Evaluating cyclic liquefaction potential using the cone penetration test

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Abstract: Soil liquefaction is a major concern for structures constructed with or on sandy soils. This paper describes the phenomena of soil liquefaction, reviews suitable definitions, and provides an update on methods to evaluate cyclic liquefaction using the cone penetration test (CPT). A method is described to estimate grain characteristics directly from the CPT and to incorporate this into one of the methods for evaluating resistance to cyclic loading. A worked example is also provided, illustrating how the continuous nature of the CPT can provide a good evaluation of cyclic liquefaction potential, on an overall profile basis. This paper forms part of the final submission by the authors to the proceedings of the 1996 National Center for Earthquake Engineering Research workshop on evaluation of liquefaction resistance of soils.

Cyclic resistance based on laboratory testing

Much of the early work related to earthquake-induced soil liquefaction resulted from laboratory testing of reconstituted samples subjected to cyclic loading by means of cyclic triaxial, cyclic simple shear, or cyclic torsional tests. The outcome of these studies generally confirmed that the resistance to cyclic loading is influenced primarily by the state of the soil (i.e., void ratio, effective confining stresses, and soil structure) and the intensity and duration of the cyclic loading (i.e., cyclic shear stress and number of cycles), as well as the grain characteristics of the soil. Soil structure incorporates features such as fabric, age, and cementation. Grain

Although void ratio (relative density) has been recognized as a dominant factor influencing the CRR of sands, studies by Ladd (1974), Mulilis et al. (1977), and Tatsuoka et al. (1986) have clearly shown that sample preparation (i.e., soil fabric) also plays an important role. This is consistent with the results of monotonic tests at small to intermediate strain levels. Hence, if results are to be directly applied with any confidence, it is important to conduct cyclic laboratory tests on reconstituted samples with a structure similar to that in situ. Unfortunately, it is very difficult to determine the in situ fabric of natural sands below the water table. As a result, there is often some uncertainty in the evaluation of CRR based on laboratory testing of reconstituted samples, although, as suggested by Tokimatsu and Hosaka (1986), either the small strain shear modulus or shear wave velocity measurements could be used to improve the value of laboratory testing on reconstituted samples of sand. Therefore, there has been increasing interest in testing high-quality undisturbed samples of sandy soils under conditions representative of those in situ. Yoshimi et al. (1989) showed that aging and fabric had a significant influence on the CRR of clean sand from Niigata. Yoshimi et al. (1994) also showed that sand samples obtained using conventional high-quality fixed piston samplers produced different CRR values than those of undisturbed samples obtained using in situ ground freezing. Dense sand samples showed a decrease in CRR and loose sand samples showed an increase in CRR when obtained using a piston sampler, as compared with the results of testing in situ frozen samples. The difference in CRR became more pronounced as the density of the sand increased.

Based on the above observations, for high-risk projects when evaluation of the potential for soil liquefaction due to earthquake loading is very important, consideration should be given to a limited amount of appropriate laboratory tests on high-quality undisturbed samples. Recently, in situ ground freezing has been used to obtain undisturbed samples of sandy soils (Yoshimi et al. 1978, 1989, 1994; Sego et al. 1994; Hofmann et al. 1995; Hofmann 1997). Cyclic simple shear tests are generally the most appropriate tests, although cyclic triaxial tests can also give reasonable results.

Cyclic resistance based on field testing

The above comments have shown that testing high-quality undisturbed samples will give better results than testing poor quality samples. However, obtaining high-quality undisturbed samples of saturated sandy soils is very difficult and expensive and can only be carried out for large projects for which the consequences of liquefaction may result in large costs. Therefore, there will always be a need for simple, economic procedures for estimating the CRR of sandy soils, particularly for low-risk projects and the initial screening stages of high-risk projects.

site-specific experience. The friction sleeve measurement for the CPT can vary somewhat depending on specific CPT equipment and tolerance details between the cone and the sleeve and, hence, can be subject to some uncertainty. The

Recommendations

For low-risk, small-scale projects, the potential for cyclic liquefaction can be estimated using penetration tests

For medium- to high-risk projects, the CPT can be useful for providing a preliminary estimate of liquefaction potential in sandy soils. For higher risk projects, and in cases where there is no previous CPT experience in the geologic region, it is also preferred practice to drill sufficient boreholes

As mentioned earlier, it is clearly useful to evaluate CRR using more than one method.