SRWs Connection Strength - How Much is Enough?

In North America, the use of segmental retaining walls (SRWs) has gained wide acceptance as an economical alternative to both conventional cast-in-place concrete retaining walls and mechanically stabilized earth (MSE) walls using metallic reinforcements. Procedures for determining the internal and external stability of SRWs, and for determining the long-term allowable strengths of the reinforcement have become well established state-of-the practice procedures (i.e., NCMA Design Manual for Segmental Retaining Walls - Second Edition, AASHTO 1997 Interim Bridge Specifications). However, there still exists some controversy with respect to the design of the connection between the segmental retaining wall units and the geosynthetic reinforcement. The interaction between the geosynthetic reinforcement and the SRW unit at each reinforcement placement elevation must have sufficient connection strength to preclude rupture or slippage of the reinforcement due to the applied tensile load at the face of the wall . Connection strength is an important consideration when designing an SRW, and if ignored may lead to unacceptible wall performance. Photograph 1 shows a connection that has pulled out of the SRWs.

The key issues in this controversy are: 1) what is the allowable strength of the connection and 2) what is the required strength of the connection.

Allowable Connection Strength

Several procedures exist today for determining the allowable connection strength of SRWs. In 1991, when connection strength was just starting to be considered an important design consideration, Chewning and Collin (1991) recommended that the allowable strength of the connection be the lesser of the following equations:

$$T_{ac} \leq \frac{T_{cn(peak)}}{FS}$$

$$T_{ac} \leq T_{cn(3/4)}$$

where

T_{ac} = Allowable connection strength

$T_{cn(peak)}$ = peak connection strength determined from connection tests

$T_{cn(3/4)}$ = connection strength at 3/4" deformation - determined from connection tests

FS = factor of safety (FS=2.0)

Photograph 2 shows a connection test setup to determine the peak connection strength.

The NCMA "Design Manual for Segmental Retaining Walls" has adopted a similar procedure for determining the allowable connection strength, that only differs from the above method in that the factor of safety is reduced from 2.0 to 1.5. This reduction in the factor of safety was based on NCMA's successful experience with SRWs. The procedure is presented below:

The ultimate strength of the connection is evaluated using the limit state connection strength

$$T_{c\lambda} = \frac{T_{ultconn}}{FS_{cs}}$$

where:

$T_{c\lambda}$ = long-term allowable connection strength

$T_{ultconn}$ = ultimate connection strength determined in accordance with NCMA Test Method SRW U-1

Fs_{cs} = factor of safety against connection failure, typically equal to 1.5.

Limiting movement of the wall face over the life of the structure is also considered with the NCMA procedure, as with the Chewning and Collin procedure.

T_{cs} = $T_{conn\,@\,3/4"}$

where:

T_{cs} = long-term connection strength based on serviceability

$T_{conn\,@\,3/4"}$ = connection strength at 20 mm (3/4 inch) deformation determined in accordance with NCMA Test Method SRW U-1.

In 1993, Collin and Berg proposed a more rigorous allowable connection strength criteria, for transportation related projects, that considered specifically durability and creep of the connection. The State Departments of Transportation had expressed concern with respect to the long-term performance of the connect. In response to these concerns the following methodology was developed:

The limit state connection strength is:

$$T_{c\lambda} = \frac{T_{ultconn}}{RF_{CR} \times RF_{D} \times FS}$$

where: $T_{c\lambda}$ = long-term allowable connection strength

$T_{ultconn}$ = ultimate connection strength determined from connection tests

RF_{CR} = reduction factor to account for creep of the connection determined from 1000 hour connection tests

RF_D = reduction factor to account for durability of geosynthetic at the connection

FS = factor of safety, typically 1.5.

To limit deformations at the face of an SRW a serviceability criterion was also provided.

$$T_{cs} = \frac{T_{conn@3/4''}}{RF_D}$$

where:

T_{cs} = long-term connection strength based on serviceability

$T_{conn@3/4''}$ = connection strength at 3/4" deformation determined from connection tests

RF_D = reduction factor to account for durability

In 1997, AASHTO officially recognized SRWs in their Bridge Specifications. This recognition included the development of an allowable connection strength criteria similar to the Collin, Berg procedure. However, the AASHTO procedure is based on 10,000 hour creep tests (Collin and Berg procedure is based on 1000 hour creep tests). The AASHTO methodology is presented below:

The allowable connection strength is the lesser of the limit strength and a serviceability state.

$$\mathrm{T_{ac}} = \frac{\mathrm{T_{ult} \times CR_u}}{\mathrm{RF_{CR} \times RF_D \times FS}}$$

where:

T_{ac} = long term allowable connection strength

T_{ult} = ultimate strength of the reinforcement determined in accordance with ASTM D 4595

CR_u = reduction factor to account for the reduction in strength of the reinforcement at the connection, determined from connection strength tests.($T_{ult} \times Cr_u = T_{ultconn}$)

RF_{CR} = Reduction factor for creep of the connection determined from 10,000 hour creep tests on the geosynthetic

RF_D = reduction factor to account for durability of the geosynthetic at the connection

FS = factor of safety, typically 1.5

AASHTO also limits the deformation of the connection:

$$T_{ac} = \frac{T_{ult} \times CR_s}{FS}$$

where:

CR_s = reduction factor to account for the reduction in the reinforcement strength at the connection at 3/4" deformation of the reinforcement at the front face of the SRW unit, determined from connection tests.

Using published data for one specific segmental retaining wall unit and geosynthetic reinforcement, the allowable connection strength has been determined for the four methods presented above (Table 1).

Table 1—Allowable Connection Strength

Method	Limit State(lbs/lft)	Serviceability State (lbs/lft)
Chewning and Collin	1629	1741
NCMA	2171	1741
Collin and Berg	1394	1582
AASHTO	771	1160

The allowable connection strength, depending on the method selected, varies from 771 lbs/lft (AASHTO) to 1741 lbs/lft (NCMA and Chewning and Collin). The difference in calculated allowable connection strength for this connection between the AASHTO and NCMA method is 2.25 and is due to the reduction factors for creep and durability used in the AASHTO method. SRWs have been designed and successfully constructed using the specific SRW units and geosynthetic reinforcement used in the above analysis. Many of these projects used the NCMA criteria, which give an allowable connection strength 2.25 times greater than the strength as determined using the AASHTO criteria.

If the AASHTO criteria is correct, how can the SRW designed using the NCMA criteria perform without failure? The answer to this question, in my opinion, has to do with the load side of the equation. The load that the connection is designed to resist is greater than the actual load at the connection.

Required Connection Strength

As with the determination of the allowable strength of the connection, there are many different approaches to determining the required connection strength. NCMA procedure, used for the design of many commercial projects, requires that the connection be able to resist the calculated maximum load in the reinforcement. AASHTO requires that at the bottom of a wall the connection be able to resist the maximum load in the reinforcement. At the top of the wall, AASHTO requires the connection be able to resist approximately 75% of the load in the reinforcement.

It has been proposed by others (Barrett and Ruckman, Wu, and Koerner) that the required connection strength is a function of the spacing between reinforcement layers and not the overall height of the wall. The required connection load using this approach is determined as follows:

$$T_{cr} = \tfrac{1}{2} K_a \gamma S_v^2$$

where:

T_{cr} = required connection strength

K_a = active earth pressure coefficient

γ = unit weight of reinforced fill

S_v = vertical spacing of reinforcement

This procedure has not readily been adopted by industry either for private or public sector projects to date.

The required connection strength for a 20 foot high wall with a reinforcement vertical spacing of 24 inches for the three methods present above is provided in Table 2.

Table 2

Method	Required Connection Strength at the bottom of wall (lbs/lft)	Required Connection Strength at top of wall lbs/lft
NCMA	1645	427
AASHTO	1645	320
Barrett and Ruckman	80	80

Once again, as with the allowable connection strength, there is considerable variation (i.e. over 20 times) in the design connection load between methods.

Figure 1 shows instrumentation results from three geosynthetic reinforced retaining walls. One of the three walls, the Algonquin Wall, constructed as part of an FHWA research program, was an SRW. The Tanque Verde Wall (Collin et. al. 1994) is a full height tilt-up panel, geogrid reinforced wall, and the Lithonia Wall is an articulated panel geogrid reinforced wall. These instrumented structures suggest that the measured load at the connection between the reinforcement and facing is approximately 50% of the load using either NCMA or AASHTO.

So back to the original question: how much connection strength is enough? What method should a designer of SRWs use to determine the allowable and required connection strength to assure the desired long-term performance of the connection?

To the author's knowledge, there has never been a connection failure of an SRW when the SRW was designed and constructed in accordance with the NCMA or AASHTO guidelines. In fact, walls have been successfully constructed using the method proposed by Barrett and Ruckman, where the required connection strength is 20 times less than that required by either NCMA or AASHTO. However, the Barrett and Ruckman method has been used on only a few walls (50 - 60) to date. The NCMA method, on the other hand, has been used successfully to design hundreds of wall annually. This method has a proven track record. Until such time as the Barrett method or another new approach has been developed and field verified, I recommend that the NCMA connection strength approach be used. Engineers designing SRWs with the NCMA connection strength methodology, will have designs that are safe and much more economical than the same structure designed using the AASHTO connection strength criteria.

References

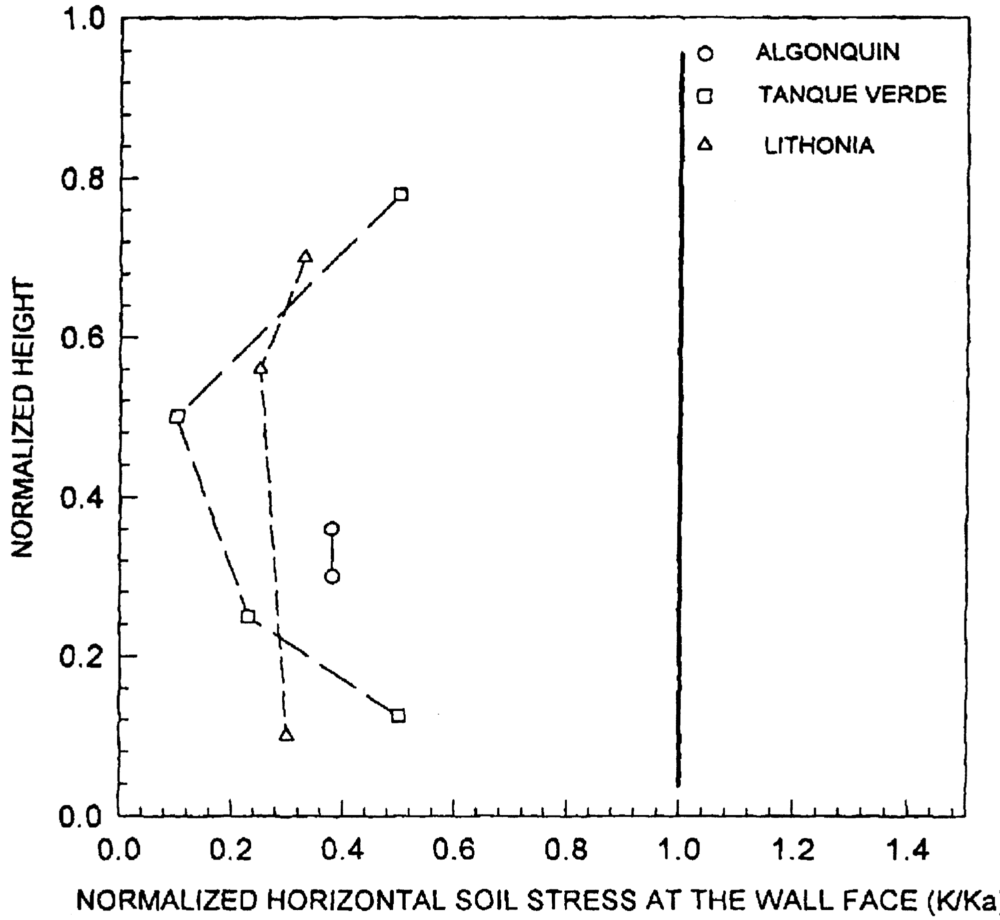
AASHTO Standard Specification for Highway Bridges 1997 Interim's.

Simac, M.R., Bathurst, R.J., Berg, R.R., and Lothspeich, S.E. (1993), Design Manual for Segmental Retaining Walls, first edition, National Concrete Masonry Association, Herndon, VA.

Collin, J.G., Bright, D.G., and Berg, R.R. (1994) "Performance Summary of the Tanque Verde Project - Geogrid Reinforced Soil Retaining Walls", Proceeding of the Earth Retaining Structures Session of ASCE National Convention, Atlanta.

Collin, J.G. and Berg, R.R. (1993), "Connection Strength Criteria for MSE Walls," Transportation Research Board, 72 Annual Meeting, January 10-14, Washington DC.

Chewning, R.J. and Collin, J.G. (1991) "Evaluation of Geogrid to Wall Facing Connections for Modular Block Earth Retaining Wall Systems," Proceedings Ohio River Valley Soils Seminar XXII. Lexington, Kentucky.



Normalized horizontal soil stress at the wall face.