SRW: A NEW DIMENSION IN LANDSCAPE DESIGN

BY ENGR. SYED FAIZ AHMAD
Saudi Oger Ltd
Riyadh, Saudi Arabia

ABSTRACT

Segmental Retaining Walls (SRW) are reinforced-soil earth-retention structures, sort of composite structures relying on the principles of soil-structure interaction. These are extensively tried & tested and have proved to be an useful alternative technique for soil-stabilization, earth-retention and are fast replacing the conventional concrete retaining walls; principally due to the merits offered by it in trusted performance, economy and ease of construction. This type of design is already very popular in North America, where this technique is being commonly used for the earth-retention problems. This system is of great interests to the academics & the industry and if introduced in the Kingdom of Saudi Arabia, this has great potential of becoming popular here as well. This paper is therefore focused to generate awareness about SRW in the region.

INTRODUCTION

Segmental Retaining Walls (SRW) are dry stacked, mortar-less walls made of 100 % low absorption, high strength concrete units. SRWs are comparatively more economical and easier to install than cast-in-place concrete or conventional masonry walls. Its principal features are as follows:

- It is mortar-less.
- No footings are required.
- It is flexible, and tolerates movements.
- Walls up to 1.2 m high can be built without any geo-synthetic soil reinforcement, as shown in Figure 1.
- Walls greater than 12 m height can be built with geo-synthetic soil reinforcement, as shown in Figure 2.
- It is easy to build and economical as compared to conventional concrete walls.
- Curves, corners, stairs, columns and freestanding walls can be easily created with great variety of commercially available design patterns.

SRW is of interest principally to Landscape Designers, such as landscape architects, site/civil engineers, geotechnical and structural engineers, while contractors & inspectors also find interest in it. With the popularity of and trust & faith in SRW, vis-à-vis its applications, as retention structures in public gardens, community & private homes, highway earth retention structures, etc., it is now possible to create beautiful landmarks with comparative ease & economy. Until recently, it used to be too expensive to design something to make it look nice & appealing. However, today the hard-scape is becoming more of a landscape. And, as rightly said by some engineers, "we're seeing a boom in what we call pretty structural engineering".

Today in USA and other parts of the developed world, SRW is considered the one and the only ticket to many a challenging problem faced to the landscape architects, geotechnical and structural engineers. To name a few real life challenges, the first one is building of an upscale town-house community project called HIGHLANDS on top of a 19 m cliff in northern New Jersey. Being located on a cliff, the project required some innovative techniques for transforming mountainous rock into livable space together with ensuring the stability and integrity of the surrounding terrain. To surmount these and other daunting challenges, SRW system was selected for its design flexibility, aesthetics, ease of installation and durability. SRW system was thus considered the perfect fit and using the same as compared to a cast-in-place or any other type of wall

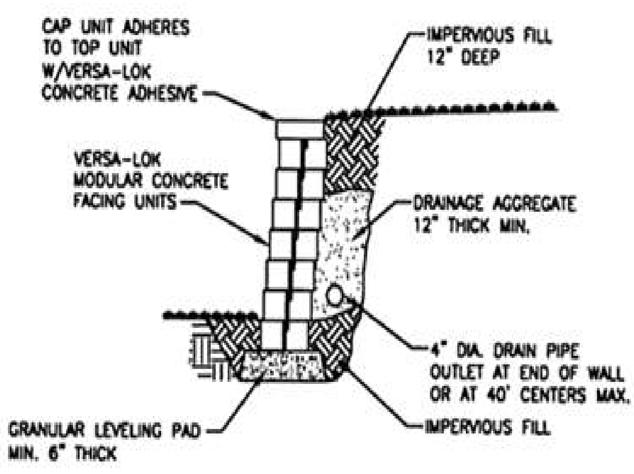

Figure 1: Typ. Section-Unreinforced Retaining Wall

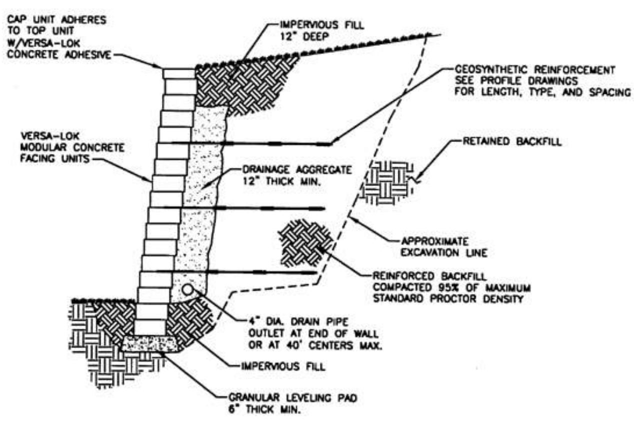

Figure 2: Typ. Section-Reinforced Retaining Wall

system was by far the most aesthetically pleasing and cost-effective choice [1].

In yet another equally challenging project, the Irvine Company (Orange County, California) was faced with a challenge to develop the steeply sloping site, at Newport Coast to develop a luxury community. SRW with integral space for vegetation helped the company realize its goals. Developing the hillside coastal site for Newport Coast were posed with numerous challenges, chiefly: preserving the appearance of a natural hillside, tackling the technical challenges of drainage, slope stability, consideration of floodplains and wetlands, besides the structural issues that building in the earthquake zone entails. One option was to go ahead with Mass Grading with linear tiers; this was not considered for obvious reasons. However, choosing SRWs allowed the Company to adopt Contour Grading, in agreement with the natural topography of the site, with economic benefits and reduced site development.

The scope of this paper is focused to introducing this new & novel method of earth-retaining system to the engineers, the academics, and to a layman who in the capacity of a home-owner, a client and/or a commercial builder would be interested in considering adopting this in any of his/her project. For this purpose a discussion follows on the evolutionary history of SRW, its design philosophy, its construction details and information on SRW standards the future design code that is in the process of its formulation.

EVOLUTIONARY HISTORY OF SRW

SRW has a remarkable evolutionary history that dates back to early-to-mid 1970s in Canada where it was basically invented by Angelo Risi, the founder of Risi Stone Systems. The Segmental Concrete Wall units produced on concrete products machines were marketed then, in USA and Canada, under the name of Pisa Stone, after the Leaning Tower of Pisa in Italy. In one of his articles Angelo Risi described how and when the idea of SRW came to his mind. He wrote, "*I noticed, especially in the street where I lived, that the municipality used to tear down and put back up, almost every second year, some rubble walls*". He continued, "*Sometimes they would use broken pieces of sidewalk stacked up*". According to him, "*with the frost we have in Canada, invariably the wall would start moving around and in a couple of years they would be rebuilding it all over again*". He added, "*I thought to myself, my uncle is in the business, and if he could build something that would lock itself into place, that would solve the problem of constantly rebuilding these walls*". He further added, "*We came up with the idea of basically a slab with a broken face and a tongue and groove to it so that they would lock into each other. We tried it, and we called it Pisa Stone after the Leaning Tower of Pisa in Italy*". This is how SRW system was conceived and invented by Angelo Risi. The result was well received and, over the years, Risi and his brother Tony bought their uncle's concern and created Risi Stone Manufacturing, Thornhill, Ontario. They started making Retaining Wall systems, as well as continued some products that their uncle was making at that time. Less than a decade later, a couple of others (that includes two of the major industry leaders of the US today) introduced their own proprietary systems in the US and the growth of the industry began in earnest.

By the end of the 1980s, there were several more proprietary SRW systems licensed in the US and in other parts of the globe. And, from the late 1980s SRW use grew at a rate of 20 to 25% annually. In 1998 the National Concrete Masonry Association (NCMA) organized a meeting of over 30 stakeholders in the SRW industry. The group consisted of concrete products manufacturers, licensors, material vendors, engineers and others with interest in the SRW market. The consensus of the group after approximately six hours of deliberations was that use of SRW would double by 2003. This indeed did happen more or less the same. The evolutionary history of SRW and the achievements of Angelo Risi is summed up in one beautiful expression, "*After all these centuries, it only took imagination and engineering, and a desire to help his*

Plate-1: Landscaping in Front of a Villa

Plate-2: Landscaping in Front of a Villa

Plate-3: SRW for a Golf Course

Plate-4: SRW for a Community Park

community save money, for an inventor to develop the Segmental Retaining Wall system" [2].

Segmental Retaining Wall units are considered a high-end value-added product, which have evolved into a significant part of the product mix of many concrete masonry-manufacturing operations. It has especially grown during the past 15-20 years to become a popular choice as an earth-retention structure, replacing in most applications the conventional concrete retaining wall, and becoming a popular alternative in the landscape designs. But all these didn't occur overnight. It is stated that the ongoing success of the SRW is a direct result of the investment of the major concrete industry licensors into the multi-faceted marketing efforts. It is a fact that this is the actual fuel that drives the industry. From education and design guides to exhibits at trade shows, these significant financial & human resources maximize the popularity of SRWs. It is also agreed that the success of SRWs is a blueprint that can be emulated in all aspects of the concrete business everywhere. Blending attractive, quality and proven products with qualified people, and investing in strong marketing measures, all add up to long term financial gains and industry growth.

One may ask as to why does the use of SRW systems continue to grow. The answer to this difficult question is rather simple. That is, the SRW systems are in fact environmentally friendly, easy to construct, aesthetically appealing & economically proven, and offer flexibility and versatility in design. In June 1998, Drexel University in Pittsburgh, Pennsylvania published Geosynthetic Research Institute Report # 20, entitled, "Earth Retaining Walls Costs in the USA", authored by Dr. Robert M. Koerner et al, which documents the relative costs of various styles of retaining wall systems. The SRWs are stated to be clearly the most economical one [3]. Some pictures of use of SRW in landscaping are shown as above.

DESIGN PHILOSOPHY

SRWs systems are basically a sub-set of Mechanically Stabilized Earth and for all-purpose are principally Earth Retention Structures. For normal conditions, experience has shown that SRW systems work solely as Gravity Systems, where unit weight provides resistance to earth pressures. Frictional forces between units and tight pin connections hold units together so walls behave as one coherent structure. When weight of units alone is not adequate enough to resist soil loads, horizontal layers of geo-synthetic materials are used to reinforce the soil behind walls. The choice of type, thickness, embedment lengths, and number & spacing of layers of these synthetic materials are all dependent on actual ground conditions and are determined by proper design undertaken by structural engineers. Design of SRWs is a serious subject and is dependent on several factors including: soil parameters at the site such as unit weight, internal friction angle and cohesion, ground water table, and the height of wall.

It is important to mention here that globally SRWs are designed using the NCMA Design Manual for Segmental Retaining Walls known as NCMA Publication # TR-127A. This Design Manual is recognized worldwide as a valid design methodology for SRWs. In fact, the NCMA Design Manual is cited by the US Army Corps of Engineers as an acceptable Design Methodology for SRWs on Corps' projects. Reference to provisions in the Design Manual are also found in the American Association of State Highway and Transportation Officials (AASHTO) which is adopted by nearly all the State highway transportation departments within the US and is also often specified in local commercial and international projects. This Design Manual is also supplemented by a Design Software for Segmental Retaining Walls termed as NCMA Publication # CMS-11711. There is also a Seismic Design Manual and Software (NCMA Publication # TR-160 + CMS-11711) for undertaking design under seismic loading conditions. NCMA Publication # TR-212 (Retaining Walls—A Building Guide and Design Gallery) is yet another bestseller. This was printed in 2003 and this is by far the only authentic book on the subject of SRW installation. In addition, the book includes a gallery of beautiful completed SRW projects from commercial to residential and engineered to do-it-yourself. All these Design Manuals remain incomplete without the Segmental Retaining Wall Drainage Manual (NCMA Publication # TR-204), which extends the Design Methodology to hydrostatic loading that may be required to address the presence of sub-surface water and surface water infiltration. This is also focused to help prevent poor SRW performance when surface and ground water issues are not properly addressed. It is worth noting that SRW performance problems are commonly attributed to the failure to properly route water during and after construction or account for hydrostatic load during the design phase. This Manual ensures adequate guidance is available to the design community and preserves the integrity of the SRW industry.

The design analysis of SRW employing the NCMA Design Manual for Segmental Retaining Walls considers the External Stability against sliding and overturning. It also considers Internal Stability and Facial Stability of the reinforced-soil mass. This Design Manual performs Internal and External Stability analysis using the recommended minimum factors of safety in this manual.

Global Stability analysis is also important in SRW design, particularly when walls are over 2 m tall, are tiered, involve slopes steeper than 3H:1V, or are to be constructed on soft soils. It involves the general mass movement of the wall structure and the adjacent soil. This particular aspect of Stability Analysis of SRW is however handled by yet another NCMA publication called TEK-15-4A: SRW Global Stability Analysis [4].

CONSTRUCTION DETAILS OF SRW

It is needless to underscore the fact that regardless of the time and money spent on developing, designing and manufacturing quality products and systems, the ultimate test is the product or system's performance in the field. It is more often the case, than not, the installation of products dictates how they will perform and be perceived by the public or owner. It is a fact that one such product in which performance is directly controlled and often measured by installation practices is Segmental Retaining Walls.

The basic construction steps are simple but should be understood thoroughly to ensure that the end-product comes up to the expectations of the end-users. These steps in the sequential order are described as follows with some caveats to be specifically noted and complied:

a. **Inspection:** The site should be thoroughly inspected. Unusual ground conditions should be noted and reported to the Designer.
b. **Excavation:** The site should be excavated to the lines and grades shown on the project grading plans. All surrounding structures should be protected from the effects of wall excavation.
c. **Foundation Preparation:** Following the excavation, the foundation soil should be examined to assure the actual soil strength meets or exceeds the assumed Design Bearing Strength. Soils not meeting the required value should be removed and replaced with infill soils as directed by the Designer. Foundation soil should also be proof-rolled and compacted to 95 % standard proctor density and inspected prior to placement of leveling pad materials.

d. **Leveling Pad Construction:** Leveling Pads should be placed as shown on the retaining wall plans with minimum thickness of 150 mm. The Leveling Pads should also extend laterally at least a distance of 150 mm from the Toe and Heel of the lower most SRW unit. Granular Leveling Pad material should be compacted to provide a firm, level bearing surface on which to place the first course of units. Well-graded sand can be used to smooth the top 6 to 12 mm of the Leveling Pad. Compaction should be with mechanical plate compactors to achieve 95 % of maximum standard Proctor density.

e. **SRW Unit Installation:** All SRW units should be installed at the proper elevation and orientation as shown on the drawings. The SRW units shall be installed in accordance with the manufacturer's recommendations. First course of SRW units should be placed on the Leveling Pad. The units should be leveled side-to-side, front-to-rear and with adjacent units, and aligned to ensure intimate contact with the Leveling Pad. The first course is the most important to ensure accurate and acceptable results. No gaps should be left between the front of adjacent units. All debris should be cleaned from top of units and the next course of units installed on top of the units below. Connection pins should be inserted through the pinholes of each course unit into receiving slots in lower course units. Pins should be fully seated in the pin slot below. Units should be pushed forward to remove any looseness in the unit-to-unit connection. Prior to placement of next course, the level and alignment of the units should be checked and corrected.

f. **Geo-synthetic Reinforcement Placement:** All geo-synthetic reinforcement should be installed at the proper elevation and orientation as shown on the drawings. The highest strength direction of the geo-synthetic must be perpendicular to the wall face. Also, geo-synthetic reinforcement layers should be one continuous piece for their entire embedment length. Splicing of the geo-synthetics in the design strength direction (perpendicular to the wall) is not permitted. Utmost care should be taken for the geo-synthetic reinforcements already laid. For instance, tracked construction equipment should not be allowed to operate directly on the geo-synthetic reinforcement. A minimum of 150 mm of backfill is required prior to operation of tracked vehicles over the geo-synthetic. Rubber-tired equipment, however, may pass over the geo-synthetic reinforcement at slow speed, which is at less than 8 kph. The geo-synthetic reinforcement should be free of wrinkles prior to placement of soil fill. The nominal tension should be applied to the reinforcement and secured in place with staples or by hand tensioning until reinforcement is covered by 150 mm of fill.

g. **Drainage Materials:** Drainage aggregate should be installed to the line, grades, and sections shown in the drawings. The aggregates should be placed to the minimum thickness shown on the drawings between and behind units. Drainage collection pipes should be installed to maintain gravity flow of water outside the reinforced soil zone. The drainage collection pipe should daylight into a storm sewer or along a slope, at an elevation lower than the lowest point of the pipe within the aggregate drain.

h. **Backfill Placement:** The reinforced backfill should be placed as per details in the drawings in the maximum compacted lift thickness of 250 mm and should be compacted to a minimum of 95 % of standard Proctor density, at a moisture content within 2 % of optimum. The backfill should be placed and spread in such a manner as to eliminate wrinkles or movement of the geo-synthetic reinforcement and the SRW units. Only hand-operated compaction equipment should be used within 1 m of the back of the wall units. Compaction within 1 m behind the wall units should be achieved by at least 3 passes of a lightweight mechanical tamper, plate or roller. At completion of wall construction, backfill should be placed level with final top of wall elevation. And, in any case care should be taken to ensure water runoff is all the time directed away from the wall face.

i. **SRW Caps:** SRW caps should be properly aligned and glued to underlying units with appropriate adhesive. Rigid adhesive or mortar is, however, not recommended. It is desirable that the caps overhang the top course by about 20-25 mm. Slight variations in overhang are, however, are acceptable to correct alignment at the top of the wall.

j. **Construction Adjacent to Completed Wall:** The construction activities adjacent to the completed wall should not be allowed to disturb the wall in any manner. Heavy paving or grading equipment should be kept a minimum of 1 m behind the back of the wall face. Equipment with wheel loads in excess of 7 KN/m² should not be operated within 3 m of the face of the retaining wall during construction adjacent to the wall [5].

STANDARDS AND THE FUTURE DESIGN CODE

Material property testing is essential and SRW units are no exception. Recently the focus of material property testing within the SRW industry has shifted from geo-synthetics to SRW units. It is reported that now owners, designers, and specifiers are increasingly requiring SRW unit durability and geo-synthetic interface testing on their projects in addition to unit physical properties. The increasing number of new SRW units entering market makes it imperative to understand the performance of these units from the standpoint of material property, durability, and geo-synthetic interface.

Evaluation of physical and durability properties of SRW units is conducted in accordance with ASTM C1372 (Standard Specification for SRW units) and ASTM C1262 (Standard Test Method for Evaluating the freeze-thaw durability of manufactured Concrete Masonry), respectively. Furthermore, Geosynthetic-to-SRW unit interface capacity is tested according to ASTM D6638 (Standard Test Method for determining Connection Strength between geo-synthetic reinforcement and Segmental Concrete units) and NCMA SRWU-2, which is to do with Determination of Shear Strength between Segmental Concrete Units.

Although there are facilities available commercially elsewhere also, however, NCMA is cognizant of its responsibilities and as such has equipped the NCMA Research and Development Laboratory to conduct multiple testing programs for determining the performance characteristics of SRW units. NCMA is working in close cooperation with all the stakeholders in developing Specifications, Design & Manufacture of the systems through the Industry Design Guides, ASTM standards, specifications & test methods, and Manufacture Quality Control and Assurance plans. As a result we have seen remarkable developments in the industry of SRW. Recently ASTM approved a new Standard for testing the Shear Capacity of SRWs. Developed within ASTM D35 Geo-synthetics Committee, Standard Test Method for determining the Shear Strength between Segmental Concrete Units (modular concrete blocks) is used to determine the Shear Strength between two layers of SRW units. The test is carried out under conditions determined by the user that reproduce the facing system at full scale. The results of a series of tests are used to define a relationship between Shear Strength developed between Segmental Concrete units and normal load. This data is then utilized within SRW Design Software, such as NCMA's SRWall Ver 3.22, to evaluate the Facing Stability of conventional gravity and reinforced soil SRWs. This Standard is identified as ASTM D6916.

NCMA is also actively engaged with ANSI (American National Standards Institution) in development of a National Standard for SRWs. NCMA created a Committee comprised of Designers, Producers, Specifiers and Academics that was entrusted to oversee the development process and abide by ANSI guidelines. The NCMA Board of Directors supported Committee recommendations to review a new Draft Standard incorporating revised Internal Stability provisions. The members of the SRW design Manual and SRW-ANSI Task Groups have worked vigorously to develop a revised Standard that incorporates New Internal Design provisions. They presented to ANSI Standard Committee, responsible for seeking consensus to the Building Code Requirements for Design of SRW, with revised Internal Provisions based on a Trapezoidal Earth Pressure distribution in place of the classical Rectangular distribution. The proposed Distribution is supported by many years of research, including NCMA funded research conducted at the Royal Military College of Canada.

The Task Group members met and reviewed results from a parametric study evaluating the effects of the proposed new Internal Distribution on final geo-synthetic requirements. The study also considered the impact of geo-synthetic spacing, geometry of backfill above the top of Wall and Wall batter. Upon review of the Study results, it was determined that incorporating the revised Earth Pressure Distribution was founded on sound engineering principles and provided designs that appropriately model structural performance as seen in field instrumented structures. This finding is revolutionary indeed.

The new Draft Standard (Building Code Requirements for Design of Segmental Retaining Walls) is supposed to be balloted to the ANSI Standards Committee and finally the Draft for the development of the SRW model Building Code is due to be submitted to the International Code Council for final adoption as an ANSI recognized SRW Standard in the 2006 International Building Code [4,5,6].

CONCLUSIONS

SRW is a time-tested earth-retaining and earth-stabilizing technique, which has successfully made in-roads into the construction industry worldwide. The architects, structural & geotechnical engineers and the contractors now prefer this system over the conventional reinforced concrete cantilever retaining walls for many reasons; the economy being the over-riding factor. However, this system is little known in this part of the world. Hopefully with this article, SRW will be understood and introduced here also on large scale.

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