Paper No. 197, Bull. ISET, Vol. 16, No. 3, Sept. 1979, pp 117–121

GEOPHYSICAL METHODS IN MICROZONATION

V.N. Singh[1] and R.C. Agrawal[2]

Introduction

It is a usual practice throughout the world to divide a country into various zones showing the expected earthquake effects or damages in terms of Modified Mercalli intensities. Maps of regions showing such zones, the so called Seismic Zoning Maps, are usually included in building codes to be used by a design engineer for earthquake resistant design of structures. Earthquake damage, however, is a complex function of many parameters viz., seismicity, soil type, water table elevation, geology and the type of structures.

In the case of a large city within the area of which there may be no significant differences in seismicity, the earthquake damage is mostly controlled by soil conditions and extremely local geology. The influence of soil type on the extent, kind and amount of damage caused by earthquakes is very well demonstrated during the 1934 Bihar - Nepal, 1950 Assam, 1964 Alaska, 1964 Niigata, 1967 Caracas and 1971 San Fernando earthquakes. There are three significant ways in which soil deposits in an area contribute to damage. These are liquefaction, loss of strength and densification. The intensity of these effects critically depend on such factors as confining pressure, water table elevation, permeability, relative density, granularity, thickness of soil layers, porosity etc. (Gaus & Sheriff, 1972). Shallowness of water table has been associated with increased earthquake intensity. It has been suggested that earthquake intensity is a function of acoustic impedance of geologic materials.

Thus, for microzonation purposes, data on layer thicknesses, depth to bed rock, depth to water table, wave velocities, dynamic elastic modulii, etc. are required. A basic requirement of microzonation work is that in-situ data are needed. It is not possible to drill enough boreholes to study the layering and to obtain subsurface samples for testing. This calls for indirect means of determining the depth and layer thickness parameters. Moreover for microzonation considerations, the parameters determined should have engineering significance. The values of the parameters of interest should be related to the mechanical properties of soil and rock with particular emphasis on their dynamic aspects of those properties (Murphy, 1978).

The above considerations adequately suggest the suitability of geophysical methods for obtaining the kind of data required by engineers engaged in microzonation work. The requirement of dynamic values of certain mechanical properties e.g. shear modulus, suggests the use of seismic methods and their borehole. Of the other geophysical methods, only the electrical resistivity method is of some significance for determining depth to water table.

The Seismic Methods (Surface)

Of the two major types of seismic methods in current use, the seismic refraction method and the seismic reflection method, the former is more suitable for engineering applications. This is because of the fact that it is possible to measure directly the wave velocity. In seismic

1 Department of Geology and Geophysics, University of Roorkee, Roorkee (India)

2 Department of Earthquake Engineering, University of Roorkee, Roorkee (India)

refraction method P wave velocities are measured alongwith depths tc bed rock and layer thicknesses.

The instruments used for seismic surveys have been developed to a high degree of sophistication because of their wide spread use in petroleum exploration. For engineering purposes, however, portable instruments of low cost have been developed. A six or twelve channel field seismograph is quite sufficient for shallow investigations.

For microzonation purposes, seismic surveys are required to be done in highly congested and typically urban areas. This restricts the use of dynamite and requires greater use of non-dynamite sources of energy e.g. air guns, weight drops, gas exploders, vibroseis, etc. With some of these energy sources e.g. vibroseis, new techniques of data processing and signal enhancement can be used. Special attention is required to be paid to some other factors which are the product of city conditions e.g., traffic interference, near surface localised conditions due to buildings and trench excavation, and backfilling etc.

The seismic refraction method has been modified so as to measure directly the shear wave velocity. In one such modification a bi-directional energy source such as a sledge hammer striking steel plates in opposite sides of a test pit is employed. Horizontal rather than vertical grophones are employed with their sensitive axis aligned in a horizontal plane transverse to the direction of wave travel. Other details regarding plotting of time-distance curves and interpretation of results are the same. The penetration of the method can be increased by increasing the intensity of the energy source and spread length. This method is subject to all the limitations of conventional method. The seismic refraction methods can be advantageously used under conditions when there is sufficient working space to achieve the desired penetration. With non-dynamite energy sources they do not require to drill holes, and are thus least expensive for obtaining seismic velocity data beneath the site to sufficient depth (Schwarz and Musser, 1972).

Although seismic refraction method has received greater attention, attempts have been made to use reflection method for shallow investigations. Attempts have been made to use hammer blow equipment and identify reflections. Special instruments have been developed for this purpose which pick up reflections and discriminate against other events such as refractions, etc. (Meidav, 1969).

Bore Hole Methods

Seismic velocity logging has been used for shallow engineering applications, e.g. for determining in-situ elastic properties in layered media and in other soil studies (Swain 1962). In-situ measurements ot P and S wave velocities of the ground have come to take an important significance, as being the fundamental data which evaluate the dynamic characteristics of the ground.

In microzonation work, measurement of in-situ shear wave velocity is an imprtotant problem. A special borehole method called cross-hole method has been developed. In this method the time for body waves to travel along a horizontal path between two points in a soil mass is measured. Body waves are generated by a vertical impulse applied at the bottom of one borehole. The arrival of energy in the form of P and S waves is monitored in a second borehole with a vertical velocity transducer. Knowing the distance, the wave velocity can be calculated. The knowledge of the two wave velocities enables us to determine the Poisson's ratio. The method can be used for boreholes of different depths and thus variation of velocity with depth can be determined (Stokoe & Woods, 1972).

A modification of crosshole method has been developed for insitu measurement of shear modulus of soil deposits. This technique utilizes a continuous vibratory high energy driving source with velocity transducers in adjacent holes. Shear waves are generated at depth in the form of sine waves in one borehole and their characteristics are measured horizontally in two adjacent holes. A large energy vibratory source is used so that the soil mass may be subjected to strains approaching earthquake levels. The strains, shear wave velocity and the dynamic shear modulus are determined from the measurements (Miller and Brown 1972).

The crosshole method is especially useful at locations where there is no sufficient space to conduct a seismic refraction survey and where data is required at relatively shallow depths. Locations where high ambient seismic backgronnd noise is prevalent are suitable for cross-hole method. When measurements are made near a seismic interface, significant errors may be introduced by the occurrence of refracted rather than direct travel paths between the energy source and geophone. This method is comparatively expensive because of the number of drill holes required and the necessity to keep a drill rig on site to deepen the hole.

Another borehole method, known as Down hole method has been developed to measure in-situ shear wave velocity. It uses a reversible bi-directional energy source located at the ground surface near the top of a drill hole. The seismic energy is recorded at various elevations in the drill hole using a horizontal geophone oriented in the same plane as the axis of the energy source. The geophones are firmly clamped in the drill hole to provide good coupling. Two seismic recordings are made with energy impluses to the right and left using a single geophone. The process is then repeated with the geophone moved to other elevations (depths) until a complete set of data is obtained throughout the entire length of the drill hole. Seismic data is obtained from which both velocities of P & S can be determined. Correlations between material changes and velocity changes can then be made. This technique yields better average seismic velocity data in stratified media than obtained either from the refraction or the cross hole method. A low velocity stratum lying between higher velocity strata can also be detected by this method (Schwarz and Musser, 1972).

The Down hole method is comparatively inexpensive because a single drill hole is required and a drill rig is not required to standby at the site while measurements are being made. From measurements in 242 holes spread at different places in Japan, Imai (1977) found a relation in the variation of P-wave and S-wave velocities with the geology and soil type, in regard to Alluvial, Diluvial and Pliocene Tertiary deposits. On further examination of data, a fairly good correlation between S-wave velocity and engineering properties of soils, such as N-value of standard penetration test or unconfined compressive strength, was also found.

Elastic Modulii as a Function of Strain

The elastic properties of near surface earth materials i.e., soils, are found to be a function of strain induced in them. This is especially the case with the level of strain induced by strong earthquake motions. The strain dependence of elastic modulii of soils, especially their shear modulus, is in turn controlled by the in-situ structure of soil and the natural state of stress. The insitu determination of elastic modulii of soils is important from this point of view, viz., the in-situ structure of soils is preserved and the necessity of knowing the natural state of stress is eliminated.

The wave propagation methods of determining in-situ elastic properties of soils involve strain levels of the order of 10^{-4} percent or less which are comparatively low. In the laboratory, the determination of shear modulus can be made at various strain levels. Trancoso et al. (1977) have described wave propagation experiments in the field by impulse generated shear wave velocity measurements. The shear strains at the point of measurement was estimated as a ratio of the velocity of a soil particle moving perpendicular to the direction of wave propagation to the wave velocity. As a result of these tests, it emerged that shear modulus decreases with an increase in the shear strain level. This decrease in shear modulus is different for different soils. The over-consolidated soils have larger values of shear modulus than normally loaded soils.

Electrical Resistivity Method

It has been suggested that earthquake intensity increases when depth to water table decreases (Gauss & Sheriff, 1972). A knowledge of depth to water table is thus essential in microzonation work. The depth to water table can be determined easily by electrical resistivity method which depends upon differences in electrical conductivity of saturated and unsaturated rocks. The instruments used for conducting the electrical resistivity survey, the field procedures adopted and methods of data processing, are the standard ones and the results obtained from such surveys are fairly reliable.

One important aspect of microzonation work is that the dynamic elastic modulii values should be obtained at strain levels experienced during earthquakes. Most of the methods described above fail to meet this requirement. The elastic modulii of soils depend critically on the strains induced in them. The data made available by the geophysical methods have to be modified according to properly developed scaling laws.

Concluding Remarks

The geophysical methods appropriate for microzonation purposes have been described and their suitability examined from the engineering view point. It is felt that with newer developments in geophysical technology more confidence will be placed on the efficacy of geophysical methods in solving problems of engineering significance.

Acknowledgement

Authors express their sincere thanks to Prof. & Head, Department of Earthquake Engineering, Roorkee University, Roorkee for providing all the facilities in carrying out this work.

References

Gauss, M.P. and Sheriff, M.A., 1972, Zonation and Microzonation; Proceedings of International Conference on Microzonation for safer construction research and application, held at Seattle, U.S.A., Oct. 30-Nov. 2, p. 3-11.

Imai, T., 1977, P and S wave velocities in subsurface layers of ground in Japan; Proc., 6 WCEE, New Delhi, p. 2384.

Meidav, T., 1969, Hammer reflection seismics in Engineering Geophysics; Geophysics, V. 34, p. 383-395.

Miller, R.P. and Brown, F.R., 1972, Shear Modulus determination of soils by in-situ methods for earthquake engineering; Proceedings of International Conference on Microzonation for safer construction research and application, held at Seattle, U.S.A., Oct. 30-Nov. 2, p. 545-55.

Murphy, V.J., 1978, Geophysical Engineering investigation techniques for microzonation; Proccedings of International Conference on Microzonation for safer construction research and application, San Francisco, U.S.A., Nov. 26-Dec. 1, p. 153-178.

Schwarz, S.D. and Musser, J.M., 1972, Various Techniques for making in-situ shear wave velocity measurements - A description and Evaluation; Proceedings of International Conference on Microzonation for safer construction research and application, held at Seattle, U.S.A., Oct. 30-Nov. 2, p. 593-608.

Stokoe, K.H. and Woods, R.D., 1972, In-situ shear wave velocity by cross hole method; journal of soil mechanics and foundation division, A.S.C.E., Vol. 98, No. 5.

Swain, R.J., 1962, Recent techniques for determination of in-situ elastic properties and measurement of motion amplification in layered media; Geophysics, V. 27, p. 237-241.

Troncoso, J.H., Brown, F.R. and Miller, R.P., 1977, IN-SITU impulse measurements of shear wave modulus of soils as a function of strain; Proc. 6 WCEE, New Delhi, p. 2316-2321.