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PROBLEMS IN FORMULATING A COUNTRY'S CODE OF PRACTICE FOR EARTHQUAKE RESISTANT CONSTRUCTION

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INTRODUCTION

A survey of the methods of construction in severely seismic areas such as Japan, Assam and Himalayan regions Greece and Italy etc. shows that a process of trial and error had led people to adopt practices which increased the resistance of their dwellings to earthquakes. For example, it was appreciated that the lightest materials such as timber. bamboo etc. be used either as means of strengthening or as walls and roofs to make dwellings safe against earthquakes. Other considerations – availability of materials and skills, climatic requirements etc. – also determined the form of construction but there is hardly a doubt that relative performance of heavy and light constructions during earthquakes must have gone to suggest these practices. In other areas where occurrence of shocks was not so frequent no special steps were taken and brick and stone masonry construction continued to be used without strengthening.

The changes in functional requirements and ease in construction, durability and relative costs have necessitated adopting other forms of construction. It was however, realized that it was necessary to design structures for a horizontal force in proportion to the weight of the structures as a safeguard against earthquakes. Yet this knowledge was utilized only in very important structures. The idea of having a code of practice to account for earthquake forces did not take shape till the beginning of this century and the task has been taken more seriously only in the last 20 years or so. The objective of this paper is to describe the questions that arise in drawing up of a code and how far its provisions remain arbitrary.

SEISMIC ZONING MAP

The first requirement of a code of practice is to suggest the divisions of a country into areas with different order of seismicity. The information required for the this purpose is :

(a) Epicentres of the Past Earthquakes.

Except for very large earthquakes resulting in considerable damage, the data available does not extend into centuries before the present one since before this there were not many seismographs.

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It is usually assumed that future earthquakes in the next two or three centuries may be expected to occur in the same regions as they have occurred so far. This approach gives reliable information for zoning if sufficient data is available. In areas, where occurrence of earthquakes is not recorded, this method may lead to underestimation of seismicity.

Another factor that will determine zoning is the frequency of occurrence of earthquakes in a region. Data is generally not adequate to take it into account, but where a major earthquake has not occurred inspite of tectonic possibilities in the last one century or so a lower order of seismicity is assumed in the interest of economy.

(b) Tectonic Features

A detailed geological mapping indicates tectonic features except where rocks are not exposed such as in alluvial plains. A problem arises here whether tectonic features indicated in the exposed areas are active at present and are likely to cause earthquakes in the next two or three centuries or they are dormant This can be decided only through a long-period recording of micro-tremors by sensitive seismographs in various regions. Many seismic areas do not have a close-enough network of such instruments. If it were there, it will also locate faults underlying alluvium In the absence of adequate information the historical information discussed in (*a*) should decide, assisted by distinctly active tectonic features. If we were to give more weightage to tectonics without sufficient data about recent movement, it may lead to overestimation of seismicity. A network of instruments is, therefore, a necessity for a precise zoning map. Till then zoning in many parts will continue to be arbitrary.

It may be appreciated that overestimation of seismicity leads to a good deal of additional expenditure on all structures designed on this basis while underestimation runs the risk of a disaster. Generally speaking, it is difficult to convince the designers of taking large earthquake coefficients into account merely on the basis of indications of tectonics. Actual occurrence of earthquakes alone convinces them of the need to design for high seismic factors. Thus it is essential to keep the map under review constantly to take into account more data as it becomes available through occurrence of earthquakes or recording of micro-tremors or detailed geological mapping.

BASIC DESIGN COEFFICIENTS

It is realized that an earthquake is a dynamic phenomenon consisting of a series of impulses of random magnitude and direction occurring at varying intervals of time. Thus drawing up rules to take such a motion into account necessarily would be based upon some arbitrary assumptions. Some of these are :

(i) The dominant effect of an earthquake is equivalent to a static horizontal and a vertical force applied one at a time or simultaneously depending upon the characteristics of the structure to be designed.

(ii) The magnitude of forces may be determined on the basis that full resonance will not develop during earthquakes.

(iii) Earthquakes will not occur very close to the structure and the fault slips do not occur under the structure itself.

Dynamic analysis has shown that structures which are flexible and have displacements relative to the ground are subjected to bigger inertia accelerations near the top than down below it. To assume a uniform force to be applied along one axis at a time is a simplification justified only by the necessity to curtail the effort involved in a dynamic analysis. Further justification is that the structures designed on this basis in the last 75 years or so have stood earthquakes well, and so specifying a coefficient for equivalent static design is adequate for average structures with the proviso that all important and special structures are designed on the basis of dynamic analysis.

The choice of a coefficient presents an economic problem. We have to consider (i) additional initial cost of a structure when designed for a certain level of earthquake forces (ii) acceptable damage (short of collapse) depending upon the cost of repairs (iii) energy absorbing capacity of materials to stand strains beyond yield limit and yet before instability is reached, and (iv) type of foundation. Further, there can be two ways of designing—one to adopt low coefficients and low working stresses and the other to have high coeffieients and high working stresses. Naturally, the latter will enable a larger portion of the structure to be utilized to a higher stress capacity.

It may he appreciated that the earthquake forces are dependent upon the dynamic properties of the structure itself. Thus to provide for a uniform coefficient for all types of structures in a zone is itself a gross simplification. Further, an ideal design requires the resistance of a structure to an earthquake to be as uniform as feasible. A uniform coefficient cannot achieve this. Inspite of all these problems. it is convenient to allow for a specified uniform coefficient in the designs which by and large serves the purpose. The values of the coefficients are fixed arbitrarily taking into account the economics of design as explained earlier. The coefficients in zones away from the epicentral tract are fixed taking into account attenuation expected but, more or less, they are also arbitrary.

Structures designed on the basis of coefficients specified in the Code should be able to stand moderate earthquakes without much damage and escape collapse in major shocks. The coefficients should not be considered to have a direct relationship with actual earthquake forces but they are factors for which if a design is worked out the structure will offer much better resistance to earthquakes.

DYNAMIC DESIGN

The above discussion will show that for important structures use of arbitrary coefficients is not advisable. An appropriate way of dealing with the problem is to design the structure for a chosen accelerogram for an actual earthquake. This will need to be modified to suit local conditions—seismicity and foundation characteristics. For example, in hard rock conditions, a frequency of 10 to 15 cycles per second for the impulses will be appropriate, whereas in soft alluvium the frequency may fall to 2 to 3 cycles per seeond. The amplitude may be fixed in accordance with the distance from the expected epicentre[1,2].

A design prepared on the basis of actual accelerogram however, should take into account full energy absorbing capacity i. e. with a small load factor. The only limitation will be that the 'deformation' of the structure should not exceed the limit of stability. Reduction in load factor is feasible because an actual ground motion has been accounted for and not an arbitrary equivalent coefficient. The design on this basis is rational and must be left to the specialist because choosing an accelerogram and modifying it to suit local conditions requires judgement and experience, and it is difficult to specify rules in this respect in a code of practice.

As an example, an earth dam situated in Himalayan tracts where the rock formations are not very solid but much better than alluvium, the El Centro Earthquake record of May

18, 1940 could be used by decreasing the time base of the record appropriately. In hard rock such as granite or trap formations this, may be increased further and may be of the order of 12 to 15 cycles per second.

Dynamic analysis rationalises design. An earth dam which according to the code will be designed for a uniform coefficient of say 20% g may be found to be more rationally designed through dynamic analysis by taking varying factors as in figure 1.

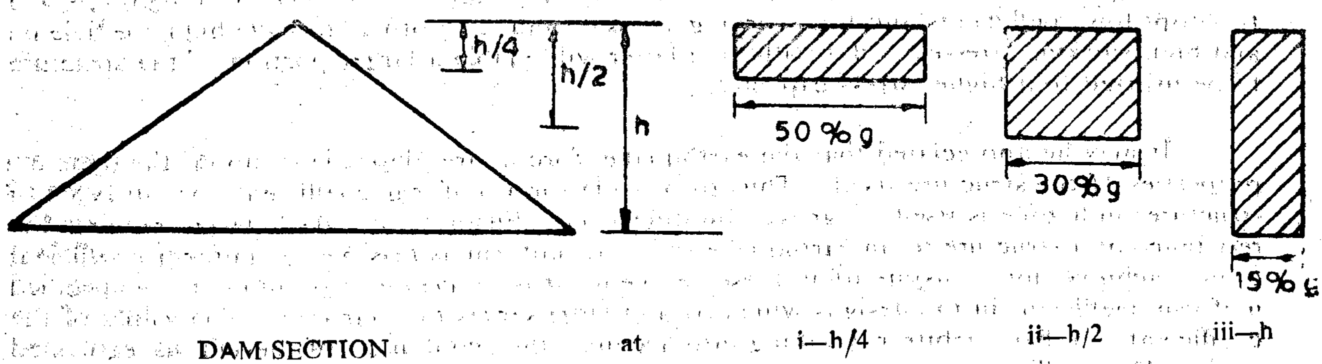

Figure 1. Acceleration For Testing Stability of Dam Section

It may be mentioned that the values—50% or 33% or 15% will differ with the section of dam and are stated here only as an example. This provides strength in sections as it would be required to resist an actual earthquake. Yet a code of practice provides for a uniform coefficient for the sake of convenience so that a preliminerv section could be arrived at, which then be tested by dynamic analysis for an appropriate accelerogram.

PERMISSIBLE DECREASE OF SAFETY FACTOR

Increase of permissible "Working Stresses" for elastic design and decrease of "load factors" for plastic design, when earthquake forces are taken into account, go very much with the basic design coefficients. The decrease in the margin of safety is justified because an earthquake force is an occasional one and lasts for a very short duration. The extent of this decrease is a function of the reliability our knowledge with respect to the properties of materials and analysis of the structural behaviour. At the same time the extent of damage or deformation that could be accepted in the event of a major earthquake and whether the basic coefficients are high or low will also determine this. For example, in materials like steel or R.C., the analytical methods and properties of materials are fairly well known and considerable reduction of safety (say to 1.5 for low to moderate coefficients as in Indian Code and to 12.5 or so for high coefficients as in Japanese Code) consistent with level of equivalent seismic forces, is justified. For the bearing capacity in poor soils, no reduction of safety may be permissible. In earthen structures, such as dams where repairs are not expensive small damage can be accepted consistent with stability. There the safety factor may fall to one only.

For convenience, however, a uniform provision for increase of working stresses, and a uniformly reduced load factor is made. In important cases, a detailed consideration of the materials and structural behaviour is advisable particularly when use of dynamic analysis discussed earlier is justified and basic coefficients are not used.

PROPORTION OF LIVE LOADS FOR DESIGN

The designer requires information about the proportion of live load that should be allowed for along with the earthquake forces. It is indeed very difficult to estimate it and it would be an overestimate if full design live load is assumed to act simultaneously with the earthquake, and also it would be incorrect. A design load consists of several parts ; (i) Moveable load but more or less permanently present such as furniture in a building (ii) actually moving load and (iii) impact due to the moving load. Since the inertia force due to an earthquake acts on the mass of the structure, the impact should not be included in calculating the earthquake force while moveable load should always be included. It is only the proportion of moving load that has to be estimated. In estimating this the nature of loads has also to be considered. For example, a moving vehicle absorbs a good deal of energy in its springs and also kinetic energy if it moves due to the earthquake force. These proportions will, however, vary from vehicle to vehicle. A Code cannot take into account all factors and therefore, provisions are made for average conditions. Wherever more specific information is available, it should be used in preference to the provisions in the Code.

OCCASIONAL LOAD COMBINATIONS WITH EARTHQUAKE FORCES

The occasional loads that occur in bridges and dams are :

(i) Wind

(ii) Flood and

(iii) Earthquake

In the case of buildings Wind and Earthquakes only occur.

It is generally assumed that strongest wind and severest earthquakes will not occur simultaneously and the probability of this occurring is extremely low. Similarly, the assumption that strongest wind, severest earthquake and the highest flood are not likely to occur together is sound. Yet what level of flood and how strong a wind could be blowing at the time of earthquake is a question, a designer has to estimate. The Code recommends that in the case of concrete and masonry dams, highest flood and severest earthquake may be considered together. In earth and rock-fill dams wind can also be important since an earth dam cannot stand any overtopping, and the situation can be aggravated by the compaction of material and consequent settlement due to an earthquake. Average wind force, mean annual flood and the severest earthquake are perhaps a reasonable combination to allow for but an element of arbitrariness cannot be escaped.

In the case of bridges also, mean annual flood with corresponding depth of scour could be taken to occur along with the severest earthquake. All the same, an element of remote probability of everything at the worst occurring together cannot be ruled out, but it would be reasonable to risk that accident rather than investing huge sums of money in all structures on this basis. Perhaps the loss suffered once in a thousand years will be a lot less than the gain due to additional facilities built from savings by ignoring the extreme combinations. A Code, therefore, provides for average conditions only.

CONCLUSIONS

A Code of Practice gives guidance for designing average structures in average conditions. More important structures should be dealt with through detailed dynamic analysis, but even their design on the basis of the provisions in a Code will provide in them a good deal of more resistance to earthquakes than they would otherwise have. In any case code provisions are indispensable for preliminery designs. Dynamic analysis will lead to more efficient designs.

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