# PROBLEMS IN EARTHQUAKE RESISTANT DESIGN

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## SYNOPSIS

In earthquake resistant design, due to lot of uncertainty of several parameters, judgement has to be exercised by the designer at various stages. This paper highlights the assumptions involved in the evaluation of the seismicity of a site, determination of ground motion parameters, soil-structure interaction effects and modelling of structure. It is concluded that at present, earthquake resistant design is an art even though a good deal of progress has been made in recent years to provide it a scientific basis. The paper highlights the unanswered questions to provoke further thinking to make the designer's task easier than it is at present.

## INTRODUCTION

Earthquake engineering research has made good progress during the past fifteen years with the rapid spurt in theoretical investigations made possible by digital computers. Experimental work has relatively lagged behind. However, the basic problems of a designer remain without a precise answer, such as the knowledge of the probability of occurrence of a damaging earthquake close to a site; the choice of earthquake parameters for such an earthquake; the evaluation of suitable dynamic soil/rock properties for the foundation model; the estimation of a probable combination of various types of loads under earthquake condition; the stresses to be permitted in the materials and the damping to be assumed in the design. This study examines some of the above problems.

It is well realised that when seismic coefficients as given in codes of practice are used, it amounts to a certain degree of insurance without an estimate of it. For important structures, a detailed evaluation of the seismicity of the site is usually attempted. The assumptions involved in deriving ground motion parameters are discussed in this paper. Except in hard soil, soil-structure interaction effects must be considered and its evaluation is examined. Problems associated with the evaluation of stiffness parameters, particularly with respect to buildings are mentioned. The estimation of live loads present in structures at the time of earthquake and their effective contribution are also discussed. The damping factors could only be taken in a nominal manner in the design.

In view of the various assumptions involved in different stages, the design would strongly reflect the individual views of the designer.

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## SEISMICITY OF A SITE

The first problem in any earthquake resistant design is to evaluate the seismicity of a site. The seismicity is usually expressed in the form of a probable magnitude, epicentral distance and focal depth. Even though the magnitude of an earthquake is instrumentally determined, the magnitude assigned to a shock has a nominal value and the true value may be as much as $\pm$ 0.5 from the nominal one. Equally, there is an uncertainty regarding estimation of focal depth.

Considering the site as the centre, in an area of about 300 km radius, the information from past macroearthquakes are plotted. On this map, the tectonic features are also delineated. Most often, it may be possible to associate past epicentres with a tectonic feature. There is a strong evidence that future epicentres may be anywhere along a fault and not necessarily at the location of a past epicentre. Therefore, for design, the probable epicentre is shifted along that fault closest to the site. If data for past epicentres associated with a particular fault is not available, it becomes necessary to estimate the activity of a fault.

The present practice is to locate a network of sensitive micro-earthquake recorders and determine the activity of faults. Such studies may be carried out for important structures like Dams or Nuclear Power Plants. However, no definite correlation is available so far between micro and macro activities. As an example, one can quote an instance of a period of intense activity of minor earthquakes in a region near Delhi (Sonepat) with out any macro earthquake activity following it. In any case microtremor records give some idea of the activity of the region even if a decision regarding seismicity may be a matter of judgement.

If it is assumed that the seismic parameters have been estimated, the next question is to determine associated ground motion parameters, namely, peak acceleration, velocity, displacement, waveform of motion, etc. At this stage, the type of foundation soil also enters into the picture. There are a number of empirical relationships available such as, in reference (1,2). Unfortunately, the various formulae give a wide scatter of values probably due to the fact that there are errors in the determination of magnitude, and the various recorded accelerograms are considerably influenced by local soil conditions. None of the formulae has been accepted as a standard. There is thus uncertainty in deriving ground motion parameters from estimated seismicity of a site. All the same, the practice of estimating intensity at a site (Mercalli or similar scale) and then deriving ground parameters having been discarded being even more crude, the method using magnitude is a good guide.

## GROUND MOTION PARAMETERS

For the purposes of design, ground motion parameters may be expressed directly or indirectly in several ways. The simplest form from the point of view of design is to specify seismic coefficient at various levels of a structure. A number of codes of practice, like the Indian Standard Code (3) do specify ground motion indirectly in this way but it is realised that these values are rather ad-hoc in nature and must be used only for preliminary design of important structures. Further, codes do not and cannot cater for special conditions.

The ground motion is ideally specified in the form of a time history acceleration. Usually, two time histories are at least specified. The time history may be obtained from modification of actually recorded data or generated artificially. The intensity of a time history motion could be expressed in several ways namely, (i) peak acceleration value, (ii) peak velocity value, (iii) peak displacement value, (iv) response spectra intensity (v) root mean square value of peak accelerations (4). For the various criteria mentioned above, the time history derived may be different. The preference of authors would be to use peak velocity criterion as it has been shown that the amplitude of the highest acceleration pulse is not by itself significant for structural applications but the greatest area of acceleration pulse that may occur may be significant (5,6).

An indirect method of arriving at ground motion which is popularly used is to specify design response spectrum for the site (7). These are particularly useful for linear systems using modal analysis. One of the greatest drawback of this method is that a further criteria is to be evolved regarding combination of modes. Probably, there could be an agreement in the choice of shape of spectra to be used for a site. However, there is a great controversy over the choice of multiplying factor to be used for the determination of the ordinate of the spectrum for a site (8). The multiplying factor would depend on whether the spectra has been normalised with respect to peak acceleration, velocity, etc. and on the way ground motion parameters (acceleration, velocity, etc.) are specified for a site.

Irrespective of the method of specifying ground motion, atleast two intensities are taken for design, one corresponding to elastic design for frequent earthquakes and the other permitting limiting stresses for the largest shock occuring once in the lifetime of the structure. Once again several methods are used to define these two intensities. Two sets of magnitude-distance could be specified. Alternatively the acceleration ordinates of time history or spectral ordinates of one set may be scaled by a factor to obtain the second. The latter method is particularly followed in Atomic Power Plants for relating Safe Shutdown and Operating Basis earthquakes.

Quite often it would be necessary to specify ground motion in all three coordinate directions. However, it is the practice to consider vertical component along with one horizontal at a time. Given a horizontal component, a convenient procedure adopted at present is to take the vertical component as some fraction of the horizontal, and this is quite adequate.

## SOIL STRUCTURE INTERACTION

If the structure is not founded on rock/firm ground the input motion at the level of basement, raft or pile cap would be different from that of free field where the ground motion is specified. The soil is usually replaced by a set of translational and rotational springs both at the base of the structure as well as at its embedded sides. In the case of raft, the base springs are arrived at from the elastic half space theory but there are no standard methods for the evaluation of side springs (9). The base springs depend upon the effective dynamic modulus of rigidity and poisson's ratio of the soil medium. The evaluation of equivalent elastic dynamic soil properties is subject to a lot of doubt as the soil material is hetrogeneous and non-linear. The amount of uncertainty is very much greater in the case of soil damping as compared to soil spring that the values chosen for design may be termed as arbitrary. In the case of pile founaations, the evaluation of even the equivalent springs is doubtful. Recently attempts have been made to carry out field tests on piles to evaluate soil springs. However, extrapolation to actual condition is complicated due to the group action of piles and interaction of super-structure.

Finite element techniques offer an alternative for evaluating soil-structure interaction but the problems associated with assignment of material properties to the elements, simulation of radiation damping, assumption of boundary conditions, etc., introduce a lot of uncertainty and these techniques, time consuming as they are, hardly lead to a more reliable solution.

The problem of increase (or decrease) of strength of soil under dynamic conditions, the relative strengths of various types of foundations (raft, pile, etc.) under earthquakes are difficult to estimate. The evaluation of the influence of the soil-foundation is thus a matter of judgement only.

## MODELLING OF STRUCTURE

Matrix structural analysis is invariably used in which stiffness, damping and mass matrices are needed for modelling the structure. For most structural applications, finite element techniques can be used to obtain reasonably good stiffness matrix. However, if the example of a building is taken there are a number of uncertainties. The modelling of a building into an idealised three dimensional space frame involve estimation of effective flexural rigidity of vertical and horizontal members. In the case of vertical members of reinforced concrete structure subject to axial load and bending, if the concrete is assumed to carry no tension, the extent of bending action being unknown prior to analysis iterative methods would be necessary. In the case of concrete, it is wellknown that the modulus of elasticity varies with strain as well as age. The practice, is however, to assume the entire section to be effective with an assumed modulus of elasticity. This uncertainty renders use of elaborate techniques unfruitful. For horizontal members, due to T beam action over a certain portion of the length, the determination of equivalent flexural rigidity is a matter of conjecture. If there are brick in-fill walls sometimes their contribution to stiffness is ignored resulting in a flexible model but it introduces uncertainty about actual behaviour.

When nonlinear deformations of the structure are considered, the structural system is highly idealised. There is a voluminous literature available on idealised multistoreyed structures. Considerable judgement has to be exercised in modelling an actual system.

Among the various parameters required for earthquake resistant analysis, the mass matrix can be determined more exactly than others. The mass matrix is usually assumed diagonal, with the quantities lumped 'physically' at the nodes. The more exact consistent mass matrix formulations can also be used in the analysis. Uncertainty arises in the inclusion of effective live load. There are two aspects - one concerning the amount of live load incident at the time of earthquake and the other due to non-rigid mounting of the live load (10). The amount of live load for earthquake design is always less than that for static design but the reduction factor is a matter of judgement.

The least known parameter for structural modelling is the Damping matrix. Necessarily, for the convenience of analysis, simplified assumptions have to be made. It is quite often taken as some linear combination of mass and stiffness matrices. If modal analysis is used, damping in various modes are either assumed to have the same value for all modes or in some ascending fashion with increase in modes. If a structure comprises of several material, then weighted approach based on energy is used (11). The damping thus can be deemed to be considered only in a nominal manner particularly because it also varies with state of strain. In the initial stages of strain, it is very small. Later as cracking developes it increases depending upon the type of construction.

## CONCLUSIONS

In spite of the tremendous growth in research in earthquake engineering, there are a number of uncertainties in various stages of design. The choice of ground motion and soil-structure interaction parameters pose a challange to the designer. Since intuition and experience has to play a big part, the design worked out by two different groups could have a considerable difference. Earthquake engineering design could be rightly termed as an art at present although no longer arbitrary in view of the fact that considerable deep thinking has gone into various parameters recently and broad limits of various parameters have been specified and methods of approach identified.

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