SEISMIC DESIGN AND ANALYSIS PROVISIONS FOR THE UNITED STATES

by

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SYNOPSIS

The seismic design and analysis requirements presently used in U.S. building codes were largely developed in the Recommended Lateral Force Requirements and Commentary published by the Seismology Committee of the Structural Engineers Association of California in 1959-1960. Since that time, improvements and modifications have been made at frequent intervals. Several years ago it became apparent that a comprehensive review should be made of the provisions, the latest state of knowledge should be evaluated, and a coordinated set of provisions should be developed. This paper describes the basic concepts and summarizes some of the details of the structural design provisions of a new code developed by the Applied Technology Council.

INTRODUCTION

A cooperative program to develop new provisions was initiated in the Fall of 1974 by the Applied Technology Council (ATC) under a contract with the National Bureau of Standards (NBS) funded by the National Science Foundation (NSF) - RANN program and NBS. The performance of buildings during recent earthquakes was evaluated and weaknesses in present code provisions were studied.

The new provisions represent the efforts of 85 participants in 14 Technical Committees organized into 5 Task Groups. This paper is concerned primarily with the effort of Task Group II, on Structural Analysis and Design, although it draws in part on the work done by other Task Groups. Professor Newmark is Chairman of Task Group II and also Chairman of the Task Group Coordinating Committee. Mr. Degenkolb and Professors

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Chopra and Veletsos are Chairmen of the 3 Technical Committees in Task Group II, Professor Rosenblueth is a major contributor to the work of the Group, and Mr. Sharpe is Project Director of the program for the ATC.

A working draft of the new provisions was distributed in February 1975 to some 500 reviewers in practice, industry, professional organizations, government agencies, and universities. Upon completion of a review by the Technical Committees of the comments received, another draft for limited review will be completed this fall, and the final report will be issued in the late spring of 1977.

It is intended that the final recommendations will be of such a form that they can be adopted by jurisdictions through the United States.

BASIC CONCEPTS

The new ATC design recommendations are intended to be logically based, with explicit consideration given to factors that are generally implicit in previous codes and design provisions. The earthquake hazard is defined in the code by a map with contours indicating the "Effective Peak Acceleration" (EPA) in various regions of the United States. Interpolation between contours is permitted. These values range from 0.05 g to 0.4 g, with these extremes being the lowest and the highest values considered in any region of the country. In some regions, consideration is given to the longer durations of somewhat less intense motions by using a map showing Effective Peak Velocity (EPV). Rules are prescribed for determining the design spectrum corresponding to any given levels of EPA and EPV. These are discussed more completely in a companion paper by Whitman et al.

Buildings are classified from the point of view of design by hazard exposure factors and building design categories. When these are selected, the procedure that follows depends on the design spectrum. This design spectrum is used both for simplified analyses through the use of an equivalent lateral force factor or with a modal analysis. The design spectrum is modified by a soil factor which is a function of the type of soil conditions, considered in three categories, as firm soil or rock sites, deep soil sites, and soft soil sites. The response spectrum is also modified by a spectral reduction factor, R, which is used to divide the basic spectrum to obtain the design spectrum appropriate for the particular category of structural framing and materials.

The spectral reduction factor is a function of the ductility factor appropriate to the particular structural type, materials, framing, and category, and any variation in damping consistent with those parameters, if the damping differs from the standard level of 5% of critical damping. The factor also includes an experience or judgment factor to take account of the inherently better capabilities and performance in actual earthquakes of some types of structures and materials compared with others. Tables are given in the recommendations for the selection of the spectral reduction factor.

The base shear is determined in standard ways from the design spectrum and the mass of the building, through the use of an appropriate fundamental period of vibration for the building. The latter can be determined from relations given in the text for different building framings and types or may be computed by fundamental methods of structural dynamics.

The distribution of seismic forces over the height of the building for the purpose of computing shears and overturning moments, is based on an extrapolation between a linear and a parabolic distribution of accelerations over the height, by means of relations which prescribe a linear distribution for periods less than 0.5 seconds, and a parabolic distribution for periods greater than 3.5 seconds, with a linear interpolation between those limits.

Overturning moments computed from the seismic force distributions may be reduced under certain conditions, but generally not in the upper ten stories of the building, and not by more than 20% in the building itself, with an additional 10% reduction being permitted in determining the foundation forces under the building.

Provisions are given in the code for calculation of drift, and for torsional requirements. Recommendations for construction and design details, in lieu of requiring detailed analyses, are stated for buildings in areas with nominal seismicity.

All of the above factors are stated explicitly in the design provisions. Of particular interest are the requirements for construction and design details, varying in degree of rigor with the seismic zone or acceleration level for the building and its seismic hazard exposure factor. Also, as a function of these quantities, methods of analysis are specified, including a constant coefficient method which may be used in only the least hazardous seismic zones, for buildings of lowest hazard exposure factors, an Equivalent Lateral Force method (ELF) for buildings in general in all zones, and modal analysis which may be used and is recommended under some conditions for the most highly seismic zones for buildings with the highest hazard exposure factors.

The design base shear is computed from the product of the design spectral coefficient C_s multiplied by the effective weight of the building W. The quantity C_s is given by the relationship:

$$C_s = 1.2\ AG/RT^{2/3}$$

In this relationship, the quantities are defined as follows:

A = Effective Peak Acceleration value based on the EPA or EPV maps.

G = soil profile factor ranging from 1.0 for rock and stiff soil sites to 1.5 for soft soil sites.

R = response modification coefficient depending on type of structural system, including vertical and horizontal lateral force distribution systems.

T = measure of fundamental period of vibration based on framing method and geometry of building.

The value of C_s need not exceed 2.5 A/R for rock or stiff soil sites or deep soil sites nor 2.0 A/R for soft soil sites.

Finally, provisions are made for increased seismic forces when the safety of the building is dependent on the survival of a single major force resisting element; and similar provisions are made for increases in seismic factors when large discontinuities in story strengths or stiffness occur.

SOIL-STRUCTURE INTERACTION

Two different approaches can be used to assess the effects of soil-structure interaction on the seismic response of structures. The first consists in modifying the stipulated free-field design ground motion and evaluating the response of the structure to the modified base motion, whereas the second consists in modifying the dynamic properties of the structure and evaluating the response of the modified structure to the prescribed free-field ground motion. The design provisions used are based on the second approach.

The interaction effects in this approach are expressed by (1) an increase in the fundamental natural period of the structure; and (2) a change (usually increase) in its effective damping. The increase in period accounts for the compressibility of the foundational soil, whereas the change in damping accounts primarily for the effects of the energy dissipated in the supporting soil by radiation and hysteretic action.

For the assumptions made in the development of the recommended design provisions for fixed-base structures, soil-structure interaction reduces the design forces below those applicable to a fixed-base condition. Accordingly, the structure may be designed conservatively without consideration for interaction. Hence the use of the relations for soil-structure interaction is optional with the designer. Because of the effect of foundation rocking, however, the displacements of the floors relative to the base may increase, and this would increase the requirements on separation of buildings and the P-Delta effects.

Formulas are given in the recommended provisions for the reduction in total lateral force or base shear for the structure, as a function of the effective weight of the structure, and the seismic coefficients applicable to the fundamental natural periods of vibration and the effective damping factors of the structure (a) with a fixed base and (b) with interaction with the soil. It is assumed that the soil-structure interaction affects only the response component contributed by the fundamental mode of vibration of the fixed base structure.

In defining the effective coefficient of damping, account is taken of the damping in the structure and both material and radiation damping in the foundation. The fundamental period of the structure and foundation takes into account the translational and rotational stiffness of the foundation material when forces are applied to a rigid slab on the foundation. These stiffnesses are given in terms of the shear modulus of the foundation, which is taken as a fraction ranging from about 0.4 to 0.8 times the shear modulus for very low foundation strains.

COMMENTS ON PROCEDURES

Some of the departures from previous procedures and codes are of special interest. The design acceleration spectrum decreases with the 2/3rds power of the fundamental period, in contrast to the theoretical value of decrease with the period on firm ground and with the period squared on very deformable ground. The reasons for using the rate of decrease in the ATC code are to provide uniformity and simplicity, and to take account of the fact that for long periods the cost of the building is less sensitive to seismic reliability in general and one can afford to design more conservatively. Moreover, the longer the period the higher are the losses likely to be caused by failure. It is desirable to be more conservative for long periods because of the higher probable number of significant degrees of freedom, and the likelihood that there may be a concentration of ductility requirement over a small portion of the structure in a tall building compared with a short building. Other reasons for the conservatism in the requirement include the uncertainty in the computed periods and the changes in the periods and mode shapes due to nonlinear behavior.

Accidental torsion is considered by use of an eccentricity of horizontal seismic force corresponding to 5% of the width of the building in the direction of the force considered. This provision is believed to be adequately conservative although under some extreme circumstances, occasional values somewhat higher than 5% may be found.

The maximum overturning moment arises from combinations of modes that are different from those corresponding to those that contribute to the maximum shear in the lower levels of the building, and some reduction is necessary in the seismic coefficients that are used for computing overturning moments from those used in computing maximum shear. The reduction factor is limited, however, for conservatism.

When the shape of the fundamental mode of vibration is unusual, due to large discontinuities in mass and/or stiffness of adjacent stories, criteria have been developed to identify these conditions and are used as a basis for then specifying that modal analysis is mandatory. These criteria involve making a static analysis plus one cycle of a Stodola-Vianello deflection calculation, and a comparison of the story shears in the static analysis compared with those of the single cycle calculation. If the difference is greater than some factor, say approximately 30%, modal analysis is required.

For simplicity the spectral reduction factor R is kept constant over the whole range of the frequencies of the design spectrum, rather than to use two factors with the smaller one applicable only to the acceleration sensitive region of the response spectrum.

Stresses and deformations due to earthquake motions in two directions at right angles horizontally are considered by taking into account the forces due to the motions in each direction plus 30% of the forces due to the motions in the horizontal perpendicular direction. In addition, under some circumstances, the effects of vertical motions are combined with those for horizontal motions. Also, relationships are given for computing the increases in forces to account for the vertical dead load effects produced by horizontal displacements, the so-called P-Delta effect.

The specific numerical provisions of the new design recommendations are still under study and may be modified slightly in value but not in principle before the final draft of the provisions is issued.

DISCUSSION

J.K. Minami (Japan)

The basic concepts and structural design provisions of the new seismic code being developed by the Applied Tech. Council have been noted with much interest because of their relevance to earthquake structural engineering.

In the evaluation of the design spectral coefficient C_s, a soil profile factor G ranging from 1.0 for rock and stiff soil sites to 1.5 for soft soil sites is proposed.

Studies carried out by the writer and his co-workers on the seismic response of soil-foundation-building systems (page 4-25, 6WCEE pre-prints) suggest that the values of the soil profile factor G may be 1.5 for rock and stiff soils, 1.0 for soft soil sites and perhaps 0.5 for recent filled ground. The values of C_s would vary, of course, as shown by the Multiple Spectra Response Curves in Fig. 2 and 3 of our paper.

The writer is of the opinion that rock and stiff soils, because of their hardness and stiffness have large earthquake force input capability. On the other hand, soft soils because of their weakness and deformability have small earthquake force input capacity.

Explanation of the rationale for the soil factor values would be appreciated.

A. Rijhsinghani (India

It has been said in the paper that the spectral reduction factors are applied in consideration of factors like ductility. Whereas this approach may be satisfactory for collapse limit state, would it not under estimate serviceability limit states in R.C. structures, particularly, width of cracks which is an important design criterion in liquid retaining structures, cement silos etc.

For checking serviceability limit states under combined gravity and earthquake forces what value of modulus of elasticity 'E' for concrete would you suggest ?

Author's Closure

Not received.