Discussion of “Analyzing Liquefaction-Induced Lateral Spreads Using Strength Ratios” by S. M. Olson and C. I. Johnson

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The authors have presented an excellent study that provides theoretical and empirical justification for the use of the Newmark sliding-block method in estimating displacements of lateral spreads using residual strength values. The discussers believe that this is insightful work and will have a strong impact on research and practice, and would like to commend the authors on their efforts. The purpose of this discussion is to examine the use of index test values that were derived from other index test values through some conversion by means of statistical correlation. This type of conversion was used for a number of the case histories presented by the authors and the discussers believe that an open discussion is warranted.

The authors present the concept that lateral spread case histories exhibit effective stress-normalized undrained strengths (s_u/σ'_{vo}) during liquefaction, called the mobilized shear-strength ratio, which are similar to values back-analyzed from liquefaction flow failures. To support this 39 lateral spreading case histories were back-analyzed using the Newmark sliding-block method. The results are presented as plots of SPT and CPT measurements with respect to the mobilized shear strength ratio. Of those case histories 29 had measurements using both the SPT and CPT, but 10 case histories were deficient in one or both of these common index tests. As presented by the authors; in Table 4 of the original paper;

- Cases 5, 38, and 39 have CPT only;
- Case 24 has SPT only;
- Cases 18, 19, 20, and 22 have SPT and SWS (Swedish weight sounding); and
- Cases 21 and 23 have SWS only.

When a conversion between index tests based on statistical regression is used to estimate one index test value from another the uncertainty of the predicted value is a function of the measurement uncertainty of the index tests and the uncertainty that is a function of the conversion. For discussion we take the simple linear conversion of q_c (CPT tip resistance) to N (SPT blow count) as used by the authors:

$$q_c \cong \alpha \cdot N \quad (1)$$

where q_c is in units of MPa; α =conversion factor; and N =SPT blow count. N in this case has a certain amount of measurement uncertainty associated with the process of field testing. The conversion between these two test measurements is imperfect and can be best demonstrated by Fig. 1. As can be seen in the plot there is some agreement between the two tests but it is a function of the median grain size.

Fig. 1. Data indicating an interrelationship or correlation between CPT and SPT index measurements (after Kulhawy and Mayne 1990)

If we assume that we are dealing mainly with sands, because it is the most common material that liquefies and results in lateral spreading, then Fig. 2 demonstrates the uncertainty in the conversion between the two tests. A histogram of the data for all soil types indicates that a lognormal distribution is a reasonable assumption for the frequency distribution of the data. When tip resistance is predicted based on this linear conversion the central tendency or median is not unexpected, but the variance now includes the uncertainty from the measurement process and the conversion. Here we use a simple first-order second-moment approximation (Ang and Tang 2007) to propagate the uncertainty through the linear function [Eq. (1)]

$$\mu_q \cong \mu_\alpha \cdot \mu_N \quad (2)$$

$$\sigma_q^2 \cong \sigma_\alpha^2(\mu_N)^2 + \sigma_N^2(\mu_\alpha)^2 \quad (3)$$

If we assume values for the central tendency and the dispersion we can evaluate the influence of the conversion process from SPT to CPT. Kulhawy and Mayne (1990) report a coefficient of variation (standard deviation/mean) for the SPT test to be nominally 15% (but can be upwards of 100% in some cases). Converting from SPT blow counts to CPT tip resistance shows a coefficient of variation on the order of 40% for all sands (Fig. 2). If we use a median value of $N=8$, a median conversion factor of $\alpha = 5$, and assume that the distributions are not highly skewed (i.e., mean $\sim$ median), then the resulting coefficient of variation of tip resistance is approximately 43%. When compared to a typical coefficient of variation of a directly measured tip resistance of nominally 7% (but can be upwards of 12%), this shows a five- to sixfold increase in the uncertainty of the converted value (Fig. 3).

(Note: Conversion factors from SPT to CPT differ if the older units of kg/cm² or the modern units of MPa are used. The metric units of kg/cm² are in mass whereas the SI units of MPa are in force, with gravity being the difference between the two. Therefore previous conversion factors were typically around 0.5 and modern conversion factors are typically around 5.0).

When converting from SWS to SPT and then to CPT we find even greater compounding uncertainties. SWS is a manual operated test that requires a small auger which is hand screwed into the soil with successive half turns of a t-bar handle under a prescribed dead load. The correlation of SWS to SPT or CPT is questionable. In theory this test should render compatible results with the SPT and better yet with the CPT but the statistics show otherwise.

Ishihara et al. (1993) reported a conversion in a paper on the Luzon earthquake that related SWS to SPT with the equation, $N = 2 + 0.067(\text{SWS})$, where SWS is the number of half turns per 100-cm-depth increment. This is the same paper that the authors derived the SWS data on lateral spreads from. Unfortunately there were no statistics reported with this equation. The discussers assume that this is the relationship the authors used when converting the Luzon SWS to SPT, which was then converted from SPT to CPT.

Fig. 2. Inferred distributions of different grain size bins based on statistical results

The discussers, over the past two years, have conducted field experiments to evaluate the correlation between the SWS and the CPT. The concept that a screw twisted into soil would produce similar results as a cone pushed into the same soil appears valid. The results however show a very weak relationship with a correlation coefficient of $\rho = 0.235$ (where perfectly correlated measurements would render $\rho = 1.0$ and measurements that were not correlated in any way would render $\rho = 0$). Because there is a weak correlation the scatter of $(qc/Pa)/\text{SWS}$ is rather large resulting in a coefficient of variation of approximately 123%. This large uncertainty means that converting from SWS to CPT produces ambiguous results, and there is little confidence in the median value. If we use the same approach to uncertainty propagation as before, along with the equation recommended by Ishihara et al. (1993), and assume that SWS has a coefficient of variation from the testing process similar to SPT, and that the scatter between SWS and SPT is similar to that between SWS and CPT, the estimated SPT distributions appear as shown in Fig. 4. If we then convert from SWS to SPT to CPT the results are shown in Fig. 3.

Fig. 3. The distributions of measured tip resistance versus estimated tip resistance using a conversion. All distributions show the same median value with differing standard deviation as a function of method used.

Fig. 4. The distributions of measured SPT N values versus SWS to SPT conversion N values. Both distributions show the same median value with differing standard deviation as a function of the method used.

As can be seen the process of converting from one index test to another is a process where the informational content can become diluted by compounding uncertainties, to the point where the median value or any other measure of central tendency is ambiguous and ill-defined. This results in little confidence in the converted median value, and little confidence in subsequent analyses or calculations using the converted median. It is recommended that engineers that need to convert from one index test to another develop the conversion factor for their particular project by sampling with the desired index tests and then developing a site-specific correlation. If this is infeasible then the engineer should design conservatively by using a “mean plus standard deviation” approach to account for the uncertainty that propagates

with a conversion. With regard to the paper being discussed, it is recommended that the uncertainty described here be evaluated with respect to their results to determine if it impacts the conclusions, in other words a sensitivity study. The discussers believe that the propagation of uncertainty demonstrated in this discussion will not impact the authors overall results but may affect some reevaluation of the finer points of mobilized shear strength ratio with respect to lateral spreading.

References

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