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Opinion paper on

What is the current status of soil testing for dynamic soil properties, and what are the major sources of bias and uncertainty?

by

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The fields of one-directional dynamic soil testing and cyclic soil behavior have matured and reached high levels of sophistication in many of their aspects. However, there are still some fundamental aspects of cyclic soil behavior and testing that are either disregarded by researchers and professionals as irrelevant from the practical point of view or are perhaps not known to them. An example of such a fundamental aspect of cyclic soil behavior is the effect of the rate of straining (or loading) and its variation in a single cycle on the modulus and damping properties of soil. Disregarding this effect may result in the modulus reduction curves and damping curves that do not represent properly the field cyclic soil behavior. In fact, a rather gross misrepresentation of the field cyclic soil behavior can happen. Below are two examples.

Example 1: Construction of the normalized modulus reduction curve, G_s/G_{max} versus log γ_c

The G_s/G_{max} versus log γ_c modulus reduction curve is usually constructed by connecting the tips of the initial uniform cyclic loops obtained at different levels of cyclic shear strain amplitudes, γ_c . The cyclic tests are conducted at certain frequencies, i.e., certain levels of average strain rate. By applying different frequencies (average strain rate) at different levels of γ_c the concave downward, horizontal, or concave upward G_s/G_{max} versus log γ_c curves can be easily obtained up to approximately γ_c= 0.01 %. Note that the horizontal G_s/G_{max} versus log γ_c curve represents perfectly linear material, which under regular circumstances cannot be soil. Accordingly, the shape of the G_s/G_{max} versus log γ_c curve depends quite strongly on the variation of the frequency of cyclic loading along the log γ_c axis. This effect is pronounced at small strains up to approximately γ_c= 0.01 %, which is about the most relevant range of γ_c in seismic response and many other dynamic analyses. The effects of the average rate of straining and frequency on the secant shear modulus, G_s, and G_s/G_{max} versus log γ_c curve at small strains were first presented systematically for one clay by Isenhower and Stokoe (1981). These effects have been thoroughly investigated for many different soils at UCLA just recently by Matesic and Vucetic (2002), Vucetic and Tabata (2003), and Vucetic et al., (2003).

Example 2: Construction of the equivalent viscous damping ratio curve, λ versus log γ_c

Because soil is a viscous material, the shape of its stress-strain curve depends on the variation of the rate of shear straining. Uniform cyclic straining can be applied with various shapes of strain-time histories, which are usually triangular, sinusoidal or trapezoidal. For each of these shapes the variation of the rate of straining during loading and unloading phases in a single cycle is different, resulting in different shapes of cyclic loops and thus different areas of cyclic loops. In conclusion, the area of the cyclic loop and corresponding equivalent viscous damping ratio, λ, depend on the shape of cyclic straining. For clays these effect can be very large in the domain of small strains up to approximately γ_c= 0.01 %. For example, 100% larger λ can be obtained under trapezoidal loading than under triangular loading, while more that 50% larger λ can be obtained under sinusoidal loading than under triangular loading. These effect and its consequences were studied at UCLA and published just five years ago by Lanzo and Vucetic, (1999), and Vucetic et al., (1998).

According to the above examples and results presented in the cited papers, by “playing” in the laboratory with different rates of straining very different modulus reduction and damping ratio curves can be obtained. It is evident that the outcome of seismic site response analysis depends seriously on the rates of straining applied in the laboratory. In other words, the lack of understanding or disregard for the strain-rate effects can seriously hamper our ability to predict seismic ground motions, i.e., the ability to develop more realistic procedures and charts for the prediction of the ground motions. It must be noted that the above effects have been studied thoroughly just recently, in last 10 years, and that now the modulus reduction and damping design curves will need to be modified accordingly, or they will have to be approached differently by practitioners.

Summary and conclusions:

1. If the fundamental stress-strain properties of soils are not very well understood, some fundamental errors can be easily made. The knowledge of soil behavior under cyclic loads is the foundation upon which the seismic site response and similar analyses are developed. We

know that a superstructure will not perform well without a solid foundation, and we should apply this analogy to our soil dynamics research.

2. The research on very fundamental aspects of the cyclic stress-strain behavior must be taken seriously and properly supported. It must not be assumed that we have already learned most of what is there to learn about the fundamental aspects of the one –directional cyclic stress-strain behavior of soils.
3. The knowledge about the cyclic soil stress-strain behavior is acquired almost exclusively in the cyclic soil testing laboratories. The successful investigations based on high-quality testing are usually long-term and relatively expensive, and require significant soil testing experience that can be gained only in the laboratory doing series upon series of actual tests. In that sense, the experienced experimentalists are those who not only understand what it takes to conduct a quality test, but also how complex the cyclic soil behavior is and which aspects of the soil behavior we still do not fully understand. In other words, the experimentalists are best qualified to answer questions such as: What is the current status of soil testing for dynamic soil properties, and what are the major sources of bias and uncertainty.

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