# Uncertainties in Site Response Modeling: A Practitioner's Perspective

**Opinion Paper**

**By**

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This opinion paper provides an overview of approaches used in seismic design of large infrastructure projects – from my perspective as a practitioner. Following this overview are my thoughts on two issues related to site response: spatial variability of site conditions and uncertainties in soil testing results. Finally, I provide several comments regarding future research needs.

## What is Done during Day-to-Day Seismic Designs

In my role as a geotechnical engineer in a large engineering design firm, I am involved in the seismic design of all types of infrastructure – from transportation systems to water storage and treatment facilities to environmental cleanups. The constructed value of these projects ranges from a few tens of thousand of dollars to many million, but most are in the million dollar plus range. Most of these projects are designed to some building code and, therefore, almost all involve seismic site response evaluations – in the form of peak ground motion and response spectrum determination.

While most (but not all) of our designers recognize the uncertainties associated with seismic site response evaluations, the hard reality is that rarely are site-specific response studies involving one-dimensional site modeling with a computer program, such as SHAKE, carried out to assess seismic site response. For virtually all of our projects, site response is evaluated using site response factors given in the International Building Code (IBC) or various NEHRP documents. Only the largest of projects seem to warrant more than this standard approach.

This current state-of-the-practice for our work is driven by several related factors:

- Economic pressures are to minimize the extent of field investigations. While a limited number of borings and cone penetrometer test (CPT) soundings will likely be conducted, few projects seem to include shear wave velocity measurements – either by borehole (single or multiple) or surface wave methods. If additional money is spent on seismic site response evaluations, it will normally involve additional analyses to evaluate the effects of various realizations of site conditions – as many additional analyses can be conducted for the cost of a single additional exploration.

- There isn't strong evidence that additional data, in the form of in situ measurements or cyclic testing in the laboratory, will result in a more confident set of design recommendations. In fact many designers and some regulatory individuals will choose to use nothing less than the code-specified site-response factors and spectral shapes for liability reasons. The exception to this is for Site Class F soils, where some type of site-specific response evaluation is required. Normally, the site-specific studies for the Site Class F soil would not involve use of a nonlinear code, such as

DESRA. Rather, SHAKE would be used, while realizing that SHAKE by itself often doesn't provide a better estimate of site response if liquefiable soils are present.

- Other than Site Class F soils identified in IBC 2003, little guidance exists to indicate where site-specific response analyses are needed or will be beneficial, and in the case of Site Class F soils, the commercially available software can provide a poor model of site response. Combined with the recognition of uncertainties associated with the definition of input records and uncertainties in material property characterization, many practitioners wonder whether there is a value in site-specific seismic response analyses.

This situation seems to suggest that the practicing engineer needs to have some evidence that uncertainties associated with site-specific analyses can be resolved by going to the effort and expense to conduct such analyses. Realizing this, at present site-specific response studies are limited to the most important of structures, such as at existing or proposed nuclear facilities, major bridges, or other critical infrastructure projects. Even with these projects, the state-of-the-practice relies on oversimplified representations of field conditions, published empirical models of soil behavior, and simplified one-dimensional, equivalent linear wave propagation models.

## Spatial Variability

Part of the limitation of our current approach is the difficulty in adequately representing the spatial variability of the soil. Rarely will the site be characterized with more than soil borings and CPTs at 100-foot spacing (or more), and a single shear wave velocity profile. The cost of more detailed explorations simply hasn't been demonstrated sufficiently to justify the expense – at least from a seismic site response standpoint. Intuitively, it would seem that this simplification sometimes (often?) misses important wave propagation effects; however, little guidance exists on when these effects are important.

This is where the seismologists could provide an important contribution to this workshop. Their understanding of wave lengths associated with seismic wave propagation should give some understanding of what features are important to the wave propagation process and which spectral frequencies appear to be most affected. Likewise, guidance from the seismologist is needed on the effects of sloping boundary conditions. The answer to these needs should not be elaborate two- and three-dimensional computer codes but simple guidance on when further field studies are needed, and what simplified methods can be used to represent these conditions.

Likewise, if spatial variability is a concern, the practitioner also needs simplified, reliable methods for evaluating this variability. Boreholes and CPTs offer one approach for providing this information, but these field methods quickly become costly. Discrete shear wave velocity measurements using crosshole, downhole, or inhole methods are also possible but are even more expensive – and the number of consultants providing high quality results is limited. While surface wave methods (e.g., SASW) would appear to offer a less expensive method of field characterization, the ability to detect spatial changes is understood to be limited and decreases with depth. These limitations may not be critical to many site response problems; however, there are currently no guidelines for deciding what is important and what is not.

## Resolution of Laboratory Testing Uncertainties

Another current limitation is uncertainties associated with laboratory testing of soils. The uncertainties associated with laboratory testing are well established – and include soil sample disturbance during sampling and laboratory test setup, boundary conditions in the laboratory tests, and simplifications related to the interpretation of laboratory data. With few exceptions, these are the same difficulties that were identified in the mid 1970s and early 1980s at the peak of the laboratory testing era. While there have been some improvements in testing methods at universities, such as the combined Resonant Column/Torsional Shear (RC/TS) equipment used by the University of Texas and the Dual Sample Direct Simple Shear (DSDSS) equipment used at the University of California at Los Angeles, the general procedures used by practitioners today differ little from what was used 20 to 30 years ago, with the approach being to obtain a modulus profile in situ and then combine this with laboratory modulus ratio ($G/G_{max}$) and damping ratio (D) versus shearing strain curves. Only now empirical curves showing $G/G_{max}$ and D versus shearing strain curves are usually used rather than laboratory testing, and empirical relationships are often used to estimate $G_{max}$.

This current approach would seem to suggest that in situ characterization has been adequately resolved. In other words the practitioner can estimate $G_{max}$ from a Standard Penetration Test (SPT) blowcount or CPT correlation with some degree of confidence, and then use published correlations for the $G/G_{max}$ and D curves. Sometimes but not always, the uncertainty is introduced in this approach by considering a range in $G_{max}$, $G/G_{max}$, and D values or perhaps, on the most significant projects, considering different realizations of the soil profile and soil property variation to bound the uncertainty issue.

The premise throughout this process is that the laboratory $G/G_{max}$ and D are fairly well established by conclusions reached during past laboratory testing programs, thereby justifying the use of empirical relationships. However, recent test results from a ROSRINE testing program sponsored by the Lifeline Research Program at the Pacific Earthquake Engineering Research (PEER) Center (Anderson, 2003; Stokoe et al., 2003; Tabata and Vucetic, 2002) suggest that there is much to be resolved in the area of laboratory testing. Intuitively, these uncertainties would seem to be important to the site response modeling process; however, little information exists to decide how important.

As an example, during a recent phase of the ROSRINE testing program, companion samples of high quality, intact soil specimens from ROSRINE sites where tested by DSDSS equipment at UCLA and combined RC/TS methods at the University of Texas. An attempt was made to compare results under similar confining pressure conditions to evaluate the effects of laboratory testing methods. Representative results from these tests are shown in Figures 1 and 14[1]. When compared, they show significant differences in the absolute value of shear modulus, more similar material damping results, and virtually identical $G/G_{max}$ results. The in situ modulus is noted on these plots – sometimes the in situ modulus is close to the low-strain laboratory modulus and sometimes it is significantly higher as is normally assumed.

These comparisons of test results would seem to support the normalized modulus curves and damping data that appear in the literature. However, on reflection, the results could also suggest that no matter what the quality of sampling and testing, the process of sampling soil and testing discrete soil samples in the laboratory masks any of the natural characteristics of the soil. A clear conclusion from this possibility is the need for in place testing methods that adequately measure in situ soil response at large strain or deformation levels.

The need for testing methods that determine properties in situ at high strains or deformations is not new. The dilemma is that little progress has been made in this area over the past 30 years. The available methods currently seem to be limited to high-strain crosshole methods that were introduced over 25 years ago – which have yet to be accepted by many within the profession – and research work that has been led by Professor Mike Riemer at the University of California at Berkeley and funded by Caltrans. Unfortunately, the work by Riemer has stalled for funding reasons, though it does show considerable promise.

It is a somewhat dismal situation when the profession has progressed so little in what many believe to be such an important area. This lack of progress is believed to be related to the lack of evidence that more accurate information would result in ground response predictions that have a higher level of confidence.

## Recommendations

As a practitioner, there are a number of recommendations that I would like to see from the workshop participants:

- A consensus on the importance of spatial variability – including whether spatial variability is important and what properties are most affected (e.g., pga or $S_a$ at longer periods), whether there are conditions that warrant special consideration of spatial variability, and simplified methods for quantifying spatial variability (e.g., surface wave procedure).
- Endorsement of the need for methods which quantify the behavior of soil at large stress or deformation levels in situ. The in situ testing method needs to enable determination of material damping in situ, as well as the variation in shearing stress with shearing strain.
- Recommendations regarding the in situ measurement of material damping – at low to high shearing strain levels. Efforts have been made to make these measurements; however, they are not routinely done. This would seem to introduce a significant uncertainty into our material property characterization, as it means that there is no common method for calibrating laboratory values of material damping. At least with modulus computations, we use the in situ shear modulus to anchor the modulus-strain curve. No such similar method exists for material damping.
- Guidance on when material property variations are important. This guidance needs to

consider the overall uncertainties in ground response modeling process – from the uncertainties in characterizing input motions for the analyses to uncertainties in material properties to limitations in the modeling method themselves.

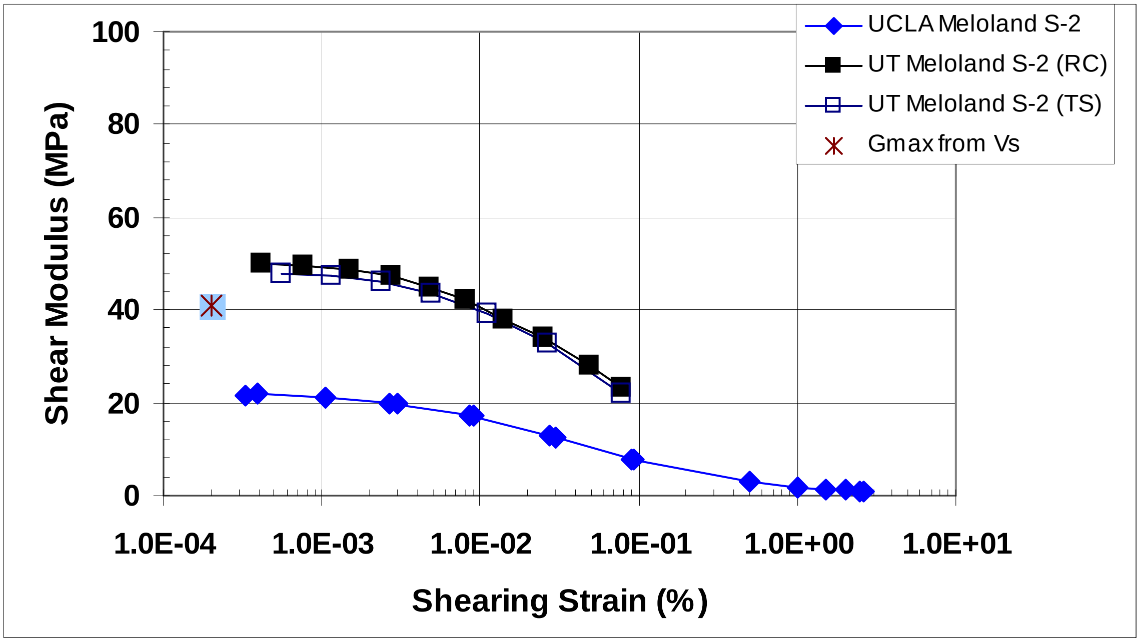
This workshop has assembled a wide cross-section of individuals representing all of the key elements of the site response modeling process. It is hoped that the collective views of these participants will result in some clear and achievable recommendations in this important area.

## References

Anderson, D.G. (2003). *Laboratory Testing of Nonlinear Soil Properties: I & II*, prepared by CH2M HILL, Bellevue, Washington for the Lifeline Research Program, Pacific Earthquake Engineering Research Center, University of California at Berkeley, December.

Stokoe, K.H., Choi, W.K., Meng, F-Y, and Valle, C. (2003). *Linear and Nonlinear Dynamic Properties Determined by Combined Resonant Column and Torsional Shear Tests; Phase II of the ROSRINE Project*, Geotechnical Engineering Report GR03-1, Geotechnical Engineering Center, Civil Engineering Department, The University of Texas at Austin, March.

Tabata, K and Vucetic, M. (2002). *Results of Cyclic Simple Shear Tests on Fifteen Soils Conducted for PEARL Project and Other Research Purposes*, UCLA Research Report No. UCLA-Eng 02-233, Civil and Environmental Department, University of California at Los Angeles, November.



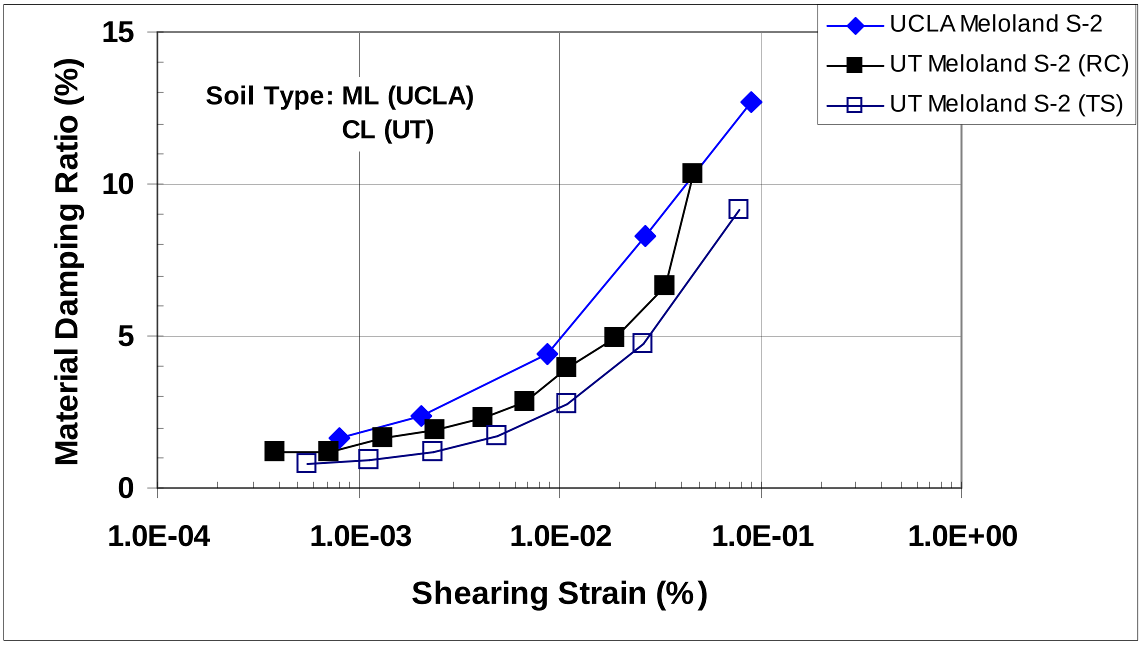


**Figure 1Modulus and Damping Comparisons (Meloland S-2)**

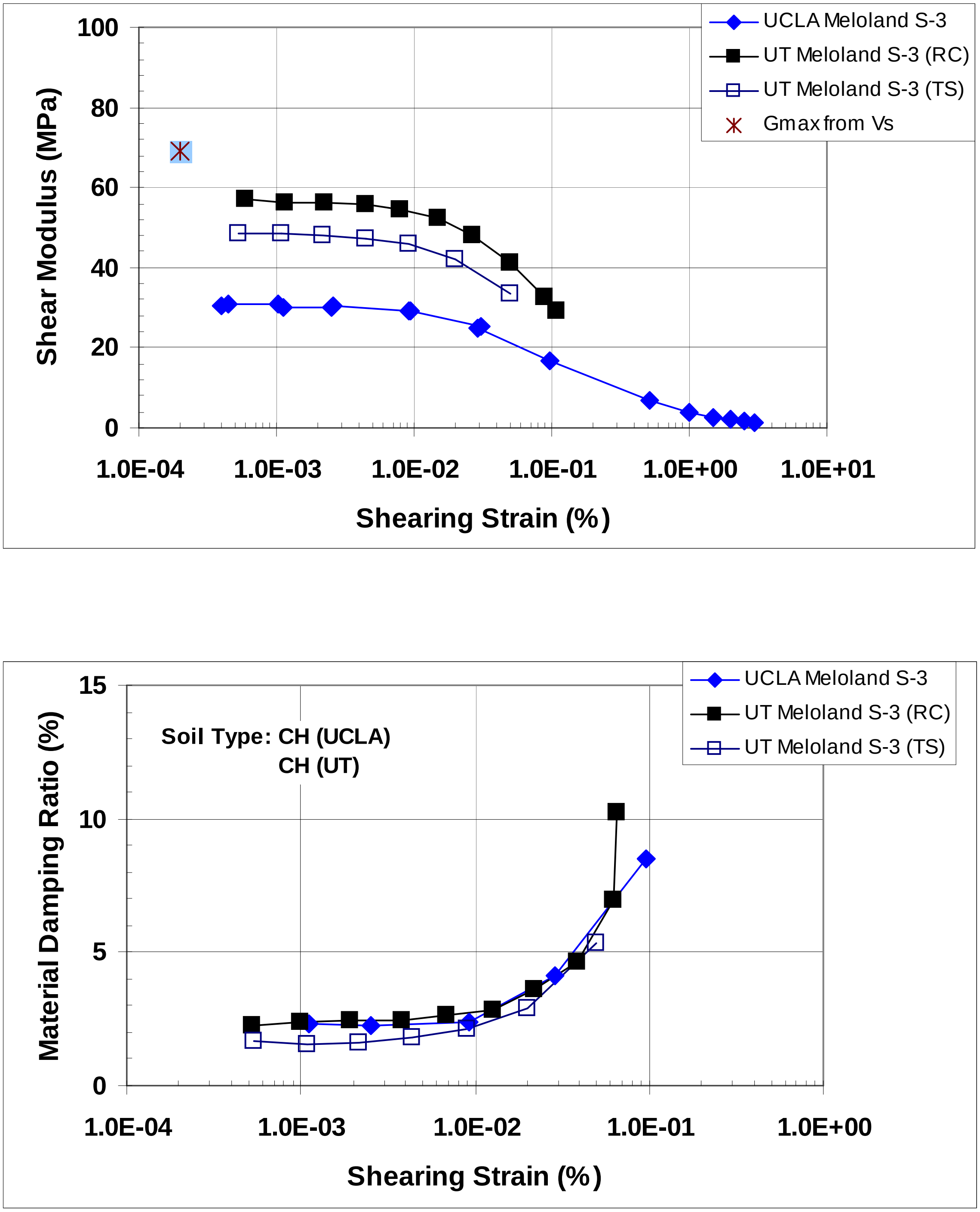
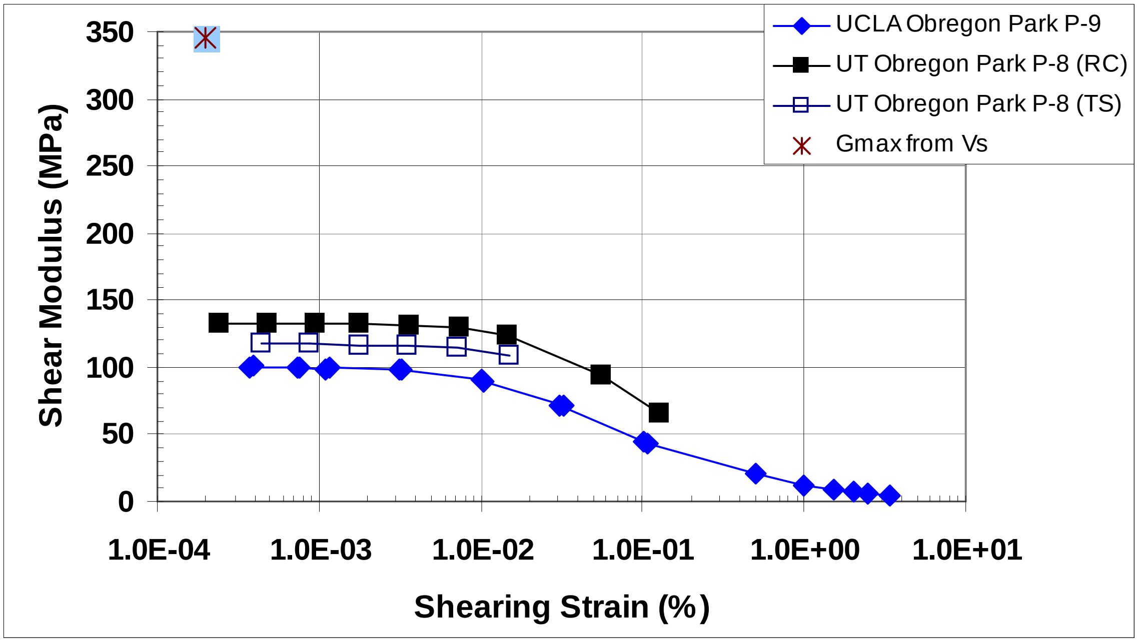


**Figure 2Modulus and Damping Comparisons (Meloland S-3)**



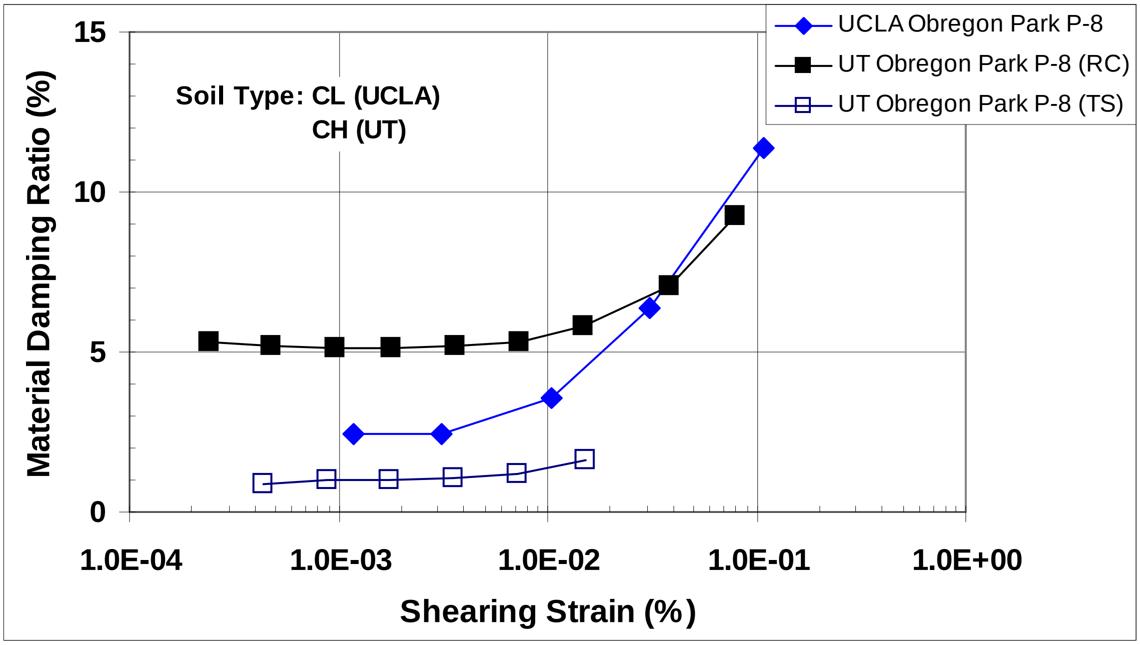


**Figure 3Modulus and Damping Comparisons (Obregon Park)**

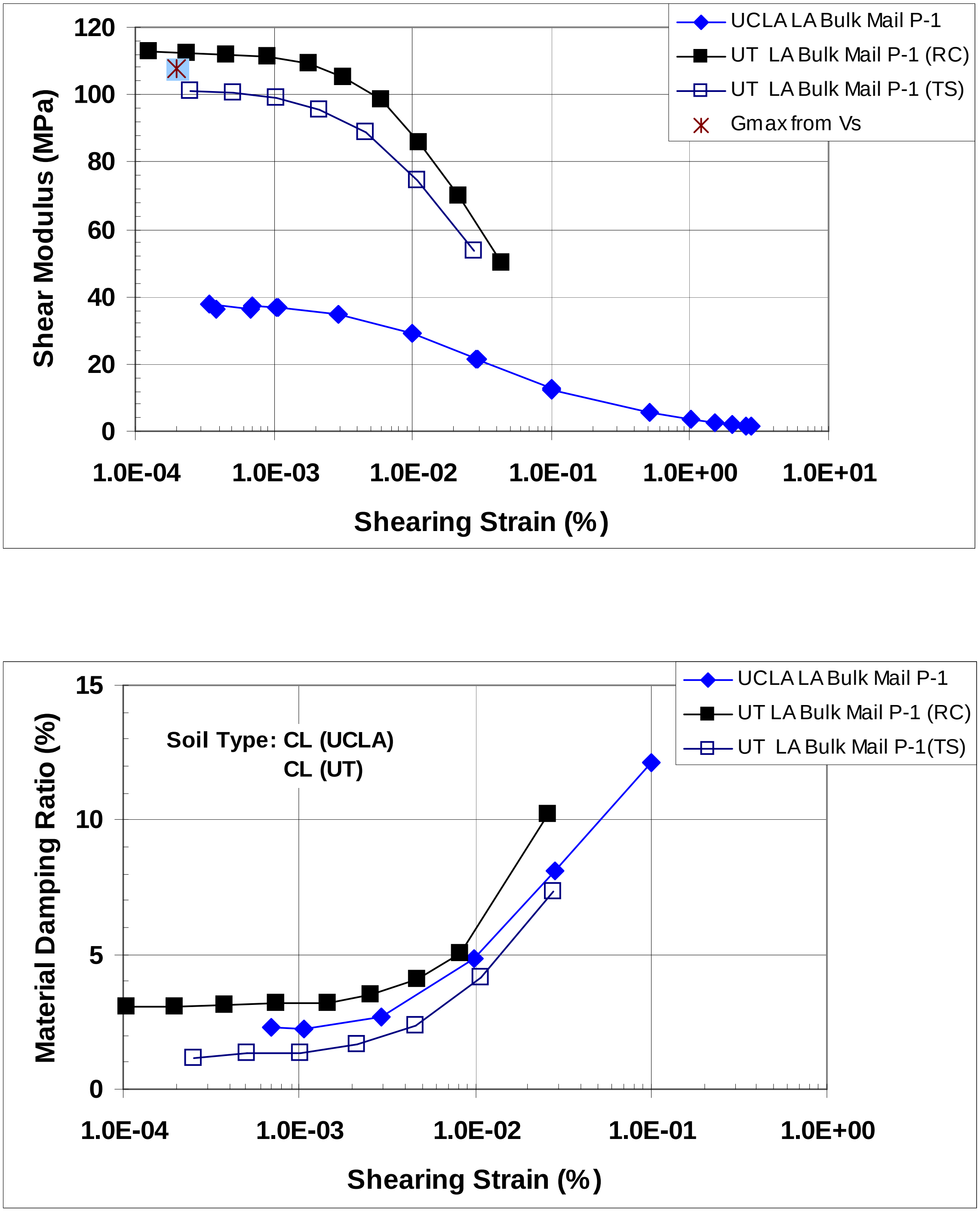
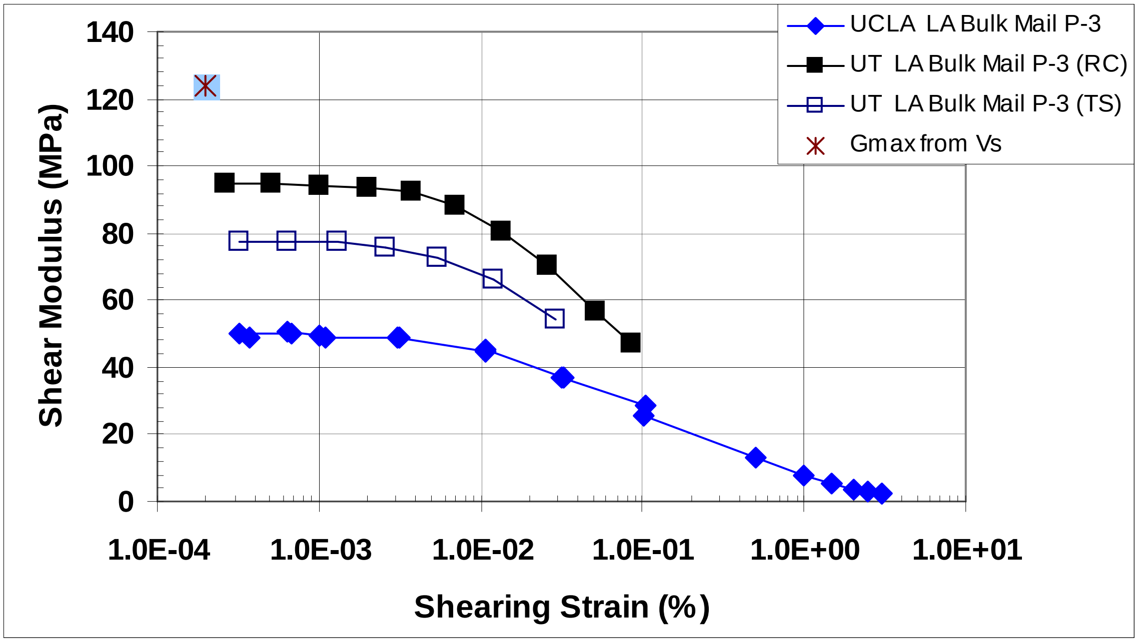


Figure 4Modulus and Damping Comparisons (LA Bulk Mail P-1)



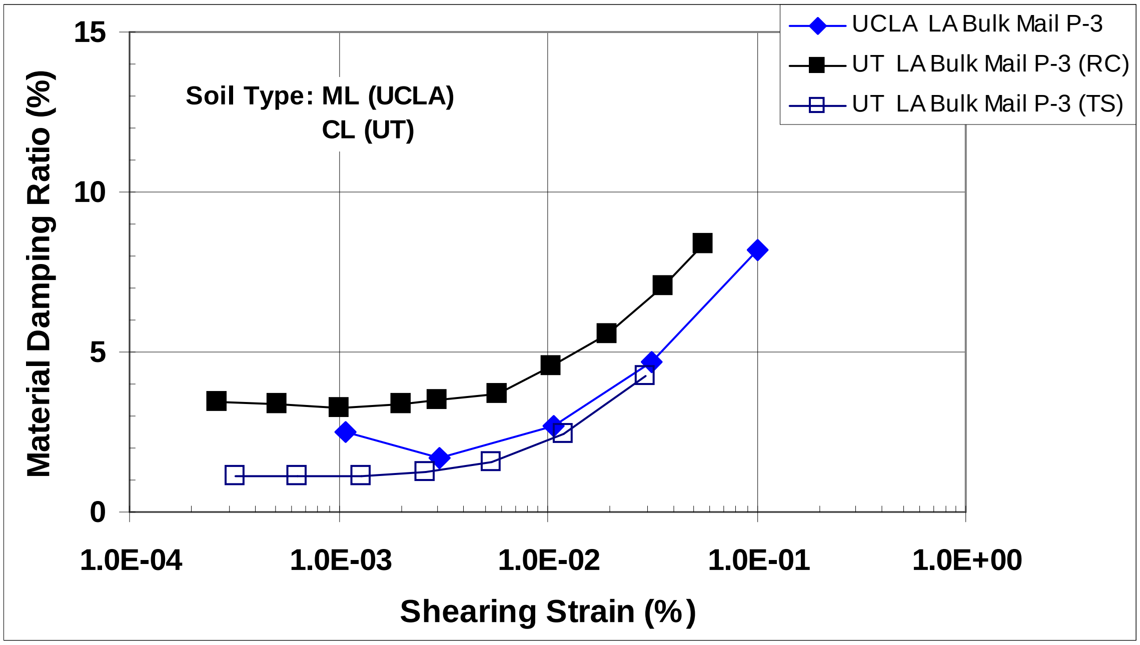


**Figure 5Modulus and Damping Comparisons (LA Bulk Mail P-3)**

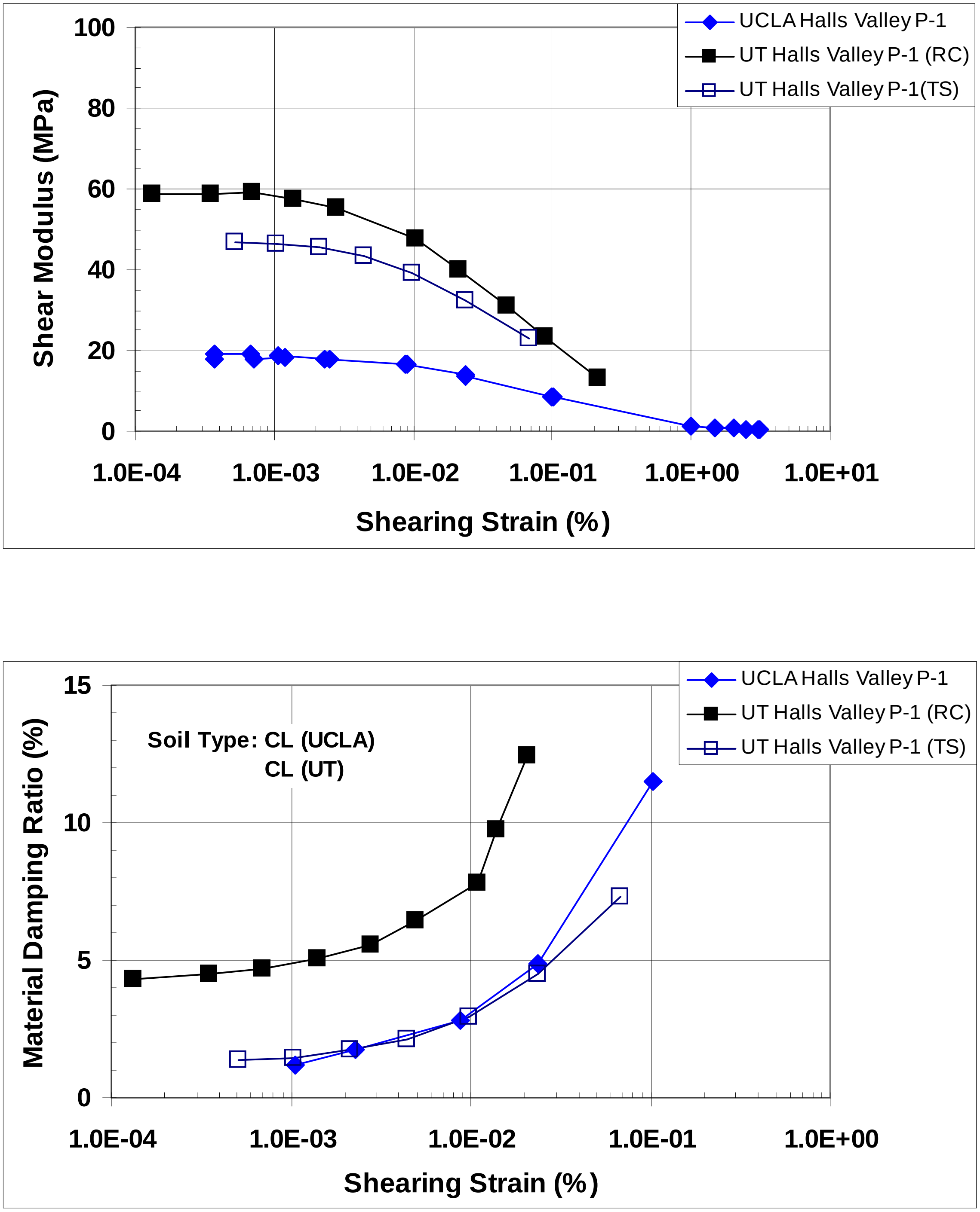


Figure 6Modulus and Damping Comparisons (Halls Valley P-1)

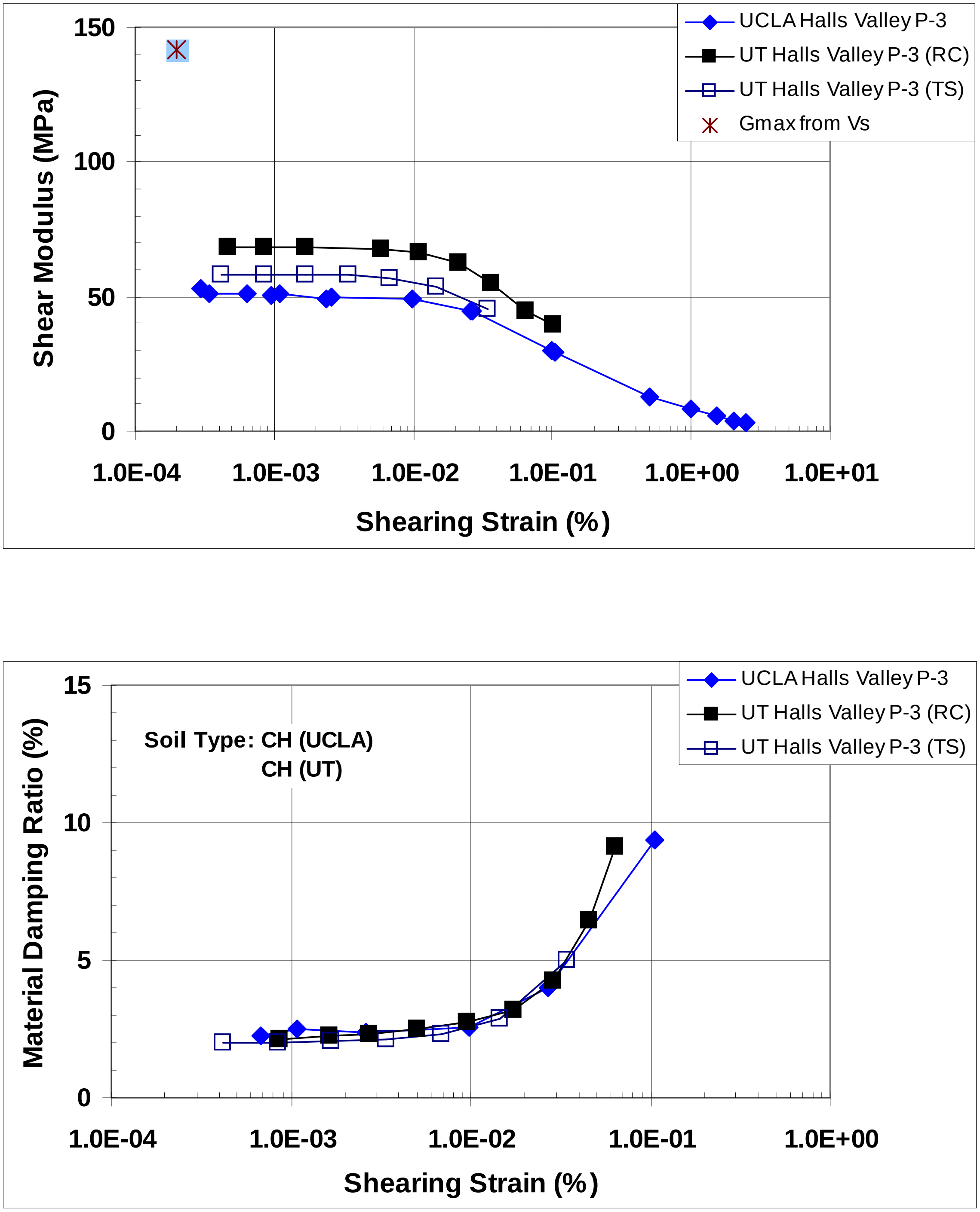


**Figure 7Modulus and Damping Comparisons (Halls Valley P-3)**

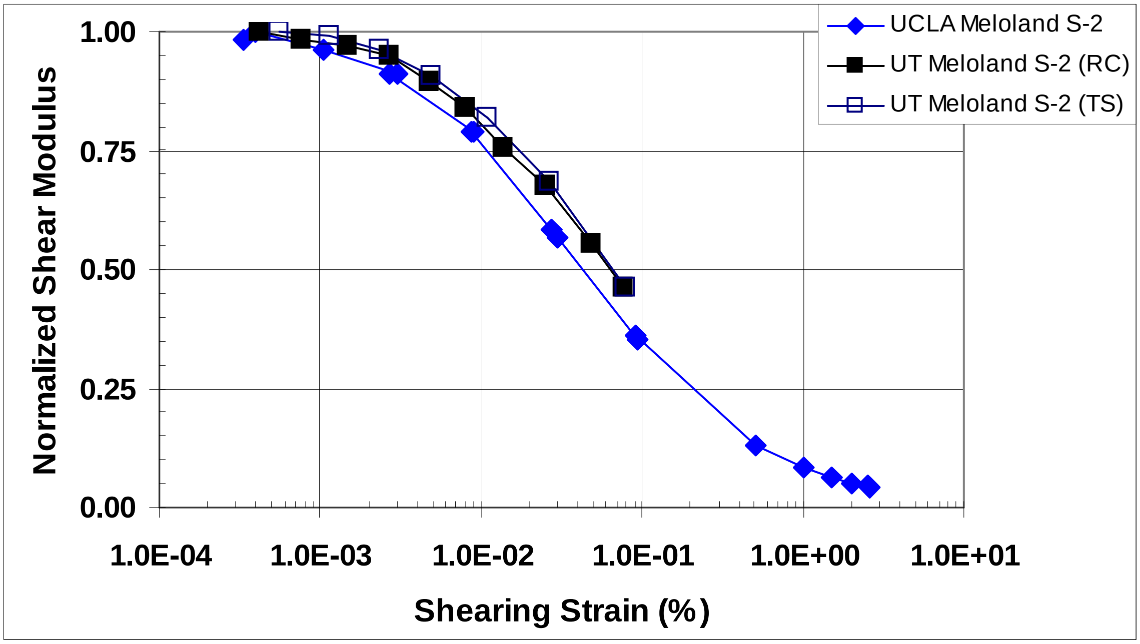


**Figure 8** **Normalized Shear Modulus Ratio Comparisons (Meloland S-2)**

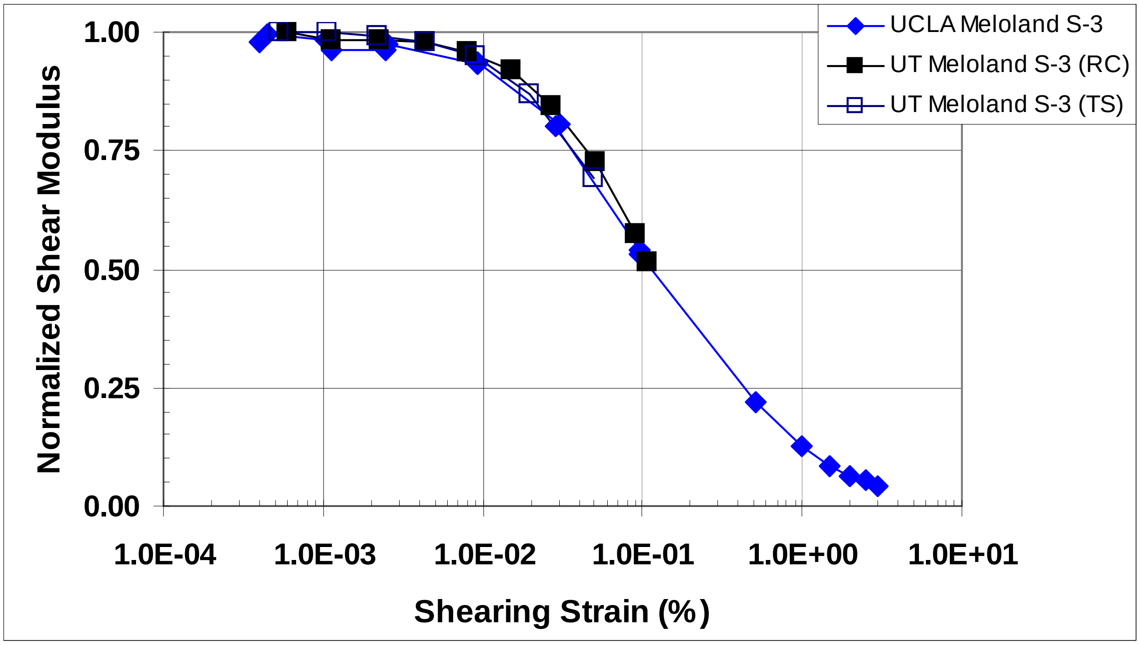


**Figure 9** **Normalized Shear Modulus Ratio Comparisons (Meloland S-3)**

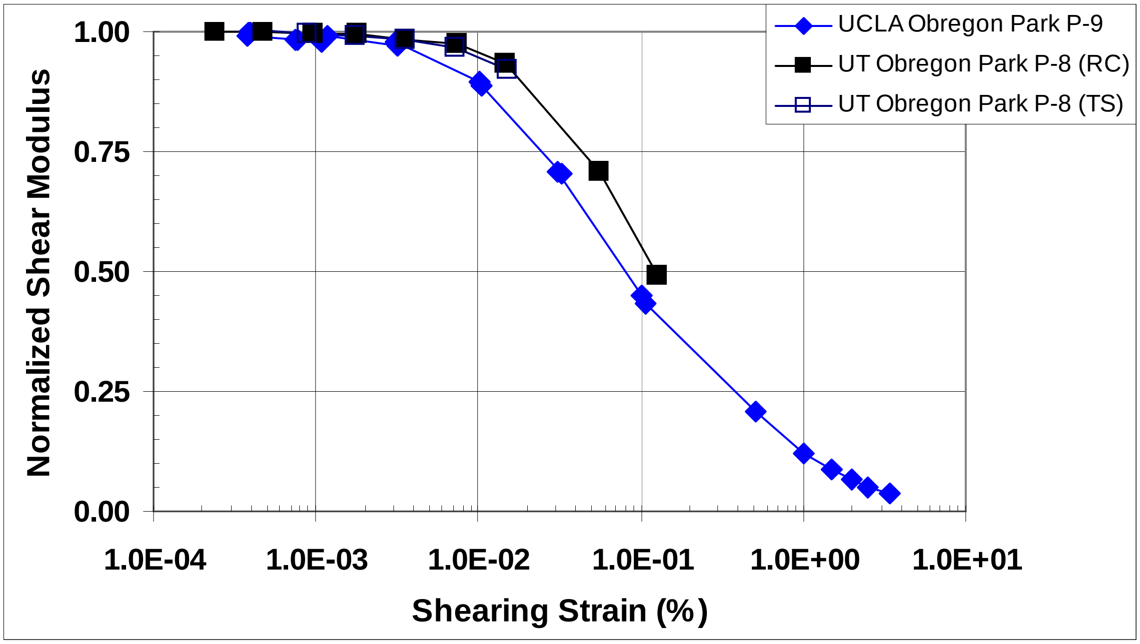


**Figure 10** Normalized Shear Modulus Ratio Comparisons (Obregon Park)

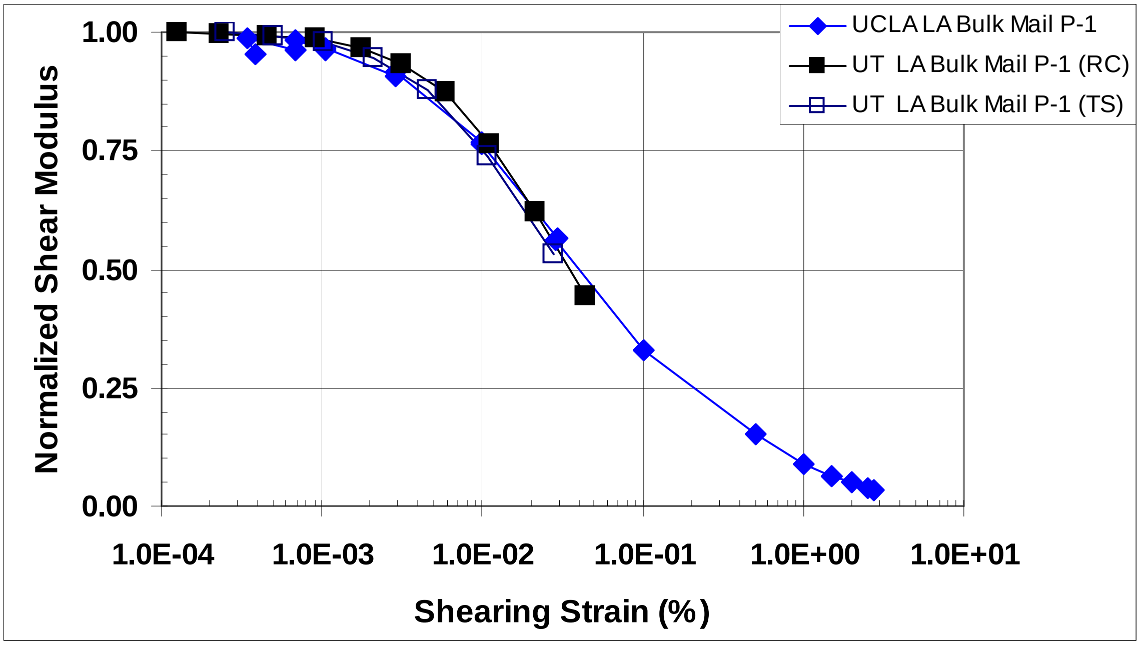


**Figure 11** Normalized Shear Modulus Ratio Comparisons (LA Bulk Mail P-1)

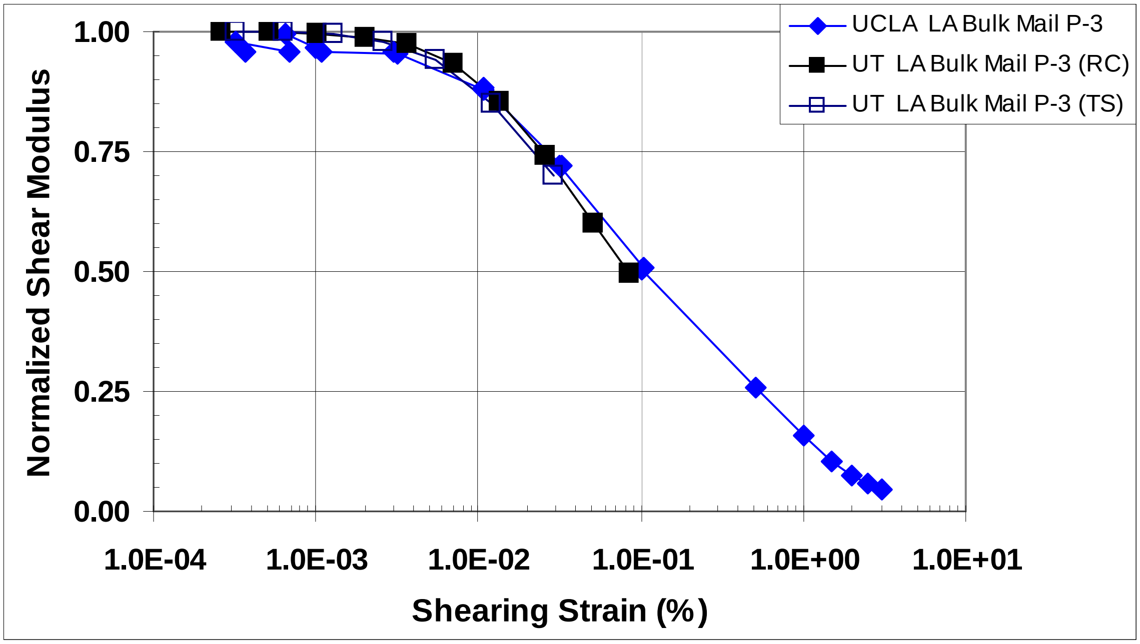


**Figure 12** Normalized Shear Modulus Ratio Comparisons (LA Bulk Mail P-3)

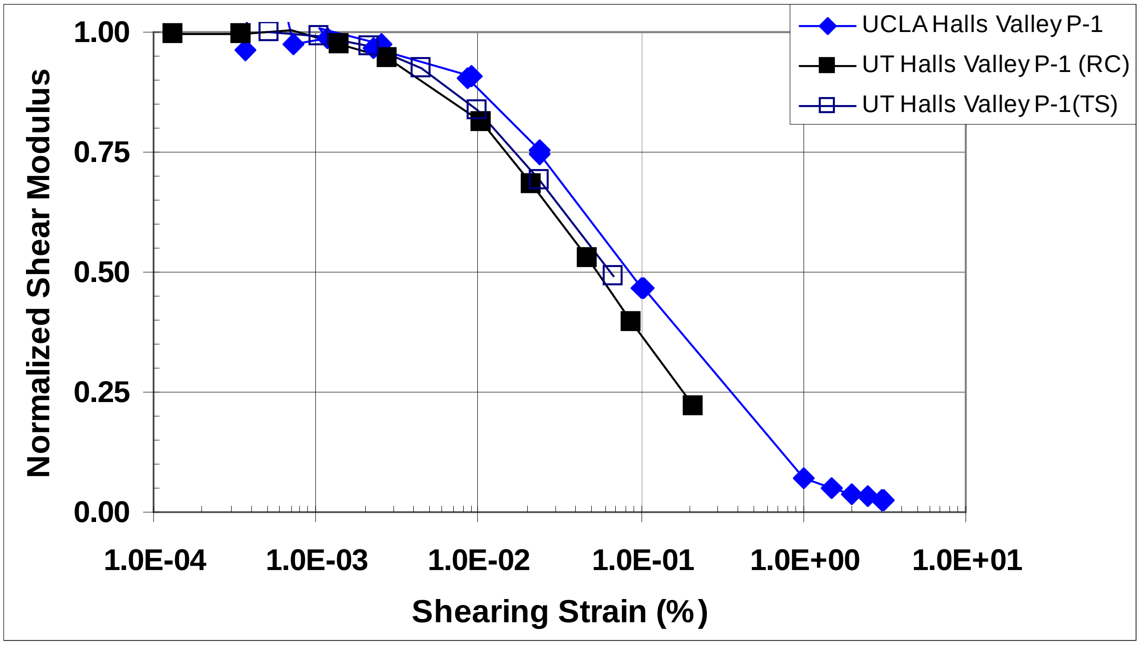


**Figure 13** Normalized Shear Modulus Ratio Comparisons (Halls Valley P-1)

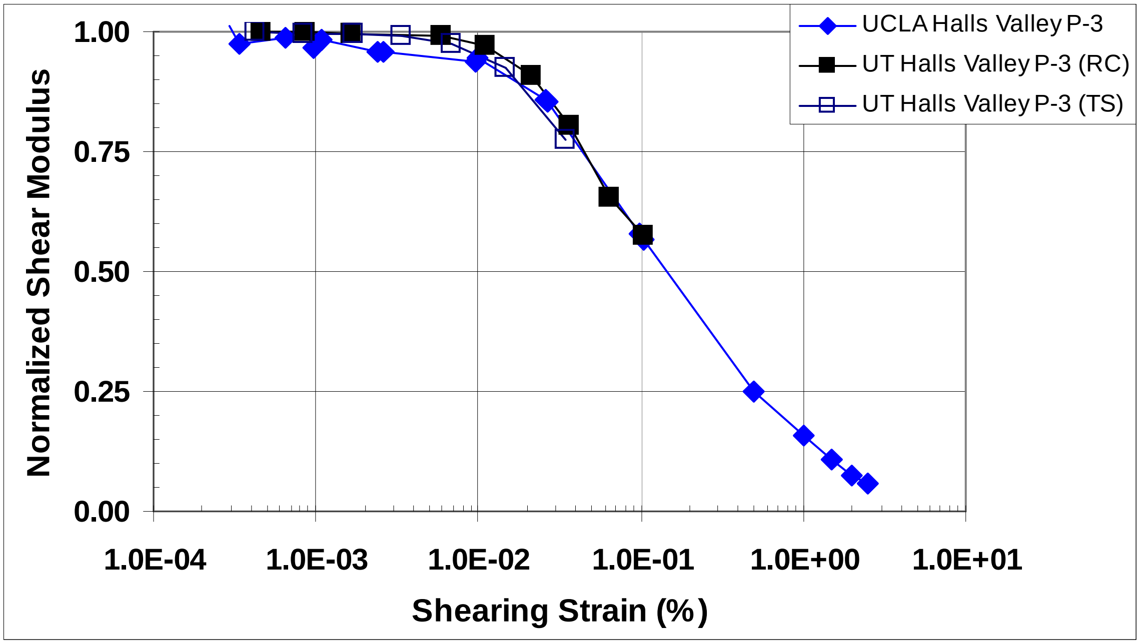


**Figure 14** Normalized Shear Modulus Ratio Comparisons (Halls Valley P-3)

[1] Results of all comparisons are included with this opinion paper in the hopes that these results will stimulate specific discussions during the workshop and future research on the factors affecting modulus and damping properties measured by laboratory testing methods.