PROBLEMS IN THE CONSTRUCTION OF MICROZONING MAPS

by

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SYNOPSIS

Problems arising in the construction of microzonation maps have been studied in this paper by evaluating the current techniques used for their preparation. Two of the commonly used methods, often used in engineering practice, the Impedence Technique and the Microtremor Technique have been critically assessed, indicating the various assumptions involved in each method and their weaknesses. An index for the preparation of microzoning maps has been proposed and a general methodology for microzonation been suggested.

INTRODUCTION

Past experience from recorded earthquakes has shown that the intensity of strong ground shaking can vary considerably over relatively short distances. This observation has led several investigators to develop microzoning techniques, so that zones of relatively higher seismic hazard can be isolated. Zoning maps are thus obtained and are used for structural design as well as future urban planning.

Though microzonation has been carried out in several parts of the world today, there appears to be no generally accepted philosophy behind the actual procedures involved. In this paper, microzonation has been looked upon in the context of its purpose, as a relative hazard scaling procedure leading to risk evaluation in urban areas prone to seismic shaking. After defining the concept of microzoning, some of the currently used microzonation techniques are reviewed and their viability assessed in the light of the current state-of-the-art in earthquake engineering and engineering seismology. An index of earthquake hazard, from an engineering viewpoint, has been proposed and a methodology of approaching the microzonation problem has been suggested.

MICROZONATION FOR STRONG GROUND SHAKING

Since microzonation deals with the quantification of the earthquake hazard, it is important to recognize that the total hazard at a given site may be contributed by various types of earthquake effects. It appears reasonable then that different microzoning maps be made for the different specific earthquake effects such as, the run up of tsunamis, surface faulting, etc. This paper deals with microzonation in the context of strong ground shaking. Broadly speaking, the effects of strong ground shaking can be categorized as 1) hazards caused by spatially localized geologic effects (like those created by specific

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local material conditions) such as landslides, liquifaction, etc. and 2) hazards caused by the nature and intensity of strong ground shaking. In a sense, the second category is of primary importance since various geologic effects may be triggered at different levels of ground shaking. It is this category of earthquake hazard that we principally address here.

The nature of strong ground shaking caused by an earthquake event at a particular site is dependent on the nature of the source mechanism, the transmission path characteristics and the local geologic effects. It is therefore necessary that all these three factors be suitably reflected in any microzonation map. However, though the effect of the nature of the local site conditions may at times be tractable, the nature and effects of the transmission path differ from event to event, as also, in general, do the type and location of the source mechanisms. The uncertainties associated with these factors would then lead to a probabilistic approach to the microzoning problem in regard to the parameters that quantify the hazard level.

COMMENTS ON SOME CURRENT MICROZONATION PRACTICES

Though microzonation maps are being drawn to delineate areas of potential landslide, areas of potential liquifaction and regions of active faulting [1], most frequent studies of microzonation, however, address the problem of estimation of expected differences in amplitudes of shaking as they may influence the degree of structural damage. The purpose of these studies is essentially to evaluate the risk in a given zone by incorporating microzonation maps into the building codes or design practices. We next examine some aspects of microzonation for the expected differences of strong shaking.

The most popular methodology in microzonation is now based on the principles involved in finding the transfer function properties of the near surface soils and geology [2,3]. The main assumptions in this approach are that 1) the earthquake source generates a broad band spectrum with relatively uniform amplitudes, that 2) the transmission path has little or no effect in further modifying the source spectrum, and that 3) the transfer function representing the influence of local soil and geologic conditions at the site is independent of the horizontal and vertical angles specifying the direction of the predominant energy arrivals.

Numerous analytical as well as numerical methods have been proposed and used in the analysis of soil and geologic columns. Typically, a random function with broad band spectrum or recorded accelerations are being used as an input into such calculations whose output then reflects the influence of the site conditions[1]. In an effort to either experimentally verify this approach and/or to provide an alternative for estimating the local site effects, multiple earthquake recording or microtremor studies have been explored [4,5]. While some of these studies have indicated that local soil and geologic site conditions can have a profound effect on the recorded motions, it has not been shown so far whether multiple recordings at the same station from different earthquakes indeed lead to repeatable patterns of local site amplification. In fact, our studies of microtremors and earthquake records in El Centro, California, have shown that different earthquakes can lead to different spectra recorded at the same point and that the source mechanism alone could account for almost all the observed differences. Spectral analysis of microtremors in the same area indicated that there is little or no similarity between the microtremor and earthquake spectra. These differences are caused by the different nature of the sources of microtremor and earthquake excitations and their relationship to the site conditions. One such discrepancy results from different directions of wave approach toward the station for earthquake and microtremor waves. Earthquake waves have the tendency to arrive from the side or from below the site and propagate from a fault to the station. On the other hand microtremor waves often result from a variety of steady or transient sources located in all directions from the recording station and primarily arise near the ground surface. This suggests that if the response of local soil and geologic strata is sensitive to the direction of the wave approach, zonation on the basis of one or several earthquakes or on the basis of microtremors may not be valuable.

The essential and perhaps the most important requirement which would guarantee the success of any microzonation scheme would be that the relative effects predicted by a microzonation map be repeatable from one earthquake to another. While it is useful to understand the detailed nature of shaking and the resulting damage in relation to the soil and geologic conditions in the areas, the fact that the consequences of one earthquake sometimes can be interpreted by a simple site model (and is therefore often cast into a "microzonation map") does not in itself even suggest that the same pattern of shaking may be repeated in the future. It appears therefore that until enough data is collected for shaking in the same area but resulting from different earthquakes, and this done for many representative areas, the current methods of microzoning for expected variations of strong motion amplitudes will rely more on judgment rather than a proven observational fact.

In the studies in which the observed damage is used to test the adequacy of a map which might be used for microzonation, typically only spectral amplitudes of recorded or estimated strong motions are considered. Since damage tends to increase with an increase of amplitudes of strong shaking, the spacially varying effects of soil and geologic conditions at and near the site are portrayed through a map showing the relative or absolute distribution of overall spectral amplitudes. This logic combined with the general observation that damage tends to be higher on alluvium than on sound igneous rock have led to the acceptance of simple models of local site conditions which typically suggest amplification of incident wave amplitudes whenever there is a low velocity soil or alluvium layer overlying harder material. It appears, however, that seismic waves are not always amplified by superficial alluvium and soil deposits and that the amplification when it does take place may not be as high as it is often predicted by simple models of local site conditions. Recent studies [6] have indicated that the duration of strong shaking may be up to two to three times longer on alluvium sites than on hard basement rock sites and that the resulting increase in the number of strain reversals in a structure may be another key factor in determining the degree of the resulting damage. Empirical studies of spectral amplitudes have indicated that the amplification of incident waves by alluvium and soil deposits typically takes place only for intermediate and long wave lengths corresponding to periods longer than about one second. For high frequency waves on the other hand, spectral amplitudes tend to be slightly higher on basement rock than on the alluvium sites [7]. Consequently, if a microzonation map is to reflect the expected variations of possible structural damage and thus equalize the risk by weighting the design accordingly, careful consideration must be given to the frequency bands for which the maps may be applicable.

The value of microtremors as an aid in the development of microzonation maps seems to be questionable. Though some studies have shown [1,2] that adequate analyses of microtremor recordings can be useful for better understanding of the site soil and geology, the very nature of their sources of energy which are located on the ground surface leads to the sampling of shallow site characteristics. Strong shaking, on the other hand, even when it results from shallow and surface earthquakes is caused by faulting which may extend tens of kilometers into the earth's crust. As a result, the strong-motion waves also sample and depend on the characteristics of earth materials at considerable depth. It seems then that microtremors which do not take into account the effects of variations in source mechanism may not even sample the complete geologic cross section which influences the observed variations of surface shaking and damage.

In summary, it appears now that the earthquake source mechanism, transmission path and the site geologic conditions all have significant influence on the amplitudes of recorded strong ground motion. Microzonation maps as currently prepared offer to be useful only in special cases where it can be shown that the local geologic conditions will lead to much larger effects than the source mechanism and transmission path effects and when these local conditions are independent of the direction from which the seismic waves arrive to a station.

A PROPOSED TECHNIQUE FOR MICROZONATION

An essential prerequisite for microzonation is to arrive at a suitable set of characteristics of strong ground shaking which could be used to index the spacial variations of hazard levels. Various indices have been used by researchers in the past [1]. Typically, parameters like Modified Mercally Intensity (M.M.I.) and peak accelerations have been utilized. However, from an engineering standpoint, the yardstick used must be suitable for making definitive evaluations of structural hazard. One such yardstick is the response spectrum. The response spectral amplitude computed from earthquake accelerograms at a given frequency is a measure of the energy input of the earthquake (at the recording site) at that particular frequency. However, in addition to the total energy contained at a particular frequency, a parameter of considerable importance in the analysis of structural damage is the duration of time over which that particular frequency component of motion lasts. These two functions of frequency, the response spectrum and the duration, appear to form an adequate choice of indices for the construction of microzoning maps. These indices being functions of frequency would be, in general, superior to indices like the peak acceleration, peak velocity and peak displacement which essentially sample only the high, the intermediate and the low frequency regions of the earthquake spectrum.

Having motivated the need for a probabilistic approach to the microzonation problem, any rational scheme for solving it would need to rely on a large statistical data base. Furthermore, since the response spectrum amplitudes and the duration of shaking appear to be useful indices in the evaluation of structural response and possible damage, it is useful to have recorded information in the area.

The first step in the process of microzonation would be to collect magnitude, or when this is not available the M.M.I. statistics of the various earthquakes in the area, together with the spacial and temporal distribution of earthquake epicenters to build a suitable seismicity model for each of the several seismically active zones around the area where microzoning is to be carried out. Typical seismicity models of the form

$$\log N = a - bM \quad ; \; a,\, b \text{ constants} \tag{1}$$

where, N is the number of earthquakes of magnitude M or greater occurring in a given span of time, can be utilized. Knowing this, the probability of having an earthquake of magnitude M in a given span of time can be ascertained in any of these seismically active zones. Special attention may need to be given to the nonuniform time rate of earthquake occurrence during the time span considered.

The area to be microzoned could next be divided into a grid. Given that an event of magnitude M has occurred in a particular seismically active zone, the next step would be to determine the joint probability that the response spectral amplitude, A, and the duration, T, of ground shaking for a frequency, ω, do not exceed values A_0 and T_0 respectively. We observe here that this is simply a probabilistic attenuation relation and should take into account such features as the uncertainties involved in the transmission path characteristics and the local site conditions. One form of specifying such a relationship, for example, could be [7]

$$\log[A(\omega),\, T(\omega),\, p] = M + F_1(R) + F_2(M,\, s,\, d,\, p,\, n) \tag{2}$$

where $A(\omega)$ and $T(\omega)$ are the spectral amplitude and the duration of the frequency component ω, R is the epicentral distance, s is a site condition parameter, d is the direction of ground motion, p is the confidence level and n is the fraction of critical damping.

The third step then is to obtain the joint probability distributions of the response spectrum amplitudes and the duration of shaking at a frequency ω, for each point of the spatial grid. Thence the spectral amplitudes and durations which would not be exceeded at a given confidence level, for a given length of time, can be found. For a fixed duration T_0, contours of spectral amplitudes for each frequency ω can then be drawn. Thus a series of microzoning maps would be obtained each drawn for a particular frequency and a specific time duration of shaking at that frequency. These basic maps can then be further appropriately condensed into one or more maps depending on the purpose for which the microzonation is desired.

This methodology offers a vehicle for the derivation of microzonation maps, which are based on physical principles and which through the probabilistic formulation allow one to utilize the geologic data and to express the uncertainties associated with the result. Whether such maps are needed and justified, however, will have to be decided in each particular case. The usefulness of such maps will depend on whether there is a significant difference between the index values computed between two relatively distant points, in comparison with the statistical uncertainties which characterize the calculation of each of the indices.

CONCLUSIONS

1. It appears that microzonation maps for strong ground shaking to be meaningful, should in general reflect the complete earthquake hazard problem constituted by the earthquake source, the transmitting medium and the local site conditions.

2. Due to the large uncertainties in ascertaining the effects of these three factors, probabilistics concepts need to be used in the construction of microzonation maps.

3. Both the microtremor and the impedence method ignore the effects of source mechanism and transmission path characteristics and are therefore deficient in this respect.

4. A set of index functions based on engineering usage for microzonation maps has been proposed, and a general methodology for the construction of such maps has been indicated.

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DISCUSSION

P.W. Taylor (New Zealand)

As the discussor understands your proposed method, spectrum amplitude A, and duration T, are plotted for a particular frequency. Does this mean that not one single microzoning map, but an array of maps (one for each frequency) should be made ?

C.A. Cornell (U.S.A.)

In the oral presentation the authors propose to produce contour maps of both response spectral ordinate (R) and duration (T) for a given probability of being exceeded in X years. But the concept of extreme value or maximum is lost when dealing with a multivariate process, i.e. $\{R(t), T(t); 0 < t < x\}$ in other words, the extreme value of R, in time 0 to X may not occur at the same time (i.e. in the same event) as the extreme value of T. How then can the contour maps be read or used ? Most the designer use for example the 100 year mean return period value of R and the same value of T as if they are certain to occur simultaneously ?

Author's Closure

Not received.