BENCHMARK GEOTECHNICAL LABS

Residual Shear Strength: Torsional Ring Shear vs. Residual Direct Shear

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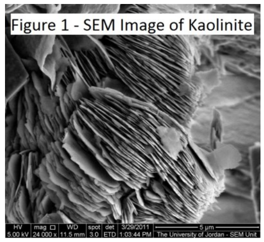
Anytime engineers face a field situation where soil has been, or may be subjected to large deformations (e.g., landslides), they have a keen interest in knowing the minimum strength of the soil. In this newsletter we compare two tests that are used to achieve this goal; residual direct shear and torsional ring shear. We at Benchmark have a clear bias. Join us as we explore the exciting world of residual soil strength.

SHEAR STRENGTH & PARTICLE SHAPE

Not all of those who read this article are geotechnical engineers. Therefore, we will briefly recap shear strength. The shear strength of soil is the ability of the soil to resist shearing forces acting upon it that would cause deformation and the sliding of soil particles past each other. The interlocking, friction and bonding between the individual soil particles resist these forces. In addition, other factors such as soil type, density, effective pressure, stress history and chemical interaction impact shear strength. Here, we will focus on how the shear strength is affected by the physical arrangement of the soil particles (i.e., orientation and shape).

Not all soil particles are created equal. Larger particles like gravel, sand and even coarse silts tend to be roughly equidimensional. Finer silts and especially clays tend to be more platelike as shown in this scanning electron microscope image of kaolinite clay. Let's look at how these differences affect a soil's strength behavior.

Figure 1 - SEM Image of Kaolinite

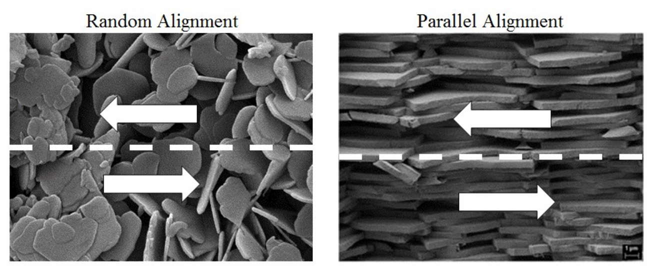


PEAK vs. RESIDUAL STRENGTH

As a typical soil is loaded and begins to shear, the strength it exhibits will rise to a maximum point (peak strength). With continued shearing, the strength will decrease until it stabilizes at a minimum strength (residual strength). Particle reorientation, among other things, is responsible for this post-peak drop in shear strength. The shape of the soil particles impacts the magnitude of the drop in shear strength from peak to residual. Soils are complex and typically consist of a wide variety of particle shapes. For this discussion, we will look at two extreme examples to illustrate why soils may exhibit either a large or negligible post-peak drop in strength.

First, we will look at soil that consists of only plate-like clays that are randomly aligned as shown in the figure below. This idealized example shows what an undisturbed soil might look like before it is sheared and the particles realign. In this random configuration, particles will interlock and shearing forces will dissipate over a large volume of soil giving rise to the peak strength. As shearing continues, the clay particles will ultimately realign to a parallel configuration (see figure below). In this arrangement, shearing forces can be focused along a much narrower zone and the soil will shear more easily. This is the residual strength condition.

SHEAR STRENGTH IN CLAYS vs. PARTICLE ORIENTATION: WHICH ONE WILL HAVE A LOWER RESISTANCE TO SHEARING?



Secondly, we will look at uniform beach sand, where all particles are roughly equidimensional and the same size. If we idealize this sand as tiny ball bearings we can imagine that, once the shearing begins, particle realignment will not affect the shearing resistance, and the force required to deform the sand will remain constant. The peak and residual strengths will be the same.

OBTAINING STRENGTH VALUES

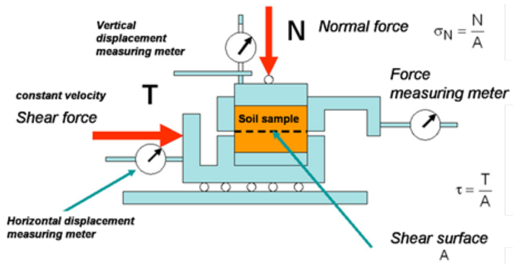
Triaxial, direct shear (DS) and direct simple shear tests are only appropriate for measuring peak strength only, due to their limited ability to deform a test specimen. Residual direct shear (RDS) and torsional ring shear (TRS) are two tests commonly used to obtain "residual" soil strength. In our opinion, only one provides meaningful results. Let's compare them.

DIRECT SHEAR/RESIDUAL DIRECT SHEAR

RDS is a modification of the DS test. The DS test has long been used to measure peak soil strength.

In this simple test, two stacked metal rings hold the test specimen. After consolidation under an applied vertical load, the shear strength is determined by measuring the force required to push the metal rings in opposite directions. See the depiction below of a direct shear test setup.

Direct Shear Apparatus

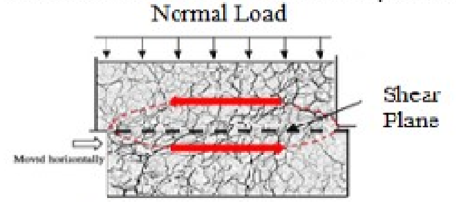


The strength is determined by measuring the force required to shear the specimen. Attributes and shortcomings of the direct shear test include:

1.The specimen is sheared in only one direction and the maximum deformation is on the order of about 1/2”. Enough to measure the peak strength only.
2. It is very sensitive to the presence of coarse sand or fine gravel, roots, and variations in density and/or particle size within the specimen. It is not uncommon to see direct shear results, obtained by experienced technicians, where the points do not line up at all due to one or more of these sensitivities
3. During shearing, the surface area of the shear plane is constantly changing as the top and bottom halves of the specimen are brought more out of alignment with each other. The normal load (in lbs) may be constant, but the normal force (in psf) is changing.

The concept of RDS is that a residual state can be achieved by reversing the direction of the (DS) apparatus repeatedly as it reaches the end of its range.

Residual Direct Shear Test Depiction

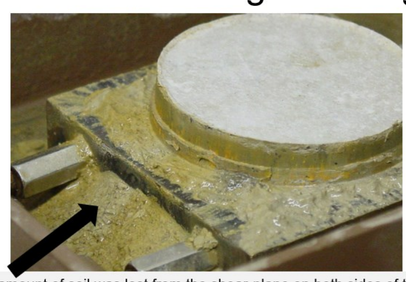


Sample Sheared Repeatedly in One Direction and Then the Other

Hmmm… The DS test has inherent problems when shearing in just one direction. Going back and forth multiple times in the RDS test compounds the issues.

With RDS, the shortcomings of the DS test are still present and new ones are added to the list:
1. There is no standard test method for RDS. This diminishes the precision and usefulness of this test.
2. It does not model the field conditions. I have seen a lot of landslides over the years, but I have never seen one go downslope then turn around and go back up the slope. If you have, please contact me and we will write a paper together.
3. A true residual state cannot be obtained because of the reversal of the shearing direction. Any particle realignment that might develop tends to be destroyed when the direction of shearing is reversed. This can also lead to significant variability within and between the shearing segments making interpretation subjective at best.
4. During shearing, portions of the upper half of the specimen overhang the bottom half. Soil then can fall from the underside, and this portion of the developing shear plane is irreversibly changed. This disturbance and loss of soil are unavoidable with RDS.

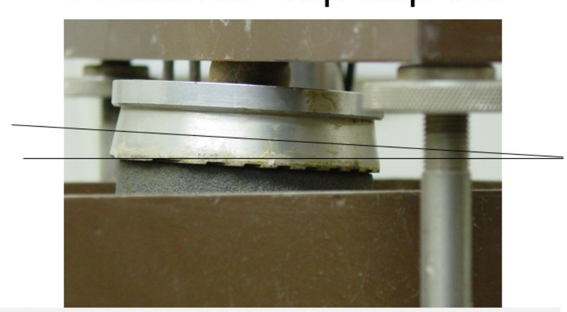
Residual Direct Shear Problems: Soil Loss During Shearing



A large amount of soil was lost from the shear-plane on both sides of the sample as it cycled from one direction to the other.

5. With the repeated reversal of the direction of shear, it is not uncommon for the top cap to tilt. When this happens it is likely to induce a more complex loading scenario with unknown consequences that cannot be quantified.

Residual Direct Shear Problems: Top Cap Tilt



The top cap has a tendency to tilt during the residual direct shear test. This may be due to the loss of material.

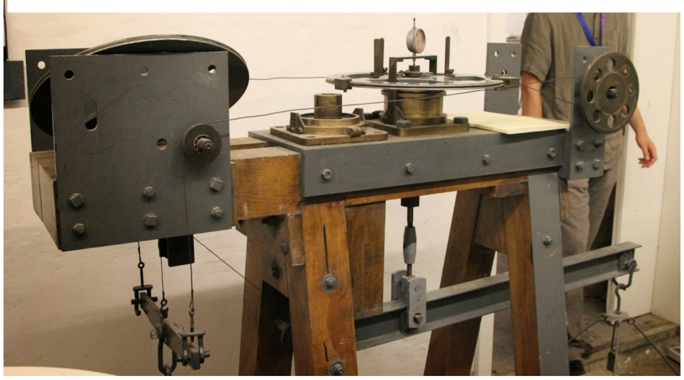
6. In our experience, RDS strengths can come out more than three degrees higher than TRS! This could lead to an unconservative design.

Pretty much any way you look at it, RDS is far from ideal for determining the residual strength. I can't think of any positive attributes of this test with the exception that the direct shear apparatus is readily available in most geotechnical labs. Fortunately, there is a much better solution.

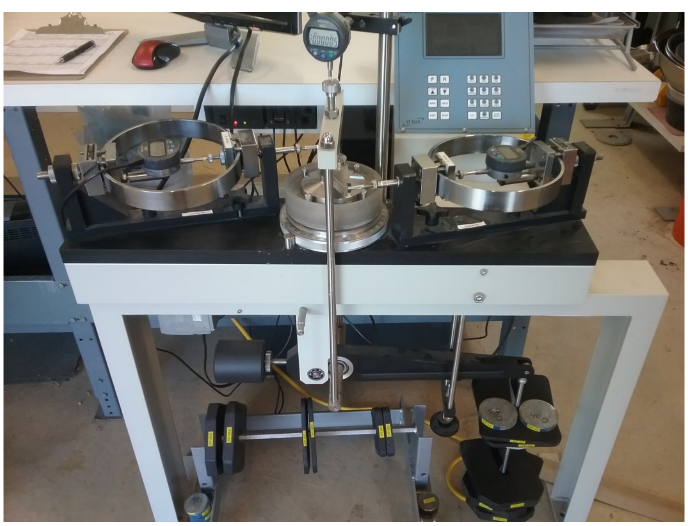
TORSIONAL RING SHEAR

The TRS test was first developed by Mikael Juul Hvorslev, one of the founders of modern geotechnical engineering.

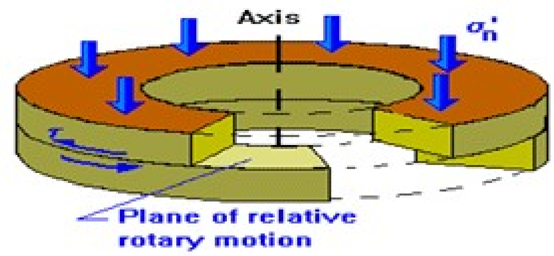
Original Hvorslev Torsional Device - 1933



Below is Benchmark's TRS device. The same basic idea with many improvements.



TRS testing is fundamentally different than RDS. The most important difference is that unlimited, unidirectional shear displacement is possible by rotation of an annular (donut-shaped) test specimen. (See the diagram of the ring shear apparatus below)

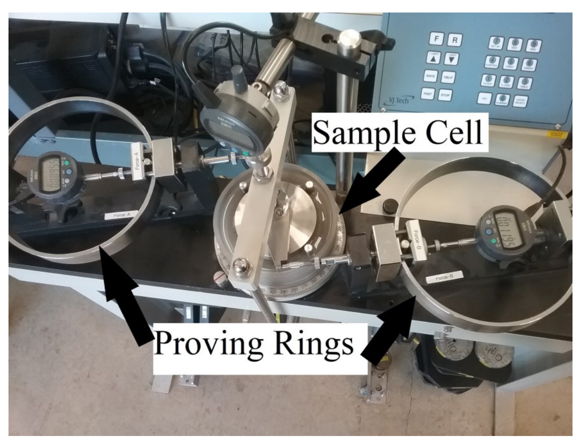


Ring Shear Apparatus

Unlike RDS, this models the field conditions well.

The attributes of the torsional ring shear test include:

1. As mentioned above, unlimited one-directional shearing. Where RDS can only shear about 1/2" in one direction, TRS specimens are sheared more than 10" before we even begin to collect residual strength data. TRS also allows confirmation that a residual state has been reached.
2. The TRS device maintains a constant cross-sectional shear surface area.
3. Both residual and fully softened strengths can be obtained with this equipment.
4. TRS specimens are reconstituted (much like a liquid limit sample). This ensures uniformity with no negative impacts from oversize particles. An undisturbed sample is not required. As long as you collect the same material that is sliding, we can recreate the slide plane in the lab.
5. TRS specimens have a short drainage path (on the order of 1-2 mm) so fully drained conditions are relatively easy to ensure.
6. While a small amount of sample extrusion occurs, it can be minimized to the point that it is insignificant. In comparison, the soil loss during RDS is staggering.
7. Our TRS equipment is loaded by deadweight (up to 24,000 psf) which ensures consistent, accurate loading that cannot drift during the test.
8. Our TRS equipment uses proving rings to measure the shearing resistance which are much more stable than load cells.



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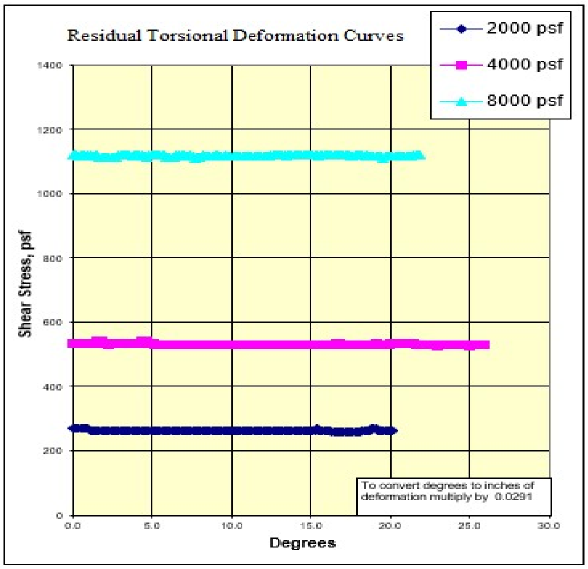
Below is a typical example TRS results from a fat clay soil. Note that the shear strength for each point is stable and does not continue to decrease.



With TRS, this kind of result is fairly easy to obtain with most soils. If there is any question in the technician's mind, TRS points are easily rerun to ensure confidence in the result.

CONCLUSION

We hope that you now might understand our bias in favor of the TRS. We have decades of experience running TRS and every time we do we see confirmation that the reliance on this test is well-founded and that our clients are being well served by it. Client feedback has been universally positive. It is no wonder that this test method has become the standard of care in the geotechnical industry for measuring the residual strength of soil.

We feel so confident you will be happy with the TRS test that we are offering a 10% discount on the first TRS test for new client companies. This will include up to three points each of both residual and/or fully softened strength. Just mention this newsletter.

WE'VE MOVED AND WE HAVE A NEW COMPANY!!!

In August of 2021 we relocated to the East Coast to be closer to family and our roots. It was a big decision to leave the West Coast and a huge undertaking. In making this move we could not transfer the Benchmark Geolabs business entity between states. Therefore, we were forced to close that company and open Benchmark Geotechnical Labs as a new company in Massachusetts. Even though we are in another state with a new slightly different name it is still us and we are looking forward to meeting your testing needs as we have done since 2017. We may now be across the country for some of you but we are still your friendly neighborhood testing lab!! As usual, feel free to give Peter a call if there are any questions or anything that we can help with.

ABOUT US

Benchmark Geotechnical Labs is an independent full service geotechnical testing laboratory. We serve the geotechnical engineering, environmental engineering and construction industries nationwide. In August of 2021 we relocated to Massachusetts and opened Benchmark Geotechnical Labs. Our first lab location in McMinnville, Oregon was originally opened in 2015 by Peter Jacke under the name of Cooper Testing Labs. In 2017, we purchased the lab equipment from CTL and opened Benchmark Geolabs. As of 2021, we are now officially named Benchmark Geotechnical Labs, LLC.

Peter has decades of experience in Geotechnical and Environmental Engineering, both in the lab and the field.

We take pride in our work, providing accuracy and quality in all our testing services. We run all of the common and many advanced geotechnical tests. See our website for more information:

www.benchmarkgeolabs.com

Questions or Comments

If you have and questions or comments about this newsletter or any testing needs, please feel free to contact Peter Jacke.