A STRUCTURAL ANALYSIS PROCEDURE FOR EARTHQUAKE LOADINGS

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SUMMARY

The research describes an approximate procedure for designing and analyzing structures subject to earthquake loads. New parameters, variables and equations are utilized based upon a fundamental energy approach which follows from a consideration of the two major sources of field data. These data bases lead to time and space variations of energy and the entire procedure is one which can be utilized by ordinary engineering design offices.

INTRODUCTION

This research is founded on three fundamental (and related) premises:

1) Earthquake engineering is a unique discipline in the overall field of applied mechanics, just as for example, elasticity and heat flow are separate and different. Therefore, earthquake engineering has its own particular invariants, parameters, equations, variables and similar quantities - and furthermore these should be very different from the other well-known terms and relations in applied mechanics. Earthquake Engineering is not simply a problem in vibration analysis.

2) The sources or fountain heads for all the quantities mentioned above (the invariants, parameters etc.) will be the two major observation banks or experimental data or field data) of earthquake engineering, these being:

   a) The accelerogram which, physically, must be related in some fashion to the variation with time of ground energy at a point in the earthquake field.

   b) The isoseismal contour map which, physically, must be related in some fashion to the variation with distance of the ground energy over the entire area affected by the earthquake.

Note, therefore, that proceeding from 1) to 2) above we are led directly to:

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3) namely, energy is the key element, the basic ingredient in the entire earthquake event, starting from its initiation (the mechanism) and proceeding timewise and spacewise until its completion with the accompanying all-too-frequent tragedy of death and destruction.

The complete research, Ref. 1 - covers every facet of the earthquake from its initiation (a mechanism) up to and including its effect on and the response of structures. New parameters, invariants, equations and similar relations are introduced and a complete unified, rational approximate theory of earthquake engineering is developed.

In this report only those portions of the study related to the structural design-analysis problem will be discussed.

THE ACCELERATION INDEX (INVARIANT)

An analysis and study of a number of accelerograms, and physical considerations, suggest that $\sum_{t=0}^{t} (a\Delta t)$ and t are the important variables in this phenomenon, and in particular $\Sigma\,(a\Delta t)_f$ and t_f are the fundamental parameters. a is the acceleration, t is the time between t = 0 (the initiation of the accelerogram record) t_f is the final time corresponding to a return to zero acceleration. $\Sigma\,(a\Delta t)$ is the area under the envelope to the accelerogram.

A mathematical derivation leads to an invariant expression which holds for "canonical" accelerograms, this being

$$\frac{\sum_{t=0}^{t} (a\Delta t)}{\sum_{t=0}^{t} (a\Delta t)_f} = e^{0.12\left[1 - \left(\frac{t_f}{t}\right)^{1.8}\right]} \qquad (1)$$

For those accelerograms that are not "canonical" we can generally superpose two or more canonical accelerograms.

By utilizing an alternate, but equivalent postulated mathematical formulation, equating equal terms, and integrating we obtain an equation for the timewise variation of horizontal ground energy at the point where the canonical accelerogram was obtained, Eq. 2:

$$\frac{\varepsilon_t}{\varepsilon_{t_f}} = \frac{\left[\left(\frac{t_f}{t}\right)^{1.8} - \left(\frac{t_f}{t_i}\right)^{1.8}\right]}{\left[1 - \left(\frac{t_f}{t_i}\right)^{1.8}\right]} \tag{2}$$

ε_t = surface horizontal energy per unit effective area between the times t_i and t at the accelerogram location.

ε_{t_f} = same for $t \to t_f$

For two or more superposed canonical records we superpose the energy expressions.

THE GEOLOGY OF THE REGION

Physically, we must assume that the "geology" of a region affects the ground behavior and structural response. We assume, at this time, 3 "geologies" similar to but different from the regions described by Newmark and Rosenblueth.

These are:

R_1 = Surface Fault Region
(The Circumpacific Belt) N-R

R_2 = Mountain Region
(The Alpide Belt) N-R

R_3 = Plains Region
(The Low Seismicity Region) N-R

In a general way, frequency of the acceleration record is accounted for in this classification. These geological designations are used in the mathematical, physical and technical formulations throughout the research, as we shall see typically, in the present structural analysis portion of the study. If necessary and desirable other or additional (or fewer) geologies may be specified.

THE ISOSEISMAL INDEX (INVARIANT)

An analysis and study of 28 earthquakes (with $M \gtrsim 5$) during the past 500 years, occuring all over the earth, as well as physical considerations, suggest that $\sum_{S=0}^{S}(IS)$ and S are the important variables in the isoseismal map representation and that, in particular, $\Sigma\ (IS)_f$ and S_f are the fundamental parameters.

A mathematical derivation leads to an invariant expression which holds for all 28 earthquakes, this being Eq. 3,

$$\frac{\sum_{S=0}^{S}(IS)}{\sum_{S=0}^{S}(IS)_f} = e^{2.0[1-(\frac{S_f}{S})^{1/3}]} \tag{3}$$

In the above, I is the Mercalli scale intensity, S is the distance to the center of the constant intensity region and the summation extends from S = 0, the epicenter, up to $S = S_f$, the distance to the intensity = III region.

By utilizing an alternate but equivalent postulated mathematical formulation, equating equal terms and integrating, we obtain an equation for the <u>spacewise</u> variation of horizontal ground energy over the <u>entire</u> field affected by the earthquake, Eq. 4,

$$\frac{W}{H} = \frac{[(\frac{S_f}{S_i})^{1/3} - (\frac{S_f}{S})^{1/3}]}{[(\frac{S_f}{S_i})^{1/3} - 1]} \tag{4}$$

W = total surface horizontal energy between the small radius S_i and any radius S

H = same as above for $S \to S_f$

THE $\Sigma(a\Delta t)_f - t_f$ - INTENSITY (ENERGY) CORRELATION

Physically, $\Sigma(a\Delta t)_f$ and t_f must be connected with the damage to structures, hence to the intensity and also to the energy at a point in the earthquake field. A study of a limited number of accelerograms (corrected for direction) that had isoseismal maps for the same events leads to a preliminary map relating the accelerogram parameters and energy, Ref. 1.

THE $\Sigma(IS)_f$ - S_f - MAGNITUDE (M) CORRELATION

Physically, $\Sigma(IS)_f$ and S_f must be related to the magnitude, M, of the earthquake. Using the 28 earthquakes previously mentioned, such a correlation (including geology effects) has, in fact been approximately established, Ref. 1.

THE MAGNITUDE - INTENSITY (ENERGY) - DISTANCE CHART

Using the equations and correlations given above, for a given M and geology, R, we can determine $\Sigma(IS)_f$ and S_f and the corresponding isoseismal map may be computed and plotted from which the energy field may be estimated.

THE STRUCTURAL ANALYSIS

The structural design/analysis procedure utilizes all the proceeding equations, curves and charts. The connection with energy is the basic element and the connection is made by utilizing elementary concepts of strain energy suitably modified to account for the behavior of structures during earthquakes.

The approximate approach assumes overall conservation of energy and introduces a procedure which will account approximately for soil - structure interaction, damping and - quite important - brings into the structural considerations in a rational form all of the parameters and variables that should enter into an analysis of structures subjected to earthquakes.

The complete details are covered in Ref. 1.

For our present purposes we may say that, tentatively, for buildings, four different stain energy design procedures appear warranted, depending upon height - base length ratio of the building and the type of construction.

Thus, Type 1, a tall building with $\ell/d \gtrsim 5$, a free-free vibrating beam analysis is suggested, Ref. 1.

For Type 2, $\ell/d \lesssim 5$, concrete block or brick or similar walls, a shear energy analysis is suggested.

For Type 3, $\ell/d \lesssim 5$, reinforced concrete, open steel framing, steel framing plus facing (generally moment connections and continuity), a combined bending and shear energy is suggested.

For Type 4, truss structure, steel framing, pin connected members, a tension - compression energy analysis is indicated.

For other structures (dams, stacks etc.) the appropriate energy analysis may be determined.

In all cases, it is necessary to design the structure so that it will absorb the energy generated by the earthquake (a known quantity) as strain and potential energy without overstressing, cracking or rupturing.

CONCLUSION

The design process, as in all engineering design, starts with specified or code or judgement design decisions. These could be, typically,

a) A specified canonical accelerogram or cluster of canonical accelerograms with given separate $\Sigma(a\Delta t)_f$ and t_f values and geology.

or

b) A given earthquake magnitude, efficiency, geology from which $\Sigma(IS)_f$ and S_f are obtained.

or other similar data.

From these, using the equations and charts derived from this theory, one can determine all of the necessary earthquake engineering parameters required for the rational, analytical assessment of damage and for the structural design.

REFERENCES

1) S.F. Borg, "Earthquake Engineering - Damage Assessment and Structural Analysis," Wiley Heyden Publishing Company, London, England, in press.
Also, a series of reports and abstract presentations.

a) A Mathematical-Physical Model of a Deep-Focus Earthquake Mechanism, Eleventh Annual Modeling and Simulation Conference, Univ. of Pittsburgh, Pittsburgh, PA, 15261, May 1-2, 1980. Also Technical Report ME/CE-79, Department of Mechanical Engineering (Civil Engineering), Stevens Institute of Technology, Hoboken, N.J., Nov. 1979.

b) Accelerogram, Intensity, Damage - A New Correlation for Use in Earthquake Engineering Design, Seventh World Conference on Earthquake Engineering, Istanbul, Sept. 8-13, 1980. Also Technical Report ME/CE-791, Department of Mechanical Engineering (Civil Engineering), Stevens Institute of Technology, Hoboken, N.J., Dec. 1979.

c) An Isoseismal-Energy Correlation for Use in Earthquake Structural Design, Seventh World Conference on Earthquake Engineering, Istanbul, Turkey, Sept. 8-13, 1980. Also Technical Report ME/CE-792, Department of Mechanical Engineering (Civil Engineering), Stevens Institute of Technology, Hoboken, N.J., Dec. 1979.

d) Extended Analyses of Isoseismal-Magnitude-Intensity Index Correlations in Earthquake Engineering, Tech. Rept. ME/CE - 81-1, Department of Mechanical Engineering/Civil Engineering, Stevens Institute of Technology, Hoboken, N.J., May, 1981.

e) Some New Approximate Procedures Relating to the Analysis of Structures Subjected to Earthquake Loadings - Part 1, Elastic Theory, Tech. Rept. ME/CE - 80-1, Department of Mechanical Engineering/Civil Engineering, Stevens Institute of Technology, Aug. 1980.

f) Some New Approximate Procedures Relating to the Analysis of Structures Subjected to Earthquake Loadings - Part II, Applications, Tech. Rept. ME/CE - 80-2, Department of Mechanical Engineering/Civil Engineering, Stevens Institute of Technology, Hoboken, N.J., Dec. 1980.

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