Double the Factor of Safety for MSE Walls and Reduce Costs

Robert K. Barrett, July 2012

Preface

NCMA officials report a 2-8% failure rate with MSE walls. I expect this is more or less accurate, based on our company's experience in review and repair of failures in these systems. Dr. Jim Collin speculates that the average cost of a failure is around $500,000.

I am concerned, and on two fronts. The first is that I am at least partially responsible for developing the AASHTO design protocols. I went on to discover errors in our early assumptions, and, as of yet, am powerless to remedy. The second front is that, with a failure rate, the factor safety and the expected longevity of some walls now standing are in doubt. I know how to practically end this continuum of failures. Use GCS® Tails and quit using dirt for backfill.

You should not expect to understand all of this on first reading. The paradigm gap is too large for most MSE-tieback mindsets. My expectation or at least hope is that some day in the future, perhaps through an epiphany from above, you will recall this treatise with the requisite new understanding. One of those "oh, now I get it!" moments.

Background and Discussion

The first experiments and demonstrations of what I now call Geosynthetically Confined Soil (GCS®) were conducted by the John Steward and John Mohney of U. S. Forest Service and Dick Bell of Oregon State in the 1970's. This work was expanded by the author and Al Ruckman at the Colorado DOT. All the early demonstrations and constructions were with very weak geotextiles and with close spacing (≤12 inches), and referred to as "Fabric Walls".

Fabric Wall technology gained momentum in part due to merit and in part due to the rapid ascension of Reinforced Earth® and its metallic inclusion counterparts, supported by Jerry DiMaggio and the FHWA. We were immersed in a monumental paradigm shift from externally supported retaining systems to internally supported systems.

Our research was greatly enhanced when Dr. J. T. H. Wu joined the faculty of the University of Colorado/Denver and brought higher levels of inquiry and accuracy to our early research. The one area that seemed enigmatic to all was that these fabric walls always exceeded predicted failure criteria. It never occurred to us that we were entirely wrong in our assumptions on internal mechanisms that control Fabric Wall behavior.

As with MSE walls today, we assumed that behavior was based on element contribution and that spacing of the inclusion could be varied based on the strength of the inclusion.

Our models were analogous to simple tiebacks. There were really no choices and certainly no challenges to this approach.

Parallel to our exciting and expanding research, there was a mini explosion in the geotextile industry with many companies vying for this new market. There are a host of instructive boom and bust stories, but I shan't digress to recount. In summary, we now have a consistently high quality selection of geosynthetic inclusions from which to choose. The road behind is littered with the debris of failed attempts for market share.

Verne McGuffey of NYSDOT created the immensely popular Task Force 57 on Geotextiles at the Transportation Research Board in the 1980's. It grew to full committee status and I was the first chair of the Committee on Geosynthetics (90-97). Note the name change. Our committee and friends wrote the first MSE design specifications. (They are little changed today, which is a part of the problem.)

The first geotextiles were nonwoven varieties made by the cotton fabric industry. Testing was based on their criteria as well. For example, we had Mullen Burst tests which were developed to see how much elbow pressure a shirt could take. Funny as it was, these cotton clothing tests provided a way to consistently measure and compare properties. ASTM protocols evolved that are more definitive for our applications.

Costs for non wovens and the next generation of slit film wovens had been driven to commodity levels through intense competition. Many manufacturers dropped out of the market and all of them ceased support for reinforcement applications. The volumes of woven geosynthetics required for walls were much too small to cover marketing costs. You will even see statements to the effect "not suitable for reinforcement applications". But the real goal now is to up-sell to grids, which cost 3 times more.

What saved the reinforcement market and led to our retaining wall failure rate was the introduction of the geogrid. Changing the name and claiming a different suite of properties for the same polypropylenes or by changing chemistry….mostly marketing hype to triple the price….created a new economic force driving the geosynthetic retaining wall industry. And the in-air stiffness was appealing, particularly to bridge engineers. Never mind that all the geosynthetics we use are stiff when confined.

We all leaped off the cliff and into the comfort of Rankine, element contribution (simple composite) approaches to MSE design. We could make heavier and heavier grids and widen the spacing with abandon. NCMA quit promoting CMUs and invested into SRW facing blocks, and all based on tieback-analogous concepts. My TRB committee and friends (geotechs) were at the forefront and wrote the first suite of design equations and which were adopted by AASHTO and placed in the hands of bridge engineers. This proved to be a continuing mistake, but only indirectly germane to subject of this treatise on Doubling the Factor of Safety for MSE Walls.

Also indirectly germane is that within this same time frame, Dr. Wu's fellow researchers in Japan under the leadership of Dr. Fumio Tatsuoka developed their version of MSE walls on the premise that geogrids were expensive and concrete was inexpensive. One of their versions, the Reinforced Railroad/Road with Rigid Facing Retaining Wall System (RRR for short) was a massive concrete trapezoid facing unit with geogrids on wide spacing behind. With this concept, they could both maximize spacing and minimize horizontal width. Sorta like today's giant concrete block designs we see in the U. S. These work and you will soon see how this validates our research findings.

Having had a major role in the evolution of MSE design and construction specifications and leading the one of the largest research efforts, this author and team then continued to investigate MSE nuances. (We still did not understand to decouple our closely spaced Fabric Wall findings from the quasi-tieback MSE criteria.)

It was my expectation that intense scientific inquiry would continue as with all developing technologies. However, that did not happen. The market forces that produced MSE was most complacent with our quasi science behind those designs; moreover, everyone seemed to buy into the continuing travesty of "design by others" or "design by vendors" or "design by contractors". Which translates into acceptance of today's MSE failure rate. No one knows how to design with geosynthetic inclusions. Ask yourself….what do I really know about the derivation of those equations? What do I really know about performance limits? Why do I check overturning…when they cannot overturn? Why do I embed these automatically? Why do I always use a .7 B/H? What am I doing to improve the state of my art and the state of my practice?

Too many of our young engineers are relegated to "SuperTech" roles, applying only established practices and avoiding risk. But I digress.

As we continued to conduct research and demonstrations into the 1990s, we were constantly faced with enigmatic performances. Counterintuitively high failure limits. Of course, we used very weak inclusions and on close spacing for smaller scale laboratory convenience, i. e., Fabric Walls, not the robust MSE systems with stiff grids and heavy facing. Our research was supported and verified with like demonstrations and results by the Federal Highway Administration. Their term for a Fabric Wall is Geosynthetically Reinforced Soil (GRS). (I call it Geosynthetically Confined Soil (GCS®) to better describe the function of the inclusion.) Mike Adams and his team finally were able to fail a Fabric Wall and it required **22 tons per square foot** to achieve this.

The only other research of note during this time was self serving MSE industry work to shore up and freeze their offerings forever in time.

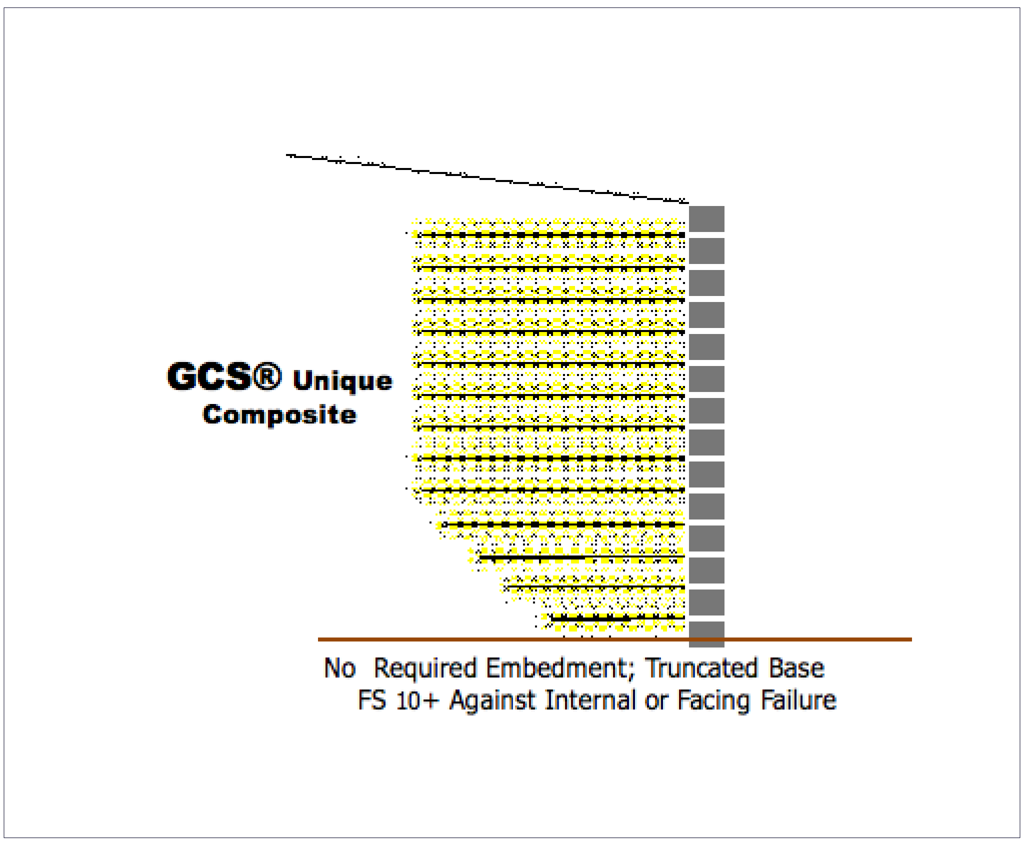
The Breakthrough

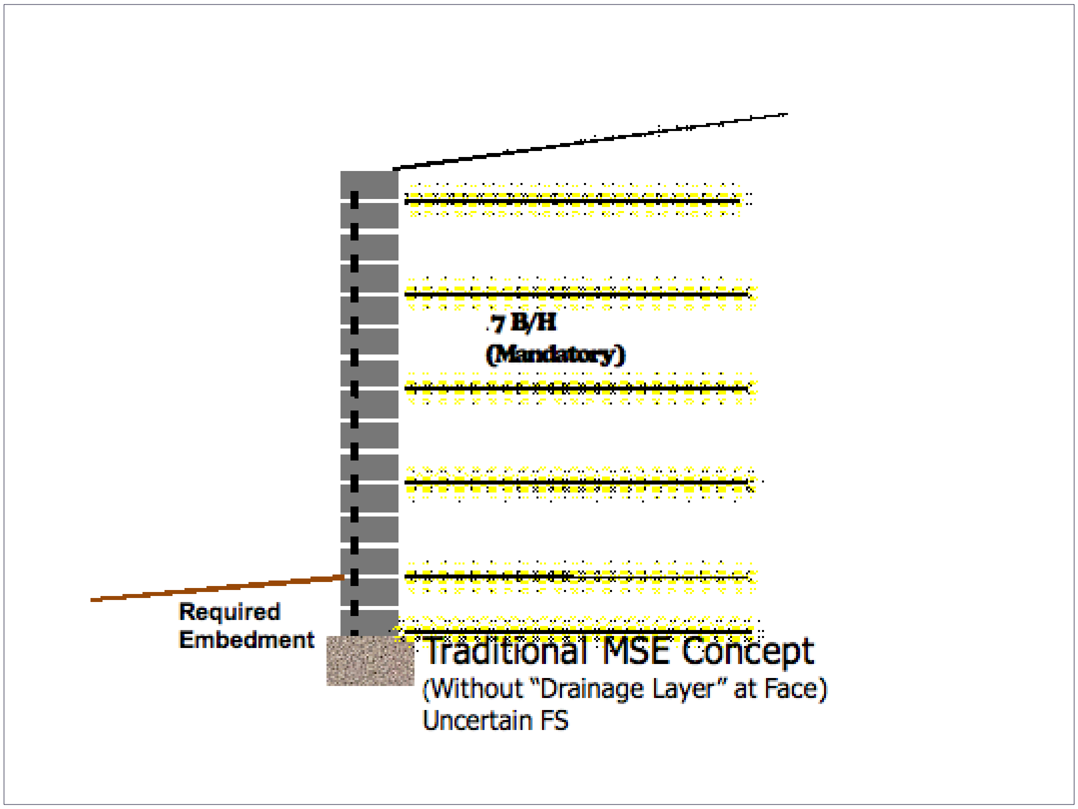
Colby Barrett, President and co-owner of 3 geotech design/build firms that routinely build GCS® structures, puzzled through all those research findings over several years. He finally had that momentous occasion, the breakthrough that is of the essence of invention. As he explained to me and the world, Fabric Walls are Unique Composites.

As we observed time and again, Fabric Wall performance is not a conventional sum of the elements. Tiebacks (and widely spaced MSE systems) can be designed as simple composites through element contribution. As spacing in reinforced soil systems drops below 12 inches, confining effects and element interaction increase exponentially. MSE and GCS® are very different technologies. They follow different rule sets. GCS® is an order of magnitude more difficult to fail than MSE.

This revelation is profound. It is a paradigm shift in comprehension and design theory that hardly anyone can grasp. Unique Composite. Like concrete and asphaltic concrete and sandstone bedrock. We don't test constitutive elements and predict their performance before combining. We perform post-mixed and cured compressive testing on cylinders from the finished products.

Just as FHWA did in their full scale GRS research and achieved the impossibly high 22 tons per square foot. And that result is possible only in a Unique Composite where, like concrete and sandstone, particle dilation is no longer a failure option. The only failure mode remaining is "through the particles", hence, as with bedrock and concrete, 22 tons per square foot. Counterintuitive, indeed. Modeling? That is yet another challenge. Luckily, with failure so remotely possible, there is little urgency.





Double the Factor of Safety

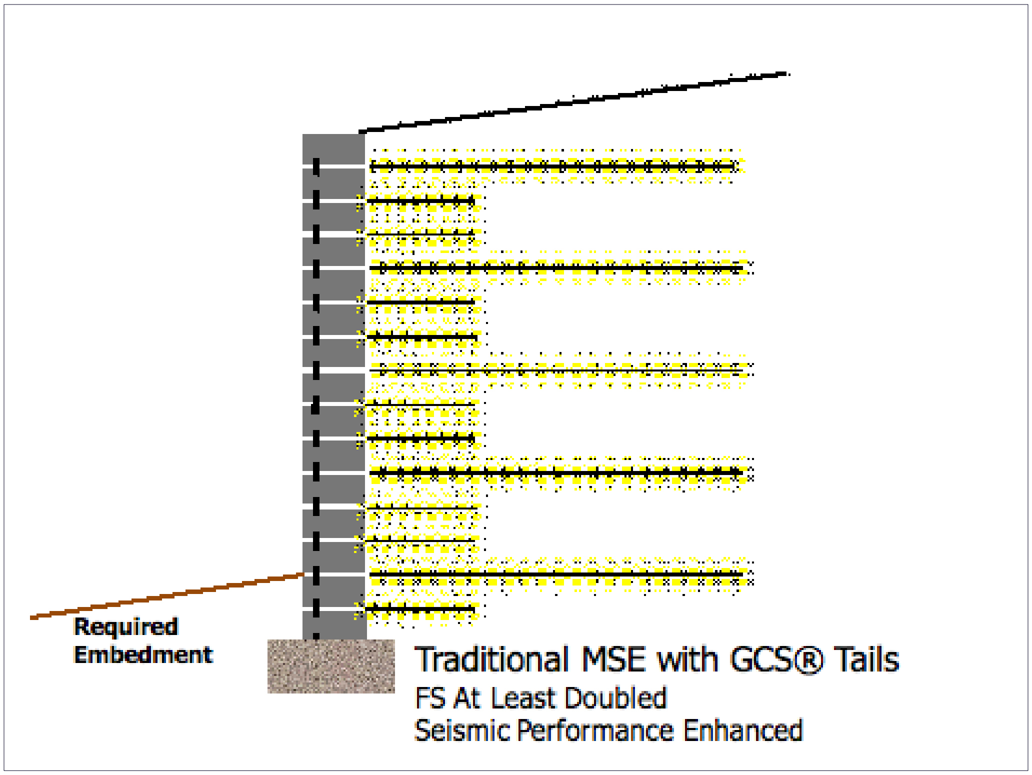
One of our research projects with Dr. Wu at UC/D that explored the counterintuitive behavior of Geosynthetically Confined Soil (GCS®) was to build a wall with alternating short and long inclusions, all on 8 inch spacing. Following Japanese research findings, we wanted to see if a stiff, "flexible" face alone improved performance.

What we demonstrated in full scale GCS® walls was that performance was about the same for walls with full length inclusions and walls that alternated full length with 3 foot "GCS® Tails". The only reason we did not implement this in our private practice (wehave built well over a 1000 of these walls and abutments) is that my partner, Al Ruckman, was concerned that construction crews would get mixed up on schedules and miss some of the primary sheets. Moreover, the woven geotextiles we use are so inexpensive that the saving was not worth the risk of field error.

MSE designers can use these generic GCS® Tails……a 3 foot wide strip of silt fence….between each block that does not have a grid scheduled, which is most of them, and create this super strong Unique Composite facing that will behave much as our research demonstrations and the Japanese concrete RRR trapezoid.

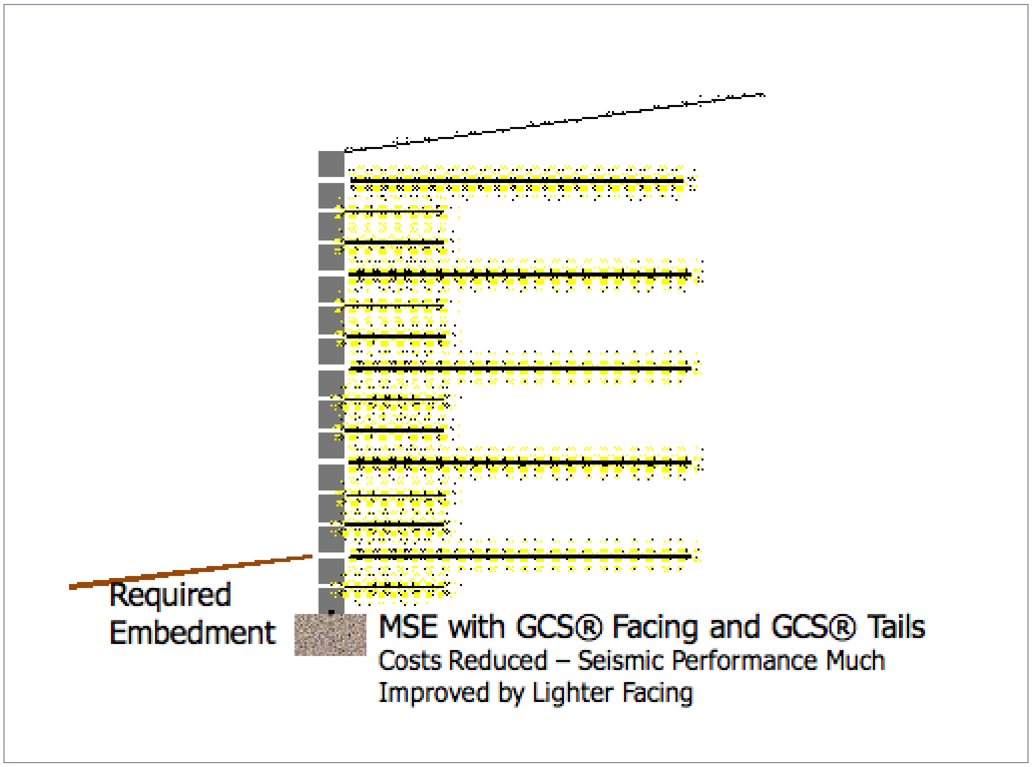
Not only will this technique create the a strong face, there is the secondary assurance of better compaction in that the contractor will have to place the backfill in 8 inch lifts.

That alone will reduce your failure rate. A tertiary benefit is that GCS® Tails will improve seismic performance.



Double the Factor of Safety and Cut Costs

Now that we can substantially increase the stability with a de facto stronger, wider facing on MSE walls, why not use ordinary CMUs as facing? Facing loads drop to near zero (11 pounds per square foot, to be more precise) with 8 inch inclusion spacing. Friction connections are more than adequate for this design, and this was also the opinion of Dr. Richard Bathurst in conversations long ago . Primary benefit is about $3 per square face foot savings and secondarily, seismic performance is futher enhanced with lighter facing elements.



Closing Commentary

In closing, my primary reason for authoring this treatise is to bring a measure of closure. I accept that MSE systems will persist for at least a generation or two with unexamined design criteria. What I continue to see around the U. S. and around the world are static, defensive positions on current practice, both within the design communities and in AASHTO and related guideline purveyors . However, you now have major improvements that can be readily incorporated…..and without violating any rule base. Second tip….don't use dirt for backfill. Cohesive soils can get wet and creep.

And you now have a primer on what GCS® technologies are about. Research has given us a fantastic window to view this new facet of advanced soil mechanics. I look forward to the seeing the bright faces of those take the time to pull back the shades and look to the future.

Also, please watch the video we made to better explain Fabric Wall technologies. In this 1994 video, we called in MSB technologies…..it is the same as GCS®. http://gcswall.com/video-genericmsb.html

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