CONSIDERATIONS FOR A "DESIGN" EARTHQUAKE

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ABSTRACT

Any structure is only as good as its foundation material. Under earthquake the properties of foundation materials can change drastically. Recent advances in soil dynamics indicate that the simplifying assumptions on which our seismic building code is based, are not adequate to cater for the variations in foundation conditions. The code provides clear definition of seismic design forces, in terms of acceleration and period, but ignores any possible effects of displacement, velocity or wavelength. Currently available methods of design and analysis can provide for calculation of ground period, displacements, velocities, accelerations and stress values at any point in a soil mass. Although not perhaps suitable for detailed code recommendations these methods can be used by designers where needed and the code could contain simplified but conservative data on the use of such methods. The design forces to be imposed on a structure and variations of these are defined exactly in the code, but these are not matched by the definition of base motions, which are influenced by magnitude of the earthquake, distance and soil properties. It should be possible to provide for a "design earthquake" which takes into account, type of structure, nature of risk, magnitude of earthquake, distance from active seismic areas and soil properties. Even relative factors, initially based on overseas research, relating these things would provide a more rational basis for seismic effects on structures than the simplified structure mass acceleration method used at present.

INTRODUCTION

Recent advances in seismic research indicate that the design criteria in the Building Code for the "input" design seismic forces at the foundation level of a structure should be completely revised. Under the present Code the earthquake provisions are set out quite clearly in Chapter 8 of N.Z.S.S. 1900 which gives the design assumptions for applying forces to a structure, but it completely ignores variations in foundation materials and the effects these have on seismic motion.

The Code defines very clearly what variation is to be allowed in the application of acceleration and forces at various heights in a building, but this is on the basis of a particular ground acceleration at the base. In Zone A for example the acceleration is to be 0.16g maximum reducing to 0.08g for increased period of oscillation. Nothing is stated about the influence of ground conditions on the base acceleration of the structure, although this is referred to in the Commentary on the Code M.P.12, and there is nothing to guide a designer in assessing the ground period to be expected at any given type of site. The influence of velocity, displacement and wave length are completely ignored.

The Code states in section 8.34.2 "the static forces .... are assumed to represent the dynamic response of the structure by simulating the effects in shears, moments and direct forces of earthquake ground motion."

GROUND MOTION

It is worth briefly considering what we know about "earthquake ground motion" which for design purposes is reduced to a single acceleration.

The motion is a succession of displacements in any direction in sequence, each movement having an acceleration, a velocity, and the whole sequence of movements having a range of periods. The total oscillatory motion can be resolved into vertical and horizontal components for application in design. It can be inferred that seismic waves have wave lengths which are related to the frequency and velocity of wave travel. Also the various types of waves travel with different velocities in different materials. Taken together with reflection and interference effects this gives quite a complex picture of how a point on the ground might move in an earthquake.

Obviously simplifying assumptions are needed but the basic factors which influence the motion should be clearly understood.

The first influencing factor is the magnitude of the earthquake, the next the distance from the epicentre, then the nature of the ground, the depth of surface alluvium over bedrock and the shape of any bedrock basin. These factors are obviously important in creating the resulting motion of the ground. The surface motion at any point has oscillatory periods of displacement, particle velocity and acceleration together with wave lengths and wave velocities. Cut of all these the choice offered by the code for design purposes is an acceleration and a period on which to base the mathematical analysis of a structure on the ground surface. Providing that we choose the correct acceleration, forces of the right order of magnitude can be calculated on the basis of "force equals mass times acceleration". If the resonant frequency of a structure is outside

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the frequency spectrum of the earthquake the building is assumed to be safer. This is questionable for the single pulse type of earthquake movement which may have very high shearing displacements in one direction.

The periods and amplitudes of motion at any point are dependant not only on the magnitude and distance of the earthquake, but more particularly on the nature of ground at the point concerned. Two places quite close together can have quite different responses to the same earthquake and this is essentially a function of type of ground material and the geology of the site.

The best structure is in fact no better than its foundation materials. A thorough investigation of dynamic properties of foundation materials could greatly improve the assessment of ground response to an earthquake and hence provide a better design input for any structure on this ground.

Although not all required in any one design problem factors such as velocity, displacement, wavelength could be taken into account in assessing a design earthquake for any particular locality in addition to the values of acceleration and period already covered in the code.

GROUND VELOCITY

It has been recognised by some overseas investigators that velocity has a much greater influence on damage potential than is normally recognised. The kinetic energy of motion given by $\frac{1}{2}$ M.V.^{2} can be quickly transferred to any mass of material or a structure. If this amount of energy cannot all be absorbed and is more than can be dissipated in the same time by elastic movements or damping, then there must be damage as the energy will be absorbed in non elastic movement, displacement and cracking (ref. 1). Hence the need for plastic design of structural components. An attempt should be made to relate expected velocities to ground conditions in New Zealand as has been done elsewhere (2) (9). The assessment of velocities and the duration of a pulse movement are important as these can provide a value of the energy transferred to a structure.

Although velocities can be obtained by integration of the acceleration record or instantaneously for any particular period by the relationship, acceleration = angular frequency x velocity (A = wv) there could be advantages in having a design code table of "Design velocity" maxima or maybe coefficients which could be applied in different localities and different types of ground.

The records of strong motion ground surface velocities are very limited and expert opinions differ on what might be an upper limit of velocity. From the known records velocities of 20 inches to 40 inches per second are common (3) near epicentres.

Possibly the use of strong motion velocity measuring seismographs would give more precise data because accelerations could be obtained by differentiating this record and displacements by integration.

DISPLACEMENTS

The prediction of maximum oscillatory displacement have been attempted by overseas investigators as early as 1956 (4). A lot of statistical data is required for this and the accurate measure of displacement is difficult. Oscillatory displacements do occur so they cannot be ignored but to obtain displacements by double integration of acceleration records can lead to considerable errors. Values of displacements known to have occurred in strong motion records are of the order of 15 inches to 18 inches. During the Inangahua earthquake the ground movements in some localities could have exceeded 12 inches as indicated by shearing movements at several different places on bridge abutments and building displacements. As with acceleration and velocity the magnitude of maximum displacement is very dependent on the nature and depth of ground materials. In 1957 comparative records were made in California (5) showing that alluvium thickness and water table level can influence not only the amplitude of shaking but also change the predominant period. The affect of ground can in some cases increase the intensity of shaking by five to ten times that of the base rock and although the average acceleration on the rock base may be no more than 0.05g for a magnitude 7 earthquake, this can be magnified to an acceleration of 1.0g or more on "poor" ground.

WAVE LENGTHS

Wave lengths and wave velocities practically never enter any calculations for seismic design of structure, because they are probably unimportant except for the special cases of long structures. This has received some attention overseas (7) (8) and ground resonance effects have also been related to ground conditions, but more research particularly in N.Z. Localities is needed before any wave length effects could be related to a code.

Measurements of seismic wave length have not been reported except in general terms. It would be very worth while having available on call three seismographs for the purpose of establishing an array of three interconnected strong motion recorders 500ft to 1000ft apart to obtain direction, wave velocity and wave length of a seismic movement. Where to put the recorders is the first problem, but an installation to record after shocks immediately following any major earthquake could serve the purpose. The wave length is likely to be different in different types of material but it is generally accepted that seismic wave lengths are 1000ft to 5000ft. However these could be as short as 200ft for shear waves travelling at a 1000ft per second with a period of 0.2 seconds. Short waves of high frequency attenuate relatively quickly and therefore do not get recorded on distant seismographs, but they could be present in damaging proportions in areas 10 to 20 miles from an epicentre.

The presence of even one short wave motion in a series of seismic waves could be very serious for structures longer than about a quarter of a wave length, because the two ends of the structure would have out of phase displacements.

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With so much variation possible in different ground conditions (6) is it not time our Code recognised this and made some attempt to provide quantifying guidelines? Careful definition of the forces on a structure is not likely to make the structure any safer if our assumptions about the applied base forces are somewhat arbitrary.

Proper investigation of ground properties (wave velocities, dynamic moduli and density) can be done on any site and techniques are now established to make complete dynamic analyses of sub surface strata. This is a lengthy process and should be done only on the large important structures. With full details from a site investigation of dynamic moduli and strata depths it is now possible to assess the time history during an earthquake of the mode shapes, periods of vibration, displacements and stress in the ground mass.

Code guidelines based on investigations of particular soil types, could indicate what degree of amplification of motion or modification of period can be expected in certain types of soils and also what effect can be expected with depth changes of alluvium and water table levels. Detailed studies of this sort have been published by Medvedev (9) and his findings for intensification coefficients could be used initially as guidelines in an earthquake code until more details are collected for N.Z. conditions.

It would be possible under our existing zoning to provide for a particular magnitude of "design earthquake" for New Zealand. The magnitude chosen and the distance from say Zone A would take into account changes in severity or intensity for different areas. Statistical prediction of earthquake magnitudes and return frequencies have already been done for various parts of New Zealand (10) and this or an updated version of it, could be used as a starting point.

Magnitude and duration values could be suggested as shown in Table A below.

Displacements, velocities and accelerations can be related to these magnitudes but reduced in relation to increasing distance from epicentral areas and increased in relation to local ground conditions where motion amplification could occur. Even arbitrary factors relating types of ground and depth would provide a better assessment of the earthquake potential of any area than the present Code method.

For assessing the period of oscillation to be expected in any area the Code could provide guidance on the use of the simplified formula :-

$$T = \frac{4H}{v} = 4H\sqrt{\frac{d}{Gg}}$$

where T = period
H = depth of stratum
G = shear modulus
d = density
g = gravity constant

and how data can be obtained for this.

The proposals embodied here are substantially in line with suggestions previously made by R.J.P. Garden (11). With the advance of knowledge and research there is now enough basic data to define in the Building Code a more realistic "design earthquake". Code recommendations and design criteria already established in Russia and Japan could be used as a basis for any revised earthquake design code.

The wide range of effects that ground material can have on seismic distrubances and the very nature of the motion itself, are not provided for in the existing Code. The present criteria may be establishing safe structures but it should be possible to rationalise the requirements in tne light of present knowledge and provide for a better input for seismic forces.

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TABLE A

Risk	Type of Structure	Magnitude	Duration
High	Power Stations etc	8 - 8.5	40 - 45 seconds
Normal	Public Buildings	7.5	35 seconds
	Other Buildings	7.0	30 seconds
Low	Other Buildings	6.5	30 seconds

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