APPENDIX I

SHEAR STRENGTH RATIO TRIGGERING METHODS

GEOTECHNICAL DESIGN MANUAL

January 2022

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APPENDIX I

SHEAR STRENGTH RATIO TRIGGERING METHOD

I.1 INTRODUCTION

The Shear Strength Ratio (SSR) triggering method computes the ratio of shear stress demand on the soil layer susceptible to soil SSL, to the soil's yield strength. This method, developed by Olson and Stark (2003), uses the yield shear strength ratio and soil SSL ratio to evaluate the triggering of soil SSL. This method shall be used when the maximum initial static shear stress ratio (α) is greater than 0.35 (α > 0.35). Where α is determined as indicated in Chapter 13.

I.2 OLSON AND STARK METHOD

The SSR method proposed by Olson and Stark (2003) has been adapted to evaluate cyclic liquefaction triggering for Sand-Like soils and cyclic softening of Clay-Like soils with a static shear stress in excess of 0.35. This soil SSL triggering method consists of the following 2 parts:

1. Screen Sand-Like soils for Contractive behavior based on Contractive/Dilative correlations with in-situ testing (SPT and CPT) for Sand-Like soils (Section I.2.1).
2. Evaluate soil SSL triggering of Sand-Like and Clay-Like soils by dividing the static (Section 13.9.6.1), seismic, and other shear stresses that the soil is exposed to (Demand, D) by the undrained shear strength of the soil (Capacity, C) to obtain the SSL ratio $(D/C)_{SL}$ and determine if the soil SSL triggering potential exists. The overall procedure is presented in Section I.2.2.

I.2.1 <u>Screening of Sand-Like Soils For Contractive Behavior</u>

In addition to the soil SSL susceptibility screening criteria indicated in Chapter 13, this method requires the screening of Sand-Like soils for contractive behavior. Sand-Like soils must have contractive behavior in order to be subject to slope instability that could lead to flow failure. The screening for contractive behavior is accomplished by plotting either SPT ($N^*_{1,60}$) or CPT ($q_{c,1}$) values on the horizontal axis as a function of the pre-failure vertical effective stress (σ'_{vo}) as indicated in Figure I-1. After the in-situ testing values have been plotted, the Fear and Robertson (1995) soil boundary behavior relationship is plotted on the graph as indicated to determine which Sand-Like soil layers meet the contractive soil requirement of the SSR method. The Fear and Robertson (1995) soil boundary for contractive/dilative behavior relationship equations are provided below for CPT and SPT in-situ testing.

$$(\sigma'_{vo})_{SPT-Boundary} = 9.58 * 10^{-4} * \left(N^*_{1,60}\right)^{4.79}$$ **Equation I-1**

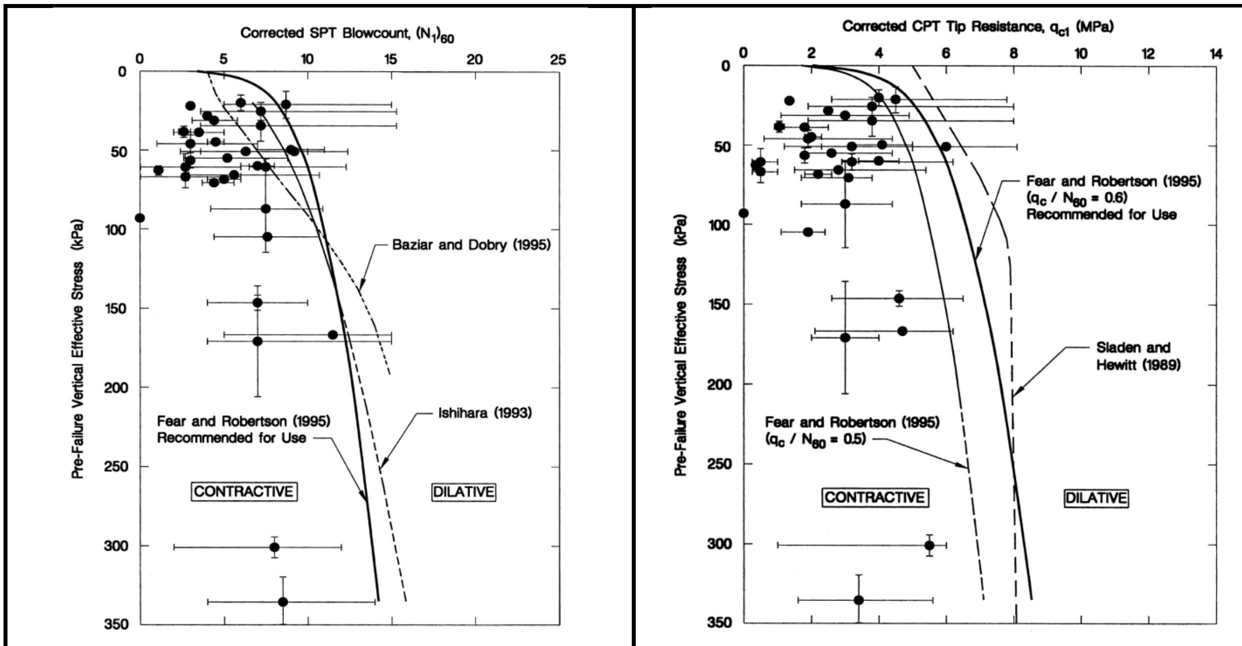
$$(\sigma'_{vo})_{CPT-Boundary} = 1.10 * 10^{-2}\left(q_{c,1}\right)^{4.79}$$ **Equation I-2**

Where,

σ'_{vo} = Effective overburden stress (or σ'_{v}), units of kPa.
$N^*_{1,60}$ = Normalized SPT-N values (Blows/foot) See Chapter 7 for SPT corrections.

$q_{c,1}$ = CPT corrected tip resistance, units of MPA. See Chapter 7 for CPT corrections.

SPT or CPT values of Sand-Like soils that plot on the *Contractive* side of the boundary (left of boundary) are confirmed to be susceptible to flow failure as indicated by the liquefaction case histories evaluated by Olson and Stark (2003) plotted in Figure I-1.



SPT ($N_{1,60}$) Contractive Behavior Evaluation	CPT ($q_{c,1}$) Contractive Behavior Evaluation

Figure I-1, Contractive Soil Behavior Evaluation
(Olson and Stark, 2003 with permission from ASCE)

I.2.2 Evaluate Soil SSL SSR Triggering Model

Soil SSL triggering of Sand-Like and Clay-Like soils is determined by dividing the static, seismic, and other shear stresses that the soil is subjected to (Demand, D) by the undrained shear strength of the soil (Capacity, C) to obtain the strength loss ratio $(D/C)_{SL}$. The LRFD equation that is used to evaluate the onset of strength loss (SL) of sloped ground site conditions is provided below:

$$\left(\frac{D}{C}\right)_{SL} \le \varphi_{SL} \qquad \textbf{Equation I-3}$$

The Demand (D) is computed by adding the static driving shear stress (τ_{Static}), average seismic shear stress ($\tau_{Seismic}$), and other shear stresses (τ_{Other}) as indicated by the following equation.

$$D = \gamma * (\tau_{Static} + \tau_{Seismic} + \tau_{Other}) \qquad \textbf{Equation I-4}$$

The Capacity (C) of the soil is the undrained peak shear strength (τ_{Peak}) as determined for either Sand-Like soils (Cohesionless) or Clay-Like soils (Cohesive) as determined from Chapter 7. The peak undrained shear strength for cohesionless soils should be estimated based on the yield shear strength ($\tau_{Yield} = S_u(\text{yield})$) and the peak undrained shear strength ($\tau = \tau_{Yield}$) for cohesive soils should be estimated from either laboratory testing or in-situ testing.

The triggering of soil SSL occurs when the strength loss ratio $(D/C)_{SL}$ is greater than the strength loss resistance factor (φ_{SL}) provided in Chapter 9.

$$\left(\frac{D}{C}\right)_{SL} = \frac{(\tau_{Static}+\tau_{Seismic}+\tau_{Other})}{\tau_{Peak}} > \varphi_{SL} \qquad \textbf{Equation I-5}$$

Since the SSR method for evaluating soil SSL triggering at a project site is a deterministic procedure, a load factor, γ, of unity (1.0) is used and the resistance factor, φ_{SL}, accounts for the site variability and the level of acceptable risk of soil SSL. As research advances and soil SSL analytical models are calibrated for LRFD design methodology, adjustments will be made in the implementation of the LRFD design methodology.

The process to evaluate triggering of soil SSL is as follows:

1. The triggering of soil SSL begins by conducting a slope stability of the pre-failure geometry. The slope stability search should evaluate both circular and sliding wedge potential failure surfaces in accordance with Chapter 17. Spencer's Slope Stability method is required.
2. The critical failure surface is then divided into *n* slices (typically 10 to 15 slices) of length, L_i.
3. Compute the static shear stress (τ_{Static}) for each slope stability slice (length, L_i) susceptible to soil SSL at the onset of flow failure, in accordance with Section 13.9.6.1.
4. Compute the average, magnitude weighted, seismic induced stress ($\tau_{Seismic}$) for each slice (length, L_i) susceptible to soil SSL in accordance with the following equation.

$$\tau_{Seismic} = \frac{0.65 * \tau_{max}}{MSF} \qquad \textbf{Equation I-6}$$

Where,

τ_{max} = Maximum earthquake induced shear stress. τ_{max} is computed using the methodologies discussed in Chapter 13.

MSF = Magnitude Scaling Factor computed in accordance with Chapter 13.

5. Compute any other shear stresses (τ_{Other}) that may be applicable such as those induced by surcharges, foundation loadings, etc.
6. Determine the value of the peak undrained shear strength ratio ($\tau_{Peak}/\sigma'_{vo} = \tau_{Yield}/\sigma'_{vo}$) for Sand-Like soils (cohesionless soils) or the undrained shear strength ratio ($\tau_{Peak}/\sigma'_{vo} = S_u/\sigma'_{vo}$) for Clay-Like soils (cohesive soils) in accordance with Chapter 7. Compute the undrained shear strength for Sand-Like soils ($\tau = \tau_{Yield} = S_u(yield)$) or Clay-Like soils ($\tau = S_u$) for each slice of the critical failure surface by multiplying the peak undrained shear strength ratio (τ/σ'_{vo}) by the effective overburden stress (σ'_{vi}) for each slice.

7. Compute the soil SSL resistance ratio $(D/C)_{SL}$ as indicated by the following equation for each slice.

$$\left(\frac{D}{C}\right)_{SL} = \frac{(\tau_{Static}+\tau_{Seismic}+\tau_{Other})}{\tau}$$ **Equation I-7**

8. The onset of cyclic liquefaction in Sand-Like soils or cyclic softening in Clay-Like soils, occurs when the strength loss ratio $(D/C)_{SL\text{-}i}$ for each slice (length, L_i) susceptible to soil SSL is greater than the LRFD resistance factor (φ_{SL}) presented in Chapter 9 as indicated by the following equation.

$$\left(\frac{D}{C}\right)_{SL-i} > \varphi_{SL}$$ **Equation I-8**

I.3 REFERENCES

Fear, C. E., and Robertson, P. K. (1995). ‘‘Estimating the undrained strength of sand: A theoretical framework,’’ *Canadian Geotechnical Journal*, 32(4), 859–870.

Olson, S. M., and Stark, T. D., (2003), “Yield Strength Ratio and Liquefaction Analysis of Slopes and Embankments,” *Journal of Geotechnical and Geoenvironmental Engineering*, ASCE, Volume 129, Issue 8, pp. 727-737.