THE UNFINISHED STORY OF GEOSYNTHETICALLY CONFINED SOIL

Bob Barrett

DISCLAIMER

The views, opinions, and technical positions expressed in this book are solely those of the author, based on his personal experience over a 50+ year career in geotechnical engineering.

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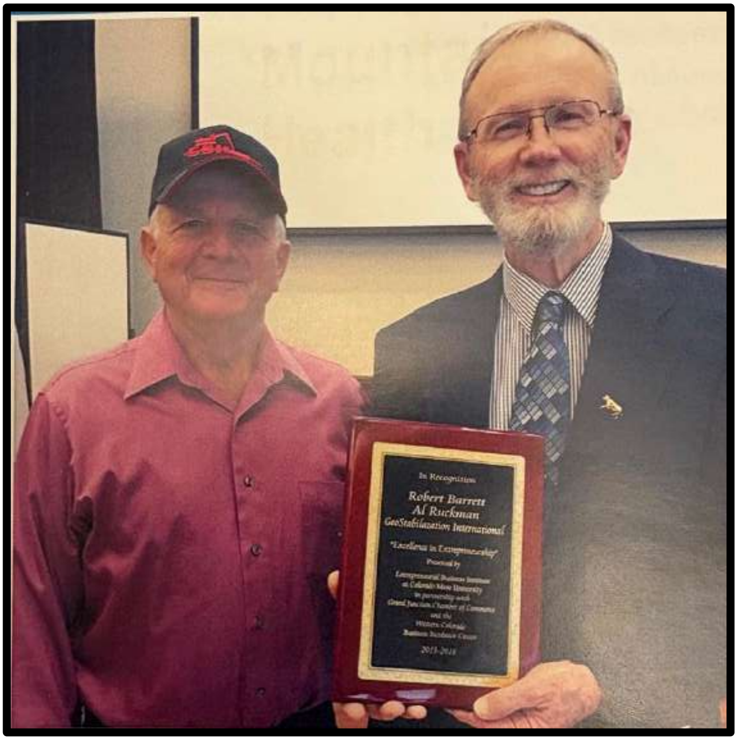

WE CREATED TOOLS AND TECHNOLOGIES THAT CHANGED STRUCTURAL AND SOILS ENGINEERING FOREVER.

It's Taken Us 60 Years. We Spent More Than 100 Million Dollars.

We Have Saved Taxpayers That 1000 Times Over.

We Are Not Finished....We Need Your Help

MY MOST IMPORTANT CONTRIBUTION

This bridge demonstration proved that Geosynthetically Confined Soil abutments and piers (GCS/GRS) provide the least expensive, easiest to construct, quickest to construct, and our longest lasting abutments and piers. And they are earthquake proof.

My demonstration here consists of 2 piers, each 24 feet high, 12 feet wide and only 5 feet deep. The abutment bearing seat is only 3 feet deep... the girders are perched on the edge.

The center pier was never loaded....but either pier could have taken the entire load...300 tons...and a lot more....450 tons at least. With 4 inch spacing in the top layers, FHWA tests verified we could have exceeded 1000 tons per square foot. GCS abutments and piers truly are superior to concrete piers where space allows.

GCS/GRS design and construction is easy...

1. A row of blocks

2. A lift of granular backfill

3. A sheet of geofabric.

And repeat. 1, 2, 3. - 1, 2, 3.

No wet concrete... we use precast sills.

Contents

MY MOST IMPORTANT CONTRIBUTION 4

PREFACE 1

THE EVOLUTION OF OUR TECHNOLOGIES 4

1. WE CREATED THE FIRST DESIGN PROTOCOLS FOR ROCK DOWELS AND SOIL NAILS AND CHANGED THE INTERNATIONAL PARADIGM ... 4

2. WE CREATED DESIGN PROTOCOLS FOR GEOSYNTHETICALLY CONFINED SOIL (GCS/GRS) 10

GCS/GRS CAN BE TESTED AS WE DO WITH CONCRETE AND ASPHALT 14

GCS/GRS – ELEGANT, POWERFUL TECHNOLOGY 18

CDOT GCS DEMONSTRATIONS 21

THINGS VENDORS DON'T KNOW – OR CAN'T TELL US 22

3. WE CREATED THE FIRST COMPUTER PROGRAM FOR ROCKFALL PREDICTION AND CONTROL 27

THE ERA BEFORE ROCKFALL MODELING 28

ROCKFALL REMEDIATION COULD BENEFIT FROM A BETTER UNDERSTANDING OF CONFINED SOIL BEHAVIOR 29

WE CREATED THE WORLD'S FIRST COMPUTER ROCKFALL MODELING TOOL 31

WE MADE HISTORY AGAIN 34

THE GCS FORTRESS BARRIER 36

GCS FORTRESS BARRIER INSTALLATIONS 37

MY ALL-TIME FAVORITE FORTRESS BARRIER 40

ONE MORE DEFINITIVE CASE HISTORY FOR GCS/GRS VERSATILITY .. 41

PHOTO GALLERY OF BOB AND AL PROJECTS 44

APPENDIX 1: BIN PRESSURE EXPLAINED 47

APPENDIX 2: CONFINING INFLUENCE EXPLAINED 52

APPENDIX 3: GCS/GRS DOES NOT REQUIRE EMBEDMENT... 54

APPENDIX 4: HOW I DESIGN GCS/GRS RETAINING WALLS, BRIDGE ABUTMENTS, BRIDGE PIERS, ROCKFALL BARRIERS AND AVALANCHE DEFLECTION STRUCTURES 59

APPENDIX 4 - A 63

THE IDEAL NEW AASHTO-BASED DESIGN PHILOSOPHY FOR GCS/GRS WALLS, ABUTMENTS, PIERS, AND ROCKFALL BARRIERS 63

BELOW – FHWA ACHIEVED 10 TONS PER SQUARE FOOT 69

APPENDIX 5: A SERIES OF CASE HISTORIES AND OBSERVATIONS 71

APPENDIX 6: EVOLUTION OF MECHANICALLY STABILIZED EARTH – MSE 109

APPENDIX 7: PREVENTING MSE FAILURES 115

APPENDIX 8: I WISH I COLD HAVE DONE THIS DIFFERENTLY 122

APPENDIX 9: CONFINED SOIL COULD RESHAPE THE FUTURE OF INFRASTRUCTURE DESIGN 127

APPENDIX 10: THE WORLD DESERVES THE ELEGANCE, THE EXCELLENCE, THE DIVERSITY, THE ASSURANCE, AND THE ECONOMY OF GCS/GRS TECHNOLOGIES 132

EPILOGUE 137

BOB'S RESUME 139

BOB BARRETT AND HIS LARGE GROUP OF COLLABORATORS: 141

PREFACE

Bob Barrett, Al Ruckman, John Steward, John Mohney, Dr. Richard Bell and Mike Adams developed a novel composite material with a granular aggregate and geofabric sheet inclusions whose measured performance exceeds conventional Portland-cement concrete across multiple structural and geotechnical applications.

This composite can be produced at approximately **10 percent of the cost** of conventional concrete, relies on globally abundant materials, and demonstrates a projected **service life 10 times longer** than reinforced concrete systems.

Our results were sufficiently anomalous and counterintuitive that we invested more than three decades and more than 100 million dollars to rigorously evaluate the material. Initial efforts focused on falsification — we had to convince ourselves that there were no hidden variables or testing artifacts that could invalidate the observed performance. Subsequent work concentrated on developing reproducible design, testing, and specification protocols to enable broader engineering adoption.

Independent research teams in Japan replicated the underlying design methodology and subjected the composite to loading regimes and boundary conditions exceeding those tested by the Barrett team. Those researchers likewise failed to find a mode of catastrophic or progressive failure. This composite simply cannot be failed in any service application...as you will see.

Measured performance of this composite challenges prevailing engineering intuition and analytical frameworks. This is a problem. In practice, many reviewers and practitioners have rejected the material not based on contradictory data, but because **its performance envelope lies outside the range of outcomes typically considered plausible within conventional material models.**

A central finding of the Barrett team is that the behavior of the composite cannot be accurately predicted by linear or reductionist analysis of its constituent materials in isolation. As with concrete —where cement paste and aggregate properties are not evaluated independently to predict final performance — relevant mechanical and durability characteristics emerge only after composite formation. Consequently, validation depends on post-combination testing rather than first-principles extrapolation from component properties.

Most people cannot grasp this... That it is counterintuitive is an understatement!

This technology will not be fully available until we have acknowledgement and support from the American Association of State Transportation Officials (AASHTO). The world waits for AASHTO to finish this story...to validate GCS/GRS technology across the board.

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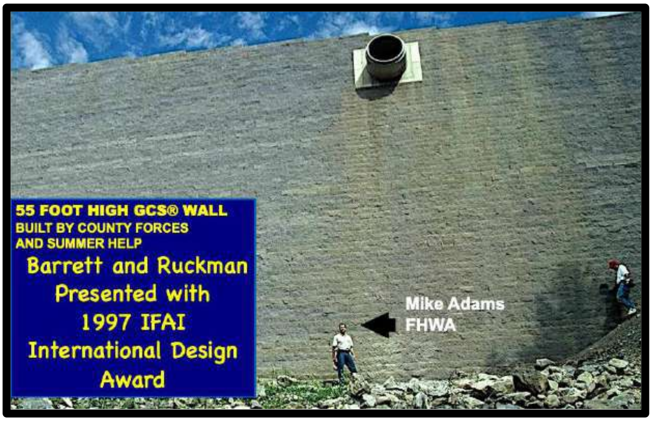

55 FOOT HIGH GCS® WALL
BUILT BY COUNTY FORCES
AND SUMMER HELP
Barrett and Ruckman
Presented with
1997 IFAI
International Design
Award
Mike Adams
FHWA


2008
MEXICO'S
FIRST
GCS®
WALL


Istanbul GCS® Wall
1995
Barrett, Ruckman, Guler

THE EVOLUTION OF OUR TECHNOLOGIES

1. WE CREATED THE FIRST DESIGN PROTOCOLS FOR ROCK DOWELS AND SOIL NAILS AND CHANGED THE INTERNATIONAL PARADIGM

I was talented in landslide analysis and remediation. With steel H piles, we used shear and bending properties...thus the 'H' section was most efficient in smaller piles used in smaller landslides. This is somewhat inefficient in that we can't mobilize the stronger component... tension.

The first soil nails were demonstrated in France in 1972. It was 10 years later before they were even discussed here in the U. S. My contemporaries looked to our Federal Highway Administration experts for the most up to date tools and technologies. These experts were proactive with the state highway groups and sponsored annual meetings nationwide to discuss the state of our practice. They were the folks who introduced Reinforced Earth Walls.

But, when soil nailing was discussed, there was a huge rejection. These skinny elements installed perpendicular to a slip plane could not possibly contribute enough shear or bending resistance to be meaningful. We needed vertical H sections.

Plus, we did not have the models for soil nail design. The French did not either.

The British developed a compressed air cannon that shot nails....1.5 inch solid steel bars, 20 feet long...into the ground. It seemed to stop slides on their rail system...The owners wanted to sell it to the U. S. market. The USFS created a demo project in 1992 and brought this cannon to the U. S. I was part of this at CDOT, and we repaired two slides with launched soil nails in Colorado in 1992.... seemed to work well, but the analytical model was a graph! Just a method of slices with some mystery inputs. They did not really know how it worked. No one did.

So, instead of doing the proper research evaluation, we sent it back to Britain.... notwithstanding soil nailing was half the cost of what we were doing within the paradigm of the day.

(As an aside, Al Ruckman and I purchased that Soil Nail Launcher in 2001 and founded a design/build/warranty company to implement CDOT research findings. It has grown to be Geostabilization International of today.)

I digress. About this same time, we were faced with a huge design problem at Reverse Curve on the I-70 Glenwood Canyon project. The optimum solution was a west bound tunnel and an east bound viaduct. However, the 400-foot-high rock face that we wanted to tunnel through was highly jointed and fractured. Blasting for the tunnel could possibly further destabilize the cliff section over our bridge.

We needed to put thousands of rock bolts into that face to assure long term stability. Our paradigm for rock bolt design required post tensioning to develop the tensile capacity of the steel. Drill a hole, insert quick set epoxy in the back, long set epoxy in the front, insert and spin the thread bar, wait, put on the exterior plate, put on the nut, set the tensioning jack, crank up the pressure and tighten the nut. All from a crane below or from ropes above.

The cost of stabilizing the massive rock feature to allow tunneling and the adjacent bridge was astronomical. Yet our environmental mandates required us to keep out of the river...we had to build a bridge.

WE WERE AT AN IMPASSE.

I have 4 a. m. revelations. I have 8 patents (some joint with others) and all were from these kinds of inspirations. I awoke one morning and jumped up...it was so obvious!

We had discovered the secret of Geosynthetically Confined Soil was simply that the inclusion prevents dilation and therefore a failure path must go through the soil particles. This creates a bedrock material vs just plain backfill.

Failure in rock and soil requires dilation! We could install passive bars...dowels half the cost and a fraction of the time. Those bars embedded in high modulus epoxy or cement would have to stretch to allow the rock to first move outward and then release downward.

At the same time, I figured out that soil nails operated on the same principle. We could use the tensile capacity of the steel. The slide material in circular and planar slides must dilate...expand in volume at the shear surface...in order to move downward. A game changer. Practice at CDOT changed and soon around the world.

The economic significance of our discovery for design protocols for passive soil nailing and untensioned rock dowels is incalculable.

Here are photos of our Soil Nail Launcher in action.


WORKS DURING THE FLOOD

2. WE CREATED DESIGN PROTOCOLS FOR GEOSYNTHETICALLY CONFINED SOIL (GCS/GRS)

"As you read this in my first person style, recognize that there are hundreds of names of people who I am omitting. Al Ruckman, my partner in crime for 50+ years....Brandy Gilmore, CDOT Chief Geotech...Verne McGuffey, John Steward, Shan Tai Yeh, Nelson Chou, Dr. Jonathan Wu, Dr. Fumio Tatsuoka, Dr. Dick Bell, Dr. Dov Leschinsky, Dr. Ryan Berg, Dr. David Elton, Dr. Erol Guler, Dr. Bob Holtz, Dr. Bob Koerner, Dr. Jim Collin, Dr. Teresa Adams, Dr. Barry Christopher, Colby Barrett of GSI, Mike Adams at FHWA.... All these accomplishments result from collaborations. We spent perhaps 100 million in today's dollars over the 20+ years of development. It reads better to omit names. This tome is not about people...its about how we can see something and not see it."

I am not very smart...my strength was to enlist talented people to perform beyond mostly self-imposed limits. "Tom Sawyer fence" scenarios where we could create tools and technologies none of us could in singular roles. And, I had a huge budget. That always helps.

(We worked nonstop for months at a time....and enjoying every second. This happens in the real world of engineering…and seldom in the world of following precedent. We had no precedents – we were creating them!)

By the time our I-70 team finished Vail Pass and moved our focus to Glenwood Canyon, we had hundreds of people involved in design and construction. We had been elevated to the Department of Transportation, and our District team had achieved worldwide recognition for our successes and innovations on our I-70 Vail Pass project. I had my own office…we had a freeze on new employees…but I had lots of money… so I arranged to "rent" geologists for years at a time from our Colorado Geological Survey…they had open FTE positions but no funding…I could also hire an unlimited number of people for 6 month temporary positions…these were just a few of the many creative things we did to keep going full throttle.

The Glenwood Canyon segment was 13 miles long and cost 1.25 billion in today's dollars….**100 million dollars per mile**…. It is the most expensive rural Interstate project in the U. S.

Glenwood Canyon was all about walls and bridges…obviously. It was also a geologic hazard area. There are rockfalls daily somewhere in the Canyon. Some thought that talus slopes were "rivers of rock" and in constant motion. The Colorado River was not to be modified. We were told we had to create pedestrian access…add a bike path where we were unsure how to build 4 lanes….we even had to get a dispensation to build a more narrow and lower speed Interstate template.

Then we discovered that the eastern half of the canyon floor was underlain by up to 60 feet of volcanic ash with zero-bearing capacity. A massive eruption and earthquake event happened less than 5,000 years ago. No one ever had heard of this.

We could see we needed more than 10 miles of bridges and retaining walls and now we did not have foundations for them in half the canyon. I started looking for ways build walls on nothing. These would have to be flexible walls capable of enduring several feet of settlement. I also wanted to determine the secret of the design for Reinforced Earth.

By this time, Reinforced Earth had competitors...VSL which used a bar mat vs the steel strips of Reinforced Earth. Bill Hilfiker had a wire basket system for facing and a bar mat for "reinforcement".

And, by this time, we had become great friends with the USFS. Their research group in Oregon had developed a most unusual wall, called a Fabric Wall, using a novel fabric made with polymers from France called "non-woven". It was a sixteenth of an inch thick, very stretchy and not particularly strong. They had built walls on logging roads up to 25 feet high with total success, even using sawdust for backfill in one of them. Two of the USFS engineers were former students of Dr. Dick Bell at Oregon State and had contracted with him to oversee and report on those walls.

We asked them for the "design"....they said they just did what the French had done. The French company was proprietary and did not answer calls.

These were totally flexible. Perfect for extreme settlement. So, we hired Dr. Bell as a consultant and built the world's largest geofabric test wall - 300 feet long and 20 feet high. We changed the design every 30 feet to see if fabric spacing or strength were critical factors. The wall settled 36 inches on one end and 18 on the other. Nothing happened. The wall did not deflect, deform, or show any signs of impending failure.

Some of our segments were much less robust than the USFS demos expecting to see some form of failure. We had construction damage on the exhumed fabric of more than 60% in some areas. We had less than 50% of the expected strength in our design....we were shocked!

In research, we need failure to determine limits and then safety factors...we failed miserably.

So we added a brutal surcharge onto the wall....nothing happened. Dr. Bell said he expected this. **Dr. Bell said if he could magically replace the fabric with paper towels, the wall would remain stable**. This was maddening. We had a wall that we now know was more than Safety Factor 10. Yet we could not understand what we had done. We could not make any sense of it in mathematical terms.

Dr. Bell could not help us develop a mathematical model. (Turns out no one can!) We kept trying to use tieback analogies...create equations with element contribution. It was not until 2011 that Colby, the new owner of GeoStabilization International...my son...came up with the simple explanation.... we had built a "unique composite", and whose definition says the performance is different than the sum of the parts. We were not prepared for the extreme difference in the performance of the composite, compared to the properties of the parts.

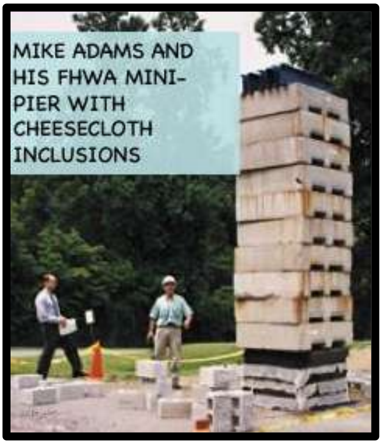
GCS/GRS CAN BE TESTED AS WE DO WITH CONCRETE AND ASPHALT.

We build mini piers – 4 feet x 4 feet x 4 feet – and load them to 80 tons. We remove the facing/forming blocks and repeat the

load cycle. If we do not see deformation, we can use that backfill for our construction. Same principle as asphalt and concrete cylinder testing. In fact, Mike Adams of the FHWA built a **mini pier with cheese cloth** as the inclusion... imagine that...proves again there is no significant load in the confining medium.

In retrospect, we could have finished Glenwood Canyon much sooner and for less cost, had we been able to see what we had actually demonstrated with this first GCS wall.

Instead, we focused on the viability of Reinforced Earth and VSL walls to sustain the extremes in settlement in the Glenwood Canyon. At one point I had 16 engineers and techs working on instrumentation and interpretation for our RE demo walls.



What we found was that when our full height panel walls settled, they also lost verticality due to the irregular geometry of the underlying low-density volcanic dust. Not a structural issue, but it put them out of alignment where they joined at the top, and we could not align the special "Glenwood Canyon Guardrail".

So we built RE walls with temporary facades 12 inches back from final alignment and after completion of settlement (4 years), we then put on facing panels and filled the gaps with flow fill concrete.

The second project, placing the final façade, cost the same as the original wall project.

(Our intensive, 2-year evaluation of Reinforced Earth and VSL revealed that these walls are heavier at the back than at the front. They literally can't overturn and can be built with a .4 or .5 base to height ratio. Facing panel loads were almost zero at any height. Connection strength requirements can be minimal...corrosion is the primary concern. Global Stability - external factors - is the controlling engineering parameter. This applies to any of the Unique Composite walls...checking for overturning means you don't understand what you are designing.)

I wrote and presented papers in several venues outside of Colorado. I was popular in our specialty engineering and maintenance committees at TRB each year and was the first chairman of the Committee on Geosynthetics (90-97).

GCS/GRS – ELEGANT, POWERFUL TECHNOLOGY

GCS/GRS works because **the inclusion prevents the granular backfill from dilating...there is practically no stress or load transfer to the inclusion.** Thus, when this phenomenon sets up during construction, the failure mode would be "through the particles" as with cement added to sand...same thing. Engineers can see but not see....we can know and not know....

Strain gauges. Dr. Wu and I spent millions over 20 years with perhaps a dozen graduate students working on strain gauge projects trying to find a way to measure the mostly nonexistent "stretch" in the geofabric. We could not accept that the loads are just too small to measure.

In this case, not seeing or knowing is costing us trillions...it is costing lives. This weighs on me every day.

I was looking at the 100% better solution...we built it ourselves....and could not see it was superior in every aspect. We can build GCS/GRS with even negative batter...I have done this dozens of times to gain platform width and to stop rocks. We can use remarkably inexpensive concrete "cinder blocks" for facing. I have purchased hundreds of thousands and all over the world...they are universal.

I can blame paradigms. We were still thinking "retaining wall", "overturning", "element contribution". I knew better. But could not articulate it. And now I keep trying to explain to everyone.... especially the leaders at CDOT who are in charge of wall and abutment selection...that it is not too late to benefit from their amazingly powerful "unique composite".

GCS behaves exactly the same in every construction. It can't fail internally. I have a standing offer for over 30 years...**design a practical way to fail a GCS/GRS wall and I will give you a million dollars.** Same with plucking a block from the face. Another million if you can pluck a block intact from the 3rd row or downward.

Yet we relied then and now on Reinforced Earth and VSL and Tensar to handle the retaining wall "designs". And I proved their systems are also "Black Box" without mathematics that make sense. We have no idea what their ultimate failure states might be.

MSE walls have experienced documented failures at rates that warrant serious attention. We use a variety of math-based quasi-tieback numerical designs that indicate a 2.0 Factor of Safety, yet the observed failure rate suggests actual safety margins may be lower than calculated. This gap between predicted and observed performance is precisely why GCS/GRS — with its demonstrated record of zero internal failures — deserves serious consideration as a complement to, and in many applications a superior alternative to, conventional MSE approaches.

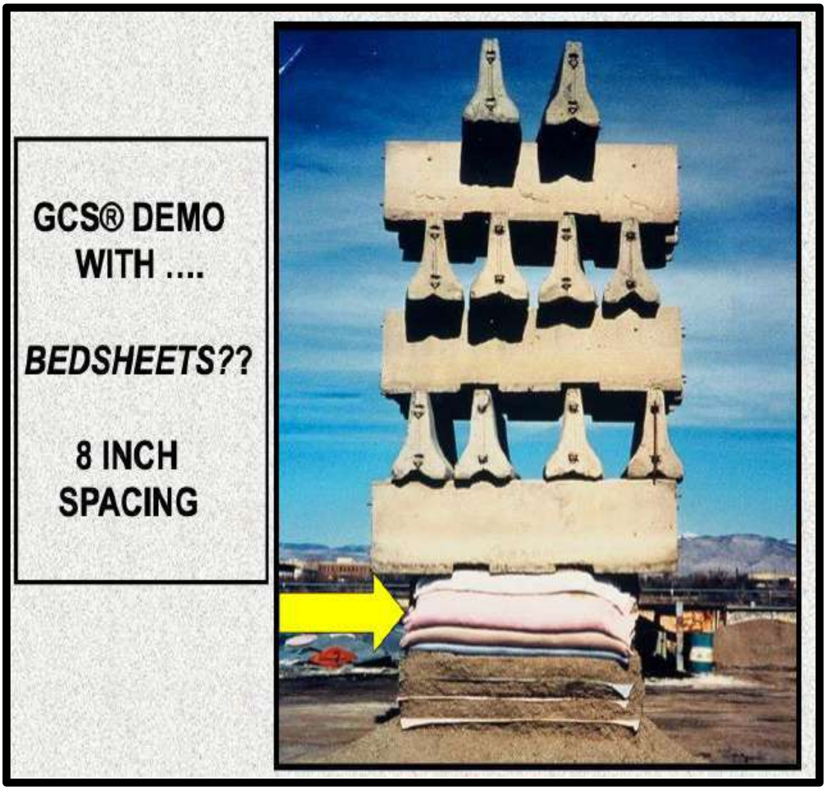
Confined Soil is a Unique Composite. This simply means the combination behaves differently than the sum of the parts. We just could not grasp the dramatic increase in strength that results from putting in a weak inclusion into a soil matrix.

Circa 2011, we began to understand the results of several thousand demos and constructions of GCS/GRS walls, bridge abutments, bridge piers, and rockfall barriers. We deduced from our full scale tests at the University of Colorado/Denver and at at FHWA's Turner Fairbank facility that the factor of safety against a Rankine failure is 20+. Yet we continue to use a 2 ton bearing capacity when we have shown it easily exceeds 10 tons.

Had I been able to understand and explain this to our CDOT leaders in 1996, it would be a different practice that you all have in 2026. Our Bridge Engineers could do as we do...just put the needed geometry on the plan. It won't fail, it can't overturn, it can't slide. Geotechs can determine external, (global) bearing and stability parameters.

Instead, I took our GCS treasure away from CDOT and made a fortune for others.

CDOT GCS DEMONSTRATIONS



Here we created a demo with cotton bedsheets as our inclusion. Dr. Jonathan Wu at the University of Colorado/Denver concluded that **we could have stacked Jersey barriers to a height of 80 feet** before we induced significant stress in the bedsheets. Imagine the factor of safety when we use inclusions 20 times stronger than bed sheets!

I have a video of this demonstration and more on my personal web site, **GCSWALL.COM**. This book is also on my site.

There is an opportunity for engineers in public service to engage more directly in retaining wall design rather than defaulting entirely to vendor-provided solutions. While vendor systems have their place, the engineering community benefits when practitioners understand the underlying mechanics of the systems they specify.

Again, If there is concern about the backfill, then we perform a simple mini-pier compression test to verify we can get at least 4 tons bearing. As per a previous photo series, we built a GCS/GRS mini pier with block facing and removed the facing to illustrate this is not a tieback feature. The jacking loads were 20 tons per jack, and we observed zero reaction in the GCS/GRS pier. Note we did deform the steel base plate.

THINGS VENDORS DON'T KNOW – OR CAN'T TELL US

When vendor-provided systems become the default for any major technology, there is a risk of slowing innovation and limiting the engineering community's ability to advance practice. AASHTO and its T-15 committee have an opportunity to play a constructive role here, as you will see later.

A. The first is that a wall made with confined soil will be heavier at the back than the front. I can sketch why and how on a bar room napkin. Think about it. Sand and gravel cannot transfer loads as does a rigid concrete cantilever. Two different worlds. We don't check for "overturning". Can't happen.

B. There is no mandatory need for sub-ex or embedment. We sometimes don't even cut the grass. There is no chance or risk of "frost heave". Configuration is an <u>external</u> design issue.

C. There is no mandatory width...no issue with a base to height ratio. The real issue is horizontal load. If the GCS/GRS feature is subject to horizontal loads, then we make it wide enough to resist those. But if the surface behind is bedrock or shotcrete, we can build to any horizontal dimension.

We have built thousands of narrow GCS/GRS facades with blocks or rocks just for visual mandates or to gain some additional width. Kentucky DOT personnel in the photo are building their first GCS/GRS feature with block facing under my direction...it is as narrow as 18 inches. Eight other DOTs have participated in my projects. It's easy and they love it.

D. We found there is no need to attach the fabric sheets to the back wall.

E. We also found splicing the fabric can be hodge podge...overlap or not...the confining effect is broad...just as with Reinforced Earth and the wide spacing of the strips.

There is no added value with heavier fabrics. Just as long as they are stronger than a bed sheet...silt fence works well, it's inexpensive and universally available.

F. We found that we can build GCS/GRS with a negative batter. Our Japanese friends decided to test this to the maximum. They built a 20 foot high test wall with a 60 degree negative batter and then placed a huge soil surcharge on it. (Ironically, GCS/GRS technology continues to be disallowed or not used in Japan...and most of the U. S.)

G. We use negative batter to shorten bridge decks and to gain platform width. The photo below is an abutment for a box culvert where negative batter reduced the length of the precast slab surface by 3 feet. The other photo is a demo wall with the New Zealand DOT and with negative batter just for fun. Took us 4 hours to build.

H. GCS/GRS bridge abutments are superior to all. Single span bridges do not need expansion joints, nor do they produce bumps. With precast bearing sills, there is no wet concrete and we can build a bridge in less than 24 hours. We have done this. So can you.

I. GCS/GRS walls, piers, and abutments are earthquake-proof. They are all the same technology and construction...we just use different names to describe the application. We paid $500,000 to prove this. I have a patent on a design nuance that makes abutments doubly earthquake proof with "earthquake wings" that preclude the superstructure from moving laterally.

J. All Weather Construction - Telluride ski area had a major project to build roads and ski trails that included 12 highway bridges over ski runs. These were designed by a traditional bridge firm and included concrete abutments on piling. The abutments were later clad with a stone facing. They completed 11 of them in the spring and summer season, but there was one that the contractor could not complete before extreme cold at 10,500 feet. Al and I were asked if we had a way to build this last bridge in subzero weather.

Sure. We used GCS/GRS abutments with open graded gravel backfill, stone facing and precast sills. We built the remaining bridge in two weeks and for a fraction of the cost of the "traditional" bridges. The temperature never got above 20 degrees Fahrenheit and was typically much colder. We used the native stone as our forming/facing element.

The owner said he regretted not finding us sooner.

K. Corrosion or soil Ph are not issues....this is huge.

L. You can use a variety of facings...anything that will serve as a form. We have built hundreds of walls with rock facing...used tires....timber...full height panels. There are negligible loads on full height panels.

M. Note that rapid drawdown is not a design issue with open gravel backfill. **N.** Earthquakes are not a limiting factor.

3. WE CREATED THE FIRST COMPUTER PROGRAM FOR ROCKFALL PREDICTION AND CONTROL

GCS GAVE US ROCKFALL LEADERSHIP

There is a rock falling somewhere in Colorado as we speak. We have more rockfall problems than our fair share...for sure!

The reason Dick Prosence hired me in 1967 and created a new position - District Geologist – which was decades before the term "geotechnical"....was my expertise in dealing with landslides. We had to build I-70 over the 11,000 foot high Vail Pass...a rugged 14-mile corridor that traversed 7 miles of post glacial landslides. My duties also included district wide services on the other state roads. Later on, county highway supervisors would ask for my assistance on specific issues. I became busy...wonderfully busy!

I had become the CDOH "avalanche expert" and, with beginning the Glenwood Canyon project, I had to become the "rockfall expert". You, the reader, have to appreciate the meteoric rise in the tools and technologies we have today in our engineering sciences. I had a slide rule and a crank calculator on my first day on the job...we typed reports with carbon paper if we wanted a copy...Xerox had not made it on the scene. I wrote everything on a legal pad and my secretary would type the reports...we used lots of “white out”.

THE ERA BEFORE ROCKFALL MODELING

Of course, everyone at that time knew there was no way we could predict when a rock would fall nor predict what that rock in motion would or could do. And we had no idea how to devise engineered solutions. Even when we made rock cuts that looked stable, some of those were producing rocks on to the road...over-blasting was the rule.

I looked beyond our borders to see if I could find more information, find someone with a background in rockfall control.

I was gaining traction at the Transportation Research Board (TRB) and had met some brilliant geologists in other states. Highway Geology as a profession was growing every year....but there was nothing of value. No one had the magnitude of problems we had. I looked for European reports and papers. Nothing of much value.

Everyone said we would never be able to model rockfall as we do with landslides.

The Japanese had some rock sheds...same design as avalanche sheds, but they did not have formal modeling...no way to predict when a rockfall would occur or what that event would produce.

(And then we had paradigm issues. Many of the CDOT leaders were still not accepting our role as responsible for rockfall prevention and remediation. This is an underlying theme throughout. Our natural tendency is to repeat established practice....which is why I continue to advocate for AASHTO to evaluate GCS/GRS on its merits that go well beyond retaining wall applications.)

ROCKFALL REMEDIATION COULD BENEFIT FROM A BETTER UNDERSTANDING OF CONFINED SOIL BEHAVIOR

I can explain...**the connections are obscure at first**.

I could model landslides pretty well, even with our primitive tools. Today's magic computers are great, but we still count a great deal on intuition. But there was no one who could stand below a hillside or a rock cliff and imagine or "feel" an engineered design with elements that will for sure keep rocks from entering the roadway.

The stakes were high. We were beginning the first stages for our Glenwood Canyon I-70 project. That 13 mile corridor has cliffs over 2000 feet high. Rocks fall there every day. Money was not the problem....we ultimately spent 100 million dollars per mile in that canyon! But we did not have the technology to predict or intercept rockfall.

I knew a ditch section could be intuitively designed to intercept most of the rocks, but those require a lot of width and depth and can be roadside hazards in themselves. This concept did not fit well within the extreme space limitations in Glenwood Canyon.

We developed rock bolt and chain link mesh techniques.

Here is a funny story. I asked around about rock bolts...no one in transportation was using them. They were a staple in underground mining. So, I contacted a local coal mine and asked about how they designed rock bolts...spacing, length? They sent their engineer to our project, and he suggested a Safety Factor of 2.

I had no idea what SF 2 meant. He explained that if we used 8 foot long bolts on 4 foot centers that we divide 4 into 8 and that is Safety Factor 2. And 16 foot long bolt should be placed on 8 foot centers. I thanked him for taking time to visit our site.

The project in the photo was more of a spot bolting design, which is easy. We don't have to know the safety factor in absolute terms. The more difficult decision is whether to secure the mesh to the bolts or let it drape rest loosely over the slope. On one of our first projects, we tacked the mesh tight. After a few years, pockets of rock developed, and the mesh ruptured and sent a lot of rocks downslope. We did not think of that. We had to go back and release all the remaining pockets.

WE CREATED THE WORLD'S FIRST COMPUTER ROCKFALL MODELING TOOL

Developing a program that could simulate a rock in motion was beyond my imagination. I submitted a research proposal to FHWA headquarters in Washington, D. C. outlining the need for this modeling tool. My proposal was for just creating concepts that should be considered in developing a working model. I did not have any idea how this could be done.

It didn't take long for the terse rejection letter. That rejection included a mandate to not use any Federal funds in this effort. Rockfall could not be modeled. The folks at the other end knew I had a lot of Interstate money and my tendency to take shortcuts.....

"No" means to take it to next higher level. Remember this.

I had about 15 employees, most of which were very science oriented. We spent our waking hours doing or thinking about projects, tools, needs, possible solutions, strategies.... We had a host of foundation problems, tunneling issues, and this rockfall nightmare. It was a great time to be alive...impossible problems but with funds to find solutions.

I had two temporary employees...married college students...and they rotated on a 6 month schedule. College for 6 months and then Glenwood Canyon for 6 months. They were math geniuses...seriously. We spent long hours at our giant white blackboard talking about what a rock was thinking when it rolled down the hill....an Asian approach where everything is animated.

We concluded there had to be limits on behavior...rocks could only go so fast, bound so high, spin so fast...thus there were limiting parameters that could go into a dynamic program. Our landslide models are static, but rockfall is obviously dynamic and there were no programs that we could adapt. Even the Texas Transportation Institute continues to rely on full scale "crash testing" in lieu of dynamic modeling for features such as new guardrail designs, or new bumpers, or energy attenuators...anything involving motion in the design.

In retrospect, I guess this was a factor when an FHWA geotech suggested the only way to deal with rockfall prediction was to roll rocks at that exact site. That is always impractical.

At this same time, I served on state and national research panels where we evaluated all sorts of proposals. One that came across was from the University of Colorado looking for uses for their new high speed digital video capability. We were just then switching from analog magnetic tapes (VHS) and exploring this revolutionary digital medium. You can see the low quality of VHS on my web site, GCSWALL.COM and a grainy video about our rockfall research and how close we came to killing our camera team.

The CU equipment could capture action in microseconds. It came to us that we could actually roll a rock down a long slope and capture translational velocity, rotational velocity and bounding patterns with great accuracy.

So, I wrote a proposal to FHWA to use my I-70 funds to experiment with this. It was turned down so we did it anyway. I found a site near Rifle, Colorado that had a 600-foot-high barren shale bedrock surface that was about 50 degrees with some nice irregularities that would produce random bounding. It was part of 4000 acre sheep ranch and was used only in winter. (The owner agreed, but only if he could watch us roll rocks.)

We set up an intense network of distance and height reference points, found a gravel pit that had hundreds of oversize, rounded rocks...some would barely fit in our largest dump trucks...and rolled rock after rock down that slope. We measured and numbered rocks...it was a smashing success. We found that rocks really have a limited suite of behaviors.

Bounding heights can be predicted conservatively...and within reasonable parameters for designing mitigation.

We called our program the Colorado Rockfall Simulation Program (CRSP) and it remains the international reference standard.

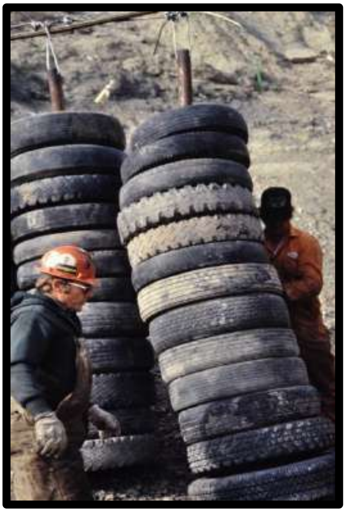
WE MADE HISTORY AGAIN

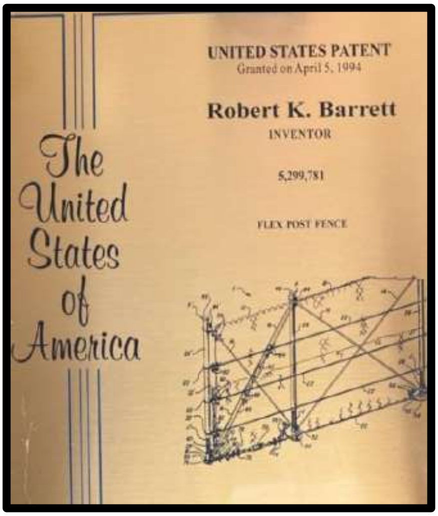
I still get excited recounting this time in my life. We could now actually **numerically design rockfall mitigation**. This was even more dramatic on the world stage than introducing the design protocols for soil nailing and rock dowels.

My team would call each other at all hours with new ideas for putting things in the way of rocks....we developed new concepts. I obtained patents for some of our inventions.

The listing for all the ways we devised to stop rocks goes well beyond the intent of my Unfinished Story about GCS/GRS.

One novel idea was that we could stage mitigation. I developed the concept of attenuation where we put flexible, moveable features in the pathway that subtracted energy and bounding height so that the final rock stopping feature was more certain to provide 100% protection. One of those was our hanging tire columns. We stretched a heavy cable above the pathway...typically a gully feature... and used tires on wheels we obtained from the local junk yard stacked onto 10 foot drill rods. You can see these on the video...GCSWALL.COM...and in this photo. They were called "rock chimes".





I invented the Flex Post Fence....you can see it in the video at gcswall.com. It is a heavy mesh fence supported by posts with powerful springs at ground level. Rocks become caught in the mesh and are redirected to the ground...that contact stops the energy and the post springs sends the fence back to vertical and throws the rock back up hill...cool.

THE GCS FORTRESS BARRIER

The most powerful and most certain rock stopper was our GCS Fortress Barrier. And that got off to a rocky beginning. Some of us thought the layers of "slick' fabric would allow sliding from high horizontal forces of a rock plowing sideways into our GCS barrier. We still did not understand the **overarching number of roles for this magical composite!**

So, back to the field for more full-scale demonstrations.

The first test was with a series of GCS double sided walls with various spacing, fabric strength and backfill quality. We rented the largest crane in the region and devised a way to swing a 500-pound rock into the test walls. We could get up to about 60 miles an hour at impact. I had to sign a liability waiver...if the barriers did decouple and not stop the rock, the crane would experience a violent toppling.

We had over 100 people attend...TV news, newspapers. Everyone was disappointed. The huge rock just stopped dead. No drama. No embedment. Every GCS variant performed exactly the same. Wow.

Next we built a more formal Fortress Barrier at our Rifle test site. The name was just for marketing...it is the exact same design for GCS/GRS abutments, piers and walls. This one was fully instrumented with

everything we could imagine. We hired Henrie Henson...freshly retired as CDOT chief bridge engineer...as a consultant to develop a design protocol. We rolled 100 rocks of increasing weight with the idea of measuring deflection and projecting where failure would actually occur...**Henrie's mission: What was the largest rock a GCS Fortress Barrier could stop?**

The performance was overwhelming. We determined that these barriers would stop anything that did not roll over top of them and that thickness as narrow as 5 feet would work. This, again, was to the disappointment of our gallery of TV and newspaper people. (People love to watch rocks roll, but it is more fun when something is destroyed.)

We did note one inexplicable quality. When hit with the giant rocks, the wall would deflect locally few inches....and move back exactly 50% of that deflection each time. Elastic behavior in a soil composite. I still don't have an explanation.

GCS FORTRESS BARRIER INSTALLATIONS

These things will stop a Mack Truck...and probably a freight train! One we installed on Wolf Creek Pass was hit with a 12 foot round boulder. We estimated 5 million foot-pounds at the point of impact. The hollow core facing blocks crushed into backfill an inch or two…and remained embedded. No repair needed.

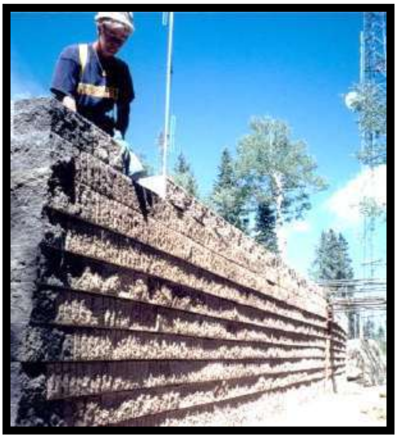
Our next design improvement was using negative batter on the uphill side. This helps quell the rotational forces in the oncoming rock. Whereas positive batter could encourage the rock to launch up and over.

MY ALL-TIME FAVORITE FORTRESS BARRIER

The Colorado State Patrol had installed a series of repeating towers across Colorado. One was near the top of a peak near Montrose. As they neared completion, someone noted the rocks scattered around the site and the high cliff behind it. And then they realized they had placed the tower in the middle of an active rockfall zone. I was contacted and visited the site. The tower was indeed in the direct path of the crumbling cliff.

I was too busy to take on a project. Two other family GCS projects in Puerto Rico and Arizona were supported by our son, Colby, when he was in high school...but he was away at college.

So, Linda...my wife... volunteered. I knew some of the county maintenance people who worked a 4-day schedule and would welcome a second job. So Linda and two county guys arranged for equipment and materials and worked 2 long weekends to complete her GCS Fortress Barrier. Her comment was that she hated negative batter. Check these photos of her and her project.



A note to AASHTO....projects like this demonstrate the versatility of GCS/GRS in applications where traditional solutions don't even exist or would be impractical or cost prohibitive. Broader recognition and understanding of GCS/GRS by this esteemed and well respected body could open the doors to many more unique solutions.

ONE MORE DEFINITIVE CASE HISTORY FOR GCS/GRS VERSATILITY

Interstate 70 construction had undercut a very unstable cliff section along the Colorado River near Grand Junction. The 200 foot high sandstone cliff was sitting on a failing shale base. Expansion for a ditch line exposed the shale and exacerbated the weathering. Rocks were routinely exceeding the narrow ditch and rolling onto the Interstate. Note in the photo how rocks were being directed onto the roadway.

Al and I designed a GCS wall placed right on top of the jersey rail and created a level platform 24 feet above the roadway level. This wall was 1000 feet long and would stop the lower erosion and provide a wide platform to serve as rock catchment.

This wall was heavily instrumented by a team of University of Colorado/Denver grad students under the direction of Dr. Jonathan Wu. **Nothing was learned…these GCS features don't tilt, strain, settle…boring.**

A 15-million-foot pound cliff section fell onto our bench 3 years later. The GCS bench saved the Interstate roadway – and perhaps a life.

PHOTO GALLERY OF BOB AND AL PROJECTS


2007
CANADA'S
FIRST
GCS®
WALL


473
DURANGO & SILVERTON


STOP

APPENDIX 1: BIN PRESSURE EXPLAINED

CDOT GCS – FHWA GRS Technology

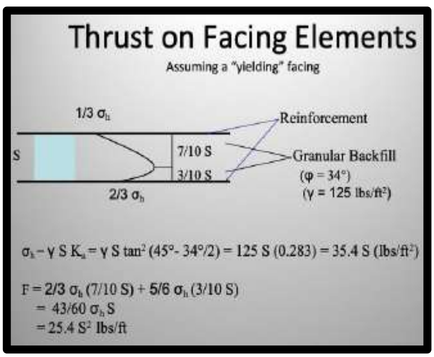
Once you internalize and accept this inexplicable behavior, then the rest is easy...you will have entered the paradigm of Confined Soil.

This is the most counterintuitive aspect of GCS/GRS....the horizontal load, bin pressure, on each of the facing blocks is not cumulative. We can build a block faced wall up to 300 feet high and the lateral force on individual blocks is the same at 3 feet, 30 feet and 300 feet.

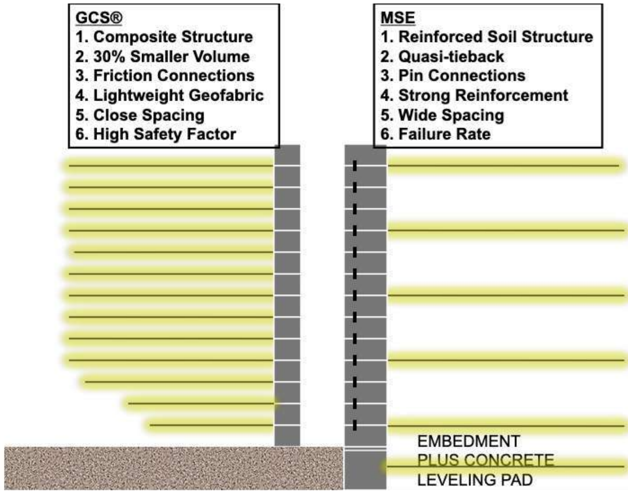
Bin Pressure is merely the failure potential of the backfill between the upper and lower sheet of inclusion. This is the only internal aspect that can be represented with equations.

This ultimate value is about 25 pounds per square foot for our typical design with 8 inch spacing. You can hold this back with your hand...almost nothing.

The prediction is "worst case". Most of our backfill has some cohesion and apparent cohesion, which increases with vertical loading. The backfill typically stands vertical without the blocks. The blocks are useful for forming and then for permanent erosion control.



I have demonstrated this counterintuitive behaviour at least 100 times in demonstrations all over the U. S. and beyond. Look at the photos below. We build the demos and then remove the facing and then load the GCS composite. This illustrates a major difference between MSE and GCS/GRS.



GCS/GRS is easy and quick and always less expensive than MSE to design and build.

MSE requires embedment. Thus, when you do the math, MSE walls are significantly larger in volume, about 30% more, compared to GCS/GRS.

For example, a 10 foot high exposed face for a MSE wall would be achieved with a 12 foot high wall. If we use a .7 base to height ratio, then the MSE wall is wider than 7 feet. Whereas a 10 high GCS wall would be 7 feet wide...it can rest on the ground. That is 70 square feet vs. 101 square feet for MSE.

GCS/GRS can be built with a truncated base...it is global stability check...not internal. Overturning is impossible..they are heavier at the back than the front.

GCS/GRS does not have a minimum width. We have built 40 foot high facades that are only 2 feet wide. GRS/GCS can be built with negative batter. This gains platform width, it can shorten the lids on box culverts and, on the uphill face of a rockfall barrier, negative batter can arrest the rotational velocity of a spinning rock.

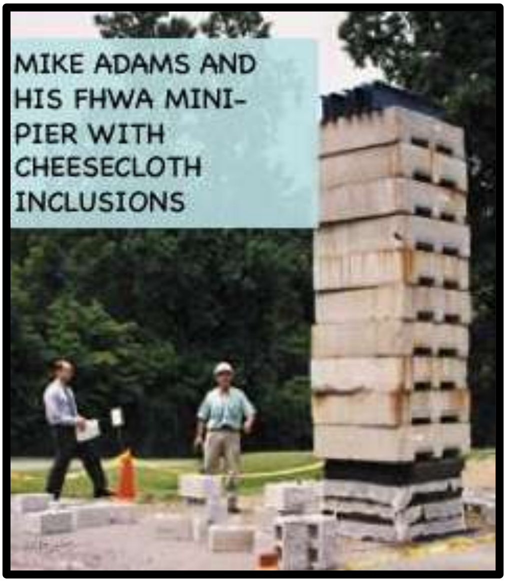
GCS/GRS is an elegant and powerful technology in the right hands.

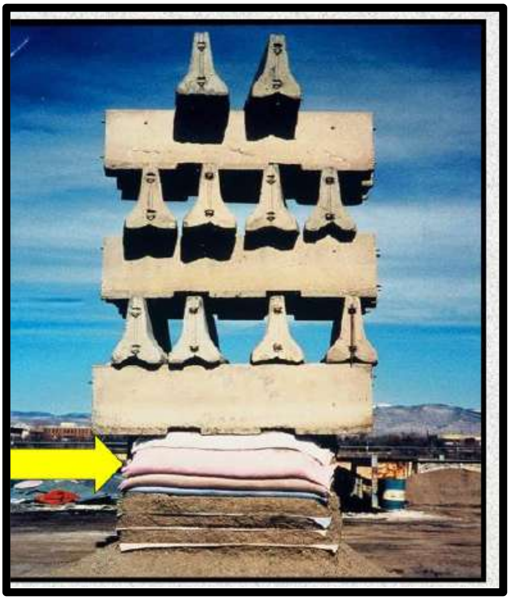
FIELD DEMONSTRATIONS OF FACING BLOCK REMOVAL

Here are some photos of demos where we removed facing blocks. Please bear in mind the fabric extends to the front face of our blocks, thus the excess fabrics are what we see on the face when we remove the facing block. I used a razor knife to cut the flaps on the lower photos. (But don't try this with MSE!)

I have a video of our Bedsheet demo on my site, GCSWALL.COM. You can watch as we build the demo with Jersey forms and then remove the forms and stack them to 25 feet high. The inclusion is not fabric....they are bedsheets! One tenth the strength of our silt fence. And we could have stacked the Jerseys to 80 feet high!

Mike Adams of the FHWA built one of these mini-pier demos and used **cheesecloth as the confining medium**, removed the facing/forming, and loaded it with concrete panels....amazing.

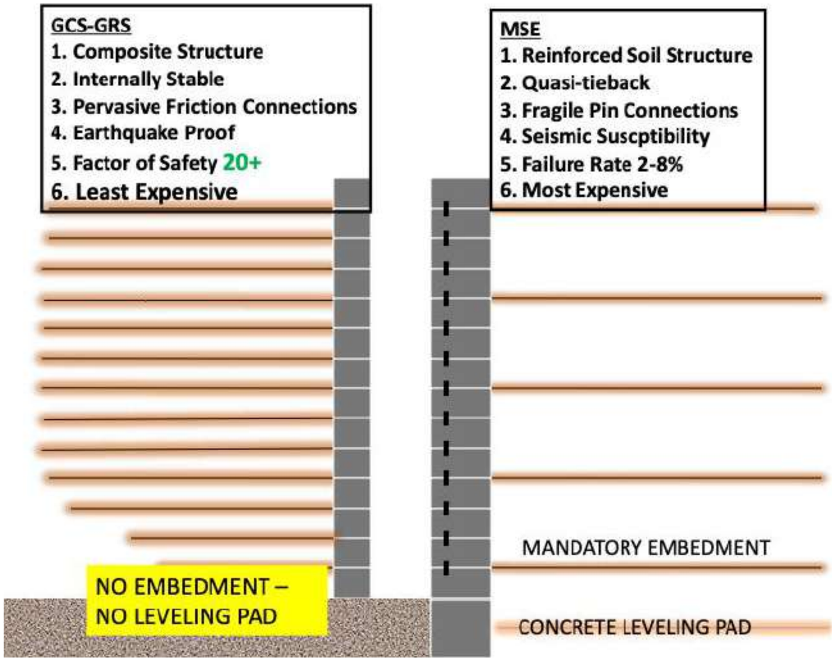




APPENDIX 2: CONFINING INFLUENCE EXPLAINED

Confining Influence is the magic

*that creates **bedrock behaviour** within common road base!*



Confining Influence is the governing mechanism by which Geosynthetically Confined Soil (GCS) transforms ordinary unbound aggregate into a composite exhibiting bedrock-like mechanical behavior. This effect arises from induced lateral restraint and stress redistribution within the aggregate matrix and is fundamentally **proximity-dependent**: the closer the geosynthetic layers are placed, the greater the mobilized confinement and resulting stiffness, strength, and load-spreading capacity.

Dr. Wu of the University of Colorado Denver conducted GCS research for CDOT and FHWA over a 30-year period. One of his most significant contributions was the **quantification of the proximity effect**. His experimental and analytical work demonstrated that geosynthetic layer spacing of approximately **4 inches** produces **maximum confinement**, with very high confinement maintained up to about **12 inches**. Beyond this spacing, performance becomes increasingly dependent on aggregate gradation, angularity, and durability.

Accordingly, the GCS backfill configuration used here with inexpensive concrete masonry units...cinder blocks....employing **8-inch vertical spacing** between geosynthetic layers—operates well within the zone of intense confinement identified by Wu's research. Within this spacing range, the aggregate behaves as **unique composite**, exhibiting stiffness and load distribution characteristics comparable to lightly cemented materials, but without the brittleness, curing requirements, or cost associated with cementitious stabilization.

In the above representation, the **red shading** illustrates the extent of this confinement envelope. Functionally, this confined zone performs **as if the aggregate were cement-treated**, despite remaining entirely unbound.

In contrast, conventional MSE is a simple tie-back wall constructed in reverse order. The backfill is just that...backfill...not a bedrock-like unique composite.

APPENDIX 3: GCS/GRS DOES NOT REQUIRE EMBEDMENT...

NOR A CONCRETE LEVELING PAD

Embedment of up to 1/7 of wall height and a concrete leveling pad are required on many or most MSE walls. GCS/GRS walls are happier being placed on the ground surface with a leveling bed made with backfill material.

A concrete leveling pad is generally a bad idea for either wall system. We found this out the hard way. We have split boulders in rock faced GCS walls on our first trials building walls with concrete footers as leveling pads.

It turns out that no matter how well we compact each lift, there will be a minor amount of additional consolidation as the height increases. With the facing elements...blocks or native stone or cut stone.... on a concrete pad, the facing behaves as if it were infinitely stiff. The geosynthetic then imposes a slight downdrag where it joins with the facing, and the cumulative loads become much higher than we could imagine...we observed induced cracks in huge granite boulders in our rock faced walls in Black Hawk, Colorado.

Concrete blocks are imperfect in shape...they are designed to have mortar between them. Thus, downdrag loads can produce hairline cracks as the blocks try to get tighter as the downdrag force increases. This does not happen with an aggregate leveling pad. By the way, hairline cracks are just cosmetic nuisances.

Concrete makes for a nice leveling pad, but it is counterproductive. Downdrag with only a few, high strength inclusions may be one of the many reasons some **MSE walls perform badly**....**shear of the geogrid at the connection**.

Of course, there are site conditions that may require special measures...but these are your engineering decisions as you proceed with design.

DESIGN EXAMPLES

A golf course in Durango, Colorado was expanding to 27 holes and needed a road across a seasonal wetlands area. Their environmental warrant required a 10 foot open bottom culvert at one location. Their structural engineer selected short stem walls for the end supports, however, they were concerned about placing those stem walls on the mushy, black, slimy, stinky, silty soils in that marsh. They wanted small piling just to be sure.

This caused two issues. One was cost. The other was that this road was the only access to the rest of the development and the time required to get the piling in place and then getting the concrete to cure amounted to several weeks. This would significantly delay their project.

Al heard about this and looked at the site. **Al and 5 guys built the culvert in 8 hours.**

They leveled each abutment site with a backhoe bucket and swept away the living plant material. Then they placed wall backfill on the black mud for a leveling pad for the facing blocks.

We had worked with swamp mud before...there is a test called "Loss By Ignition" where they heat a dried soil sample to 550 degrees C until the weight stabilizes. It is surprising how little organics there are in swamp soils....maybe 2%.

Here we had silt, so bearing capacity was a non-issue for a 5 foot high GCS wall. We found prestressed concrete lids already cast and cured and had them delivered on construction day...look at the photo...and there is no need for expansion joints or other amenities. Quick, easy, inexpensive, and super strong.

A BRIDGE IN 24 HOURS

Time and cost required to excavate a MSE or concrete stem wall foundation and then wait for concrete pad to cure can be a major factor in project feasibility. Keystone Ski Area needed a 34-foot-long ski trail bridge high on the mountain to cross a steep sided gully. Their structural engineers designed a traditional, deeply embedded foundation made of reinforced concrete.

Problem was getting those cumbersome concrete mixing trucks to the location immediately after snowmelt. I was working on a landslide repair for them and overheard the conversations. They invited us to review the site and offer an alternate design. They were in a bind for time...this was a gateway to more expansion that summer.

We designed a pair of GCS/GRS abutments that rested on the ground and had rented equipment designed for difficult terrain to carry our materials up there. We had the bridge prefabricated in two equal halves with the side rails already installed. With two crews working with lights until midnight, we had the bridge open in less than 24 hours.

No wet concrete...we used pre-cast sills. We did this for 50% of their budgeted amount.

2009 NOVA AWARD

CREATING GCS
BRIDGE ABUTMENT
TECHNOLOGY

BOB BARRETT - CDOT
MIKE ADAMS - FHWA

THE JOY OF REAL ENGINEERING

A very important note....we always worked in "client best interest". We charged only a reasonable profit, no matter the situation or opportunity. Our final plan review was to see what we could take away...not add on. Our engineers then and now were able to engage in the joy of pure engineering...unfettered problem solving. Exhilarating.

It is contagious. Clients recognize this approach immediately and projects become partnerships....and we looked forward to going to work each and every day.

You can create this environment in government service as well as private practice.

APPENDIX 4: HOW I DESIGN GCS/GRS RETAINING WALLS, BRIDGE ABUTMENTS, BRIDGE PIERS, ROCKFALL BARRIERS AND AVALANCHE DEFLECTION STRUCTURES

The Taiwan Ministry of Transportation and Communications invited me to Taiwan to participate in creating design concepts for a cross-island highway between the Nantou and Hualien Provinces. Representatives from MTC had visited our Glenwood Canyon I-70 project and noted this was the most difficult project they had seen world-wide.

This visit is where I learned to understand Confined Soil in a very different light.

We were looking at extreme mountainous terrain, too steep for traditional roads and core temperatures of 200 degrees…tunnels were excluded. They assumed that if we could build Glenwood Canyon I-70, we could do anything.

But first.... seems we always have to do something else first...they had to cross a wild river...dry in the summer, but devastating, uncontrollable flows during typhoons. The recent flood was the worst ever and it took out the remaining bridge to get to the base of the mountain.

We visited that site and we laid the topo map on the hood and looked for places to begin the project. There was a noisy discussion...very animated...and they forgot to explain in English... So, I asked my interpreter what was causing such excitement.

He said they were wondering where the river would want to have a bridge.

I thought he was joking...but...no...dead serious. I laughed a little. And then I woke up a 4 am the next morning and realized this is how to design most everything. It changed my life.

I tried this approach with landslides. It was just for fun at first. I asked them why they were unhappy and what would it take to make them happy.... Rocks....I asked unstable rocks why they were dissatisfied with their lofty perches...did they want to join their buddies on the ground? Or would they like to stay up there?

Obviously, I did not circulate my animation approach to geohazard mitigation...but I did add this to the mix when reviewing various failures. There was some level of validation via my 2018 Deep Foundations Institute Innovation Award, and the 2025 ASCE Geo-Institute Award for Contributions to Geohazard Mitigation.

Animation. Geosynthetically Confined Soil fits this alternative approach perfectly! I abused this Unique Composite in our laboratories for 20 years. Always in Falsification Research....it can't be this good...it cannot be infallible... why can't I prove this!

We spent a decade or more putting strain gauges on the fabrics, thinking there had to be strain...stretch...in the inclusion. There had to be significant load transfer into the inclusion.... we all think in a tieback mode. Even after we had used bed sheets and cheesecloth as inclusions, stuff that cannot sustain credible loads, we could not see this. I can tell you paradigm fixity is a debilitating state.

THE NEW PARADIGM OF GCS/GRS

The Taiwan experience reframed my entire approach to design. The question 'where does the river want to have a bridge?' is not mystical — it is systems thinking. In geomorphology and geotechnical engineering, every failure is the system trying to reach equilibrium. Rivers migrate. Slopes relax. Rocks shed. The insight is that design should align with force paths, not resist them blindly.

Our falsification research proved something fundamental: GCS/GRS is not reinforcement-dominated — it is confinement-dominated. The geosynthetic layers restrict lateral dilation, increase apparent confinement, suppress shear band formation, and prevent progressive failure. The soil and inclusion become a true composite material — accurately described as lightly cemented aggregate without brittleness. This is why strain gauges showed almost nothing. We were looking for tieback behavior; the system was behaving like confined granular rock.

If internal failure is practically eliminated, then design reduces to three checks: sliding, bearing, and global slope stability. The GCS block is treated as a rigid body with ductility

— a settlement-tolerant monolithic structural element. That is clean, teachable, and scalable.

Design is all about external stability, and global stability almost always controls....don't allow the circles to pass through the GCS.

We build GCS facades 40 feet high and 2 feet wide as facing for rock or shotcrete or concrete. No problem. We can build in it swamps, hillsides...always make sure it is happy.

Think about this...when a concrete panel shows up on a project, we accept it as is. That panel became a Unique Composite in the form in the yard....everything has already been determined via cylinder breaks...after we make a composite of the cement, aggregate and water.

Same with GCS...once it is in place, there is nothing more to question. Our engineering task is to make sure the GCS feature is happy with where we are putting it.

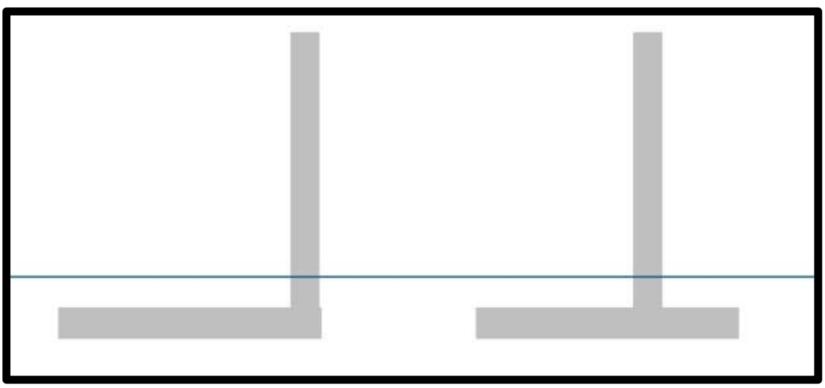
Even junior engineers can deal with this. And it is our responsibility to educate them in this technology. Once they understand, they will also understand that solving problems and designing solutions is a primary role in their careers...

APPENDIX 4 - A

THE IDEAL NEW AASHTO-BASED DESIGN PHILOSOPHY FOR GCS/GRS WALLS, ABUTMENTS, PIERS, AND ROCKFALL BARRIERS

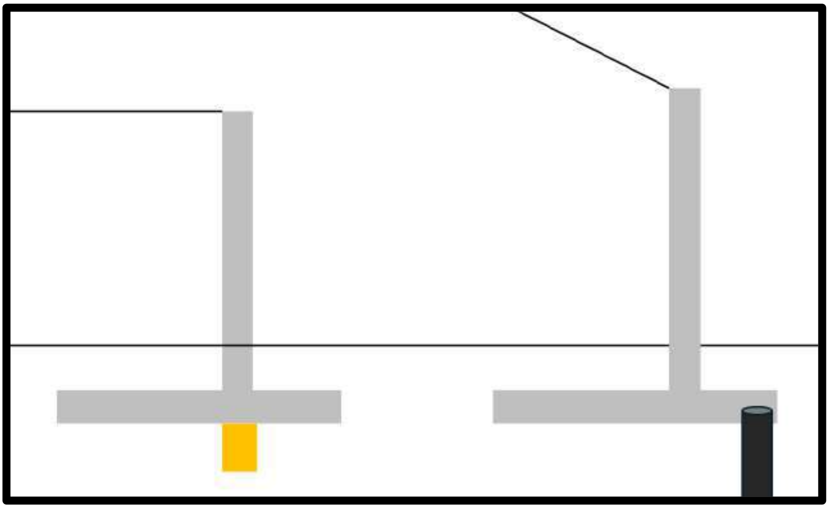
I awoke at 4 am with what may be the clearest way to explain GCS design to our structural engineering colleagues. Let's compare GCS design with today's paradigm for concrete cantilever walls.

Here's how: The concrete cantilever walls shown in sketch below are basic design features for structural and geotechnical engineers. These are the "L" walls and the typically more efficient "T" shape walls.



These old workhorses are mainstays in our practice. We can adapt the shape to fit project needs and we can keep adding elements to the basic shape to assure stability…keyways to provide additional resistance to sliding...piling to prevent overturning.

After we have determined the external configuration of our concrete structure, we then decide on internal and external stability factors...do we need keyways or piling? What is the footprint? How much embedment? Where is the optimum placement of steel deformed bar? Do we need epoxy coated bar or even fiberglass tensile elements?



Let's say we need GRFP tensile elements. Selection requires determining the ultimate tensile capacity then applying reduction factors for allowable tensile contribution, including accounting for creep rupture, crushing rupture, and environmental reduction factors. These depend on exposure...inside...outside...wet..dry..

These properties are verified with testing apparatuses...but we don't do the testing. We always accept some form of Manufacturer's Certification. This is very important to understand.

Think about it this way: structural designers rely on third party validation even more extensively than on our own knowledge and direct responsibilities. We would be at a loss...today, we could not deliver a retaining wall plan set with personal testing or knowledge of every component.

Continuing, once we have designed the outline for our concrete wall and refined it to conform to site specific soils conditions....again a critical factor typically beyond our wall designer's control or expertise....then we can go ahead and build our project.

Our design includes concrete, composed of three major components, water, cement, and aggregate. As designers, we do not test each separately. We ask that someone else test the combination. Component testing does not relate in situ performance.

This is because concrete is a Unique Composite. The sum of the properties of the elements cannot predict much of anything. Whereas in a Simple Composite, 2+2 = 4.

We can vary the components in a concrete mix to achieve desired properties.

We have the same scenario with Geosynthetically Confined Soil. GCS is a Unique Composite. Thus, we can determine properties only through testing of the final combination of elements. In this case it is easier.... we only have aggregate and inclusion. Very basic...understandable at any level of engineering.

Below are examples of the GCS equivalent of testing concrete cylinders. We have validated the fact that GCS cannot be failed internally in any working or service situation. Not even by an earthquake. We have proven we cannot pluck facing blocks. Thus the design philosophy is the same as with a concrete cantilever wall. We simply draw the shape that fits the need and address external constraints. We accept that the internal materials inside our outline will perform as predicted

In the case of GCS, we only need to address external constraints and requirements in our design. Embedment is not mandatory...if you can drive a pickup on the ground, it will typically support a GCS feature. Frost heave is almost always a fiction. Checking overturning is an insult to this elegant system.

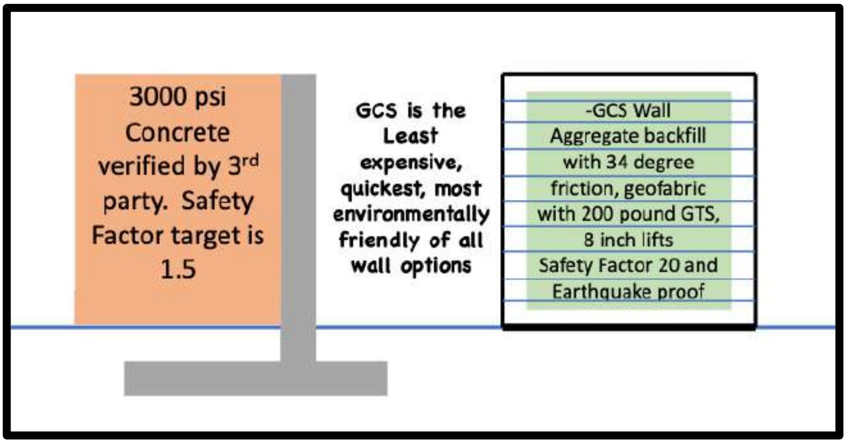
We have shown that aggregate with a friction angle of 34 degrees or higher and a geosynthetic inclusion with a Grab Tensile Strength of 200 pounds or more and on 8 inch or less spacing compacted to at least 92% of optimum has a factor of safety of at least 20. An internal stability analysis is moot...not required.

We test after we remove the concrete blocks just to make the demonstration more dramatic! It supports 80 tons without a wince.

BELOW – FHWA ACHIEVED 10 TONS PER SQUARE FOOT

SUMMARY

Here's the bottom line. Our cantilever wall designers only have to draw a T-shaped box. The properties of the materials inside the boxes, inside the lines, are predetermined and verified. The shape of the box fits the project warrants.



Same with our GCS design. We draw a box in whatever shape we need. The design effort is all about external stability. A failure through the GCS feature is not possible. It's as strong as bedrock. Embedment is not required. GSC can be just as happy on the ground. There is no Base to Height ratio. We have built as narrow as 18 inches.

This is the endorsement we are asking AASHTO to consider. The evidence supports it.

The potential savings — in cost, time, and lives — are transformative. Clients and taxpayers around the world are your beneficiaries.

APPENDIX 5: A SERIES OF CASE HISTORIES AND OBSERVATIONS

AMAZING SUCCESS WITH BRIDGES ON GCS/GRS FOUNDATIONS

Defiance County, Ohio County Engineer Warren Schlatter has built over 40 bridges using CDOT GCS technology that I introduced to him about 2005. Warren improved our design by eliminating expansion joints. He reports that typical savings over traditional bridges is about 35%, along with huge time savings. When multiplied by all the bridges built every year around the world.... the potential savings is large enough to seem unrealistic.

It means we can build 3 bridges instead of two with the same budget.

Warren traveled around the United States as a spokesman for GRS-IBS bridge abutment technology (which is based on CDOT GCS research) for the Federal Highway Administration sponsored by Turner Fairbanks researcher, Mike Adams. Toby Bogart of St. Lawrence County, NY implemented GCS/GRS abutments and became a missionary as well. He reports 50% savings on his projects.

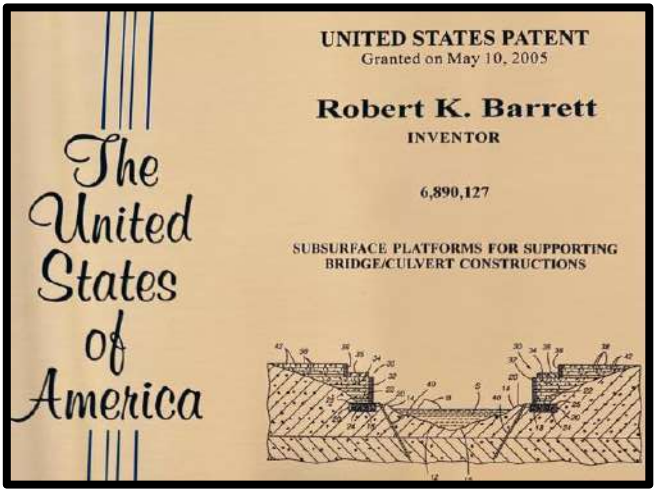
This FHWA program may wind to a halt...there does not seem to be the paradigm shift I had hoped. It would have been instructive for FHWA and AASHTO members to try to visit these special sites...it takes time and some level of immersion to understand GCS/GRS and change paradigms.

Another sour note.... I have seen projects built ostensibly under the FHWA GRS-IBS Every Day Counts umbrella that used design options that seemed to me to create reasons not to use GCS/GRS. Fabrics way too expensive, embedment way too deep, footprints way too large, blocks too big and heavy and expensive.

GCS/GRS is quick, easy, light, versatile, inexpensive and super safe. All those add-ons did nothing to reduce the chance of failure...there's no chance of failure in the first place.

IRONY OF IRONIES AT FHWA

I was developing a project in Wisconsin circa 2012 where a GCS/GRS wall would make a huge difference in cost and time. We proposed it and the local authorities carried it forward to the front offices. My proposal was turned down by the FHWA office. GRS was approved only for bridge abutments...it was not suitable for retaining walls. We needed MSE. Fighting paradigms...the status quo...is like swimming upstream.

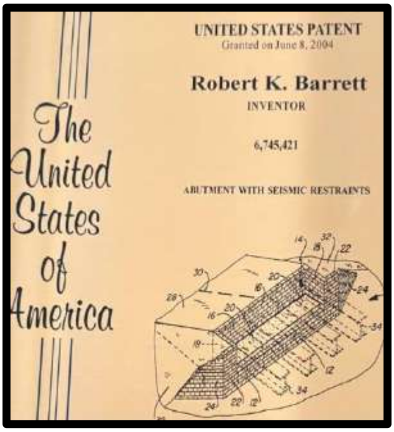


THE WORLD'S LONGEST BRIDGE ON GCS/GRS FOUNDATIONS (THIS ONE INCLUDED EARTHQUAKE WINGS)

A developer in Big Sky, Montana needed a bridge that would cross a Gold Medal trout stream. The engineering firm he hired in the beginning said the east abutment was on an ancient landslide. They wanted an array of horizontal tiebacks in the steep slope below the abutment.

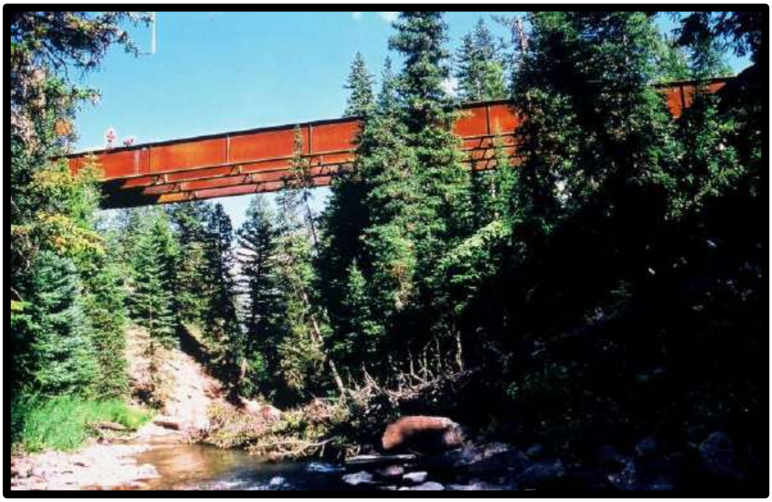
This heroic foundation improvement was required to meet the 2500 year earthquake recurrence criteria.

The Forest Service added more complications. They said the bridge had to be clear span…no piers. The span length was 191 feet. And there could be no sediment, no drill cuttings, into the creek. This precluded drilling the tiebacks into the steep slope immediately above the trout stream. There was no way to contain the silt from drills or the skid roads required to gain access.



The developer contacted me via one of my workshops and explained the issue. I told him this would be a piece of cake. I am a student of geomorphology. The post-glacial landslide had been dormant for at least 10,000 years. Therefore, there had already been, statistically, 4 earthquakes of that magnitude.

The west abutment was on bedrock. We built a GCS/GRS abutment with our patented earthquake wings...seismic restraints... on the east abutment. The landslide on the east was a mile wide and ran almost a mile upslope. This slide was dipping bedrock and would be practically impossible to



reactivate with the relatively minor loads we would impose...or anything an earthquake could engender.

The earthquake factor of concern was holding the bridge on the foundation during a seismic event. We were in Montana's highest seismic zone.

Al and I were granted a patent on "Earthquake Wings" and I included these as part of the bridge design. These Wings are

sidewalls constructed with GCS/GRS that form a pocket so that the superstructure cannot move laterally in a seismic event. This concept is a fraction of the cost of what everyone is doing everywhere else. This concept made the project feasible...costs were too high for any other solution.

We built the bridge in 1999 in 5 weeks. Of course, we had the 8 foot deep girders already constructed. Our cost was significantly less than the developer had budgeted.

THE FUNNY PART AND AASHTO

The funny story is that I called the original engineering firm and offered to host them for a project visit and offered to visit their offices and provide a workshop on CDOT GCS technology. I would assist them in adopting this technology into their practice.

But what happened was their chief engineer petitioned the Gallatin County Board of County Commissioners to issue a stop work order for our project. He explained in that petition that this design did not conform to AASHTO standards....GCS was not approved.

We rebutted with a letter stating we had a Montana engineer's stamp and that the project had a lifetime warranty from our company. We already had a contract with a local surveyor to check the elevation of the abutment every 6 months for 4 years. The Commissioners voted unanimously to allow us to continue.

The abutment never moved even a fraction. What we see here is that folks can see without seeing, know without knowing...paradigm fixity...which is why I continue to advocate for AASHTO to evaluate GCS/GRS and create an environment that supports broader implementation — consistent with AASHTO's own mission to investigate and adopt beneficial technologies.

THE NOT SO FUNNY PART OF THE MONTANA BRIDGE

Two years later...2001...the developer sent me some pictures of the bridge...he was ecstatic with the timber frame he had installed on the bridge. He wanted it to look like a wood truss bridge.

We were aghast. The dead load was enormous, but, worse, the wind loads....well you get the picture. So we recalculated as best we could and decided not to have him tear it off.

We increased the survey schedule to monthly for the next year.... nothing changed.

And then, 3 years later, they sent me a photo of a dump truck that forgot to lower his bed and ran across the bridge at 45 miles per hour...really ripped up the first few cross members of the wood frame...not sure what the bridge saw or felt from this, but it ruined the truck for sure.

THE JAMAICAN TRAGEDY –

A LESSON IN PARADIGM FIXITY

AVOIDABLE ONLY WHEN WE STEP UP AS ENGINEERS

The Jamaican people have lost trillions of dollars and this tragedy in ongoing. I can explain.

Dick Prosence retired as my boss at CDOT to take on the Papago Freeway challenge in Phoenix. We expected Dave Grounds to be his replacement, but Dick designated Ralph Trapani to take over. Dave resigned. Dave was my best friend... we loved hunting and fishing....We lived through many outdoor accomplishments that bordered on the extreme.

Dave went to work for Stanley Consultants in Florida. His company had a contract with the Jamaican government and the World Bank to design a 40-mile-long highway on the spectacular North Coast from Montego Bay to Negril. This was going to change all of Jamaica...the unemployment rate was 50% and this highway would bring in billions in investments and developments...and long-term jobs.

The issue came down to 12 bridges crossing rivers that were full of loose silt...zero bearing capacity. These deposits were a result of erosion from faulty agricultural practices. Depths reached 100 feet and filled bays where pirate ships once sought protection.

Dave heard about this and suggested to the office in charge of that project that I might be of assistance. So, Bob Jacobs of their Iowa office invited me to visit those bridge locations.

I could not walk on those riverbanks...too soft. There had been a full covering of mango bushes and whose roots form a network on the surface, thus I could walk on that mat. I could plunge a stick down 10 feet into the freshly deposited silt. They wanted to use piling for the foundation, but they could not get pile drivers to the abutment locations.

I determined the deposit was silt and not clay, thus we could load it slowly and squeeze out the water and achieve a bearing capacity. I also told them we could use GCS roads and abutments at a fraction of the cost. The Jamaican highway director, Karl Martin, heard of this and was super excited. He asked us to demonstrate this.

I was a CDOT employee, but I took time off for these special projects...I had several around the world assisting with tech transfer with our creations in GCS and rockfall.

I took Linda and our young sons, Andrew and Colby along. Carl provided a car and driver for us.

I had a large crew in Jamaica at 50 cents an hour.... we had machetes, not chainsaws! We chopped for days to get from the existing trail on higher ground down to the riverbank. Then we put down a sheet of 8-ounce woven geotextile, a revolutionary new technology at the time, and was able to build a road with a 24-inch lift of their marl rock. I made a video...you can find it on my website, GCSWALL.COM

Even I was impressed with the success. Then we installed vertical drains at the abutment location by simply pushing slotted PVC down 40 feet. We built the abutment in 24-inch increments...two 12-inch lifts, every two weeks. The water squeezed out, and the silt consolidated. We built the abutment to 10 feet in height and then placed another 10 feet of GCS on top as a surcharge to speed the consolidation. Settlement was about 36 inches in 2 years.

Stanley Consultants documented the work and provided survey monitoring. My Jamaican work team painted their flag on the bottom...they were intensely proud of their construction.

It was clearly demonstrated that piling would not be needed.

However,...the final design included piling...the Stanley bridge engineers in charge would not "stamp" the GCS concept. But they were super happy that they could use the CDOT road building technique and get a pile driver to the locations. The Jamaicans did not object to this huge and unnecessary expense...it was not their money...it was the World Bank project.

We measured 36 inches of settlement...could you imagine the magnificent "bump" coming onto a bridge on piling???? I tried to explain.

The World Bank put the Stanley Consultants plans for the 40-mile-long road out for worldwide bidding. A South Korean company won the bid. Ironically, they did not like Jamaicans and built a high fenced compound and imported their own workers. They brought food, cooks, doctors...a mini version of South Korea.

The bottom dropped out of the South Korean economy...their currency devalued 50% overnight. They reported they could continue to build the highway, but they could not afford the German steel for the bridge abutments. The World Bank refused to add money to the contract.

Bob Jacobs and the Jamaicans contacted us and asked if we could design the abutments.... well, sure, GCS/GRS design is a bar room napkin level of difficulty. This would allow the project to go forward. We were all set and excited. Our demonstration was exactly what needed to be repeated 23 more times...we could use our existing demo for one of the abutments.

However, unknown to us, the accountants at World Bank ran this concept through a major "American" bridge design company and they told the Bank it was too risky, that these would not meet AASHTO standards.

So, the project was cancelled. And the poverty still exists 30 years later.

JAMAICAN DEBRIEFING – I WILL NEVER RECOVER FROM THIS

The Jamaican tragedy weighs heavily on me to this day. This failure of our engineering community to serve was and is, finally, **my fault**. I had the superior knowledge. I could not make the case for our CDOT GCS technologies.

We had shown the world the amazing power of CDOT's GCS .... a major highway that could not be accomplished any other way. Yet we watched as countless millions of people in that future will live in poverty and despair.

So, I looked at the structure of AASHTO, and it is divided into specialty groups who meet on a regular basis to discuss their rule bases. I understand this...I have served on many of these kinds of committees.

AASHTO T-15 deals with walls and substructures. At the time, the Chair of that committee was Terry Shike, Chief Bridge Engineer for Oregon DOT.

I arranged a travel voucher for him, and he visited with Dr. Wu and our CDOT research team at the University of Colorado/Denver research laboratories. (Those facilities were and continue to be world class.)

We reviewed our equipment, methodologies and findings. Irrefutable. However, at the end, Terry said he was impressed, he was a believer, but AASHTO did not and could not lead technology advances. Their role was to evaluate practice and modify AASHTO specifications based on practice.

I asked if he understood the term "Catch 22"? If practice must follow AASHTO, and practice is limited to AASHTO guidelines, we will never get to implement our GCS research findings! Terry flew back to Oregon....and did not allow GCS experiments or demos at Oregon DOT either.

Paradigms.... AASHTO T-15 was established a long time ago and included traditional walls.... all of which could be designed with long standing equations. There was not a person on that committee with expertise in soil mechanics.

I asked if we could call CDOT GCS a "steep slope" and not a "wall" and get this technology into hands of people with soil mechanics expertise. There was agreement...but then Jerry DiMaggio of the FHWA somehow interceded and decided a "steep slope" was outside of the AASHTO T-15 purview. And it is still 45 degrees or less. I lost again.

Walls come in many forms.... **Paradigms are the strongest walls I know.** They are mostly self-imposed and self-maintained.

You can see the Jamaican video on my web site.....GCSWALL.COM

ONE OF THE MANY POSITIVES FOR GCS/GRS

GCS/GRS ski under bridge, Breckenridge, Colorado Negative batter shortened the lids by 3 feet.

THE U. S. FOREST SERVICE AND AASHTO

I worked closely with the network of geotechnical engineers at the U. S. Forest Service for many years....and well before we invented the discipline "geotechnical". One of those regional engineers, Gordon Keller, called and asked me to look at a special bridge issue in the high mountains of California. They had a rusty steel truss bridge across a Gold Medal stream, and the load rating was down to Volkswagens. This was causing severe economic impacts to the local ski area, business, and residents.

The issue...the problem...was that this bridge was on historic rock abutments and piers that had to remain in place. However, they could not find an engineer who would provide a load capacity for them. Who would know how much load they could take today and how long they could remain in service?? **This impasse had persisted for 3 years.**

I told them this was a piece of cake. I had them remove and dispose the truss and we excavated behind the abutments, built GCS abutments immediately behind the rock faces, and put a single span bridge across the stream. We knew there would be no horizontal load on those historic rock faces.

We left a 4-inch clearance gap between our bridge and the tops of the piers. If you look closely at the photo, you will see the gap. There was no settlement. Cost was less than half of their budgeted amount and left everyone happy...except the U. S. Forest Service Bridge Group. They had asked we leave at least a 12-inch gap. They expected a lot of settlement.

A 12-inch gap, I told them that what would happen is a fly fisherman would look over and see that huge gap and call 911...he would think the pier was settling!

After this elegant and amazingly inexpensive solution. I called the San Francisco headquarters and offered to meet with them and explain this technology and see if there were more opportunities to implement GCS walls, abutments and piers. They refused, saying none of this met AASHTO standards and that is their bible. Come back when all this is approved by AASHTO. Savings did not matter. And these folks are not even bound by AASHTO!

THE BUREAU OF LAND MANAGEMENT AND AASHTO

I had solved a problem for NOAA-NEXRAD with a GCS wall. They built a huge early warning tower on the side one of the highest and most remote mountain tops in Arizona. This required a major rock cut on their side of ridge because the Sierra Club had purchased the adjacent land on the other side of the ridge, hoping to prevent that construction. Complicated.

The worst of the complications was that the NOAA-NEXRAD rock cut began failing and was going to soon recede across the property boundary, which would wind up in lengthy lawsuit with the Sierra Club.

We could not use rock bolts to stabilize the cut...that would have been easy, but the drill holes would have exceeded the property boundary, and the Sierra Club would certainly not grant them an easement.

So, I designed a GCS wall to provide support to the rock face. (I added some esthetic features...look at the photo...easy with GCS.)

Access was a 24-mile-long jeep road. We could not get water to this site, so we used open graded rock for the backfill...no water needed for compaction. I also did not have a contractor available, so NOAA-NEXRAD officials provided me with a preapproved contractor list. I finally found one who would take on such an unusual project...he was from California.

I also had to have a representative on site. I was still working for Colorado DOT and could not take time off to watch this. Our son, Collby, who was 17 at the time, had finished high school early and I sent him there to monitor and report. He had helped me build the bedsheet GCS demo and some GCS rockfall barrier test walls...that's about all it takes to supervise GCS constructions...it is disappointingly simple. A row of blocks, a lift of backfill, a sheet of fabric, repeat.

Colby also monitored another large NOAA-NEXRAD GCS wall project for me that year in Puerto Rico. That was an interesting story – ask me about sometime - but this one did not involve violating AASHTO.

I digress. Our Arizona contractor was enamored with GCS technology and told me about several places he could have used this. Just after this, he was awarded a bid for a job in California for the Bureau of Land Management to build a pedestrian bridge across a wetlands. It included a pair of 100-foot spans with a center pier on piling.

When our contractor showed up on site, the local BLM office told him he could not build a road in the wetlands to get a pile driver to the center pier. He called the regional bridge office and tried to get out of the contract. They said this was his problem and if he defaulted, he would be taken off their bidders list in the future.

The contractor called me in a panic. I told him this was a piece of cake. We went over to Home Depot and purchased plywood sheets, silt fence, and some cinder blocks. We rented a powered wheelbarrow. We had road base delivered to our site. We pushed the cattails down and built a trail with the plywood and used the wheelbarrow to transport the fabric, blocks and road base. We cleared the surficial organics and built the GCS pier in 2 days and then used the road base and cement to pour a footer for bearing of the superstructure...we included rebar, but it was a very light load.

Total settlement was about 2 inches after construction. The bridges were articulated; thus, the contractor easily adjusted for that. With no need for piling, my contractor friend made a handsome profit.

We noted that there were more of these upcoming, so I called the regional BLM office and offered to visit and show them what we had done and how they could incorporate generic GCS piers and abutments with savings in money and time on future projects. Especially compared to pile foundations. They said they could get pile drivers to their other sites and that **our methods did not meet AASHTO** standards. They were not open for a discussion of potential savings.

Savings...savings are intangibles in the public sector ...my pitch today is that we can **build 3 bridges next year instead of two**, if they would adopt...or at least allow... GCS/GRS concepts. I continue to think about this.

THE TURKISH TRAGEDY

THEY HAVE LOST TRILLIONS.....

Just As We Have In The United States...

Dr. Erol Guler of Bogazici University in Istanbul was a Special Member of my Transportation Research Board Committee on Geosynthetics. He was founder of the Turkish chapter of the newly organized International Geosynthetics Society. I was the first chair of our newly organized committee at TRB – 1990-97. I could only have 25 members but could have a few seats for these special cases.

Erol arranged for me to present our GCS findings all around Türkiye...Ankara, Bosphorus, Istanbul...we spent 3 weeks traveling and staying in lodging accommodations provided by Türkiye's DOT.

CDOT's Chief Engineer approved my absence. This happened frequently. Younger son Colby and wife Linda were also on this amazing trip.

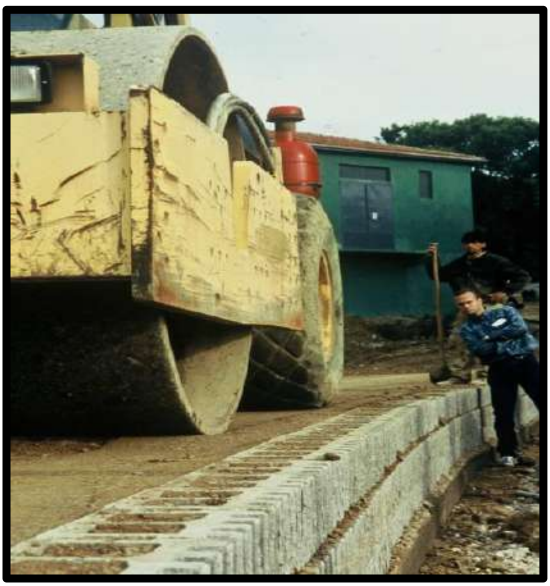
I end most of my presentations with a question for the audience on "what is your most significant soils-related problem at the moment?" In Istanbul, the answer was the most unique of all:

They had constructed a loop road around Istanbul, and it included a tunnel section that was just completed. On either end of the tunnel, the existing city streets were truncated, effectively dividing communities that had existed in some form for thousands of years.

Türkiye DOT plans did not include overpass bridges to preserve the continuity...the tunnel was in the poorest section of the city...people without political clout.

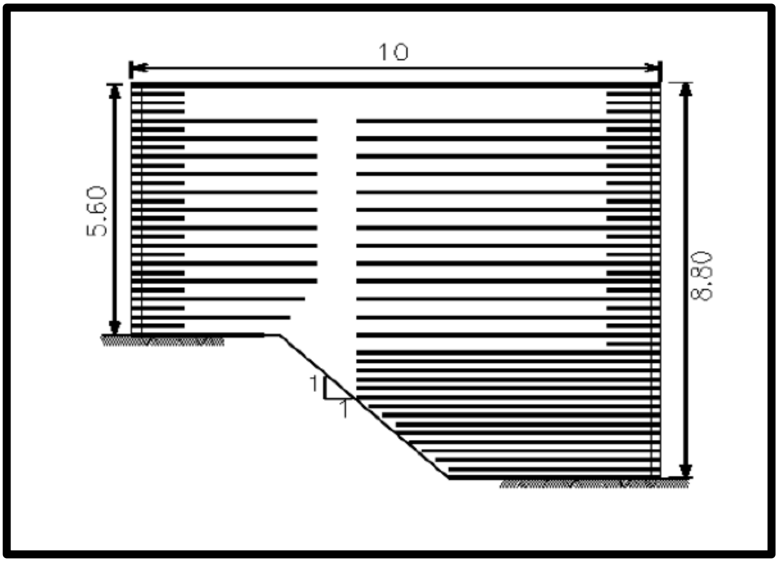
Just before my arrival, a member of those communities was elected to a major political seat and was able to halt the opening of the tunnels until the DOT could provide an overpass on his end of the tunnel to reconnect his constituents.

So, they needed a "fly over" bridge to go over the portal barrel extensions to connect the city streets. The problem was that it would take them 2 years to design and construct the bridge and they could not open their tunnel until the bridge was open.

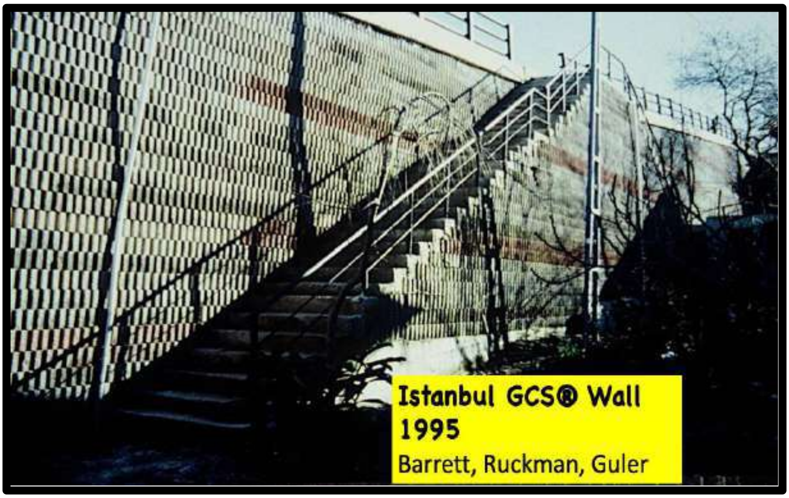


So, I told them this was a piece of cake for a GCS solution. We could have the flyover completed in 3 months for ¼ the cost.

The DOT leaders were very happy. Dr. Guler was seen as credible and endorsed the plan. We began design that day. The concept took about 3 minutes. It was a simple double-sided wall...(think Great Wall of China in cross section). It went up to the top of the portal barrel extensions on either side and had a 6% slope to maximum height of 24 feet.



Dr. Guler used our "CTI Tail" concept in his design.



We demonstrated we could run a 50 ton roller adjacent to the facing blocks...illustrating one more of the counterintuitive, stellar behaviors of GCS/GRS.

The DOT did add a wrinkle. As you can see in the completed photo, we added a double set of stairs which were built as part of the wall. This way pedestrians could go from the road down to the ground. Couldn't do this as easily with a bridge.

The cost of this was enormously less. Everyone was happy. The tunnel was allowed to open even before the GCS fly over was completed.

So, the Türkiye DOT decided to build a fly over on the other end of the tunnel. We asked them if they wanted assistance with the next CDOT GCS design. They declined and said they had the two-year window to build the bridge.

The taxpayers of Türkiye would have saved millions and millions every year if their DOT engineers would have embraced CDOT GCS technology. I see this every day here in the United States. Our top tier U. S. government and private sector engineers will look at this report and not internalize that it is now their responsibility to deliver this better technology to their clients.

We know too much to ignore this powerful technology!

P. S. There has been one major quake since construction....no damage, of course.

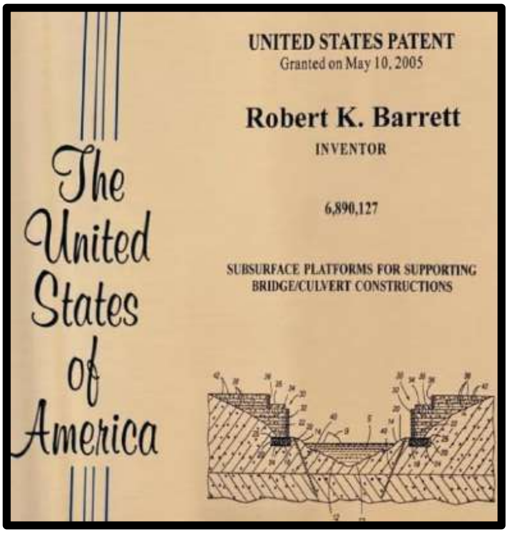
CANADA AND ALASKA

Continuing With This Theme Of Paradigm Fixity And Its Cost To Our Society

By 2012 I had successfully expanded my company into Canada. In the process of completing one of our projects, me and the crews were often delayed in a complex detour related to a bridge replacement project.

That MOT bridge replacement project took 5 months and almost 2 million in 2012 dollars. Out of curiosity, I stopped by the project office. I was told setting up and managing the detour was a major cost and that the concrete apron to prevent a "bump" was also a cost and time factor. So were seismic considerations. (You can see the extended, bump-mitigating parapet in the photo.)

I contacted the main bridge design office and they accepted my offer for an informal presentation on using GCS and Earthquake Wings for bridge abutments and piers. I used this photo as the lead in. The abutments were on rock, thus no scour issue, but it is a high seismic loading potential. I sketched how I would have designed this bridge and incorporated my patented Earthquake Wing design...I explained this patent is free to government agencies. I also explained that our FHWA had recently approved these foundations in their GRS-IBS Every Day Counts outreach.

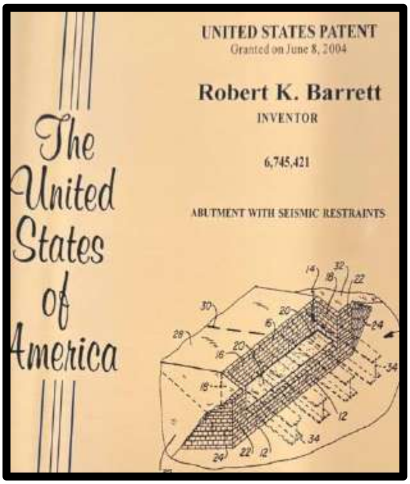


I showed them details of another patent I have for building GCS/GRS in mild scour areas and it was free to them as well. And, the icing on the cake...No Expansion Joints - **No Bump with generic GCS/GRS**.

We determined their bridge could have been completed in 3 weeks and at a cost of $600,000. **They could have built 3 similar bridges for what they spent on one with traditional technologies.**

They accepted my offer to provide design comments and assistance on any future bridge. And they accepted my offer to return with a more formal workshop presentation with the goal of transferring this simple technology into their suite of solutions I am still waiting for that call.

ALASKA DOT PRESENTATION



The very next day I made a stopover in Juneau on a trip to make a presentation in Anchorage. The AKDOT bridge engineer had accepted my invitation to discuss GCS/GRS and set aside 2 hours with him and his 24 person staff.

I showed them the Canada project and explained how much could be saved at locations that were compatible for generic GCS/GRS bridges, piers, and open bottom box culverts. I explained the concepts within my patents and told them these would be free to any government agency.

That engineer was active in the AASHTO organization and a key person on T-3, the seismic design committee. I fully expected he would see how this new Earthquake Wing option was far superior for an abutment than anything currently in use.

(Take note...my earthquake wing is still the very best choice in high seismic zones.)

I was also excited that our FHWA had recently approved GRS-IBS for trial constructions. In the course of conversations, my host said he would not consider using GCS/GRS because the **Feds were trying to shove GCS/GRS down his throat...**never did quite understand this one.

How do we change our paradigm? Let me know if and when you figure it out...I have spent decades fighting this windmill.

THE CHILEAN OPPORTUNITY LOST

I had used sawdust and wood chips in some of my field constructions and written papers on how and why we used the lightweight wood product.

(As an aside, I was awarded State of Colorado Employee of the Year in 1991 for my leadership in finding ways to dispose of used tires. One of the ways was backfill in GCS wall constructions, but that one caught on fire…that's another story…and after my award.)

Federal Highway Administration engineers in charge of international outreach followed up with me. Chile was one of their clients and the Chileans had mountains of sawdust throughout a vast region as a result of years and years of timbering. They also had hundreds of significant landslides.

So, our FHWA funded a two-week trip, approved by CDOT's Chief Engineer, where I visited several DOT offices and 3 universities with presentations on how this lightweight fill and CDOT GCS could be used in their remediation programs.

Sawdust and wood chips have a friction angle of 45 degrees and weigh about 45 pounds per cubic foot. Compaction is simply three dozer passes over a 12 inch lift. Elementary... and it will last 100+ years when cut off from air flow. We used a 12 inch soil cover over the wood to achieve that air seal.

Sawdust works well as GCS wall backfill and it will stand easily on slopes as steep as 45 degrees where light weight fill is appropriate.

I made at least 10 presentations. At the end of each, someone in the audience would comment that organics can be used because they rot. I would show the last few slides demonstrating the purpose of the soil cap. I could not convince the audience.

I looked at 4 or 5 slides where either lightweight fill, soil nails, or CDOT GCS features would result in savings of more than 50%, compared to the designs the Chileans were preparing. I sketched the solutions on a napkin. I offered to come back and help with design and construction. Nothing ever happened. Nothing ever changed.

Linda and Colby were with me...they got to stay in Santiago and ski.

THE TRINIDAD PARADIGM....VERY DIFFERENT

Luis Montego, a private sector engineer from Trinidad-Tobago, had attended my TRB Geosynthetics Committee meetings in the past and wanted to introduce both CDOT GCS and the Soil Nail Launcher to his country. The twin islands have several landslides, and they have petroleum exports to fund good roads and repairs. Luis wanted to be the interface between my expertise and his countrymen.

He set up a week of touring some difficult landslide locations and meetings with the government officials at the Ministry of Works and Transport, and two major earthwork and structural contractors. He arranged for a 30-minute TV interview for me on a popular morning show.

The landslides were classics and could be easily repaired with our tools and technologies. In reviewing those projects, Luis and his team could complete the repairs for significantly lower costs...and even more savings if we could bundle 4 slides in one contract.

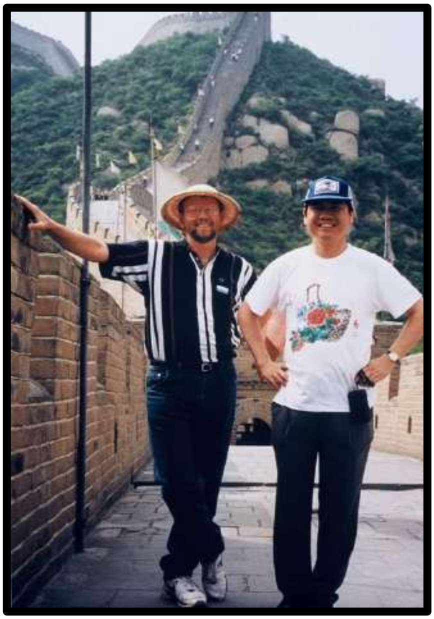
At the same time, we looked at some bridges that needed replacement. We could save about 30% with GCS/GRS abutments and piers...I offered to provide designs at no cost.

The problem was the system...the way they do business. No one is interested in doing anything differently. It seems the top government officials set the DOT budget and select the projects for that fiscal year. These are put out for bid, and the major contractors seem to take turns in getting those bids. It was rumored that some of the bid money goes back to the officials.

So, adding new technologies and new expertise puts that system at risk. It would not benefit anyone in the loop...except the taxpayers, who seem to have no voice.

Just another example or excuse for not placing value on pure engineering.... for not serving the underserved as our first priority. There are parallels here at home.

FAILURE AT THE GREAT WALL OF CHINA



I was invited by a group of Taiwanese engineers to join them on a speaking tour in China and to present a keynote address to the top officials of the Ministry of Transport of the Peoples Republic of China in Beijing. I had participated with some of them on 3 research projects in Taiwan. These were related to our CDOT Geosynthetically Confined Soil (GCS) research and our leadership in rockfall prediction and remediation with our Colorado Rockfall Simulation Program (CRSP).

At this time, I was busy. I held three full time positions at CDOT. I continued as Regional Geotech for western Colorado and added Manager of Geotech Research at CDOT headquarters and Leader of Geotech Research for our Colorado Transportation Institute (CTI). I had budgets for each office...and a million dollars annually in discretionary spending for CTI. The CDOT Chief Engineer was an ally and approved my absence.

I was Chair of the TRB Committee on Geosynthetics, Chair of a NCHRP Panel on Sealing Boreholes, and had memberships on two other TRB committees. I had a private consultancy...approved by our executive director...and worked for clients like NOAA-NEXRAD and Colorado ski areas solving soil and rock stability issues.

I traveled extensively sharing our research findings and providing innovative solutions to difficult problems. We were widely published and had continuous correspondence from governments and universities around the world. As you would imagine, I had a stellar support at my several offices at CDOT.

On arrival in Beijing, I was hosted on a private tour of the Great Wall. It is indescribable...one must see this in person to appreciate the magnitude of this public work.

Of note, I observed several brick factories along the way. Mostly small family operations. The bricks were very inexpensive. And the local engineers were proud of their fledgling geosynthetics industry. They had begun making woven geofabrics similar to ours and those in Europe.

At this time, their DOT was building a circle route around the city...a 40-mile circle. It was all elevated. They were using viaducts and some 30-foot-high double-sided walls.

Their wall construction included 30-foot panels that were precast on the ground next to where they would be used. Very labor-intensive methods and time consuming. Once the panels cured, a huge crane would lift them in place, and they would be secured with braces while the backfill was placed inside. They installed horizontal anchors...tiebacks...at intervals as the backfill was placed.

Everything You Are Doing Today Is Wrong

I saw this as an amazing opportunity. They had cheap bricks for forming/facing and inexpensive fabrics and already had the granular backfill for walls. They could build their double-sided wall as GCS/GRS walls for half the cost of what they were doing and much, much faster. They could bring back the Great Wall of China!

So, I arranged my slide presentation to focus totally on this. As I spoke, I noted a fixed stare...almost hostile glare...from my audience of perhaps 200 people. I went merrily along, thinking this was just cultural. I had great confidence in my presentation.

As we rode back to the hotel, the Taiwanese engineers told me this was a huge failure...what had happened was they used a young college lady as my interpreter, and she did not understand anything I was talking about. It came across as almost gibberish, and worse, she kept telling them that I said "everything you are doing today is wrong".

GCS/GRS apparently seems like gibberish to a lot of engineers....and I can't understand why.

THE ANCIENTS STOLE OUR BEST IDEAS

We did note that parts of the Great Wall had been constructed as Confined Soil...they used palm fronds and reeds at inclusions. We also noted that the pyramid-shaped Ziggurats of Iran...old religious features including the Biblical "Tower of Babel" ... used GCS concepts...and some are still standing. They were rock faced in the beginning, but folks later stole the rocks.

WALLS CAN BE LESS EXPENSIVE THAN BRIDGES

During several years of my tenure at the Colorado Department of Transportation and the Colorado Transportation Institute, I provided hundreds of workshops and demonstrations...many were far away from Colorado. One of the memorable interactions was with the county highway maintenance supervisor, Carl Peterson, and his team at Grand County, Colorado.

At the end of the presentation, I asked what was their most pressing problem. He said wanted to improve the "Trough Road" along the Colorado River and needed two bridges, each about 300 feet long. The cost for traditional bridges was just too much and perhaps our GCS abutments would save money??

The bridges would span deep gullies with intermittent small streams. Why build a bridge? I designed two generic GCS walls...took 30 minutes to sketch the concept...and they built them with their 8 person staff and a host of summer kids. One is 55 feet high and the other 45 feet high. Cost was a fraction of traditional bridges.

Height is limited to 300 vertical feet in block faced GCS/GRS.... after that the bottom row of concrete blocks will crush from the weight above. The road base will be stable up to about 5 miles high.

AASHTO.... take note. Opportunities to save huge sums of money are being lost every day somewhere in the U. S. I encourage you to reach out as per your mission statement to evaluate powerful technologies like GCS/GRS... especially in light of AASHTO's support of the expense, uncertainties and failures in the MSE designs. And if you are not staffed with the expertise do this.... please place this responsibility in a group with appropriate credentials to understand advanced soil mechanics.

Perhaps we need a new committee or subcommittee to address this technology and that includes subject matter experts?

APPENDIX 6: EVOLUTION OF MECHANICALLY STABILIZED EARTH – MSE

The audience I have in mind here are AASHTO members, FHWA officials and state highway bridge and geotech groups

My TRB Committee on Geosynthetics meeting in 1992 was attended by 139 people....we had people lined in the hallway. Jay Jayaprakash, our section leader, commented this was the largest attendance in the structures and geotech division ever. The next year, we had the largest room available and still overflowed.

We created this Committee in 1990. I was appointed chair, and because our CDOT group was the world's leading research group in implementation of those magic fabrics into transportation applications.

One of the reasons for this turnout was my ongoing criticism of the movement to try to take the focus of our research from the ultra-cheap woven and nonwoven geotextiles and begin to support a version of the same polymers that were heated and stretched into a stiff grid pattern. That stiffer stuff seemed more marketable to the uninformed.

Problem with our GCS was the lack of design equations....or so they say. The other reason is there is no profit, no marketing money. Everything is generic...never mind it is stronger, safer, quicker, easier and less expensive.

The newer product from the Tensar group was hyped as a quasi-tieback system with some equations that represented a behavior of sorts. They were hoping to use a wide spacing...up to 36 inches...and very heavy facing blocks held with stiff pins...and marginal soils to create an affordable yet proprietary wall system.

They adopted the "landscape" blocks that had just come on the market, and used by home owners to build walls up to 5 feet high.

Where we had years of testing for GCS and could see the merit for use in public works, the **MSE approach was more of a marketing vehicle for non-engineers** and engineers who did not want to engage in newer technologies. At that committee meeting, I told those guys that they were promoting an expensive stiff grid system that could never evolve into the myriads of beneficial uses represented by GCS....and this is true today.

I challenged the marketing claim that "Stiff Is Good"....we had demonstrated spacing was what counted, not strength of the inclusion.

The next year, 1993, Tensar brought in a box of a dozen T shirts and presented them to me at the meeting... Stiff is Good. It remains a joke. But our structural engineers did not seem to get it.

I objected to the fact the backfill in MSE was not confined. The retort was that they had "apparent confinement" between the grid openings that added stability to their constructions.

Sure enough, MSE gained traction with the people in positions of authority in transportation and AASHTO....with **vendors performing the design**. All the while we were demonstrating factors of safety more than 20 in our GCS research...unbelievable performance. But we could not present equations that predicted this behavior. And engineers, especially bridge engineers, need this.

I directed our research to expand applications for GCS. Our grand leader in academics, Dr. J. T. H. Wu at the University of Colorado-Denver, dedicated his career to finding this formula... the holy grail...that represents GCS behavior. Turns out it does not exist in the universe of mathematical proofs and predictions in which we operate for composites. I expect there are higher forms of prediction...quantum mechanics perhaps...or quark scale?

WHY NOT EXPAND OUR OPTIONS?

When put all our eggs into one basket...MSE.. and build only retaining walls and with a forced positive batter, we are missing the awesome suite of applications for GCS features.

I have seen dozens of MSE failures...and repaired dozens. We typically use soil nails and shotcrete to create an independent new wall....as per the photo with my drill installing soil nails in a bulging MSE wall.

Dr. Barry Christopher and Dr. Jim Collin spent part of their careers assisting with litigation related to MSE failures. Barry told me a long time ago that the average end cost for MSE failures was $500,000. Most of the time, he reported, the final conclusion was "cause unknown"….why…well the deisgners prove they followed all the AASHTO guidelines. The constructors followed AASHTO. What could possibly go wrong??

There has not been a failure with GCS/GRS.

EARTHQUAKES AND MSE

There will be some redundancy in this book…same story, but from a different perspective.

Another proof that MSE is a limited, risky choice is their demonstrated performance in seismic events. Poor performace is obviosly going to follow with constructions with low factors of safety….MSE has a failure rate…GCS has never failed.

I visited Taiwan in 1999 just after the 7.5 Chi Chi earthquake. My hosts took me to several failed MSE walls... They were not sure who was responsible for the damages and cost to repair....litigation stretched for years.

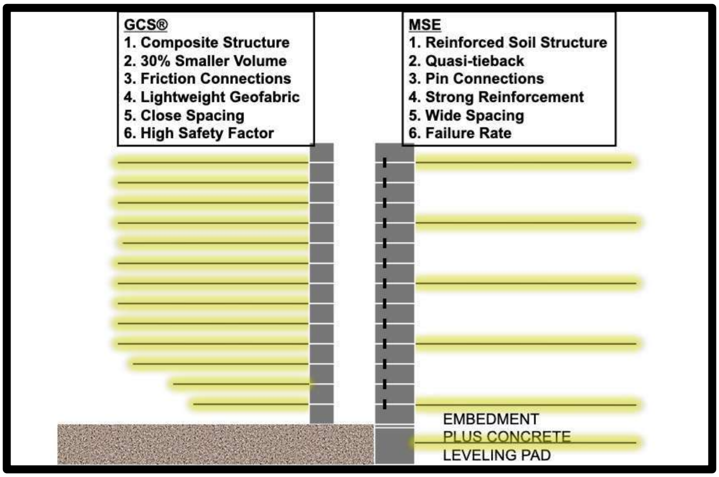
FULL SCALE
GCS®
SHAKE
TABLE
TEST
1 g sinusoidal motion at 3Hz for 20 seconds (i.e. 60 cycles at 1 g)

"The result suggests....in the strongest earthquake that has ever happened on earth, a GCS abutment (or wall) wil likely feel nothing." **Dr. J. T. H. Wu**

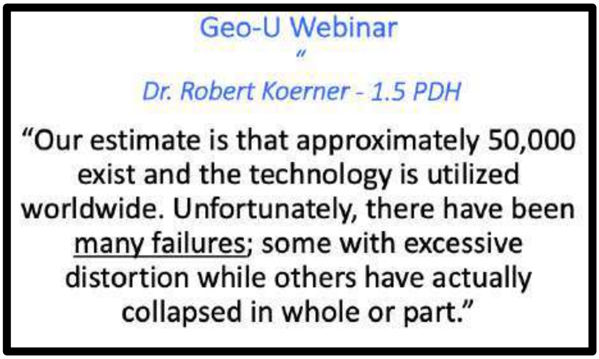
GCS/GRS CONCEPT IS A GATEWAY TECHNOLOGY

I noted AASHTO's COBS mission statement says they investigate and evaluate new ideas.

The potential impact — in lives protected and dollars saved — will be transformative when GCS/GRS technologies are fully incorporated into the transportation paradigm. I invite our AASHTO membership to take the lead in making this happen. AASHTO membership has the leaders who really can make a difference.



APPENDIX 7: PREVENTING MSE FAILURES



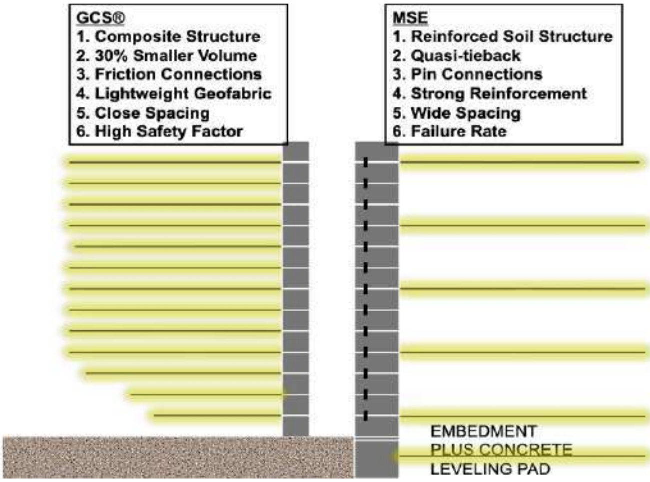
I developed a slightly more efficient design for GCS walls in 1996 that would adapt to MSE and practically end the failure syndrome in MSE.

I demonstrated this nuance in one of my walls.... the 1000 foot long, 24 feet high rockfall catchment along I-70. I called it a "CTI Tail". It is simply a skip method where we use a full sheet of fabric for a lift and then only a 3 foot wide sheet on the next lift and then a full sheet on the next lift.

This creates an "infinitely stiff" face and that easily makes up for the absence of a full sheet every other lift.

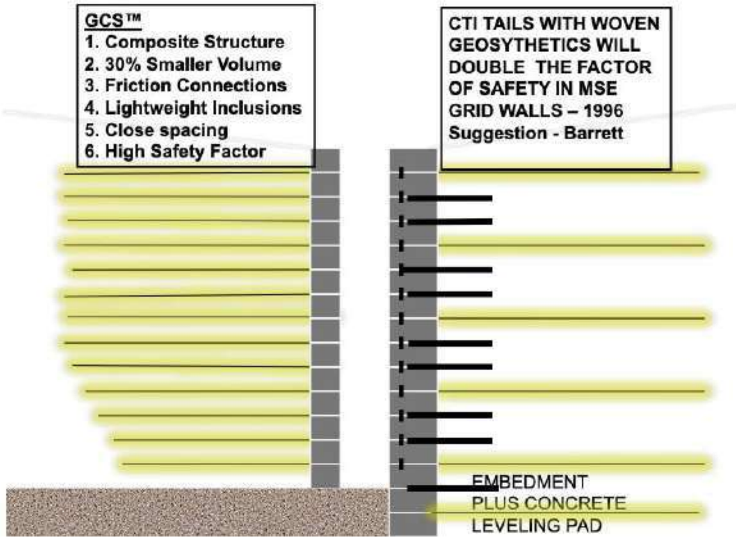
I proposed this to Tony Allen, Richard Bathurst, and others and was ignored. I circulated it around in my circles with zero responses.

This would certainly prevent the "pop open" failure mode we see in MSE that results from wide spacing of the inclusions.



We determined that this "CTI Tail" wall design is stable, and equal to our walls with full sheets every lift. However, we also found that the extra effort in cutting and remembering took away the cost advantage.

I had a patent in progress for this, but Al Ruckman suggested it was not worth it.



(I called it a CTI Tail because I was using Colorado Transportation Institute money to fund the University of

Colorado/Denver instrumentation and monitoring team on this early GCS wall.)

WHY AND HOW MECHANICALLY STABILZIED EARTH CAN CONTINUE TO BE A WALL OF CHOICE

It all started circa 1992. Al Ruckman and I had partnered in 1986 with the USFS, Oregon State University and demonstrated the amazing new world of confined soil technology. None of us understood how or why it worked.

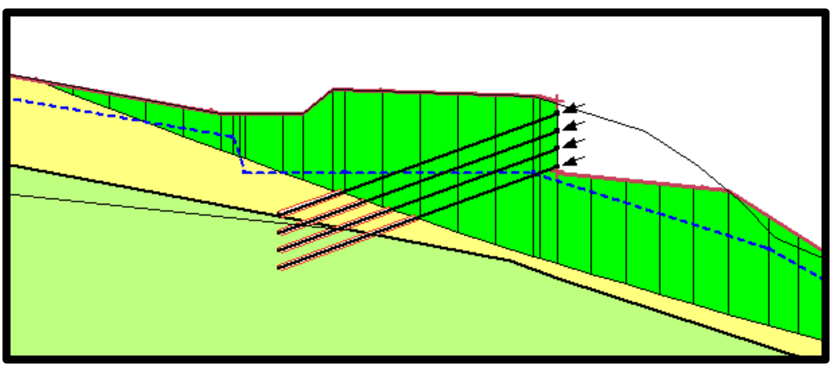
The reason for this is that we are wired to think and understand in the language of tiebacks, and not unique composites. Unique Composites are counterintuitive...our human brain thinks the sum of the parts should add up to unity. When they don't...and, in the case of GCS, where the result of the combination reaches to an extreme super performance.... Well, we just stop and watch. Disbelief. That's what I did. Deer in the headlights syndrome.

Tiebacks are easy. The distal end is fixed and strong. The proximal end is supportive. Picture someone swinging in a swing. The top end is permanently fixed. The other end is supportive. The medium...air in this case...is of no matter.

Tiebacks in geo-construction are installed ahead of ground modification to prevent specific failures. Pretty easy concepts and designs. We know to place the distal anchorage far enough past a potential failure zone and we know to spread the external support features to accommodate future loading as we excavate.

In a simple case, we need to know the engineering properties of the stuff between the two ends of the tiebacks to determine how much load we need to accommodate.

Tiebacks work like this – as the excavation proceeds, the contained medium... usually soil... begins to relax or expand or



dilate into the unrestrained excavation. The tiebacks take up exactly the amount of loading required to maintain stability. It is an interactive response that is constantly reaching new equilibriums throughout, and even after the construction phase.

MSE IS DIFFERENT

MSE, on the other hand, is a reverse tieback, and our human wiring sees it the same as a real tieback. However, as construction progresses, loading at the face, the proximal end, is out of context...out of communication with the distal areas. Thus we can get peak, unbalanced loads throughout, and these are exacerbated by poor compaction and lack of quality control that results from the wide spacing.

Moreover, the blocks are placed on a concrete pad, which can create a serious issue at the interface where the relatively weak geogrid meets the facing block.

As the construction proceeds upward (**tiebacks go downward**) there is additional densification in the backfill below, and significantly in lifts that exceed 8 inches. This creates a shear at the block interface...the geogrid doesn’t stand a chance.

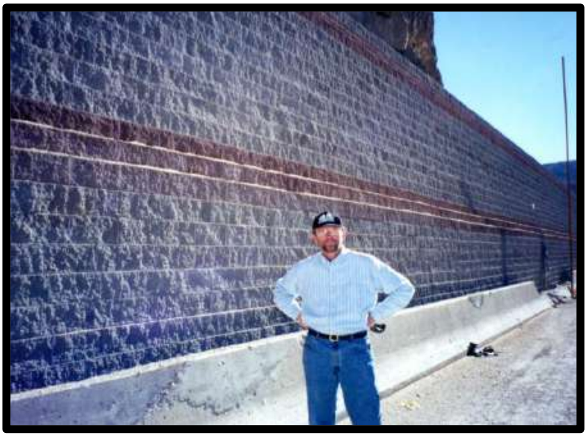
Thus, the way I see it, there is nothing “happy” in an MSE system. I think CTI Tails could change this equation.

The persistence of MSE as the default choice is driven in part by familiarity — engineers and agencies have established workflows around it. Changing practice requires effort, education, and institutional support. That is precisely why AASHTO's engagement is so critical. GCS/GRS needs advocates within the system, and I believe the evidence in this book makes the case.

WHAT IS GCS/GRS

GCS/GRS is not reinforced soil. It is confined soil – a ductile, non-brittle composite mass whose design is governed by global stability, not internal tensile mobilization.

GCS/GRS is an orphan. But, as this book verifies, we could be saving lives and trillions of dollars...if only...



APPENDIX 8: I WISH I COLD HAVE DONE THIS DIFFERENTLY

Glenwood Canyon I-70 cost about 100 million per mile in today's dollars. We were committed to build it... and after a while, money....cost of features...became secondary. I had 16 different demonstration projects ranging from how to drill in talus to blasting pathways to allow us to drive piling through talus to rolling rocks to calibrate our new rockfall prediction program. We tried compaction grouting with fly ash from a distant power plant. We experimented with used tires and railroad ties as rockfall barriers and attenuators. I spent tens of millions within my group and with outside consultants to find ways to fit an Interstate Highway into some of those super narrow segments. We had steep cliffs, daily rockfall, and uncertain foundations... all of which would certainly be problematic.

I worked on Glenwood Canyon I-70 for 25 years...longer than anyone involved with that project.

I studied alternate routes for the Interstate as well as for detours...the surrounding terrain was just too severe to create even a detour. So we had to build the projects under traffic. We could close the road for 30 minutes and then open until the traffic cleared.

We had to be prepared to allow emergency vehicles through...that was a world of its own in our traffic control plan.

In addition, we were severely constrained by our environmental and architectural mandates. Every activity carried with it a time factor as well as cost, and both then went into the big hopper where we selected our design choice. We say time is money. On the Glenwood Canyon projects, time was more valuable than money. Some of our projects took 3 years to reach final design. Seems there was always some last minute detail that defeated us....

The most narrow section was where one of two major rockslides nearly closed the canyon, leaving just enough room for old highway 6, the Colorado River, and the Union Pacific Railroad. I found a log in a drill hole in the other slide and carbon dated it to 4000 years old.

We were committed to full height concrete panel facades on retaining walls. And these had complicated fluted grooves as mandated by our inspired architects. The panels would have to be precast outside the Canyon due to time constraints for curing. So we developed a system of casting footers in place and with a stepped series of vertical threadbars to tie the panels to the footer.

Obviously, the threadbars had to be precisely located so the overshot alignment fit each panel as the crane lowered them onto the footer. The shouting...mostly profanities...could be heard for miles on the days we were setting panels onto those 30-foot threadbars. What a convoluted system!

It was as if we were trying to make this wall system the most expensive in the world....which it was, but not for that trophy.

We could not make the footers wide enough to create the resistance required to prevent overturning. Thus, we installed vertical tie down anchors through the back of the footers. Look closely at the photo and you will see the square covers for those tie downs.

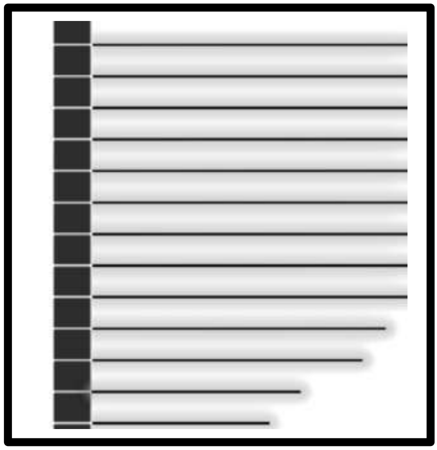
We could not retain the grout in the vertical holes in that boulder field...so I invented a sock that we inserted in the drill hole and filled it with grout and then inserted the steel bars...and then tensioned them a few days later. Most did not fail.

In reviewing this photo, note the extra width we had to create just to pour the footers and get the large drill rigs into place.

This project was controlled by our structural engineers and never with any other thoughts, ideas, or disciplines.

In retrospect, I could have built these walls in 5% of the time and for perhaps 5% of the cost. Glenwood Canyon would have been completed at least one year sooner....imagine the benefits....As I said, **this is one of the most dramatic case history in my entire career to illustrate the value of GCS technology** ....and a reason structural engineers and their support group at AASHTO should investigate and adopt...include...GCS into their everyday hopper of design choices.

Look at the construction photo again. A GCS wall has to be only 3 feet wide at the base. It does not require embedment...it cannot possibly overturn. It is heavier at the back than the front. Excavation into those massive boulders would have been a fraction of what you see in the photo. It took months just to create those foundation locations.

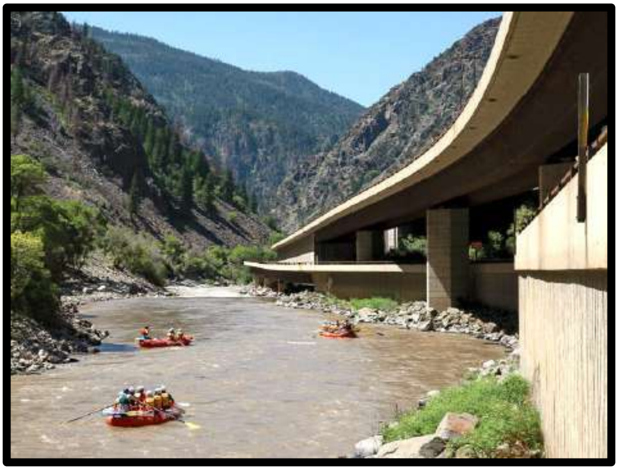


The final panels would have been the simple facades we used for the RE systems on the East End where we had severe foundation problems. RE was not used here because we thought we needed a wide base width. And mostly because we were led by structural engineers without Confined Soil expertise. 'And because I had not come to appreciate the amazing...almost supernatural powers...of GCS.

I think I could have saved 50 million dollars with what I have learned since this project....and a year of construction time**... That was 38 years ago...but if I were to follow today's AASHTO "guidelines", I could still not implement all that we learned then and what we know today.**

In the photo after completion, you can see we cantilevered the pavement over the wall. This allowed us to minimize the wall excavation on the river side. The pavement does not rest on the top edge of the wall. The entire pavement is a reinforced bridge deck design that provides **a slab that can cantilever out 6 feet without point support.**

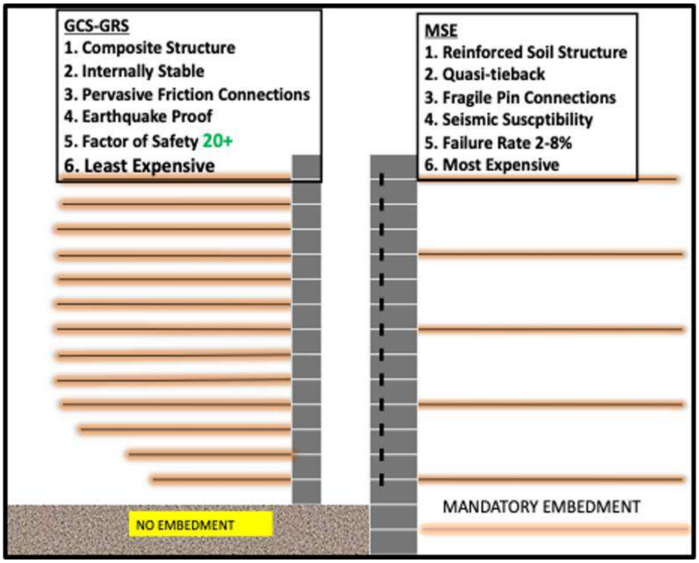
Looking closely, you can see the bike path is cantilevered at the far end. When the river is in flood and near the surface of the bike path, it is difficult to traverse this section. The roar and wild motion elicit a vertigo effect....well worth your visit!



APPENDIX 9: CONFINED SOIL COULD RESHAPE THE FUTURE OF INFRASTRUCTURE DESIGN

However, this Proven Technology is Facing an Unexpected Barrier:

IT DOES NOT COST ENOUGH!!



Geosynthetically Confined Soil (GCS), originally developed by Bob Barrett and Al Ruckman at the Colorado Department of Transportation (CDOT) in the early 1990s as an extension of U.S. Forest Service research, has evolved into one of the most resilient and cost-effective infrastructure technologies available today. Later adopted and promoted by the Federal Highway

Administration (FHWA) as Geosynthetically Reinforced Soil (GRS), this technology has consistently demonstrated superior performance across a myriad of retaining wall solutions and bridge abutments that cost less and last longer than any in the history of transportation.

Over decades of implementation, GCS/GRS has delivered faster construction schedules, significantly lower project costs, and extraordinary safety margins. CDOT-funded research conducted by the University of Colorado Denver demonstrated safety factors exceeding 20—an unprecedented benchmark in civil engineering. To date, no documented structural failure has been observed GCS/GRS applications, including in seismic regions, positioning it as one of the most reliable earth retention and foundation systems in modern infrastructure.

Perhaps It Is Also Too Easy to Design

GCS/GRS is a composite system formed by compacted granular fill layered with closely spaced geosynthetic inclusions. By preventing lateral soil dilation, the system creates a stiff, load-distributing mass that behaves more like engineered rock than conventional soil.

This structural behavior enables exceptional load-bearing capacity, reduced deformation, and long-term durability under extreme environmental conditions. The technology's versatility also allows for multiple facing options, including wrapped geotextiles, shotcrete, natural stone, and economical split-faced concrete masonry units. Compared to proprietary mechanically stabilized earth (MSE) systems, GCS/GRS often requires approximately 30% less cross-sectional area while using lower-cost commodity materials instead of expensive branded components.

GCS/GRS theory and performance are entirely different than quasi-tieback MSE features...GCS/GRS does not require embedment nor concrete leveling pads and there are no minimum widths. I have built them 40 feet high and 2 feet wide. Al built one 120 high and 12 feet wide. The only design mandate is external stability....we can't fail it internally.

Performance, Longevity, and Risk Reduction

The performance advantages of GCS/GRS extend well beyond retaining walls. Bridges constructed on GCS/GRS abutments do not require expansion joints, eliminating the common "bump at the bridge" problem, and can reduce total bridge costs by roughly one-third. In practical terms, agencies can typically construct three GCS/GRS-supported bridges for the cost of two conventional bridges.

Construction speed is equally transformative. Barrett and Ruckman have successfully completed small bridge and box structures in less than 24 hours....these systems do not require wet concrete. Larger spans—including their 191-foot bridge in Montana's highest seismic zone—demonstrate the technology's scalability.

With projected service lives exceeding 200 years for structural systems and geosynthetic inclusions rated beyond 500 years, GCS/GRS offers unmatched life-cycle value.

By eliminating internal failure mechanisms, simplifying construction, eliminating curing delays, and maintaining tolerance to settlement and environmental variability, GCS/GRS substantially lowers technical, operational, and construction risk compared to traditional alternatives.

The Adoption Gap: No Paid Champions

Despite its proven record, widespread adoption of GCS/GRS remains surprisingly limited. The primary reason is not technical—it is economic and institutional.

Unlike proprietary systems such as MSE, which are often supported by manufacturers providing design services, specifications, technical sales teams, and aggressive marketing, GCS/GRS is fundamentally a generic technology. It relies on readily available materials and straightforward engineering principles, leaving no dominant vendor with a direct financial incentive to champion its widespread use.

In an industry where innovation is often accelerated by commercial sponsorship, GCS/GRS lacks the built-in promotional infrastructure that pushes many competing systems into standard practice. This absence of "paid champions" has created a paradox: one of the safest, most cost-efficient infrastructure systems available has expanded more slowly than less effective proprietary alternatives because it does not fit the conventional business model of product-driven adoption.

Implications for Owners, Agencies, and Public Investment

For transportation agencies, municipalities, and infrastructure owners, this dynamic presents both a challenge and an opportunity. Dependence on vendor-driven systems can simplify procurement and technical support, but it may also restrict consideration of more effective, lower-cost alternatives.

GCS/GRS empowers agencies to take greater control over design, budgeting, and implementation while prioritizing performance over proprietary dependency. Beyond walls and bridges, applications such as double-sided retaining systems for rockfall barriers further expand its strategic value. CDOT testing has demonstrated that these structures can withstand impacts from virtually any scale of rockfall event, offering life-saving potential in hazardous terrain.

A Different Path Forward

The future of GCS/GRS may ultimately depend on whether the infrastructure industry is willing to evaluate innovation based on performance, safety, and public value rather than market presence alone.

As Dr. Carmen Swanwick of Utah DOT and AASHTO T-15 noted, "If someone says that's the way we've always done it, it's probably time to do things differently."

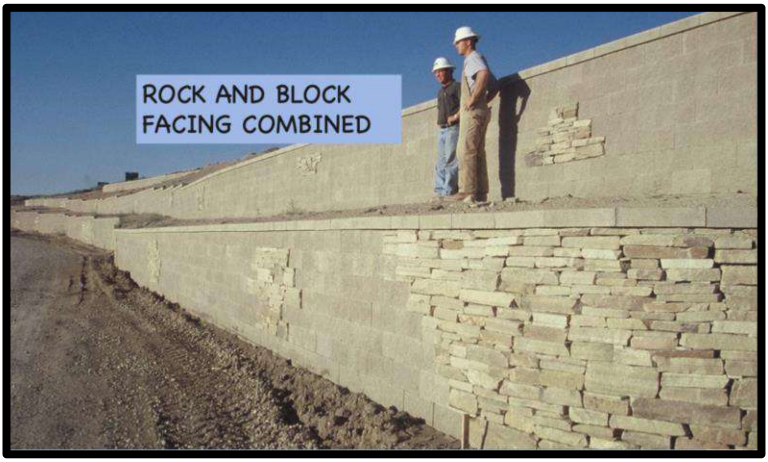
Without a traditional commercial driver, the broader implementation of GCS/GRS will likely rely on engineers, agencies, policymakers, and institutions prepared to advocate for technologies that prioritize societal benefit over vendor profitability. The question is no longer whether GCS/GRS works—it has already proven itself across decades of successful applications. The real question is whether the industry is prepared to embrace a transformative, high-value solution that could save substantial public funds, improve safety, and redefine the future of resilient infrastructure design.

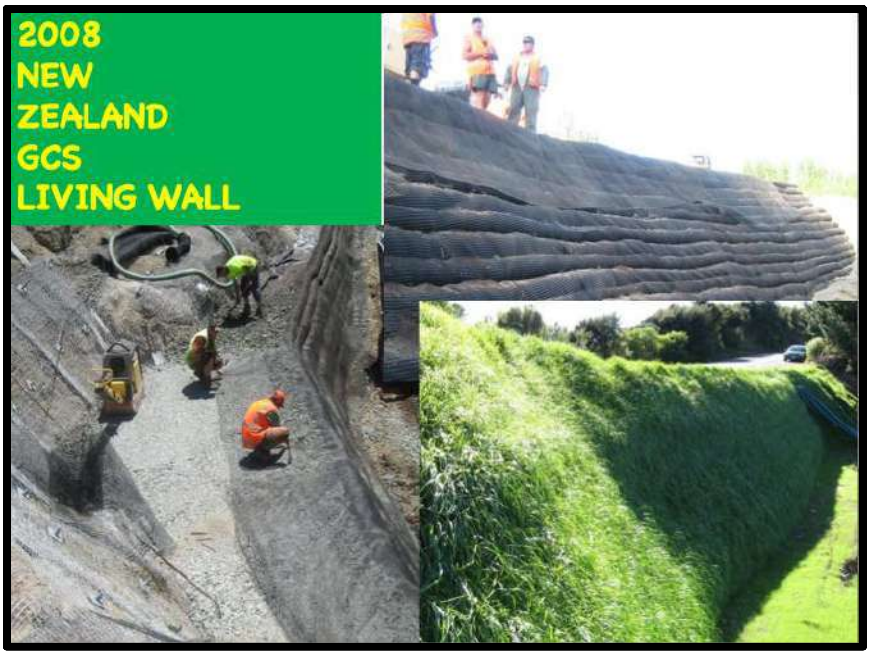
Adoption of the full suite of GCS/GRS technologies represents more than an engineering advancement—it is an opportunity to save lives, maximize infrastructure budgets, and build a more sustainable future.

Bob Barrett

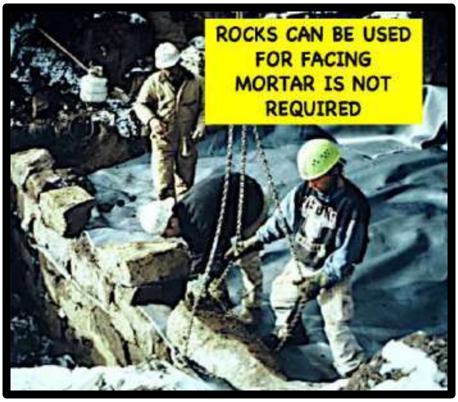
www.gcswalls.com

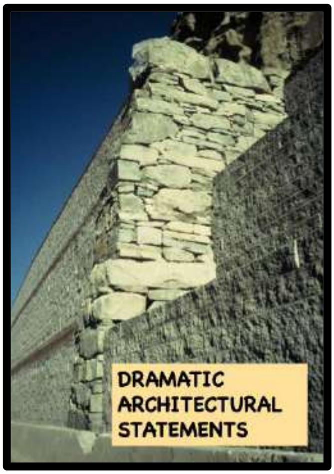
APPENDIX 10: THE WORLD DESERVES THE ELEGANCE, THE EXCELLENCE, THE DIVERSITY, THE ASSURANCE, AND THE ECONOMY OF GCS/GRS TECHNOLOGIES


ROCK AND BLOCK
FACING COMBINED


2008
NEW
ZEALAND
GCS
LIVING WALL


DRAMATIC
ARCHITECTURAL
STATEMENTS


ROCKS CAN BE USED
FOR FACING
MORTAR IS NOT
REQUIRED


DRAMATIC
ARCHITECTURAL
STATEMENTS


GCS/GRS BRIDGES ARE FASTER, LEAST COST
AND REQUIRE LESS PERMITTING


GCS WITH
ROCK FAÇADE..
NO MINIMUM
FABRIC WIDTH


Istanbul GCS Wall With Fluted Blocks,
Color Patterns And Staircases Included
In That Construction Sequence


HISTORIC RESTORATION
A 275,000 POUND LOCOMOTIVE ON A NEW GCS WALL
473
DURANGO & SILVERTON


TREATED TIMBER
FOR
FORMING AND
FACING

EPILOGUE

I am going to take a special liberty. This is likely the last technical paper or book I will ever write, and I want to leave the reader with some observations on how limiting paradigms can be.

"Paradigm paralysis" is a powerful programming feature of our survival brains. Our minds are designed to conserve effort by relying on familiar patterns and proven methods.

Unfortunately, this same mechanism can prevent us from recognizing transformative ideas. Facts and data alone rarely break the hold of an established paradigm. **Paradoxically, the more skilled we become with existing analytical tools, the more tightly we can cling to the assumptions embedded within them.**

This is why truly transformative technologies are often resisted—not because the data are weak, but because they challenge the mental frameworks engineers have trusted for decades."

Knowing this, we can sometimes make the extra effort to ask this question — **is what we are doing today our highest and best contribution** we can give to our clients??

And we can think about our legacy. When it is time to write **your memoir**, what can you say you contributed to the betterment of mankind....I know this book was a real hoot for me to write!

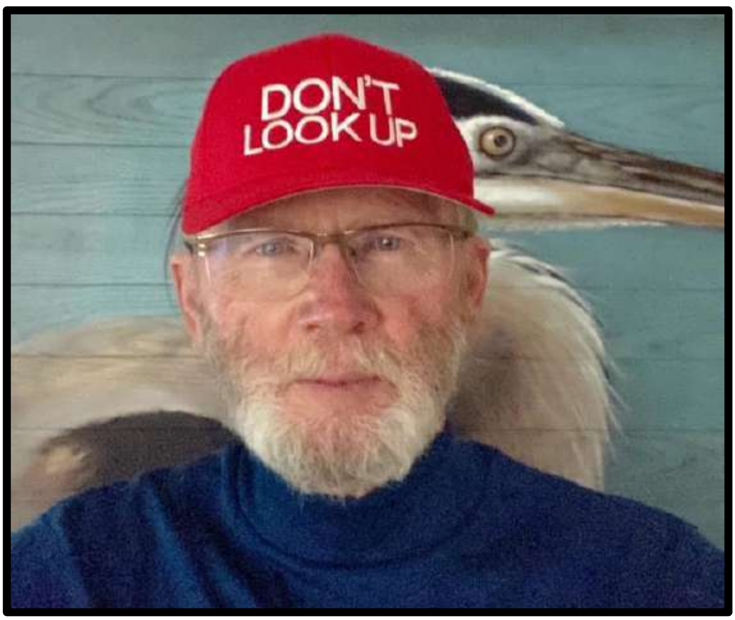
Dr. Carmen Swanwick (AASHTO and Utah DOT) summed it up beautifully: **"If someone says that's the way we've always done it, it's probably time to do things differently".** Engineering progress has always belonged to those willing to challenge the paradigm.

It's been up to 50 years ago that me and my team made these paradigm changing discoveries...They have enjoyed widespread implementation outside the AASHTO purview....perhaps it really is time to do some things differently.....

One final note...I turned my research skills into a philanthropic quest for helping folks live longer and healthier and to feed our kids better.....but **I am always available for discussion on anything GEO!** Your place or mine.

Bob Barrett, President, HealthSpan Foundation, Inc.

bob@happykids.us



BOB'S RESUME

- 1965-1967, West Virginia State Road Commission. Highway Geologist – Landslide Specialist
- 1967-1997, Colorado Department of Transportation. Responsible for geological/geotechnical design and construction in Western Colorado, including building Interstate 70 from the Continental Divide to Utah, and including the world renown Vail Pass and Glenwood Canyon segments. From 1992-1997, Barrett held 3 full time positions: District Geotech, Manager of Geotech Research at CDOT headquarters and Manager of Geotech Research at the Colorado Transportation Institute.
- 1990-1997, Conducted tech transfer and demonstration projects on Geosynthetically Confined Soil and Rockfall Prediction and Control. These were all over the U. S. and world-wide, including China, Chile, Japan, Taiwan, Türkiye, Jamaica, Canada, Mexico, New Zealand and Trinidad.
- 1985-2001, President of TerraTask, LLC, a Private Geotechnical Consultancy, approved by CDOT.
- 1997-2001, Manager of Bridge Design and Construction, Yenter Companies, Golden, Colorado
- 2001-2008, Founder and President of Soil Nail Launcher – Geostabilization International, Denver, Colorado
- 2008-2018, Manager of Bridge Design and Construction and Director of Innovation at GSI.

- 1971-2002, Memberships on Transportation Research Board Committees on Highway Geology and Soil and Rock Properties
- 1985-1987, Member, NCHRP Panel 20-33 on Facilitating the Implementation of Research Findings.
- 1987-1990, Member NCHRP Panel 20-33(2), Facilitating the Implementation of Research Findings.
- 1991, Recipient of Governor's Award for Creativity
- 1990-1997, First Chairman of the Transportation Research Board Committee on Geosynthetics.
- 1992-1995, Chairman, NCHRP Panel 12-59, Geosynthetically Confined Soil Abutments
- 1992-1995, Chairman, NCHRP Panel 21-4, Sealing Geotechnical Boreholes to Protect the Environment.
- 1997, IFAI International Design Award for a 55 foot high GCS Wall constructed by Grand County, Colorado.
- 2009, NOVA Award for Innovation for Developing GCS Bridge Abutments.
- 2018, Deep Foundation Institute Award for Developing Soil Nailing Technologies.
- 2025, ASCE Geo-Institute Achievement Award for Advancements in Geohazard Mitigation.

BOB BARRETT AND HIS LARGE GROUP OF COLLABORATORS:

1. Developed the first soil nail design guide, which opened the floodgate of applications for these passive inclusions world-wide.
2. Created the first rockfall prediction program, allowing engineers to replicate the behavior of a rock in motion.
3. Created numerous engineered designs for rockfall interceptors
4. Developed design and construction criteria for geosynthetically confined soil (GCS) retaining walls, bridge and culvert abutments, bridge piers, rockfall barriers and avalanche deflection structures.
5. Created a GCS abutment nuance patented as "Earthquake Wings" that results in a highly earthquake tolerant viaduct.
6. Built a 191-foot-long bridge on GCS abutments, the longest in the world to date.
7. Developed a design nuance that could enhance MSE performance.
8. Responsible for thousands of GCS constructions, proving GCS is markedly superior to MSE with geogrids.
9. Bob, Colby Barrett, and Al Ruckman hold 7 patents in the areas of rockfall remediation, soil nailing, scour prevention, earthquake resistant structures, and retaining wall design