

Cornell/NCMA work on this and previous projects also pointed out the critical effect of air temperature variations within a given freezer. As seen in Figure 5, some freezer locations come to the specified cold-soak threshold as much as ½ hour later than others, while the time required to reach the warm-soak threshold can vary by over 4 hours. It is also noted that the freezer's built-in temperature sensor from which overall operation is controlled is consistently the coldest location during he cooling cycle and at the warmest location during the warning cycle. To help reduce the effect of location within the chamber on test results, specimens are rotated within the chamber at each residue collection time. Beyond mere shuffling of specimen locations every 10 cycles, it is important to perform a survey of freezing equipment being used for the ASTM C1262 test to quantify this internal variation. The survey must be conducted with the specimen and container load anticipated during testing, since internal temperature is a function of the cooling and heating capacity of the unit and the thermal load. An appendix to the full research report includes instructions for performing this survey and for setting the duration of the cold-soak to minimize the number of specimens that are over-cooled or under-cooled. It was also observed that for any given freezer there is a minimum duration of the warm-soak period to bring the apparatus back to a uniform starting temperature for the overall thermal cycle. Shortening the warm-soak can lead to inconsistent freeze-thaw cycles.

Figure 4. Mass loss comparison between specimens in Test Set A and PC Series

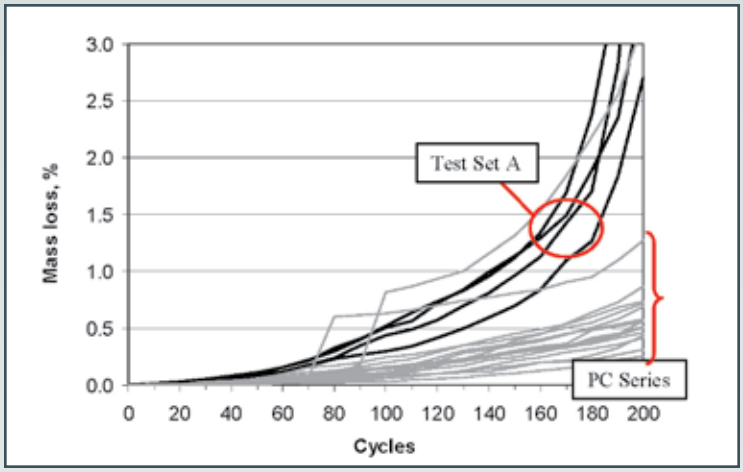
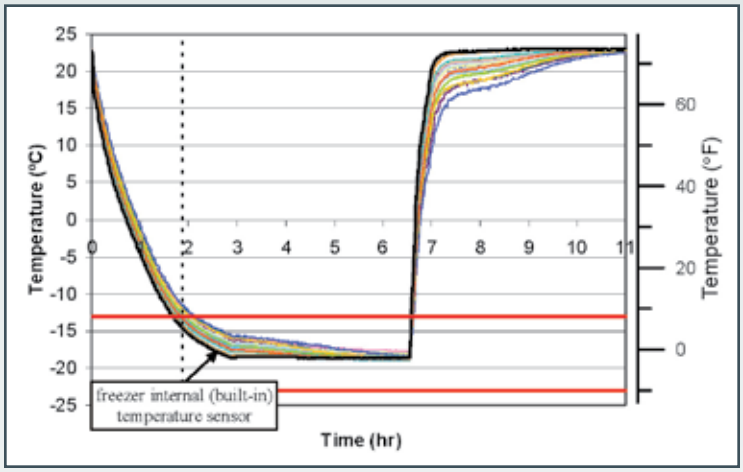


Figure 5. Variations of air temperature within the Tenney freezer



The entire 271 page final report from this research at Cornell University is available at the NCMA Foundation website, www.ncma.org/foundation.

Subsequent to this research, several changes were made to ASTM C1262, to better clarify the details of the test. As mentioned before, the chamber requirements were tightened, and currently revisions are underway to require monitoring of the temperature within the chamber during the test.

Additionally, NCMA and Cornell University have a new research project underway. This project is looking closely at the freezing and thawing cycle, specifically at the cooling and heating rates. The goal of this research is to determine the appropriate freeze-thaw cycle, and to include that within the test method to further reduce variability. CMD

ASSOCIATION NEWS

VISION 2020 CONTINUES TO GROW

VISION 2020 is a grassroots effort that will promote masonry to cities, counties and municipalities across the United States and Canada by explaining the advantages of building with masonry products. The focus of the VISION 2020 program will be to share a long-term vision with communities as they look to their future needs. VISION 2020 also has a goal of uniting the masonry industry so that in the long run the entire industry will benefit. Another component to the plan is to create "toolkits" to be utilized by local teams in their educational efforts in their communities. There exists a wealth of information and marketing materials that has been developed over the years by the wide array of promotional organizations in the masonry industry. Every member is asked to identify and supply information about their most effective marketing materials. Please take a moment to review your materials and forward information or a copy to Harry Junk, hjunk@ncma.org.

NCMA WELCOMES NEW MEMBERS

Please take a moment to welcome our newest members aboard and to reach out to them by inviting them to get involved and begin reaping the many benefits of membership:

- **NessTech Concrete Molds, Inc**. (Associate), **Jeffrey Ness**, Vice President, jeffn@ness-tech.com, Oakdale, MN, 651-777-4511, www.ness-tech.com . Molds and mold parts.
- **Garden Square Landscaping Inc.** (SRW Contractor), **Ross Causey**, SRW Installer Trainer, rosscausey@aol.com, Kennett Square, PA, 610-444-0207, www.gardensquarelandscaping.com.

If you know a producer or supplier that would benefit from membership in NCMA, contact the Membership Manager at hweiss@ncma.org.

NCMA ANNOUNCES 2010 MIDYEAR DATES AND LOCATION

NCMA will conduct the 2010 summer Midyear meeting at the Westin River North Hotel in Chicago, July 28–August 1. The Midyear meeting serves as the forum for important committee program planning, budgeting and priority setting activities. Contact NCMA's meetings department for additional information (703)713-1900.

INDUSTRY NEWS

WORLD CENTER FOR CONCRETE TECHNOLOGY ONLINE TRAINING

The World Center for Concrete Technology (WCCT) in Alpena, Michigan has released its 2010 schedule of online courses serving the concrete industry. Sixteen different courses are now available covering a wide range of subject content, including new courses in "Self-Consolidating Concrete" and "Concrete, Sustainability, and LEED®." Most of these online courses are 8 weeks in length and are scheduled to start at various times thought 2010. These courses are also instructor lead, so students have direct access throughout their course to content experts from around the country. The WCCT has lowered the cost of all their online classes to $350 per course, plus any required books (with the exception of "Introduction to Concrete Technology"). For additional information on these and other training courses offered by the WCCT, visit their website at www.wcct.net or call 989-358-7238.

LOCAL NEWS

NCMCA SIGMON SCHOLARSHIP

The North Carolina State University team of Erika Jolleys (second from left) of Manchester, England, Rebecca Hora (third from left) of Bridgewater, Connecticut, and Ana Milliones (fourth from left) of Charlotte has claimed the North Carolina Masonry Contractors Association 2009 Sigmon Memorial Scholarship Masonry Design Award and will share a semester's in-state tuition as their prize. NCMCA Past President Doug Burton (third from right) and Matt Griffith (first on left) an architect in the architectural office of Frank Harmon, Raleigh served as jurors for the October 15th competition. The competition is part of Professor Patrick Rand's (first on right) "Architectural Construction Systems" class at North Carolina State University's College of Design. Matt Griffith has the distinction of being the first contest judge that actually participated in the NCMCA design competition when he himself was a student in the Rand class. The scholarship is named in memory of David, Randy, and Dwayne Sigmon. 2009 marks the ninth year for the NC State/NCMCA design competition.

INDUSTRY NEWS

2009 INTERNATIONAL CODES FINALIZED

In the fourth and final series of meetings to finalize the 2009 editions of the International Codes (including the International Building, Residential, Fire, Energy Conservation, and related Codes) several thousand governmental officials, fire fighters and fire marshals, and industry representatives converged on Minneapolis September 14 through 23, 2008 to review and approve the latest design and construction revisions to the 2006 International Codes. The following list summarizes a few of the nearly 9,000 change proposals debated throughout this process, but is by no means intended to be a comprehensive review. A full summary of the actions taken in recent weeks can be viewed at the following link: http://www.iccsafe.org/cs/codes/2007-08cycle/results-MN.html

- **Adoption of 2008 TMS 402/ACI 530/ASCE 5 and TMS 602/ACI 530.1/ASCE 6**—The 2008 edition of the Masonry Standards Joint Committee (MSJC) Code and Specification will be referenced by the 2009 International Residential and Building Codes (IRC and IBC). This national masonry standard includes the latest design and construction requirements for masonry, including updates to structural design requirements, clarified and reorganized seismic detailing provisions, and updated construction practices, including the use of self-consolidating grout. As part of the adoption of the 2008 MSJC, the masonry design provisions in the IBC provisions have been significantly streamlined through the removal of redundant and confusing requirements.
- **Residential Fire Sprinklers**—In a groundbreaking change, the International Code Council (ICC) membership overturned previous recommendations and will now require all residential dwelling units constructed to the 2009 International Residential Code (IRC) to be protected by an automatic fire sprinkler system.
- **Structural Integrity**—In partial response to the attacks on the World Trade Center Towers, a series of new structural integrity provisions have been introduced for high rise buildings to help mitigate the potential for progressive collapse subsequent to an isolated failure or damage to a structure. These new design and detailing provisions can be easily met with reinforced masonry construction.
- **Impact Resistance**—For certain high-risk buildings and for all buildings more than 420 feet in height, wall assemblies of exit and elevator enclosures must now be constructed of materials resistant to soft body and hard body impact. Due to their proven robustness and resilience to impact resistance, concrete and masonry assemblies are automatically deemed to comply with these new requirements.
- **Gravel Ballast Roofing Materials**—A series of proposals to expand the use of gravel ballast roofing materials in hurricane regions and high-wind zones was disapproved. Investigations following natural disasters, including Hurricane Katrina, repeatedly demonstrate that concrete roof pavers and similar ballast systems outperform gravel ballast and result in less damage by minimizing wind-borne debris.
- **Air Barriers**—Proposed requirements to place unsubstantiated requirements to test for air leakage of new buildings into the International Energy Conservation and Building Codes were disapproved. While the masonry industry remains resolved in identifying and implementing energy saving measures into the built environment, the proposed performance criteria were based on inaccurate and outdated data and could not be feasibly executed in the field. As a compromise, the ICC membership approved a clarification to existing air barrier requirements for residential construction that permits either visual inspection or whole-house testing to ensure that the building envelope has been property sealed.
- **Foundation Dampproofing**—Proprietary exemptions to permit precast concrete foundation walls to be installed without dampproofing membranes were disapproved citing their lack of technical justification or demonstrated field performance.

Representing the masonry industry and the Masonry Alliance for Codes and Standards (MACS) at these hearings included Canan D'Avela (Arizona Masonry Guild/Western Block Co.), Ed Freyermuth (Arizona Masonry Guild/Superlite Block-Oldcastle), Chip Clark (Brick Industry Association), Steve Skalko (Portland Cement Association), and Jason Thompson (National Concrete Masonry Association). For more information on the activities of the International Code Council or the I-Code development process, please contact Jason Thompson; jthompson@ncma.org.

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Detail of the Month

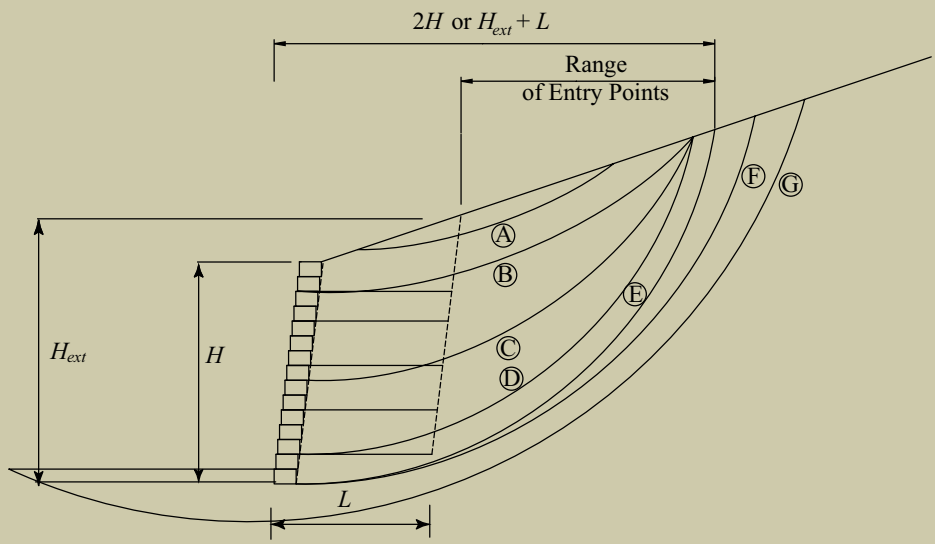
Internal Compound Stability

As the name implies, Internal Compound Stability (ICS) affects the internal components of the retaining wall system, including the facing elements, and its components. Because ICS is influenced by loading conditions outside the reinforced fill area, it is referred to as a compound analysis. It should be clear that ICS analysis is not a substitute for Global Stability analysis. For all intents and purposes, it is a special case of the broader, more generalized Global Stability analysis.

ICS analysis is the evaluation of failure surfaces that originate in a given range behind a soil-reinforced SRW, exiting at the face of the wall. The distance is the greater of twice the height of the wall (2H) or, the height of the projection from the tail of the reinforcement layers to the surface (H_{ext}) plus a distance equal to the length of the reinforcement (L).

Examples of potential circular failure surfaces are indicated in the figure below. Except for the surfaces described by A, F and G in this figure, the remaining will be considered in the ICS analysis. These surfaces describe failure planes that are outside the scope of this design manual. The surface described by A is considered to be a surficial stability concern and should be identified by the geotechnical engineer. The surface described by F includes the contribution of the foundation soil which, although important, is not part of this analysis. The surface defined by G is a global stability consideration outside the scope of ICS. The remaining surfaces, which fall directly within the retaining wall structure, will be considered in the analysis.

For given soil parameters, the soil-reinforced SRW's resistance to ICS failures is a function of reinforcement length, long-term design strength, vertical spacing, as well as the relative stiffness of the facing elements.



Source: *Design Manual for Segmental Retaining Walls, 3rd Edition*, NCMA.

Ⓐ Surficial Stability: This mode of failure is not considered in the ICS analysis.

Ⓑ Ⓒ Ⓓ Internal Compound Stability: For a given pair of entry points and exit points (block/block interface only), a series of circular failure surfaces are generated and analyzed. Included in the analysis is the contribution of (when applicable) :
- Block/Block Shear Capacity
- Block/Reinforcement/Block Shear Capacity
- Connection Capacity
- Reinforcement Tensile Capacity
- Reinforcement Pullout Capacity
- Leveling Pad sliding resistance

Ⓔ Internal Compound Stability (Bottom Block): Only circular failure surfaces tangent to the base of the bottom block will be analyzed.

Ⓕ Outside entry point limits: This mode of failure is not considered in the ICS analysis.

Ⓖ Global Stability: This mode of failure is not considered in the ICS analysis.

Scope of Internal Compound Stability (ICS) Analysis

AIA Continuing Education Learning Program

Learning Units Reporting Form

AIA Questions (Circle the correct answer)

1. In tall SRW construction it is very important to use high quality compactable soil with a low plasticity index (PI) to minimize differential settlement.
   a. True
   b. False

2. Global stability rarely governs in the design of SRWs particularly in tall walls
   a. True
   b. False

3. The correct way of installing geogrid is
   a. To connect it to the facing, then pull it back and stake it tight
   b. When placing the backfill, start at the tail of the geogrid and fill towards the facing
   c. When placing the backfill, start at the facing and fill towards the tail of the geogrid
   d. a and b above
   e. a and c above

4. Generally in tiered wall construction, if the upper wall is placed within ____ times the height of the lower wall, a load from the upper wall will be applied to the lower wall.
   a. 2
   b. 3
   c. 4
   d. a and b above
   e. All of the above

5. Global stability is the analysis involving SRWs is
   a. Long term stability in the sloping soil above a retaining wall and within a horizontal distance of 2H or Hext + L from the wall
   b. Long term stability in the soil within a horizontal distance of 2H or Hext + L from the wall and the SRW facing
   c. Long-term stability around the SRWs

6. If an Internal Compound Stability (ICS) analysis is performed on an SRW, a Global Stability analysis is not needed.
   a. True
   b. False

7. The Load and Resistance Factor Design (LRFD) method will be required by AASHTO for public sector Mechanically Stabilized Earth (MSE) walls by October 2010.
   a. True
   b. False

8. The current LRFD methodology as related to the Allowable Stress Design (ASD) method results in designs that are:
   a. Significantly more economical
   b. Relatively close
   c. Far more conservative

9. The standard used for evaluating the durability of segmental retaining wall units subjected to repeated freezing and thawing is
   a. ASTM C33
   b. ASTM C90
   c. ASTM C1272
   d. ASTM C1372

10. Due to the variability of results in different testing methods of SRW units for freeze-thaw durability, the following changes have been made to the applicable ASTM standard
    a. Walk-in chambers are no longer permitted
    b. A freeze-thaw chamber with the characteristics of a "Tenney-type"chamber is required.
    c. All of the above
    d. None of the above.

To receive one learning unit, read Skyline Ridge, Global Stability and Segmental Retaining Walls, Load and Resistance Factor Design Method, Freeze-That Durability of SRW Units, and complete the questions on this page. Return this form to the National Concrete Masonry Association.

Return forms before December 2010 to receive learning unit credits.

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December 2009

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