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Assessment of liquefaction potential based on peak ground motion parameters

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Abstract

Conventionally, evaluation of liquefaction potential of loose saturated cohesionless deposits as specified in Japanese design codes employs peak ground acceleration (PGA). However, recent large-scale earthquakes in Japan revealed that liquefaction at some sites did not occur even though large PGAs were recorded at or near these sites. As an alternative approach, an evaluation procedure based on peak ground motion parameters, i.e. incorporating both PGA and the peak ground velocity (PGV), is proposed. By performing parametric studies using one-dimensional seismic response analysis and formulating regression models, seismic-induced shear stresses within the deposit are expressed in terms of peak ground motion parameters at the surface, and these are used to calculate the factor of safety against liquefaction. Application to case histories in Japan indicates that the proposed two-parameter equation can adequately account for the occurrence and non-occurrence of liquefaction at various sites as compared to the conventional PGA-based approach. Moreover, analyses of several strong motion records at various sites show that liquefaction may occur when PGA ≥ 150 gal and PGV ≥ 20 kine, indicating that these values can serve as thresholds in assessing the possible occurrence of liquefaction.
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1. Introduction

During the last 40 years, liquefaction of loose saturated sandy deposits associated with earthquake shaking has been a major cause of damage to soil structures, building foundations and lifeline facilities. Various researchers have investigated soil liquefaction both in the laboratory and in the field. The basic mechanism of liquefaction is the progressive build-up of excess pore-water pressure due to cyclic shear stresses. When the pore pressure builds up to a point equal to the initial confining stress, soil loses its strength and large deformation occurs. Zonation for liquefaction, therefore, has been an important goal in recent liquefaction-related studies.

As far as Japanese design practice is concerned, one of the most commonly employed approaches in assessing liquefaction potential is the Factor of Safety concept. In this approach, the cyclic strength ratio of soil, R, and the maximum or equivalent cyclic shear stress ratio likely to be induced in the soil deposit during an earthquake, L, are estimated and the liquefaction potential of the deposit is expressed in terms of Factor of Safety against Liquefaction, F_L, which is given by

$$F_L = \frac{R}{L} \tag{1}$$

If $F_L < 1.0$, the shear stress induced by the earthquake exceeds the liquefaction resistance of the soil and therefore, liquefaction will occur. Otherwise, when $F_L \geq 1.0$, liquefaction will not occur.

Fig. 1 shows a summary of the liquefaction potential evaluation specified for highway bridges in Japan [1]. Note that although cyclic strength ratio, R, is generally obtained from cyclic undrained triaxial tests on undisturbed soil samples, it can be estimated through correlations with SPT N-value and other parameters, as shown in the figure. Other

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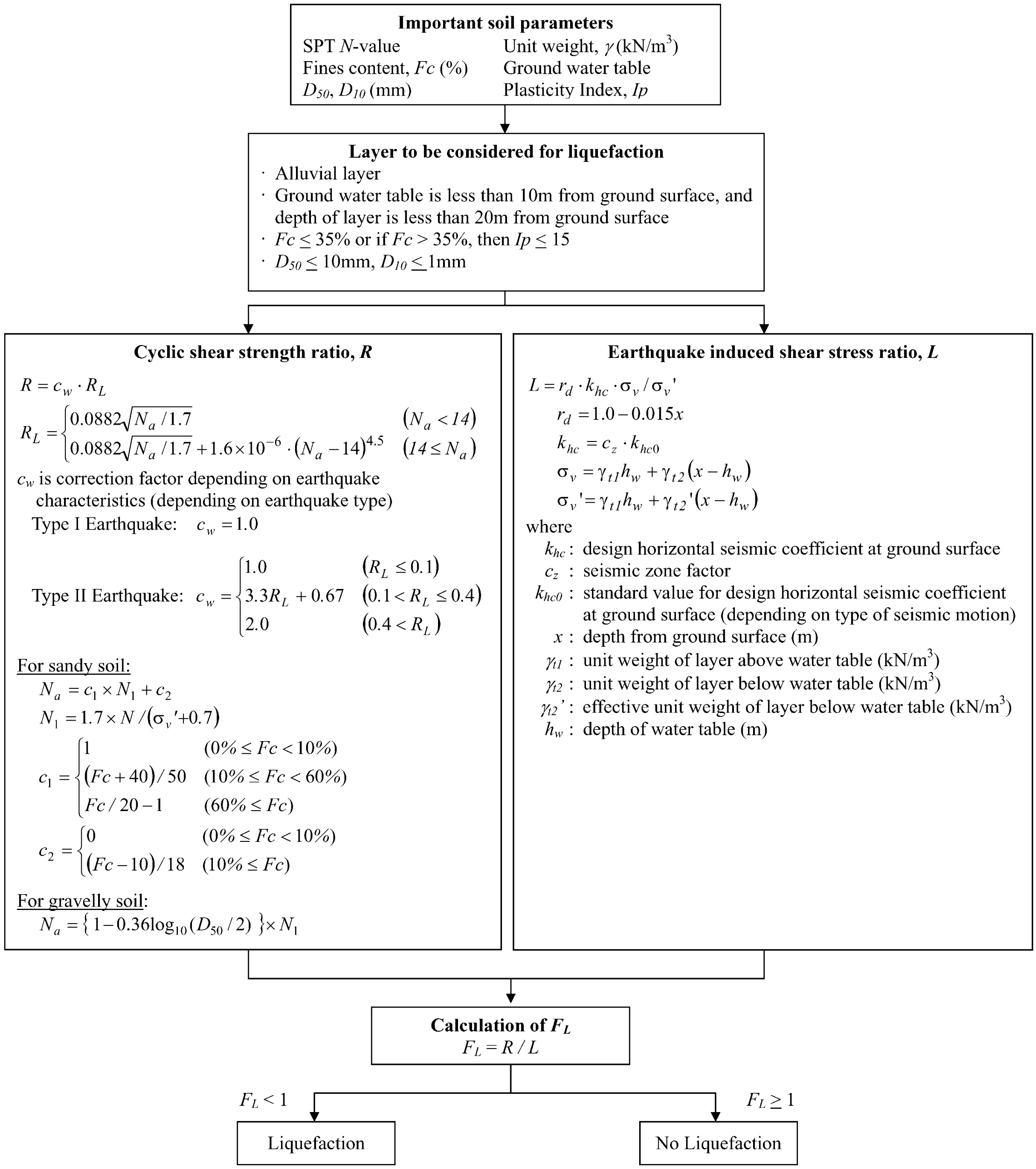

Fig. 1. Guidelines for evaluating liquefaction potential for highway bridges (after Ref. [1]).

design codes in Japan [2–4] make use of similar empirical formulas to estimate the cyclic strength of the target soil.

As for estimates of shear stress induced during seismic loading, most design codes in Japan use an equation similar to that initially proposed by Seed and Idriss [5]. In this equation, the cyclic shear stress ratio developed at a particular depth beneath a level ground surface is expressed in terms of the design seismic coefficient as shown on the right side of Fig. 1. The seismic coefficient is a function of the design peak ground acceleration (PGA).

In some practical applications though, the extent of liquefaction is assessed by using the observed peak ground acceleration instead of the design acceleration. However, the design acceleration, being typically about 15–20% of the gravitational acceleration, is different from the observed one. Moreover, since the onset of liquefaction depends on the number of loading cycles, the design codes assume that this level of acceleration is repeated in 15–20 cycles. In contrast, the observed acceleration simply reveals the maximum value and does not show anything about the number of cycles.

With the advent of highly sensitive seismometers for use in seismic monitoring networks in Japan, strong motion records showing short duration impulse of high frequency (called acceleration spikes) are not uncommon. When used with conventional liquefaction evaluation procedure, these large acceleration peaks would provide unusually high intensities, and therefore, would overestimate the shear

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