# Accounting for Ground Motion Duration in Evaluating Liquefaction Triggering

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## Objective:

To develop a mechanistically based Magnitude Scaling Factor (MSF) relationship that overcomes the shortcomings and biases in existing relationships. The new MSF will be used in developing a revised "simplified" liquefaction evaluation procedure.

## Background:

In most variants of the "simplified" liquefaction evaluation procedure, the influence of the ground motion duration on liquefaction triggering is accounted for using MSF. MSF have traditionally been computed as the ratio of the number of equivalent cycles for an **M** 7.5 event ($n_{eq\,M7.5}$) to that of a magnitude **M** event ($n_{eq\,M}$), raised to the power *b* (Fig. 1), where *b* is the negative slope of a plot of log(CSR) vs. log($N_{liq}$), $N_{liq}$ is the number of cycles required to trigger liquefaction in a soil specimen subjected to sinusoidal loading having an amplitude of CSR, typically determined using cyclic triaxial or cyclic simple shear tests.

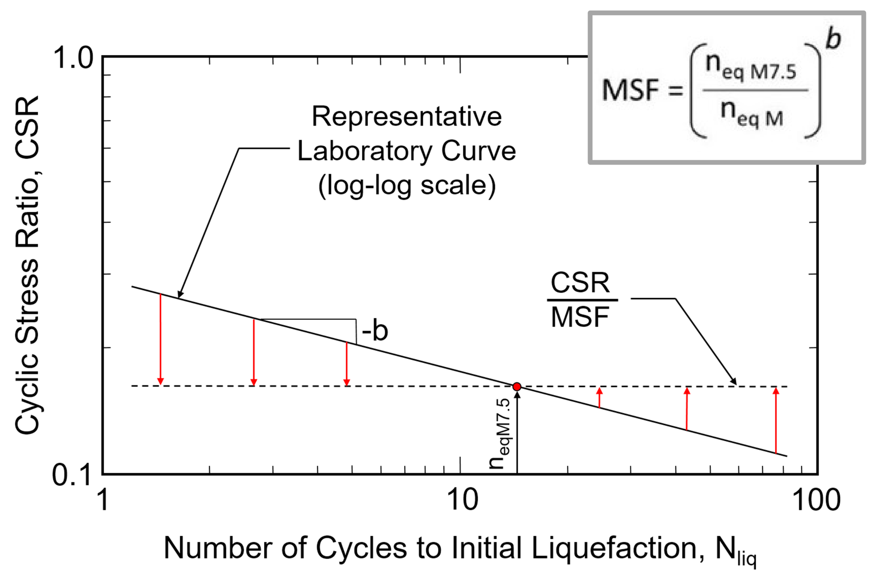


*Fig. 1. Definition and interpretation of Magnitude Scaling Factors (MSF)*

## Approach:

In this study, the low-cycle implementation of the Palmgren-Miner fatigue theory proposed by Green and Terri (2005) is used to develop a new $n_{eq}$ relationship, and hence a new MSF relationship. This implementation is illustrated in Fig. 2.

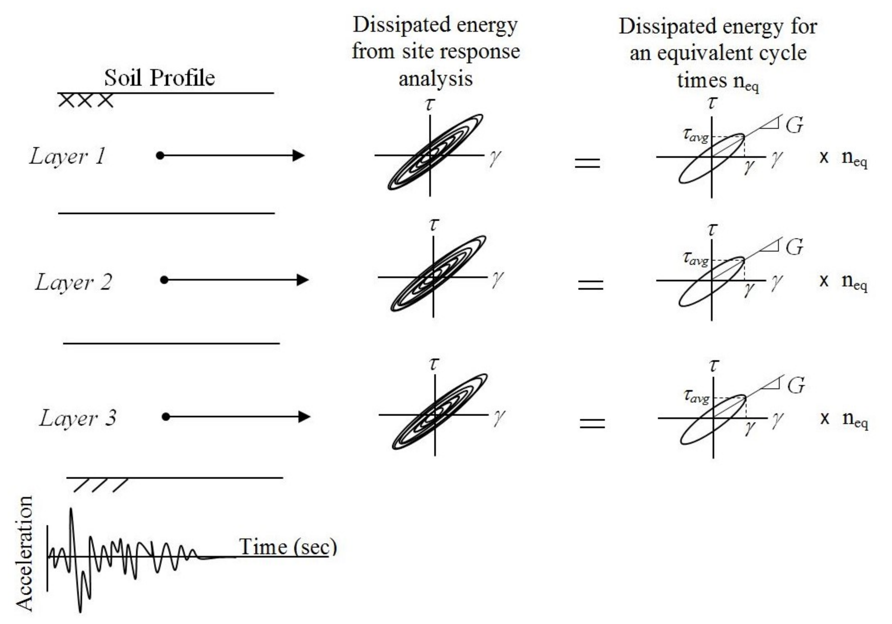


*Fig. 2. Illustration of the low-cycle implementation of the Palmgren-Miner fatigue theory used to develop a new $n_{eq}$ relationship*

The soil profiles and the magnitude and site-to-source distance distribution of the ground motions used to develop the new $n_{eq}$ relationship are shown in Fig. 3. The profiles used are those compiled by Cetin (2000) and the motions were obtained from the NGA West ground motion database (Chiou et al. 2008).

As opposed to recent studies that have shown that $n_{eq}$, and hence MSF, are dependent on site-to-source distance, soil density, induced shear strain, and induced excess pore water pressure, as well as earthquake magnitude (e.g., Boulanger and Idriss 2015), the results of this study show that $n_{eq}$ are primarily a function of peak ground acceleration ($a_{max}$) at the surface of the soil profile and earthquake magnitude (Fig. 4), and to be relatively independent of soil density, effective confining stress, etc.

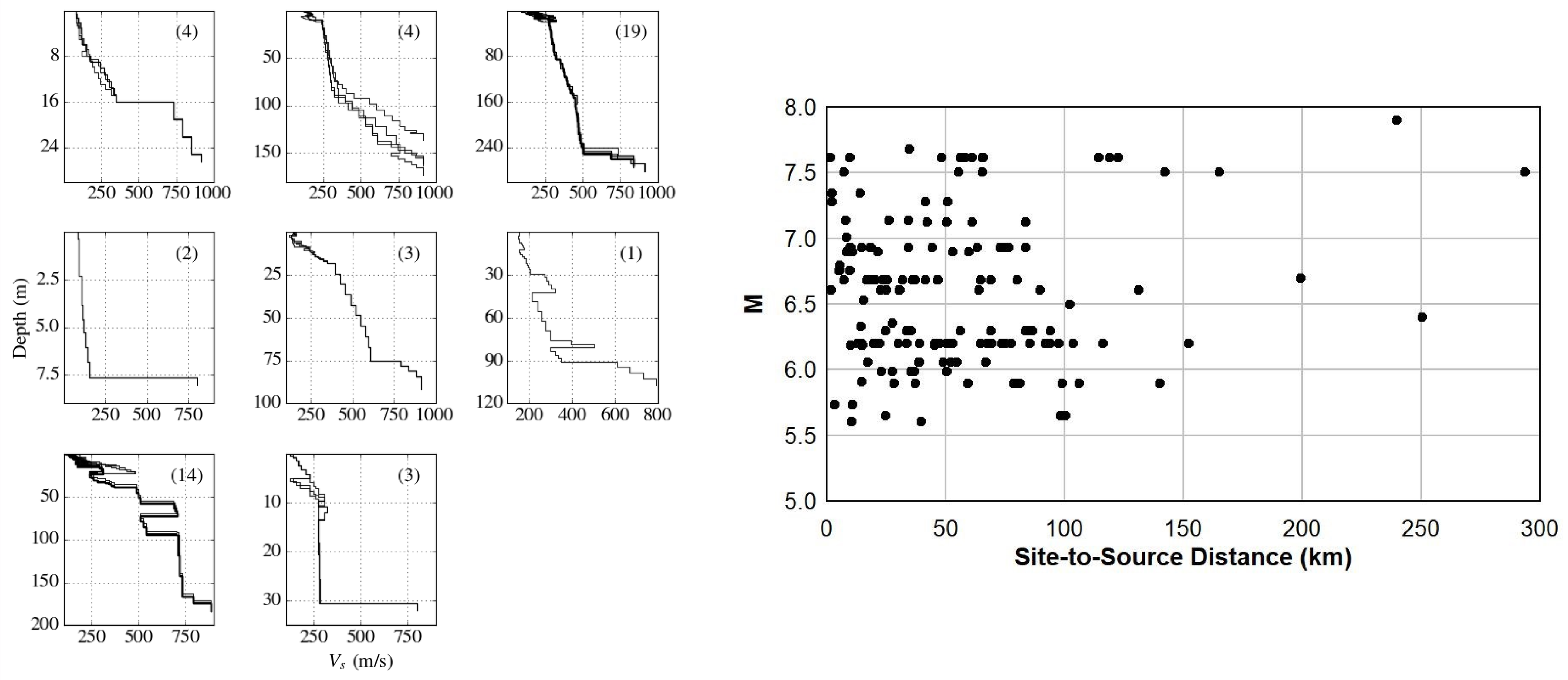


*Fig. 3. Soil profiles (left) and magnitude versus distance distribution of the motions (right) used in this study. Each point in the motion distribution plot represents a set of two horizontal motions recorded during shallow crustal events in active seismic regions on sites that have $V_{S30} \geq 650$ m/s*

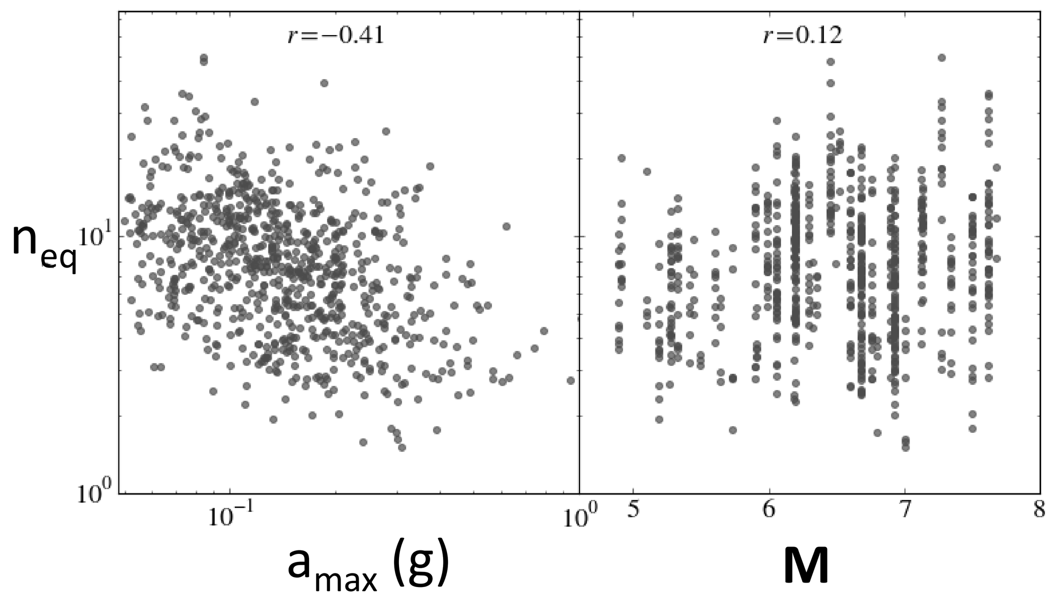


*Fig. 4. Correlation between $n_{eq}$ and $a_{max}$ and between $n_{eq}$ and **M***

The value of *b* needed to relate $n_{eq}$ to MSF (e.g., Fig. 1) can be determined from the constitutive model used in the site response analysis, by assuming that the CSR vs. $N_{liq}$ curve shown in Fig. 1 is a contour of constant dissipated energy. The degradation curves proposed Darendeli and Stokoe (2001) were used in this study to determine the *b* values for a range of effective confining stresses and soil densities, with the resulting values ranging from 0.33 to 0.35. However, *b* = 0.34 for the vast majority of the confining stress-density combinations considered and was thus used to compute MSF from $n_{eq}$ in this study.

## Results:

The resulting expression for MSF is given by Eq. (1) and plotted in Fig. 5. Also shown in Fig. 5 are MSF proposed by Idriss and Boulanger (2008) and Boulanger and Idriss (2015).

$$MSF = \left(\frac{14}{n_{eq}(M, a_{max})}\right)^{0.34} \leq 2.02 \qquad (1a)$$

$$\ln(n_{eq}) = a_1 + a_2 \ln(a_{max}) + a_3 \boldsymbol{M} + \delta_{event} + \delta_{profile} + \delta_0 \qquad (1b)$$

$$\sigma_{\ln(MSF)} = b \cdot \sqrt{\sigma^2_{\ln(n_{eq\,M7.5})} + \sigma^2_{\ln(n_{eq\,M})} - 2 \cdot \rho \cdot \sigma_{\ln(n_{eq\,M7.5})} \sigma_{\ln(n_{eq\,M})}} \qquad (1c)$$

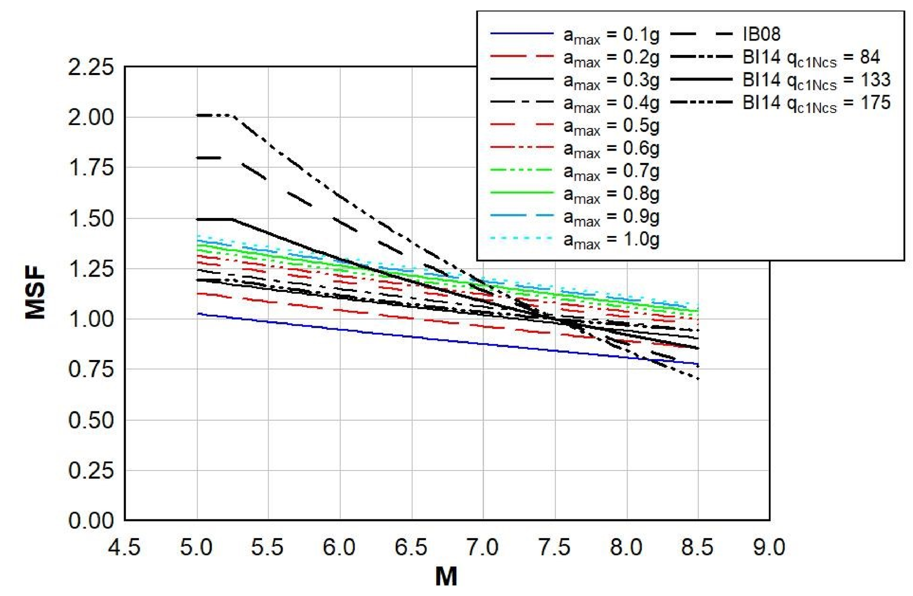


*Fig. 5. MSF developed as part of this study, along with MSF proposed by Idriss and Boulanger (2008) and Boulanger and Idriss (2015) for comparison*

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