2.1 - BEHAVIOUR AS RELATED TO DESIGN: SOILS

Robert V. Whitman

(This is a brief outline of the presentation prepared by Prof. Whitman as a last minute substitute for the scheduled speaker).

This discussion will outline the state-of-the-art in the evaluation of soil parameters needed in connection with the design of buildings. A similar outline would apply in the case of earth structures.

Geotechnical Analysis in Connection with Design

Effect of local soil conditions upon design ground motions:

This is still a controversial subject. Hence, one-dimensional site response analysis are carried out only for the most important projects -- and even then are usually used only to provide general guidance in the setting of design ground motions. For ordinary projects whose design follows building codes, the choice of a base shear coefficient is keyed to general descriptions of site characteristics or possibly to the shear wave velocity

Stability of the site: This refers to the problem of liquefaction. For ordinary building projects, the analysis consists of consulting charts based upon blow count during a standard penetration test. For very important projects, study of liquefaction potential may involve computing shear stresses by a site response analysis and comparing them with resistance to liquefaction as determined by laboratory tests with repeated loads.

Initial design: A pseudo-dynamic or possibly a crude dynamic analysis is required at this stage. Soil-structure interaction may or may not be explicitly included, but if it is included the stiffness of the soil will generally be keyed to shear wave velocity.

Final dynamic analysis: For important buildings, the final step in design is a detailed dynamic analysis to provide a check upon the adequacy of structural members and perhaps to provide dynamic motions for the response of attached equipment. Such analyses generally include soil-structure interaction, representing the soil either by lumped springs and dampers or by finite element meshes.

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Parameters Required in Analyses

For ordinary projects, where special geotechnical dynamic response analyses are not required, the geotechnical information required for aseismic design of buildings includes the blow count from standard penetration tests and possibly the shear wave velocity -- and of course a good description of the subsoil conditions including results from conventional static tests. For special projects in which detailed dynamic analyses are to be made, it will in addition be necessary to ascertain shear modulus and damping as a function of strain and to evaluate resistance to liquefaction. Intermediate levels of analysis may be appropriate in some projects, requiring intermediate levels of data.

Evaluation of Parameters

Blow count (standard penetration resistance): This is of course an old tool in the kit of the geotechnical engineer. Its use has many well-documented shortcomings. Nonetheless, good data concerning blow count -- obtained with proper attention to detail, especially to the control of ground water in the bore hole -- are invaluable, particularly for cohesionless soils.

Shear wave velocity: Shear wave velocity is best measured in-situ, as a function of depth. The cross-hole technique is perhaps the best method, although good results may also be obtained by observing the wave lengths of surface waves caused by a vibrator operated at different frequencies and (with experience) by refraction shooting. Laboratory tests, using for example the resonant column method, can be useful for checks upon velocities measured in-situ and to evaluate the changes in wave velocity resulting from future excavation and/or loading of the soil. Both in-situ and laboratory testing services are routinely available in much of the world today.

Shear modulus vs. strain: Several approaches are available, including: (a) normalizing standard curves to the low-strain modulus computed from shear wave velocity; (b) using standard curves keyed to undrained shear strength of cohesive soils or to the standard penetration resistance of cohesionless soils; (c) direct measurement in laboratory tests at different strains; and (d) direct measurement in-situ. Suitable laboratory equipment is not routinely available today. In-situ techniques are quite new. (Dr. Finn, general reporter for Topic 6 (Soils and Soil Structures), has described these techniques as the most important new development in soil dynamics since the last World Conference). Hence standardized curves are widely used.

Damping vs. strain: Essentially, just two approaches are available: (a) use of standardized curves keyed to a general description of the soil, and (b) direct measurement in laboratory tests at different strains. As with modulus, laboratory testing equipment is not routinely available today.

Resistance to liquefaction: Such resistance may either be deduced indirectly from the blow count or directly by means of laboratory tests using cyclic loading. Laboratory tests have provided our fundamental knowledge concerning the phenomenon of liquefaction during earthquakes. We know that the accuracy of data from such laboratory tests is greatly influenced by many details of testing and that resistance in-situ may differ significantly from resistance as measured in the laboratory. Hence, there is little point in undertaking laboratory tests unless the very best techniques and equipment are used, good quality undisturbed samples are obtained, and the engineer is prepared to apply judgment to the use of the results. Because of these difficulties, correlations between blow count and resistance inferred from actual earthquake experiences can be quite useful. The many factors influencing resistance to liquefaction affect penetration resistance in a similar way.

A Final Comment

These observations have been directed toward evaluation of soil properties for design. For research, there are further needs -- of which the greatest is a good three diemensional stress-strain low for soil.

DISCUSSIONS

A.S. Arya (India)

Prof. Whitman has covered the whole subject, of course, in a very short time. My question is related to the liquefaction potential. There is, in my opinion, a bit of lacuna. The laboratory studies in general are related with the relative density of the soils, whereas the field measurements are always related with the standard penetration values. When we try to interpret, the big question that arises is in regard to the relationship of relative density with the N-values and there we find quite a bit of spread in the results. In fact, for some of the standard penetration values, the relative density values, according various investigations, may range anywhere from 50 to 80 per cent. Since liquefaction is related to the relative density, I would like to request Prof. Whitman to throw some light as to what he thinks about this problem in liquefaction studies.

M. Novak (Canada)

Professor Whitman correctly emphasized the need for consideration of nonlinearity of soil behaviour at large displacements. This is done most often by allowing for strain compatible equivalent linear stiffness and damping determined from a unique set of graphs.

Further research is needed to extend this concept in order to incorporate additional factors such as the effects of history of loading and the rate of load application.

D.J. Dowrick (England)

I would like to ask Prof. Whitman his views on one of the basic structural design problems as I see it and we try to relate our designs in simple ways criteria like stress. In fact, in the occasional earthquakes which may or may not affect the structure the thing which is going to really determine whether it is all right after the earthquake is the displacement which has occurred. I would like to know the criterian of finding the residual displacement whether it is sliding or rotation.

Author's Closure

Dr. Arya's comment highlights one of the reasons why I place heavy reliance on direct correlations between penetration resistance and liquefaction potential as deduced from field experiences during actual earthquakes. Laboratory tests tell us that liquefaction potential is influenced by a number of factors - all of which also influence penetration resistance. Going from penetration resistance to relative density and from relative density to liquefaction potential invites errors; it seems better in many cases to go directly from penetration resistance to liquefaction potential.

The detailed time history of a dynamic loading no doubt is of some importance. I doubt that rate of load application is particularly important, at least so long as a failure condition is not approached. There is a great need for realistic truly non-linear analyses to provide a check upon the use of strain-compatible linear stiffness and damping.

Especially with flexible structures, relative displacements between various parts of a structure, and between the structure and the supporting ground, may well be of more concern than stresses. For example, the design of tall buildings, off-shore oil platforms, etc., may be controlled by permissible deflections rather than concern over excess stresses.