GRS/GCS®/GeoMonolith Theory, Design and Construction

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"The result suggests.... with the strongest earthquake that has ever happened on earth, a GRS abutment will likely feel "nothing."

Dr. J. T. H. Wu of the University of Colorado/Denver (Reporting on NCHRP Project 12-59[1] GRS/GCS®/GeoMonolith** shake table testing, April, 2010)

Summary

The final test, the conclusion of 4 decades of research on the generic composite of granular soil and lightweight woven polypropylene fabric has been successfully completed. As broadly interpreted by Dr. Wu, these Unique Composites are virtually indestructible by earthquakes, and by extension, virtually anything else. This disappointingly simple approach to retaining wall and bridge support design and construction will save billions in dollars and with huge time savings.

Is the world excited? Not exactly. Why?

The answer is at once as simple as it is complex. If you understand the depth and power of the concept of paradigms, then the explanation is simple. Most everyone understands the paradigm – and the simple logic – of tiebacks where composite performance is based on individual contributions of the components: soil and tensioned rods.

We looked at the remarkable behavior of the first GCS® construction in the 1970's (called "fabric walls" at that time) and concluded that the obvious reason for this, the only possible reason, was the tensile contribution of the "reinforcement" (think tieback). The complexity arises in that GCS® constructions elicit Unique Composite behavior, which is an altogether different behavior. Contrasted with ordinary composites like tiebacks, Unique Composites exist in another dimension of science.

In retrospect, we should have recognized that our first fabric wall was a Unique Composite. These can only be quantified AFTER it was constructed and then set up a triaxial testing protocol to evaluate practical combinations. We would have seen the **immense importance of soil properties and the critical, non-linear relationship of spacing of the inclusion**. We would not have taken the wrong road of placing value on strength/stiffness/connection of the inclusion.

Composite vs. Unique Composite Behavior

In the Tenth Edition of the Merriam Webster's Collegiate Dictionary, a composite is **"a solid material which is composed of two or more substances having different physical characteristics and in which *each substance retains its identity* while contributing desirable properties to the whole"** (emphasis added). Most ground modification techniques can meet this definition and including those that are created insitu as with tiebacks and soil nails, and those created by adding inclusions on wide spacing during a staged construction process, as with Mechanically Stabilized Earth (MSE).

Ground improvement schemes can be modeled by estimating the properties of each element, and described by the equation: Strong Tieback+Soil = Strong Tieback+Soil. When these structures with widely spaced inclusions exhibit "better than expected" performance, it is often due to incorrect assumptions about the constituent properties, such as the true friction angle of the backfill and other phenomena inappropriate for long term design (i.e. matrix suction).

As per his article in the June/July, 2010 issue of Geosynthetics, Dr. Dov Leshchinsky is absolutely correct that an empirical design model for MSE structures that is based on observation of a few carefully constructed walls (including, and without differentiation, walls that cross the boundaries of tieback and unique composite behaviors) is bound to lead to under conservative design in an industry already plagued with failures. Apparent cohesion, for one, can improve short term performance that may not be sustainable with time. Basic or simple composites, such as MSE, are modeled and designed through combining sustainable properties of their constituents.

There is another class of composites, and that discovery is the reason for these essays. These are called Unique Composites. The University of Plymouth's Advanced Composite Manufacturing Center defines a Unique Composite as **"a controlled combination of separate materials, resulting in properties which are superior to those of the constituents, and possibly unique."**

The foundational assumption of this definition is that the individual elements in a unique composite interact with each other to increase the properties of the whole. A volume of research has demonstrated this very phenomenon in GCS® systems, which are predicated on very close spacing and granular backfill. Researchers at the University of Colorado at Denver have demonstrated that matrix/inclusion interaction rarely extends beyond 4 inches from a planar reinforcement. For this reason, the typical spacing for a GCS® unique composite system is nominally 8 inches, which yields complete interaction between the constituent elements and the related equation: Lightweight Tensile Inclusion on Dense Spacing + High Quality Granular Backfill = Unique Composite. Therefore, and by definition, **Unique Composites cannot be accurately modeled using an additive representation of their constituent elements**.

Unique Composite – The Holy Grail

This is profound. Now you can see why there is not a reliable mechanistic model for GCS®. Each time we combine Tensile Inclusion with Granular Backfill, the variables, particularly in the Backfill, will produce a Unique Composite. Therefore the point at which we test is after the Unique Composite has been created. Just as with concrete, which is yet another Unique Composite, we test the combination of cement and aggregate.

While this testing protocol has yet to be perfected and may include wetting to negate sometimes very strong contribution of apparent cohesion as described by Dr. Leshchinsky, this new protocol will be fairly easy to adapt from triaxial and concrete cylinder methodologies. Dr. David Elton of Auburn has explored this method of testing. So has Michael Adams of the FHWA. I don't think there are any paradigm issues here. But that is what I thought in the 1970's, so we need to keep an open mind.

Discussion

We saw paradigm fixity with tiebacks in Vidal's Reinforced Earth®. It was introduced with smooth, steel strips as reinforcing elements. Our conventional mindsets in the U. S. soon forced ReCo® to change the name to steel straps and add asperities normal to the strap axis. This was in fact only because our engineering mindset saw these inclusions as analogous to tiebacks - *straps* are perceived as stronger than *strips* and tiebacks have to have frictional projections. There was nothing wrong with the system ReCo® first introduced. We have seen the enemy and it is us, as Pogo so aptly surmised.

Likewise, it seemed logical to discard the stretchy nonwovens in our first "fabric walls" (now called GRS/GCS®) and bias the rules in favor of stiff, heavy grids. To bridge engineers in particular, these were obviously better tieback materials. Nevermind wondering why the stretchy nonwovens worked so well. We first had to adjust the world to our comfortable paradigm of element contribution (tiebacks and Rankine modeling) and then apply those rules to our innovative departure from the market lock at the time of steel "straps" and mesh as tensile inclusions. In doing so, we overrode scientific inquiry into other potential explanations such as Unique Composite behavior.

What we now know is that there are no unifying analogies or translations between externally supported wall systems, (i. e. tiebacks, cantilever walls, MSE walls) and internally supported true composite wall systems (i. e. GRS/GCS®/GeoMonoliths**). The appropriate analogies to GRS/GCS® are within the family of unique composites such as concrete, asphalt pavement, fiberglass and more.

Why this seems contentious, particularly within the non-aligned, non-profit worlds of academia, FHWA and AASHTO, is beyond my explanation. This news, this turning on the light, should be a cause for joy within a community of true scientists and public servants. Who would chose to perpetuate myth and misconception to support proprietary wall systems with severe limitations in application and that have a failure rate?

MSE has a failure rate, according to NCMA. GeoMonoliths can be designed economically with factors of safety of 10 to 20. MSE invites construction errors. GeoMonoliths are comparatively much less problematic. GeoMonoliths provide a significantly expanded suite of applications. GeoMonoliths are generic.

Conclusion

The foregoing is pretty much a summary of what we have learned over the past 40+ years and what we have finally come to understand in the past 3 months. It is a personal revelation and a cause for joy. I am now able to start down the road to understanding, explanation and quantification of the counterintuitive performance of GRS/GCS®/GeoMonoliths. They are indeed Unique Composites. We will now begin developing design protocols and laboratory and field verification testing methods and equipment.

I don't expect that most readers, having gotten this far, will yet fully understand the significance of this discovery. An early scientist noted that the most fatal of errors is attempting to communicate across paradigms. Our collective engineering paradigm for quantification based on element contribution is powerfully confining. My just saying that these are Unique Composites will not have much meaning at first. I don't expect even consensual agreement in our community at this point.

Paradigm fixity, preservation of the status quo, and appropriate caution are all factors in further delay of full implementation of these powerful, generic technologies. Darker forces of self interest within the market place and egos and control within academia and government will also contribute to extended ambivalence between proprietary MSE and generic GRS/GCS®/GeoMonolithic disciplines. At least now you can make a choice, a choice not unlike earlier scientists had in deciding if the earth were flat or round. A lot of people died during the centuries of debating those opposing paradigms. I expect our course will be a little easier……well, I have been wrong before.

There are 6 Appendices that follow that are mostly redundant; however, saying the same things in different ways could bring more understanding to this profound revelation in Unique Composite theory. Supporting documentation collected over 40+ years would fill wheel barrows. That MSE and GRS/GCS® are separate technologies and that a mechanistic model for GRS/GCS® is probably not possible will begin to make more sense.

USFS Fabric Wall
The U. S. Forest Service built the first ones in the U. S., beginning in the early 70's and produced the first design manual. Co-author of that milestone, John Steward, is in the background.

** As our work in the early 80's focused on woven polypropylenes (cheap and durable) inclusions in road base-type backfills (cheap and durable) and ordinary concrete blocks (cheap and durable) as facing, Jonathan Wu at the University of Colorado/Denver and Mike Adams of FHWA decided to use the term Geosynthetically Reinforced Soil (GRS). I later trademarked what I think is more descriptive, Geosynthetically **Confined** Soil® (GCS®). GRS and GCS® are synonymous, and are unique composites as opposed to the quasi-tieback, simple composite systems with failure rates, collectively known as MSE. In that testing is appropriate only after the "Unique Composite" has been constructed, I then added the term GeoMonolith to better visualize the Unique Composite structure and appropriate verification testing for the structure.

MSE design theory, on the other hand, assumes that there are two contributing components whose properties can be measured pre-construction and behavior mechanistically predicted.

A current effort to redefine terms to emphasize that MSE is a separate discipline is also underway in British Columbia by Calvin VanBuskirk. He is an emerging international leader in development and innovation in confined soil theory and practice.

Robert K. Barrett
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