AN UPDATE OF THE SEED-IDRISS SIMPLIFIED PROCEDURE FOR EVALUATING LIQUEFACTION POTENTIAL

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PRESENTATION NOTES

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The Elements of a Liquefaction Evaluation

- ❐ Amplitude & Duration of Induced Shear Stresses (Demand)
- ❐ Shear Stresses Required to Cause Liquefaction (Resistance / Capacity)
- ❐ Triggering of Liquefaction leading to development of high pore water pressure (i.e., Capacity is ≤ Demand, or Factor of Safety is ≤ 1)
- ❐ Consequences -- Settlements / Limited Deformations / Flow Slides
- ❐ Mitigation - Available Options:
    - ♦ accept risk
    - ♦ modify design to to accommodate consequences
    - ♦ remediate to decrease or eliminate consequences

Induced Shear Stress, τ_i, at Depth z

- ❑ Calculated Using Ground Response Analysis (Equivalent Linear Total Stress Analysis; Nonlinear Total Stress Analysis; Nonlinear Effective Stress Analysis)

- ❑ Calculated Using The Equation Developed in Conjunction with the Seed-Idriss Simplified Liquefaction Evaluation Procedure. The maximum shear stress induced at depth z is given by:

$$(\tau_i)_{max} = \sigma_v \times a_{max} \times r_d$$

in which, σ_v is the total vertical stress; a_{max} is the peak horizontal acceleration at the ground surface; and r_d is stress reduction coefficient at depth z. These terms are illustrated in Fig. 1.

This maximum induced shear stress occurs at least once during the ground shaking.

Levels of stress less than the maximum induced stress would act over several cycles. In the study of the Niigata earthquake, Seed & Idriss (1967) used 0.65 times the $(\tau_i)_{max}$ to define an "equivalent uniform shear stress", i.e.:

$$(\tau_i)_u = 0.65(\tau_i)_{max} = 0.65 \times \sigma_v \times a_{max} \times r_d$$

Using this equation, a representative cyclic strength curve (based on the test results shown in Fig. 2a) and a number of recorded earthquake ground motions, Seed et al (1975) obtained the following number of equivalent cycles as a function of earthquake magnitude, M.

Magnitude	Number of Cycles
5¼	2 -3
6	5
6¾	10
7½	15
8½	26

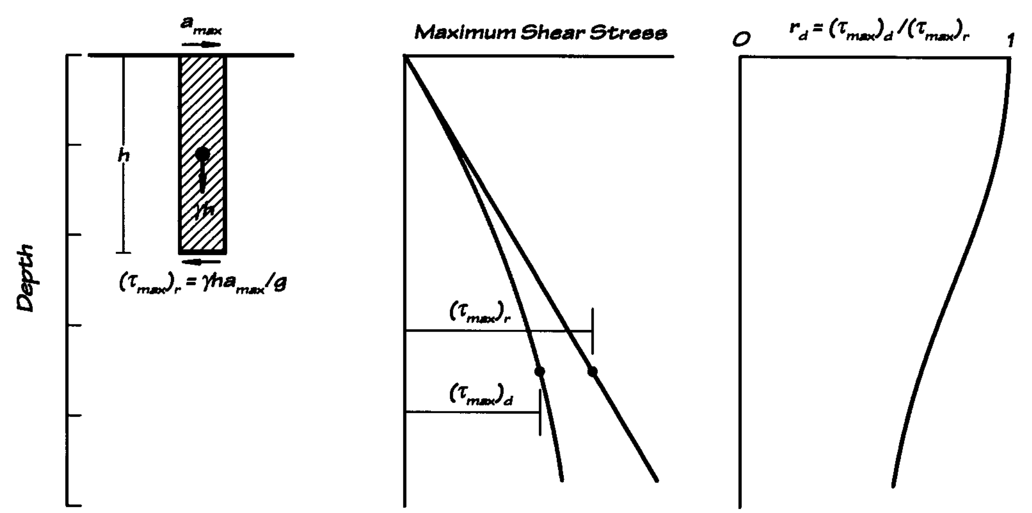
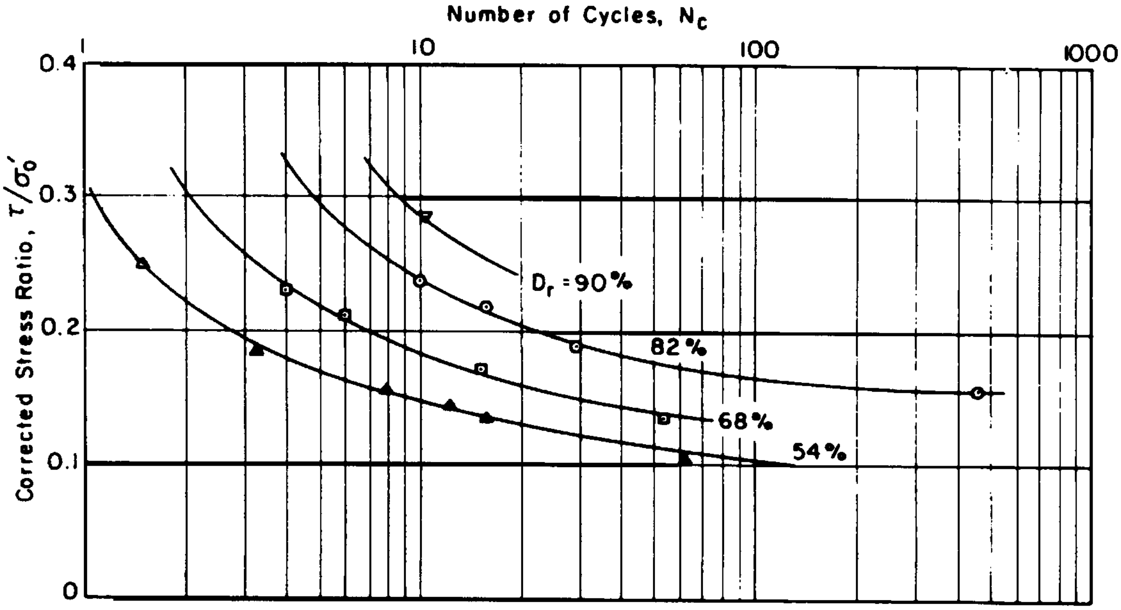


Fig. 1 Schematic Illustration of Procedure to Calculate Maximum Shear Stress, (tmax)r, and Stress Reduction Coefficient, rd (after Seed and Idriss, 1971)

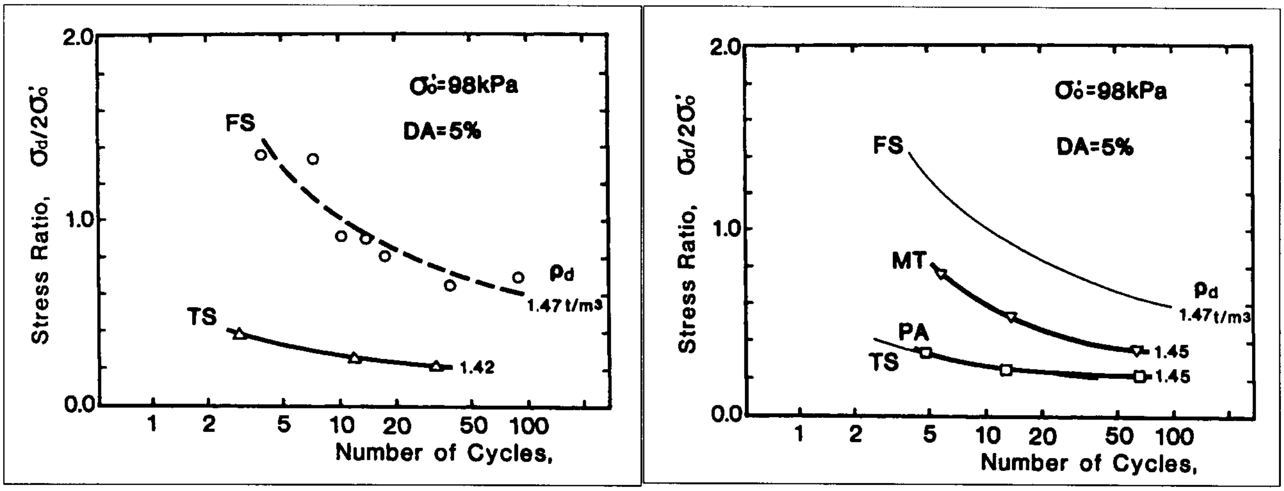


Stress ratio τ_d/σ'_{vo} versus number of cycles to initial liquefaction, from tests on a shaking table. Source: DeAlba et al. (1976).

Fig. 2a Cyclic Strength Data Used by Seed et al (1975) to Develop Number of Equivalent Uniform Cycles as a Function of Earthquake Magnitude

The number of cycles was re-evaluated using the laboratory results published by Yoshimi et al (1984), which are presented in Fig. 2b, The results shown in Figs. 1a and in Fig. 1b are presented in a Log-Log plot in Fig. 3. Note that the relationship between the cyclic stress (or stress ratio) and number of cycles must fit a straight line on a Log-Log plot for the concept of "equivalent number of cycles" to be consistent and applicable.

The results of this re-derivation are presented in Fig. 4. Also shown in Fig. 4 are the the values originally derived by Seed et al in 1975.



Undisturbed Samples
FS -- In-Situ frozen Sample
TS -- Tube Sample

Reconstituted Samples
PA -- Pluviation Through Air
MT -- Moist Tamping

Fig. 2b Cyclic Test Data From Yoshimi et al (1984)

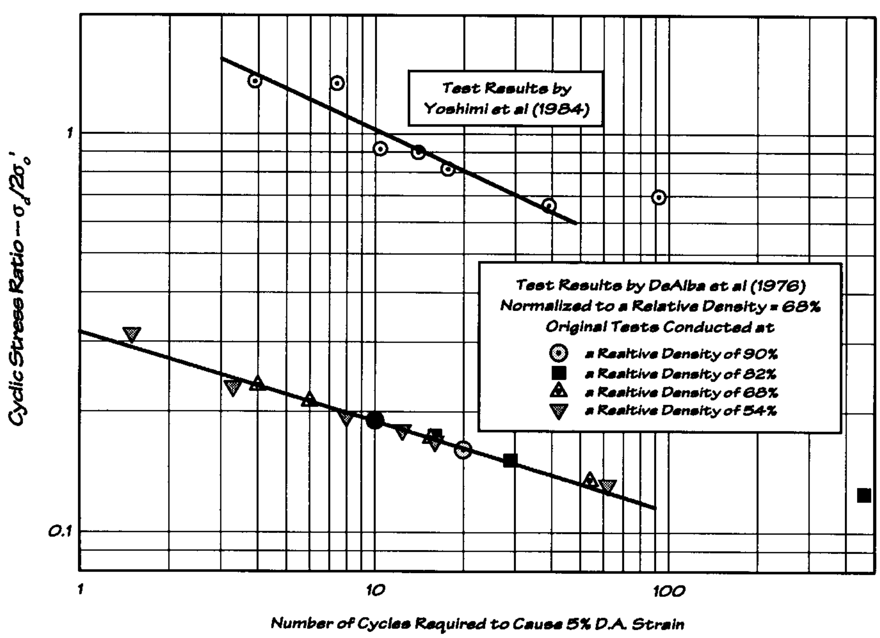


Fig. 3 Cyclic Stress Ratios Used in Re-Deriving Equivalent Uniform Cycles as a Function of Earthquake Magnitude

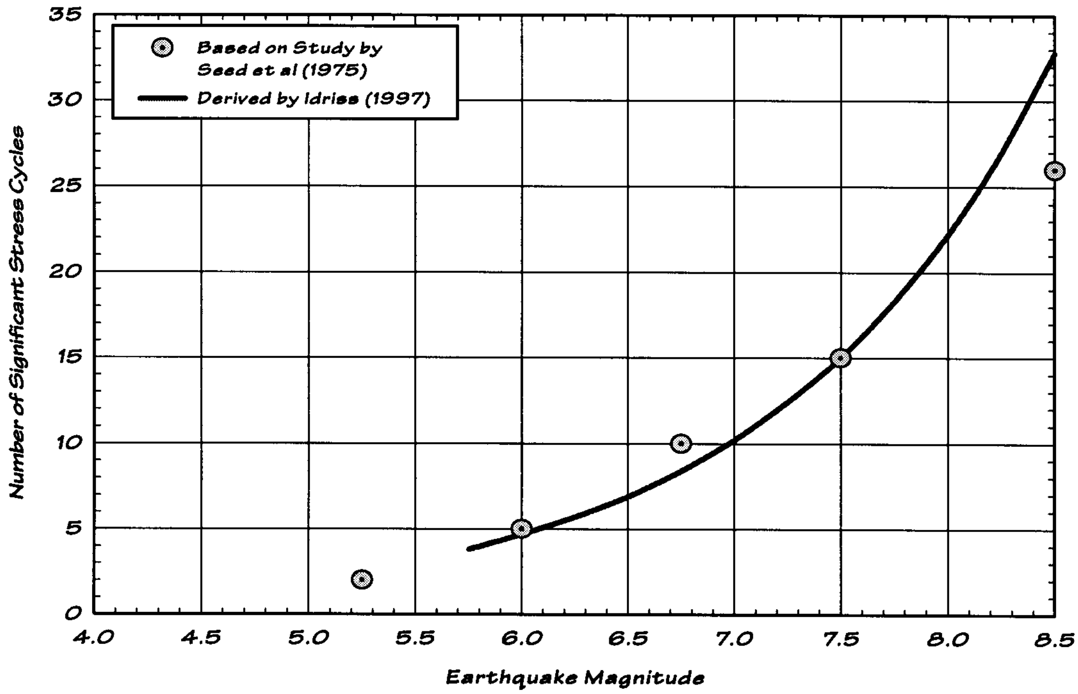


Fig. 4 Number of Equivalent Uniform Cycles Versus Earthquake Magnitude

The information in Figs. 3 (Yoshimi's data) and Fig. 4 (1997 number of cycles) were used to obtain values of the magnitude scaling factor (MSF) considering that MSF = 1 for M_w = 7½, as illustrated in Fig. 5.

These values of MSF can be expressed by the following equation:

$$MSF = 6.9\exp(-M/4) - 0.06$$

Values of MSF (using the above expression) versus earthquake magnitude are plotted in Fig. 6 together with values of MSF obtained using relationships which had been proposed by others.

As can be seen in Fig. 6, the proposed MSF is limited to about MSF = 1.82 for Mw ≤ 5.2. The reason for imposing this limit pertains to the fact that the equivalent uniform induced stress is considered to be equal to 0.65 of the maximum induced stress. The maximum stress acts over at least one-half to one cycle as illustrated in Fig. 7 for a few typical recordings. Based on the information shown in Fig. 7 (and similar data), it would be reasonable to consider that the peak shear stress would act over about ¾ cycle.

Therefore, the MSF cannot exceed the ratio of the CSR at ¾ cycle divided by that at 15 cycles and then multiplied by 0.65. Hence:

$$MSF \le \frac{CSR\ for\ 3/4\ Cycle}{CSR\ for\ 15\ Cycles} \times 0.65 = \frac{2.8}{1} \times 0.65 = 1.82$$

The equivalent uniform induced stress at a depth z considering ground motions generated by an earthquake having a magnitude M_w is then given by:

$$(\tau_i)_u = \frac{0.65(\tau_i)_{max}}{MSF} = \frac{0.65\sigma_v a_{max} r_d}{MSF}$$

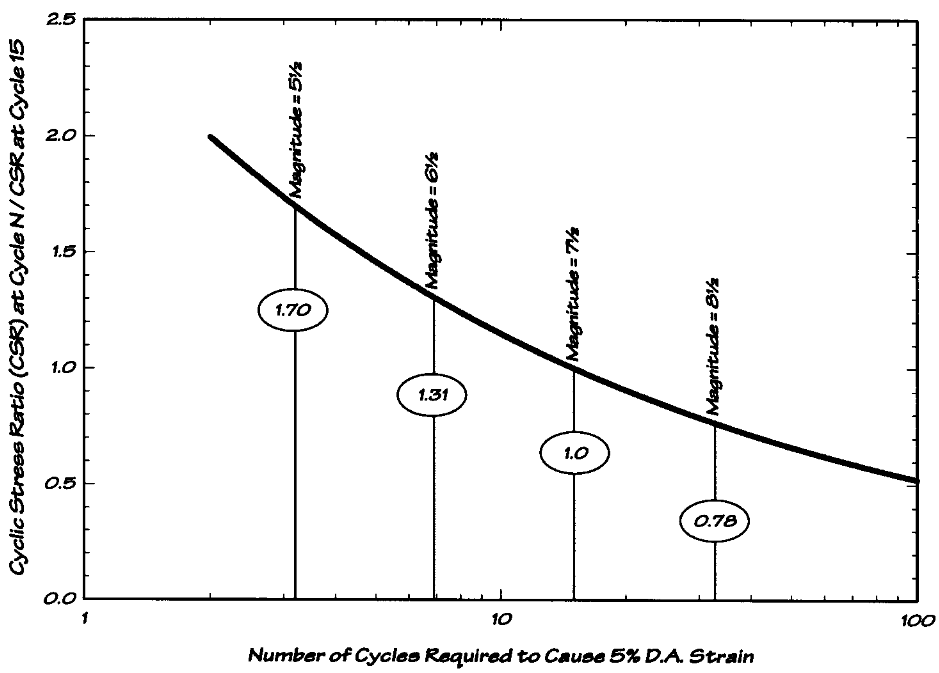


Fig. 5 Illustration of the Development of Magnitude Scaling Factors based on Laboratory Cyclic Test Data on Frozen samples

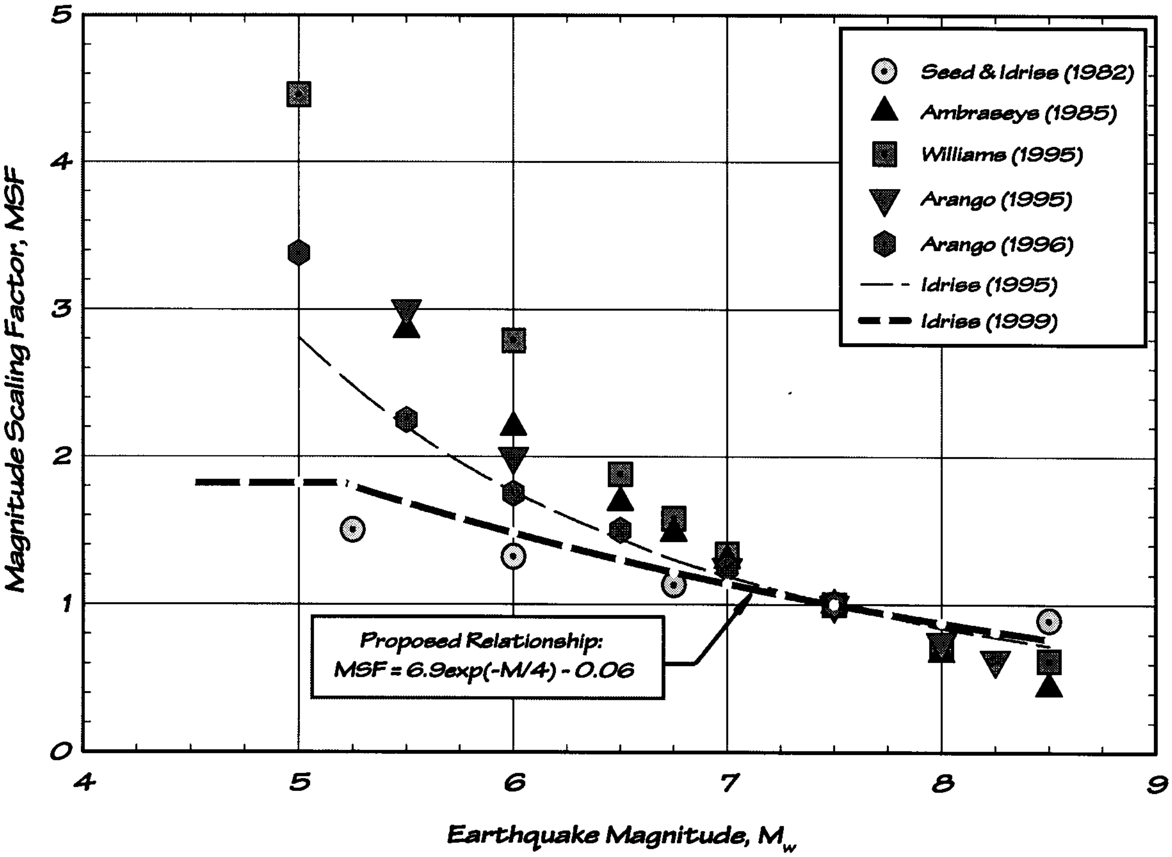


Fig. 6 Proposed Relationship for Magnitude Scaling Factor and Magnitude Scaling Factors Derived by Other Investigators

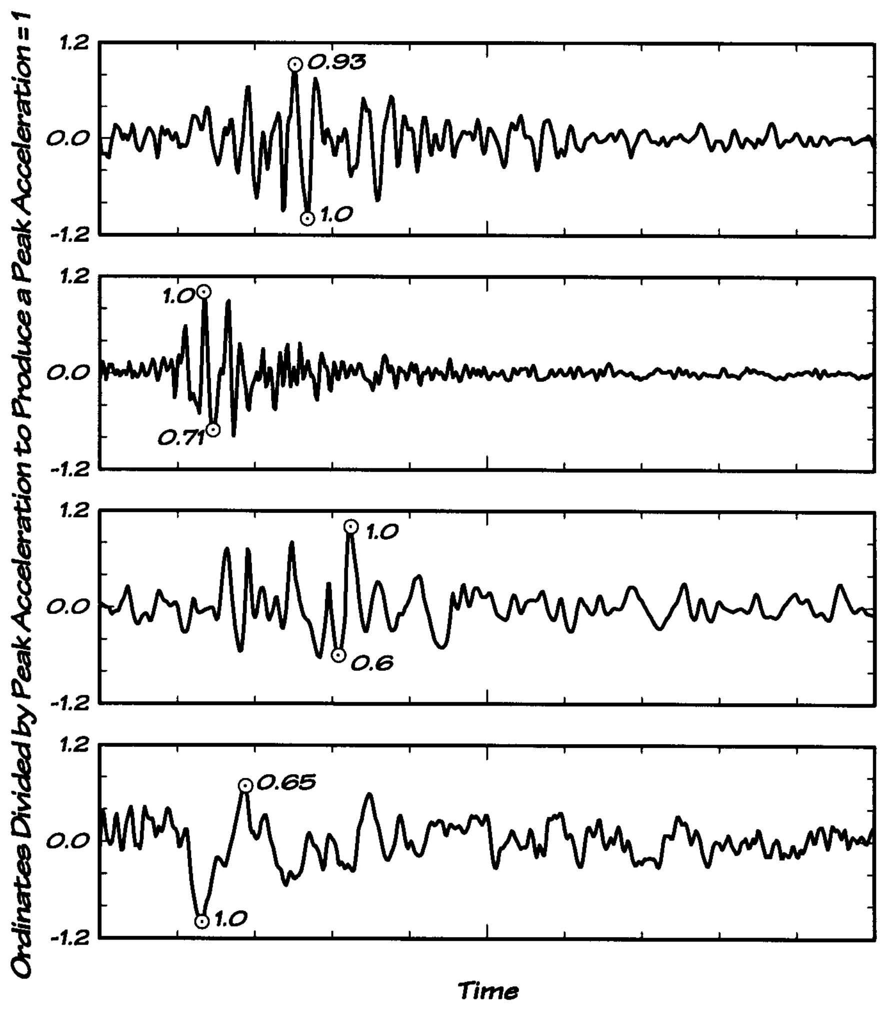


Fig. 7 Examples of Recorded Accelerograms Each Normalized to a Peak Acceleration of 1

Stress Reduction Coefficient, r_d

The stress reduction coefficient, r_d, was originally proposed by Seed & Idriss (1971) and was given in chart form with the average value ranging from 1 at the ground surface to about 0.85 at a depth of 40 ft (~12.2 m). While the full range of the parameter r_d was obtained for a range of earthquake magnitudes, the average values derived in 1971 were considered independent of magnitude. Recently, Golesorkhi (1989) conducted a comprehensive study under the supervision of the late Professor H. B. Seed to evaluate the variations of r_d with earthquake magnitude.

The results of that study were used by Idriss & Golesorkhi (1997) to derive the following relationships relating r_d to magnitude & depth (for $z \leq 80\pm$ ft):

$$Ln\,(r_d) = \alpha(z) + \beta(z) \cdot M_w$$

$$\alpha(z) = -1.012 - 1.126 \cdot \sin[(z/38.5) + 5.133]$$
$$\beta(z) = 0.106 + 0.118 \cdot \sin[(z/37.0) + 5.142] \text{ -- z in ft}$$

Additional analyses were completed in 1998, and updated expressions relating rd to depth and earthquake magnitude were derived. These expressions are as follows (for $z \leq 25\pm$m):

$$\alpha(z) = -1.012 - 1.126 \cdot \sin[(z/11.73) + 5.133]$$
$$\beta(z) = 0.106 + 0.118 \cdot \sin[(z/11.28) + 5.142] \text{ -- z in meters}$$

Plots of r_d for M_w = 5½, 6½, 7½ and 8 are presented in Fig. 8. Also shown in this figure is the average of the range published by Seed & Idriss in 1971, which is almost identical to the curve derived for M_w = 7½.

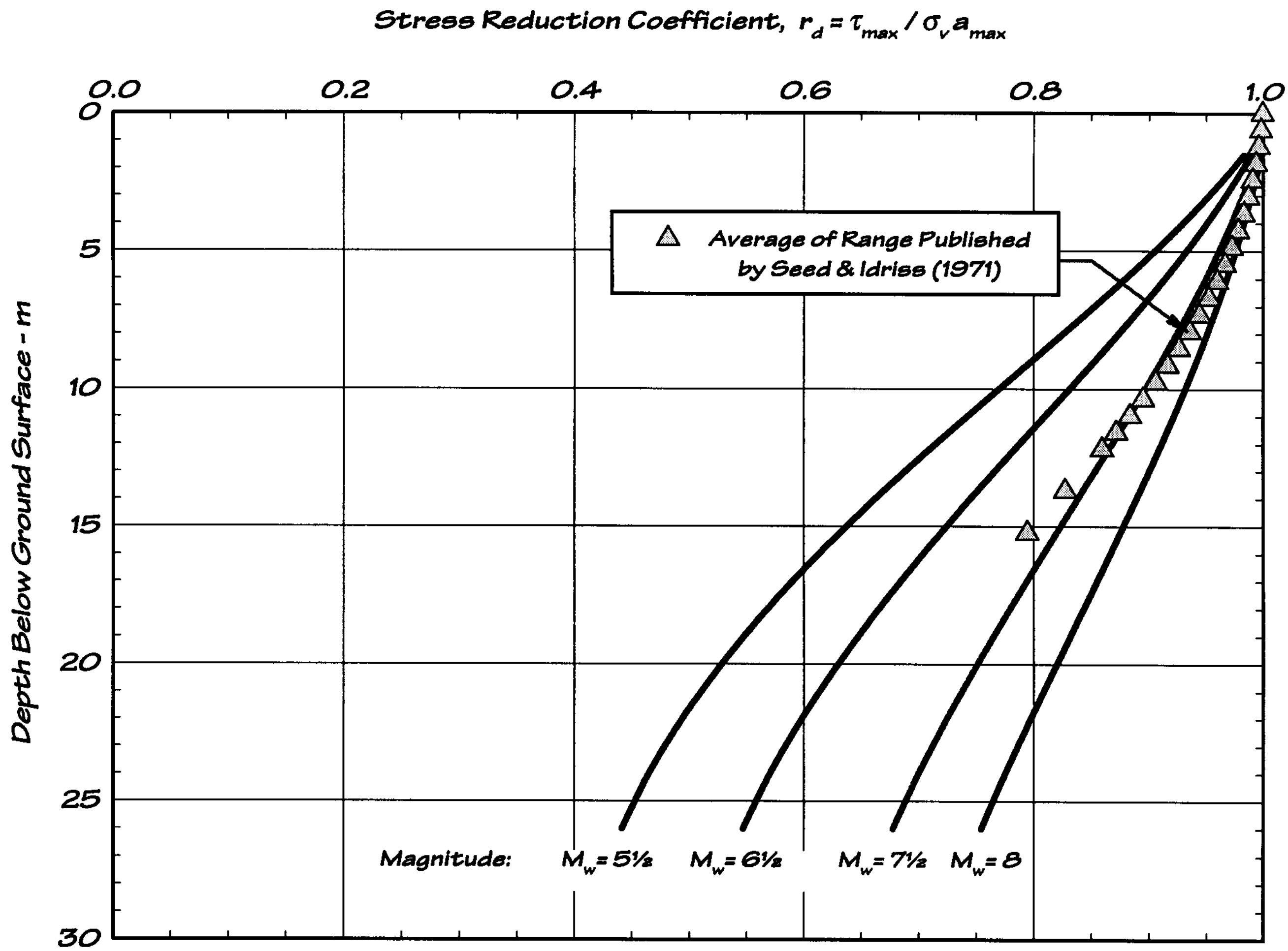


Fig. 8 Variations of the Stress Reduction Coefficient with Depth for Various Magnitude Earthquakes

The induced shear stress at a depth z caused by earthquake ground motions generated by an earthquake with magnitude M_w is then proportional to the ratio (r_d / MSF). If r_d is considered independent of magnitude, then it is necessary to adjust MSF to reflect the possible reduction of r_d with decreasing earthquake magnitude.

At shallow depths, however, the influence of magnitude on r_d is not as significant as it is at greater depths, as shown in Fig. 8. Therefore, it is essential that the two parameters (i.e., r_d & MSF) be ascertained separately and appropriately incorporated in evaluating the liquefaction potential at a site.

If r_d for $M_w = 7.5$ is used for all magnitudes (as has been the case to date), then it is necessary to use an "effective" MSF which would equal to the product of MSF for the magnitude under consideration times r_d for depth z and $M_w = 7.5$ divided by the r_d for that depth and for the magnitude under consideration.

These variations are illustrated in Fig. 9 for various depths. As would be expected, the values of "effective" MSF for small magnitudes are much closer to those proposed by other investigators because these investigators had used values r_d applicable to $M_w = 7.5$ thus needing to have much larger values of MSF for the smaller magnitude events.

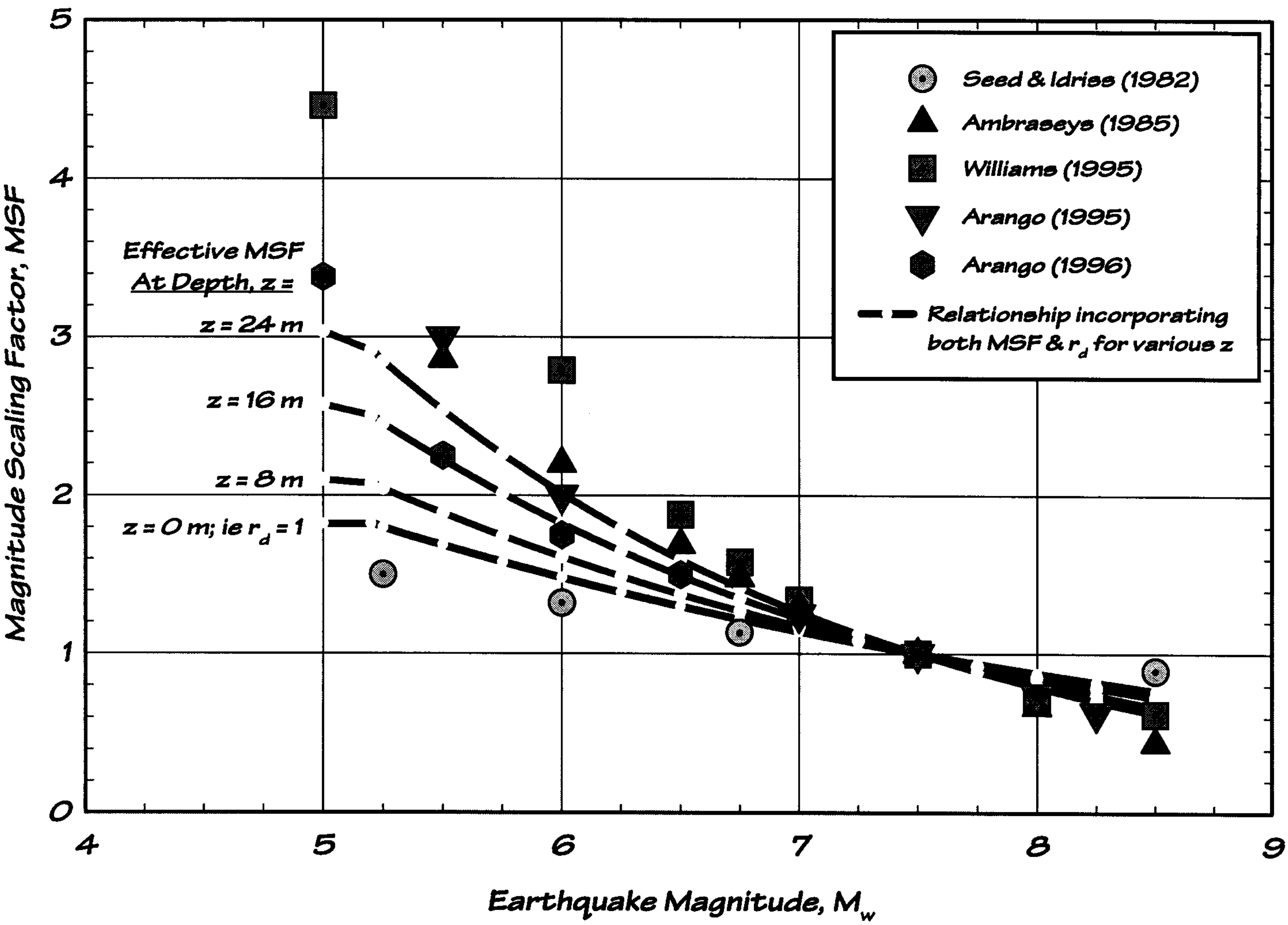


Fig. 9 Magnitude Scaling Factors Developed by Various Investigators & Effective MSF Considering Variations of rd with Magnitude & Depth

The importance of evaluating the possibility of liquefaction occurring early on in the shaking has typically been ignored. The evidence from Niigata in 1964 and again from Kobe in 1995 strongly indicated that liquefaction occurred early in the shaking.

This aspect of the problem can be important when considering lateral support for piles extending through soil undergoing liquefaction or for a soil structure supported on a looser sandy soil layer ... etc. In such cases, it is necessary to incorporate inertial forces in addition to reducing the supporting capacity of the soil undergoing liquefaction.

A simple, but effective way to take this aspect into account is to compare the maximum induced shear stress to the cyclic resistance available during one cycle of shaking. The curve corresponding to one cycle of shaking is presented in Fig. 10. It is based on the test results on frozen samples published by Yoshimi et al (1984).

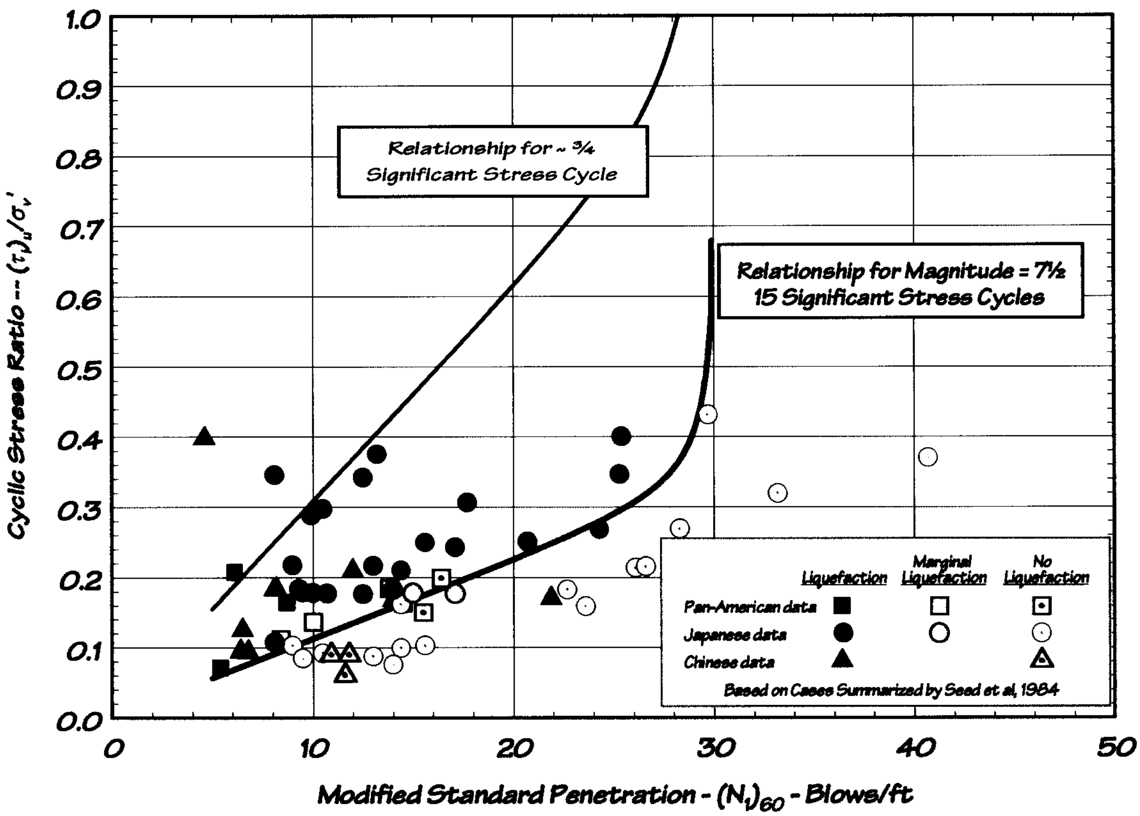


Fig. 10 Relationship Between CSR Causing Liquefaction & $(N_1)_{60}$ for Clean Sands for 15 Significant Cycles of Shaking & Estimated Curve for ~ ¾ Significant Cycle of Shaking

Example: 1964 Niigata (Magnitude = 7½) -- Apartment Building Site

The horizontal motions recorded at the site indicated that the peak acceleration, a_{max}, at the ground surface was 0.16g. The maximum induced shear stress at a depth of 33 ft is equal to:

$$(\tau_i)_{max} = \sigma_v \times a_{max} \times r_d = 3960 \times 0.16 \times 0.895 = 567 \text{ psf}$$

σ_v' = 2088 psf; hence the maximum CSR = 0.272, which would act over about ¾ "equivalent uniform" cycle. This value of CSR is plotted in Fig. 11 (which is reproduced from Fig. 10).

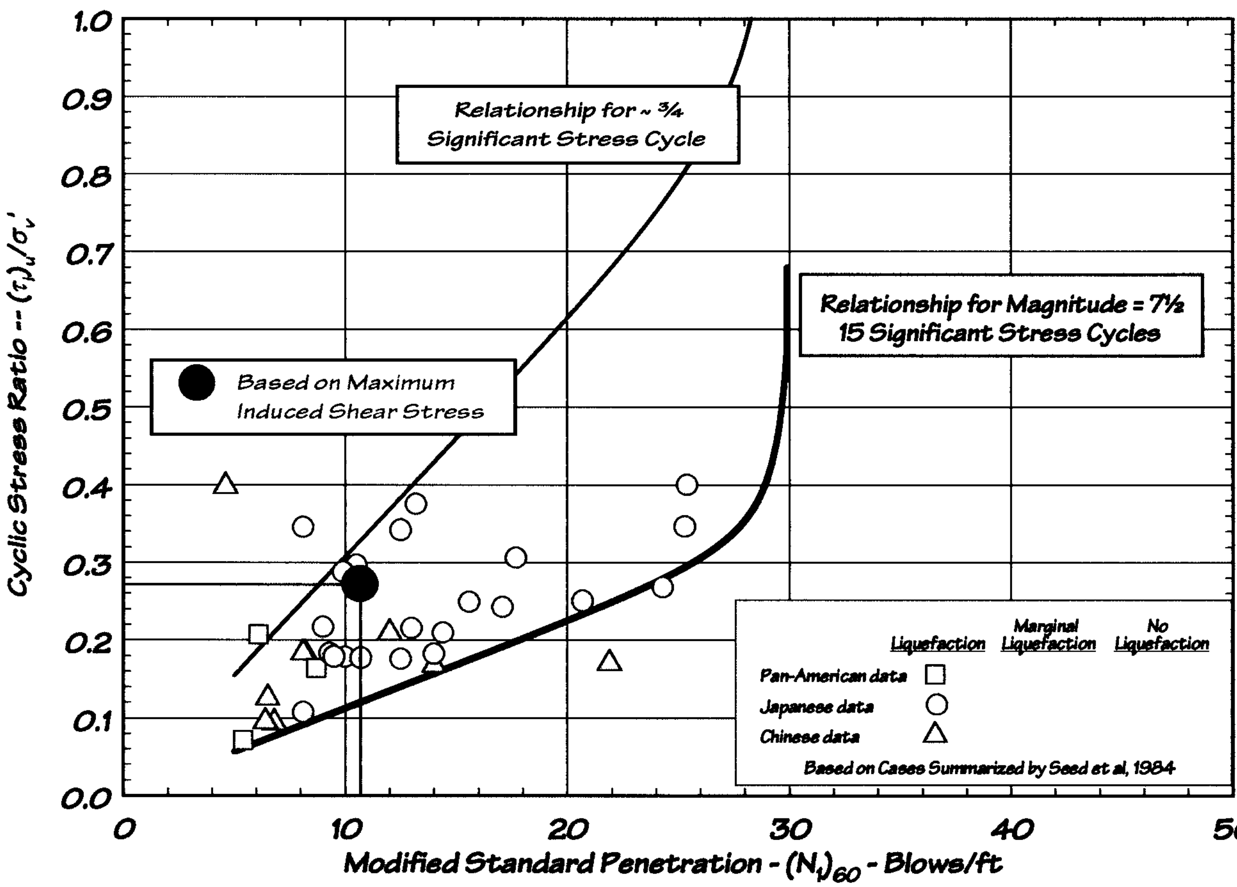


Fig. 11 Evaluation of Liquefaction Potential in Niigata Considering Maximum Induced Shear Stress and One Significant Cycle of Shaking

The curves, originally published by Seed et al (1985), relating cyclic stress ratio required to cause liquefaction as a function of (N1)60 and fines content were slightly modified at a recent workshop. The adjusted curves are shown in Fig. 12 below.

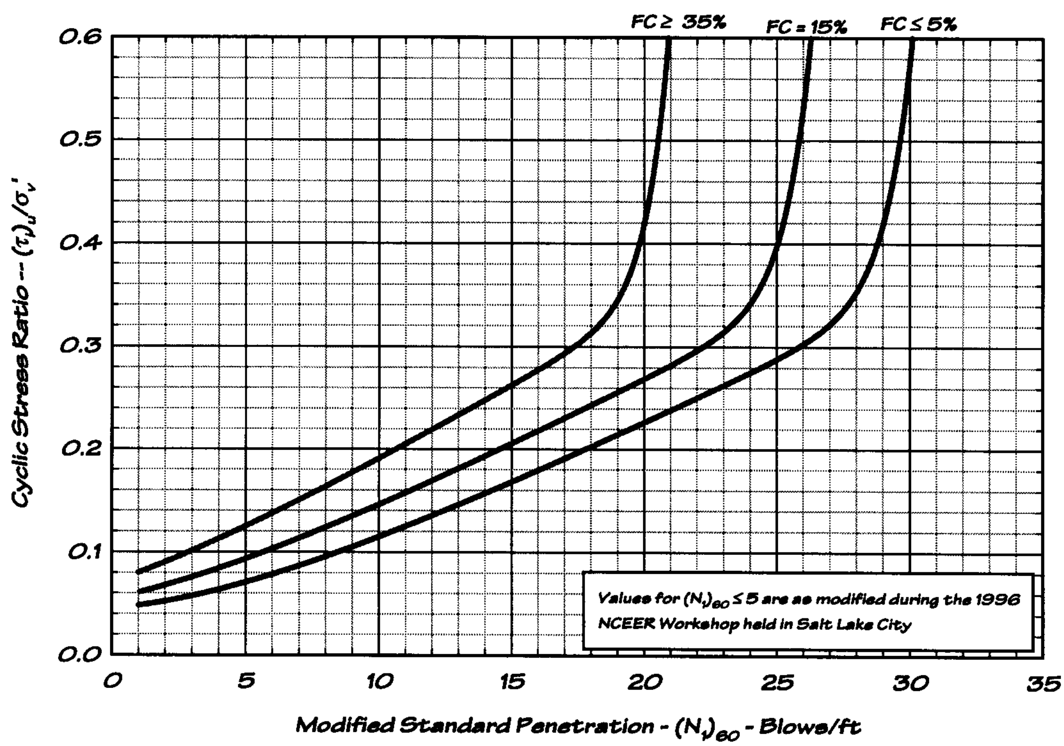


Fig. 12 Cyclic Stress Ratio to Cause Liquefaction
Earthquake Magnitude, M =7½ and sv' = 1 tsf (» 100 kPa)

Factor of Safety

Factor of safety is defined as the ratio of the available resistance divided by the induced stress (i.e., capacity/demand). A factor of safety less than one (or even slightly larger than one) would constitute triggering of liquefaction -- a stage at which a residual excess pore water pressure (pwp) ratio equal to or somewhat less than 100% is reached.

It should be noted, however, that, even when the factor of safety is significantly greater than one, the residual excess pwp ratio can be quite high as illustrated in Fig. 13 below.

It is the writer's experience that a residual excess pwp ratio greater than about 25 to 40% may be of concern.

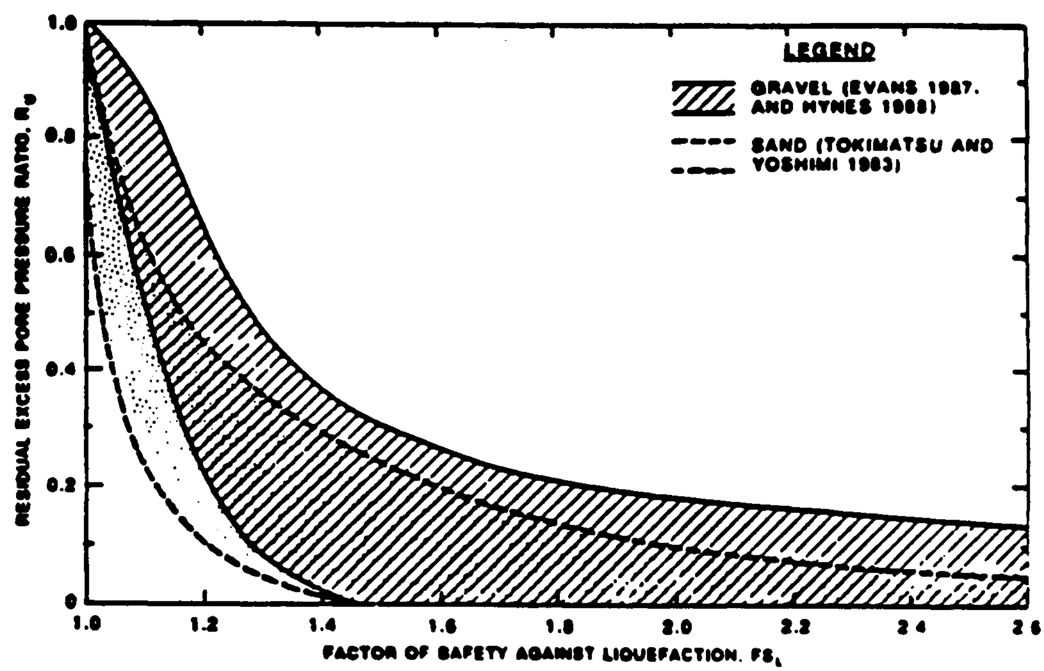


Fig.13 Variations of Excess Residual Pore Water Pressure Ratio With Factor of Safety Against Liquefaction Based on Laboratory Data (from Marcuson & Hynes, 1989)

Additional Comments:

❑ *The induced stresses (using the simplified procedure) and incorporating r_d and MSF can be compared to stresses needed to cause liquefaction obtained from :*

appropriate laboratory cyclic tests;
SPT-based charts;
CPT-based charts; or
Vs-based charts.

❑ *It is always useful to check the results using more than one procedure; my personal preference is to start with a few CPT soundings followed by SPT borings (to get N values and to get samples for grain size and other index testing). A Vs-based procedure can be useful, particularly for sites underlain by difficult to penetrate or sample sample soils (e.g., gravels, boulders ... etc). The Becker hammer may prove to be useful for the latter sites.*

❑ *More important than quantity or variety is the quality of the data being collected. This observation applies to sampling, laboratory testing, CPT, SPT, Becker or Vs measurements.*

❑ *I find the CPT to be an extremely valuable tool to ascertain layering and variability at a site. However, I do not recommend the use of a "CPT-only" procedure for any site. That is, the use of CPT may be necessary, but is not sufficient.*

❑ *If the induced stresses are calculated using a site response program, then only MSF should be applied.*

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