A SEISMIC DESIGN PROCEDURE FOR NICARAGUA

by

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INTRODUCTION

With the Iso-Contour Map for Nicaragua and Acceleration Zone Graphs for the principal population centers it is possible to determine the Peak Ground Acceleration (PGA) values of earthquake events having a given risk of exceedance during a structure life period. Appropriate levels of design earthquakes can thereby be selected at a given site such that the risk of occurrence is consistant with the use priority of a proposed structure.

This paper describes a proposed seismic design procedure which employs these consistant risk earthquake levels as load input in the form of response spectra. The essential elements of the design procedure are:

- Definition of structure use classes and their corresponding risk levels
- Statistical description of the response spectrum shape for a given region and site
- Structure modeling and computation of response
- Definition and grading of lateral force resisting systems
- Formulation of the design spectra
- Member design criteria
- Verification of drift control at the damage threshold earthquake and local ductility demands at the condemnation threshold earthquake.
- A simplified method of determining the base shear

DEFINITION OF STRUCTURE USE CLASSES AND CORRESPONDING RISK LEVELS

Planners are able to categorize the various structure uses into classes depending on their importance and need before, during and after

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a strong earthquake. Since it is neither practical nor economically feasible to provide a damage resistant structure for all conceivable levels of earthquake ground motions, each use class will have to admit its own particular probability or risk of repairable damage, P_D, and corresponding risk of total condemnation P_C, during the economic life. These risks should of course be very low for essential facilities such as hospitals and may be relatively high for a purely functional structure such as a warehouse. The risk of total collapse can be virtually eliminated by code restrictions on the type and quality of the lateral force resisting system in a building.

The use or function of structures may be organized into the following classes which depend on the desired reliabilities of operation and damage protection in the event of a large earthquake.

Class 1: Critical facilities necessary for life care and safety; hospitals; penal and mental institutions; gas, water, electric, and waste water treatment facilities; communications facilities; police and fire departments; and disaster control centers.

Class 2: Family residences; hotels; recreational and entertainment structures; churches and schools; commercial and industrial structures necessary for normal commerce.

Class 3: Facilities which are relatively non-essential for normal commerce and where damage will not create a life safety hazard. An example of such facilities would be warehouses.

The importance of the assigned acceptable risk values of P_D and P_C for each structure use class is that they, along with the site location, determine the corresponding values of A_D and A_C from the Acceleration Zone Graphs or the Iso-Contour Map (see reference 1). The design objectives are then to assure a reliable level of damage control for earthquake levels up to a PGA of A_D, and condemnation prevention against the effects of an earthquake with a PGA of A_C. The A_D and A_C values are used to scale the mean response spectrum shape (MDAF) for design purposes.

STATISTICAL DESCRIPTION OF THE RESPONSE SPECTRUM SHAPE

The PGA value given by the Acceleration Zone Graphs or Iso-Contour Map for a given return period is a prediction or forecast of a future seismic event. This future event will have an accelerogram or acceleration time history characterized by the particular PGA value given by the graph or map. However this PGA value by itself does not provide sufficient information concerning the future time history or accelerogram. This required information is most practically represented in the form of a response spectrum. The method of obtaining this predicted spectrum is as follows.

For a given region with known (overall) geologic characteristics, a sample set of past major earthquake accelerograms and their corresponding response spectra can be assembled. This data set may be from the region for which seismic design criteria are to be developed or from geologically similar regions. Each response spectrum is then scaled so as to have a unit value of peak ground acceleration (PGA), and is hence termed as a dynamic amplification factor (DAF). This sample data is then statistically analyzed to obtain the mean and the variance of the DAF shape. From this sample mean shape, a simplified practical shape (MDAF) is then adopted. This practically usable shape may be adjusted for known hard or soft soil column effects at the site. Given any forecasted PGA value, the acceleration response spectrum may be obtained by multiplying the MDAF by the PGA value. The variance information regarding the DAF shape can be represented in terms of the coefficient of variation V_S (V_S = [standard deviation]/[mean value]). Later, when design spectra are formulated, this parameter V_S is used to establish the spectral confidence level corresponding to the type of structural system.

STRUCTURE MODELING AND COMPUTATION OF RESPONSE

The basic method chosen for the computation of the structural response is the modal superposition of spectral response for a linear elastic model of the structure. This method was selected since computer programs for linear elastic response of two and three dimensional structural configurations are readily available in design offices.

Natural frequencies and mode shapes can be computed based on the mass distribution and deformation characteristics of the lateral force resisting system, but also should include the effects of stiff elements that are not part of the lateral force resisting system. Then, for a given spectrum (any one of the three design spectra) the structure response (force or deformation) is computed as the square root of the sum of the squares of the individual modal responses to the given spectrum (SRSS response). For the case where the computed deformations are beyond the linear elastic range of the structure, it is assumed that the deformation response in the actual non-elastic structure is given by the SRSS deformation response of the linear elastic model. It is recognized that this linear procedure can result in a certain amount of approximation error, however, this will be compensated for by an appropriate spectral confidence level and a requirement for special analysis for irregular structures.

DEFINITION OF STRUCTURAL SYSTEM TYPE

The definition of the basic types of lateral force resisting systems is essentially the same as the K-factor descriptions provided in the 1973 Uniform Building Code. However, in order to better represent the particular qualities or deficiencies of a given structure, a grading system is used for each K-factor type. The grades of A, B, or C are assigned according to the back-up systems, degrees of redundancy, symmetry, accuracy of analysis, past performance record, and construction quality control. The A grade represents excellent qualities and merits a lower design value than systems with B or C grades which have good and fair qualities respectively. Each structure type (such as K = 1.00B) has its particular structural damping β_T for the MDAF shape, damage deformation factor d_T, and spectral confidence level factor $(1 + k_T V_S)$.

STRUCTURE DESIGN SPECTRA

Given the structure site and use class, the risks P_D and P_C are known and the values A_D and A_C are found. Having selected the structural system type with its damping value, its reputation or reliability measure, and its ability to deform beyond its strength design level to a damage state and then further to a condemnation state, three design spectra are formed:

(1) Design Force Spectrum (DFS) - this is an appropriately modified form of the spectrum for the acceptable damage threshold earthquake with PGA level A_D. The force response from this spectrum is used as the seismic design loading for the ultimate strength design of the structural members.

$$DFS = R \cdot A_D \cdot (MDAF) \frac{1}{d_T} (1 + k_T V_S)$$

R = A Peak Acceleration Reduction Factor to represent the Effective Acceleration on the Structure. It represents the spacial average of Peak Accelerations on the effective soil-structure system.

A_D = Peak Ground Acceleration at Structure Site - having acceptable risk of being exceeded. If A_D is exceeded, then extensive structure damage may occur.

MDAF = Mean or Statistical Average of Acceleration Response Spectrum Shapes for the region. The shape can include any soil-column response effects, and together with R can represent soil-structure interaction effects.

d_T = Damage Deformation Factor for a given lateral force resisting system. It represents the ratio between the maximum acceptable deformation at the damage earthquake level and the design deformation in the highest stressed member. The d_T value depends on the K-factor type of the system.

$(1 + k_T V_S)$ = Spectral Confidence Interval Factor, where V_S is the coefficient of Variation of the spectral shape, and k_T sets the confidence level. The factor k_T allows for the degree of reliability, inherent in a system, of attaining the given d_T distortion value without excessive damage. If a system is very reliable then k_T may be zero. The k_T value depends on the quality or grading of A, B, or C of a given structural system.

(2) Damage Deformation Spectrum (DDS) - this provides the structure deformation demand of the earthquake with PGA level A_D, i.e., for the damage threshold event. The resulting deformations are used for computation of P-Delta effects, and for non-structural damage analyses (drift limitations).

$$DDS = R \cdot A_D \cdot (MDAF) (1 + k_T V_S) = d_T DFS$$

(3) Condemnation Deformation Spectrum (CDS) - this is the spectrum of the acceptable condemnation threshold earthquake with PGA level A_C. The resulting structure deformation response is used to estimate local member ductility demands and hence provides an approximate test whether or not these demands are within allowable limits. P-Delta effects and structural stability may be analyzed with these deformations.

$$\mathrm{CDS} = R \cdot A_C \cdot (\mathrm{MDAF}) \quad (1 + k_T V_S) = \frac{A_C}{A_D} d_T \mathrm{DFS}$$

A_C = PGA value corresponding to the condemnation level seismic event. Local member deformations are compared against their yield level deformations to assess whether ductility demands are within allowable limits.

DESIGN PROCEDURE RULES

The complete design sequence is as follows:

1. Given a Use class of the structure (Table 1) and its location, the values of A_D and A_C can be determined from Iso-Contour Map or the Acceleration Zone Graph (see reference 1). The appropriate design spectra can be constructed with the above information together with the parameters MDAF, V_S, d_T, d_{OT} and k_T of a given structural type and soil conditions (Table 2).
2. Formulate the linear elastic structure model and determine mode shapes and periods. Then using the DFS, obtain the SRSS force response E in the structural members.
3. Design members for load combinations on an ultimate strength basis for the following conditions.
   a) Load Factored Vertical Dead and Live Load.
   b) DFS Force plus Vertical Dead and Ambient Live Load; $(D + 0.4L) + E$.
   c) $0.8\ (D \pm E)$ for vertical acceleration effects.

   In b) and c) above, the seismic load E is based on a $(D + 0.4L)$ seismic weight of the structure.
4. Interstory drifts using DDS and calculated as the SRSS of the individual modal drifts shall not exceed 1% of the story height. This restriction is for damage control.
5. The member design procedure has produced known values for the individual member resistance values R_u, where $R_u > (D + 0.4L) + E$; $R_u > 0.8(D \pm E)$; and commonly exceeds these load combinations because of vertical load requirements, and the available section or sizing requirements as shown on the engineering plans for construction. Using the proportionality of forces to deformations in the elastic model response to the CDS, and defining the force in a member as E'_C due to the CDS, a measure of the local inelastic "ductility" demand in a member at the condemnation threshold is:

$$\mu_C = \frac{(D + 0.4L + E'_C)}{R_u}$$

$$\text{or } \frac{0.8D \pm E'_C}{R_u}$$

The computed values for μ_C are then to be compared with assigned allowable values. These allowable values are tentatively of the order as follows:

Ductile Steel Beam Joints = 5
Ductile Concrete Beam Joints = 4
Columns in Non-Ductile Frames and X-Bracing Systems = 1.5
Concrete Shear Wall Flexure = 2 (in walls without ductile chords)
= 4 (in walls with ductile chords)
Concrete Shear Wall Shear = 2 (in walls and piers without ductile chords)
= 3 (in walls and piers with ductile chords)

Conclusion: Throughout the entire design procedure, the degree of complexity is held in control so as to be compatible with the degree of knowledge concerning seismic input and structural behavior, and with the attainable level of local design and construction practice. Good lateral force system configurations and details are encouraged, rather than the meticulous evaluations of spectra, and their corresponding elastic or inelastic response. The basic objective is to assure that the asbuilt structures will fulfill the acceptable reliabilities as stated in the design objectives.

REFERENCES

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Table 1. Suggested Return Periods

Use Class of Structures	Suggested Economic Life (years)	Suggested Return Period (years) Condemnation	Damage
1	100	1000	500
2	50	500	100
3	20	100	50

Table 2. Factors for Design Spectra

Type	β_T	Plateau Value of MDAF	d_T	d_{OT}	$(1 + k_T V_S)$
0.67A	10%	2.0	3.0	3.0	1.0
0.67B	10%	2.0	3.0	3.0	1.2
0.67C	10%	2.0	3.0	3.0	1.4
0.80A	10%	2.0	2.5	3.0	1.2
0.80B	10%	2.0	2.5	3.0	1.4
0.80C	10%	2.0	2.5	3.0	1.6
1.00A	10%	2.0	2.0	3.0	1.2
1.00B	10%	2.0	2.0	3.0	1.4
1.00C	10%	2.0	2.0	2.0	1.6
1.33A	10%	2.0	1.5	3.0	1.2
1.33B	10%	2.0	1.5	3.0	1.4
1.33C	10%	2.0	1.5	1.5	1.6