Seismic design of structures

by Dr. A. M. Elsaie

Earthquakes can cause loss of life when structures fail or reach extreme deformation limits. In order to ensure structural integrity, seismic analysis has become an important design criterion. Existing engineering design codes have been based on different approaches to structural integrity such as stress intensity limits, fatigue considerations, working stresses, ultimate strength and plastic analysis. General purpose computer programs have been developed that can handle seismic analysis.

FOR the engineer or scientist involved in the examination of structures, the threat of earthquake demands a knowledge of seismic analysis, an important design criterion ensuring structural integrity. In order to predict the performance of any structure, specified design loads must be prescribed. These give evidence as to how the structure will react or perform when subjected to applied forces. In the case of actual earthquakes, loadings have a random shape along three perpendicular axes. But in an attempt to analyze how a structure will perform during an earthquake, ground motion must be prescribed in some way.

It can be assumed that the future earthquake is either similar to one in the past or averaged from previous earthquakes. The design ground motion can then be obtained by scaling the earthquake shape up or down depending upon the design site. General purpose computer programs have now been developed to handle this kind of seismic analysis.

El Centro—An Accepted Design Condition

On May 18, 1940, the ground motion of an earthquake which occurred in El Centro, California, was recorded. That accelogram is shown in Fig. 1. The motion computed from North-South component of El Centro earthquake is shown in Fig. 2. Fig. 3 represents the response spectra for the El Centro earthquake. The earthquake was considered to have produced a severe design condition for its high levels of acceleration and its long duration. The maximum horizontal accelerations were 0.35g and 0.21g. The maximum vertical acceleration was 0.21g with a duration of more than 30 seconds. Larger ground motions have been recorded, but the El Centro earthquake, suitably scaled, remains an accepted design condition. Many commercial computer programs handling seismic analysis provide El Centro ground motions as part of their programs.

A Standard Average

An alternative approach is that of a synthetic accelerogram which embodies certain average properties of past earthquakes rather than duplicating any specific one. Such an earthquake should have the general pattern of amplitudes, acceleration and duration typical of recorded past earthquakes. By studying previous earthquakes, a standard average ground motion can be produced for design purposes.

Design Spectrum Formulation

An example of a recent design spectrum formulation in Figure 4 shows the response spectrum for seismic design of nuclear power plants in the United States Atomic Energy Commission Regulatory Guide, No. 1.60, October, 1973. The figure shows the horizontal design response spectrum scaled to 1g horizontal ground acceleration. The idea is to produce relatively simple shapes roughly similar to average recorded earthquakes. It should be noted that at low frequency, the spectrum curve tends to approach constant relative displacement criteria. At high frequencies, a constant absolute acceleration criteria is reached while intermediate frequencies produce a constant relative velocity condition.

Seismic Response of Structural Components

When a structural component is subjected to an earthquake, its base or support tends to move with the ground. If the structure is rigid, it moves with the motion of its base. In this case, the dynamic forces acting on it are very nearly equal to those associated with its base acceleration. However, if the structure is flexible, large relative motion and stresses can be induced because of the differential motions between the masses of the structure and its base. In order to survive dynamic motions, the structure must be strong enough as well as ductible enough to resist the forces and deformations imposed upon it.

The energy absorption of a structure from damping depends upon the type of joints or connections within it in addition to the levels of stresses and deformation under resonant frequencies. Resonant frequencies of a structure depend upon the distribution of mass and stiffness within the structure and its

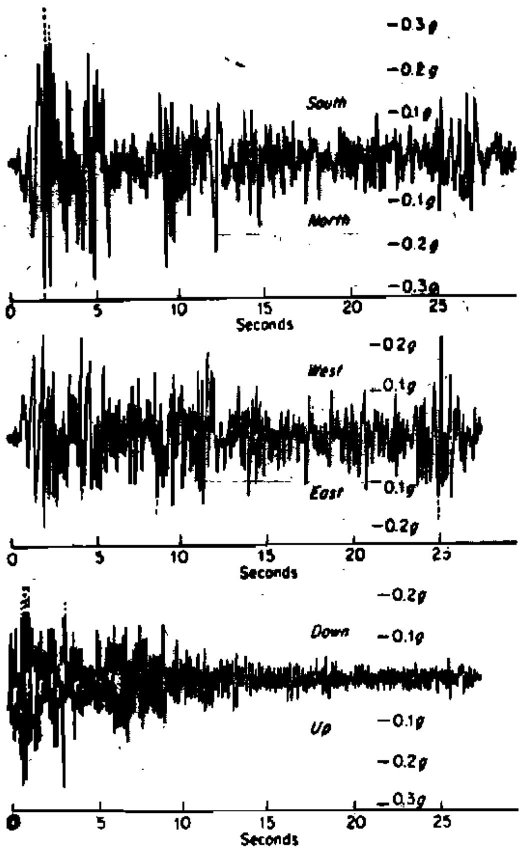

Fig. 1— Accelerograph from El Centro earthquake May 18, 1940 (from Anderson et. al., 1952).

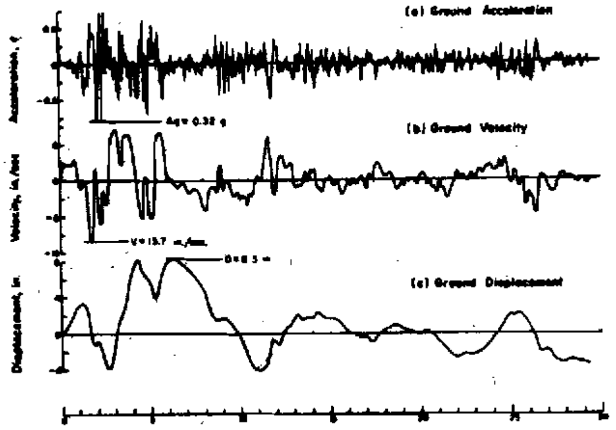

Fig. 2— Motions computed from N-S component of earthquake at El Centro of May 18, 1940 (from Newmark, 1965).

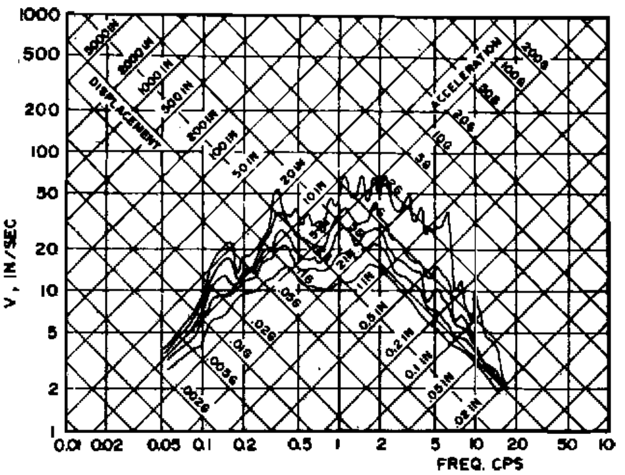

Fig. 3— Response spectra for El Centro earthquake (May 18, 1940, N-S component) plotted on special graph paper for 0, 2, 5, 10, 20% damping (from Newmark, 1967).

supporting condition.

The dynamic amplitudes and stresses of a structure depend not only on the intensity of the earthquake, but also on the properties of the structure itself. Among these properties, the most important is the energy absorbed within the structure, either due to damping or inelastic behaviour, its resonant frequencies and its strength or resistance.

Seismic Qualification

Seismic analysis of a structure should be performed to calculate the structural response due to seismic and all non-seismic forces. For seismic loading, the following procedures are among those used to transform the input earthquake motion to motion of the structure.

1. Static Analysis Method.

The dynamic load is specified in terms of a constant times the weight of the structure. The load is being applied opposite to the direction of the specified input or shock motion. With these loads a static analysis is used to obtain stresses and deflection. This method can be used if the structure can be classified as a rigid one.

2. Static/Dynamic Method.

Assuming the gravity to be acting in a direction opposite to the direction of the shock to be analysed, the static deflection of the structure is calculated. The dynamic deflections are assumed to be proportional to these calculated static deflections. On this basis, the natural frequency and the response of the shock can be estimated. This method gives reasonable accuracy for the frequency mode being approximated and results in a dynamic acceleration that varies proportionally to the calculated static deflections.

The structure to be analysed is divided into parts, the weight of each part being W_i and the static deflection being x_i. A participation factor is defined as:

$$P = \frac{\Sigma W_i x_i}{\Sigma W_i x_i^2} \qquad (1)$$

The stresses may be calculated by applying static forces L_i in the direction opposite to the direction of the shock at each position i, where

$$L_i = W_i P x_i N \qquad (2)$$

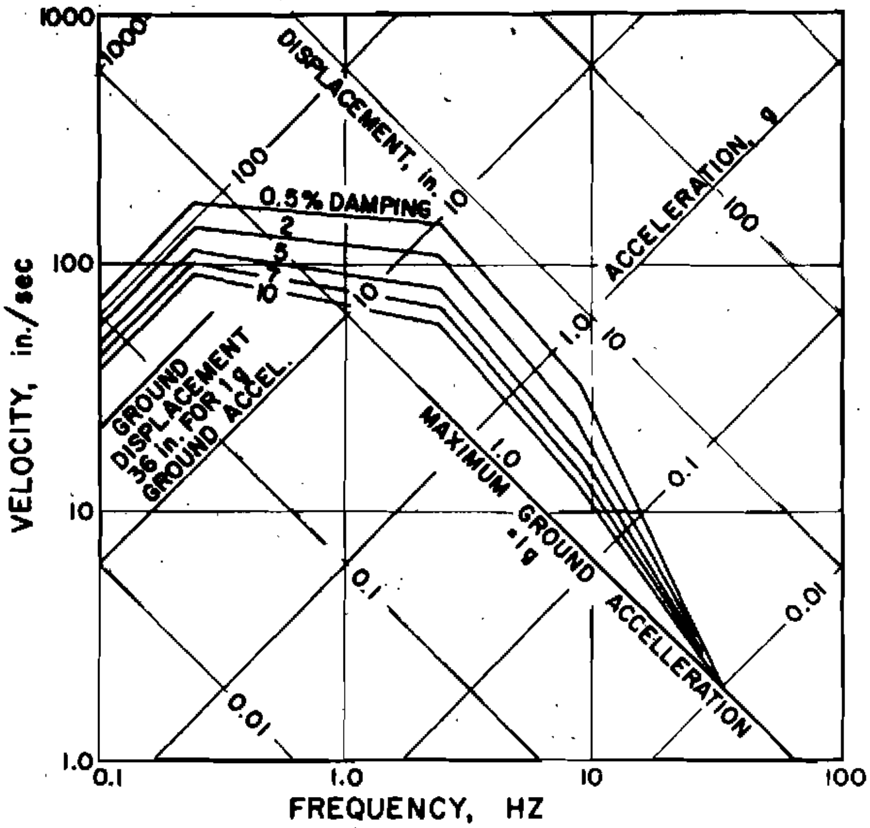

Fig. 4—Standard AEC design spectrum for horizontal ground motions, scaled to 1G.

The base shock is assumed prescribed as N in units of the acceleration of the gravity, where N may be taken from a response spectrum as a function of the frequency. The displacement response Y_i at each point i may be estimated from:

$$Y_i = Nx_i \quad (3)$$

The natural frequency with the base fixed can be estimated from:

$$f = \frac{1}{2\Pi} \sqrt{g.P}$$

where g is the gravitational acceleration and is equal to 386.4 in/sec.[2]. The application of a factor of safety to the loads L_i and the deflections Y_i should generally be considered, particularly for deflection sensitive structures.

3. Modal Analysis

Modal analysis, a procedure often used by the Ontario Research Foundation, is defined as the complete dynamic analysis of the structure when subjected to the earthquake ground motion. A mathematical model is formed by dividing the structure into lumped masses or finite elements. Using a computer program suitable for seismic analysis, the natural frequencies, mode shapes of vibration and modal participation factor are determined. The ground motions are applied to the structure to calculate the dynamic amplitudes and stresses. The calculated amplitudes and stresses from three perpendicular directions are then combined according to the relevant design code.

Engineering Design Codes

Engineering design codes ensure that structures subjected to earthquakes must be safe. Ground acceleration is assumed constant within each seismic zone. Generally, seismic analysis can be performed for mechanical or electrical equipment such as valves or generators besides structures like buildings and towers. Ontario Research and other similar organizations offer services in this area to assist engineering consultants and manufacturers in the efficient use of different techniques for seismis analysis.

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References

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