VARIATIONS IN OPTIMUM SEISMIC DESIGN PARAMETERS OF IMPORTANT STRUCTURES

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ABSTRACT :

The paper studies how the seismic design coefficient increment for important structures vary according to different concepts such as peak ground saturation, initial costs, structural capacity, and uncertainties in different variables. Optimum values are obtained on the frame of the total cost design criterion. Sites in the near-field and away from the source are under study to determine the variation of the optimum coefficients. We consider that the design is such that it minimizes the expected present value of the total cost, including initial and maintenance costs as well as losses due to damage and failure. As a first approach we assume that the incremental factor in the design parameter of important structures, at one of the sites, is optimum; after that we compute the corresponding factor for the other site. The earthquake generation process used here is composed of background activity as well as characteristic earthquakes, with both constant and time dependent magnitudes. For the site located in the near-field a saturation phenomenon is considered in the peak ground acceleration as the magnitude of the earthquake increases. This phenomenon, together with the initial costs of structures as well as uncertainties in some parameters are taken into account in order to see their influence on the optimal design values, and on the incremental factor at the different sites studied. The influence is measured by comparing the variations in the total costs. Variations in the optimum seismic design values and on the incremental factor for important structures are studied for sites with different seismicity. Preliminary results show that these factors can vary according to the site seismicity, and that their increment when uncertainties in some variables are taken into account, is appreciable.

KEYWORDS: Important structures, optimization, total cost, expected present values.

1. INTRODUCTION

Structures under earthquakes must be designed such that the structural reliability increases according to their importance. We consider important those structures whose failure or collapse might cause a large loss or public buildings that are essential during emergencies. Codes around the world takes into account the importance by multiplying spectral ordinates of ordinary buildings by a factor greater than one. Thus, the Federal District Building Code and its Complementary Technical Norms (2004) fix the importance factor at 1.5. This code requires also the participation of experts for the analysis and design of such facilities.

When we consider a site in the epicentral area there is a saturation of the peak ground acceleration of the strong ground motions for large magnitudes. That is, the intensity reaches a constant value while the magnitude increases indefinitely. This saturation phenomenon together with initial costs of structures and uncertainties in some parameters influence the value of important factors. Here, we use a methodology developed in García-Pérez J. et al (2005) in order to study this influence.

Some studies regarding optimal expected life cycle costs are found in the literature, for example, Ang and de León (1997) compute the optimal target reliability for reinforced concrete buildings in Mexico City. They include the damage, injuries and fatalities in their study. Wen and Kang (2001) deal with minimum expected life cycle costs in steel buildings.

As long as expected present values play an important role in computing optimum values we begin by discussing them. Then we adopt the methodology developed in García-Pérez J. et al (2005) for the computation of numerical values of importance factors and hence the variations in the optimum seismic design parameters.

2. PRESENT VALUES

It is customary to discount future gains and losses to obtain their present values by multiplying them by the discount function $\exp(-\gamma t)$, where t represents time and γ is a constant discount rate which is taken usually as 0.05/yr because this is approximately the average discount rate value used in financial transactions in the last decades. However, from an ethical point of view, the quality of life of those who will be most affected by the decisions, should be of great importance to a decision maker, and therefore, their preferences should guide the decision making. Surveys in the US on the discount rates (Cropper ML. and Portney PR. 1992), have shown that in general people discount money with a rate $\gamma(t)$ that decreases rapidly with time, as shown in Figure 1. Rosenblueth (1993), by using an expression of the form $e^{-\gamma t} = 0.56e^{-0.45t} + 0.44e^{-0.033t}$ finds an equivalent discount rate of $\gamma = 0.0686$/yr, which is the value that we use here.

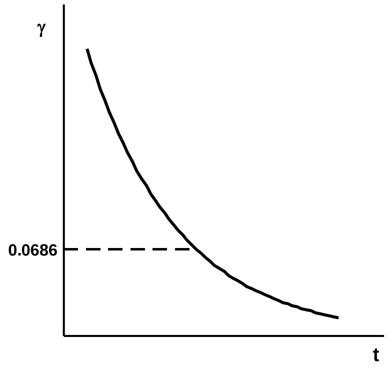

Figure 1 Discount rate

3. EXCEEDANCE RATES

We consider that earthquakes originated in a single source predominate and that their arrival times conform to a multiple Poisson process. Based on information found in the literature (Singh SK. et al 1983; Youngs RR. and Coppersmith KL. 1985) we assume that the earthquake generation process comprises two subprocesses as it is shown in Figure 2. The first subprocess pertains to the background activity and can be described by means of the annual mean rate of events greater than or equal to a magnitude as follows.

$$\lambda_1(M) = \alpha_1\left(e^{-\beta M} - e^{-\beta M_1}\right) \qquad if \quad M \leq M_1 \tag{3.1}$$

where α_1 and β are constants, and M_1 is the maximum value of magnitude M that can be generated. The second subprocess consists of characteristic earthquakes, say $M = M_2$, with an exceedance rate given by

$$\lambda_2(M) = \begin{cases} \eta & if \ M \leq M_2 \\ 0 & if \ M > M_2 \end{cases} \tag{3.2}$$

where η is a constant. Combining equations 3.1 and 3.2 we obtain the total $\lambda(M)$ as

$$\lambda(M) = \begin{cases} \alpha_1\left(e^{-\beta M} - e^{-\beta M_1}\right) + \eta & if \quad M \leq M_1 \\ \eta & if \quad M_1 < M \leq M_2 \end{cases} \tag{3.3}$$

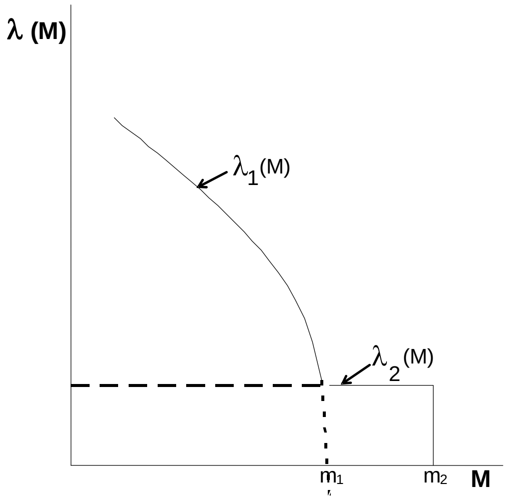

Figure 2 Earthquake generation process

Assuming a linear soil condition and long site to source distances, we may associate with the magnitude *M* and the peak ground acceleration as follows (Singh SK. et al 1987).

$$z = He^{\beta' M} \tag{3.4}$$

Here *H* is a function of the location of both source and site, and β' is a constant. In the near-field this equation still works for small *M*, but there is a saturation phenomenon for large *M*. Thus, for large earthquakes at the near-field, *z* does not increase in the same proportion with *M* as it does for the far-field (Singh SK. et al 1989). We assume in this case that at a given exceedance rate all values of *z* duplicate except z_1 which is the maximum intensity that can occur at the site of interest. We mean by intensity a quantity determining the response of the structure under study. Now, combination of equations 3.3 and 3.4 lead us to:

$$\lambda(z) = \begin{cases} \alpha_4\left(z^{-\alpha_5} - z_1^{-\alpha_5}\right) + \eta & if \ z \leq z_1 \\ \eta & if \ z_1 < z \leq z_2 \end{cases} \tag{3.5}$$

In this equation $\alpha_4 = \alpha_1 H^{\beta/\beta'}$, z_1 and z_2 correspond to M_1 and M_2 respectively. The occurrence density is given by $-d\lambda/dz$, thus from equation 3.5 we get:

$$-d\lambda/dz = \begin{cases} \alpha_4\alpha_5 z^{-\alpha_5 - 1} & if \quad z \leq z_1 \\ \eta\delta(z - z_2) & if \quad z > z_1 \end{cases} \tag{3.6}$$

where $\delta(.)$ is Dirac's Delta. We denote η as the occurrence rate of characteristic earthquakes.

4. COSTS OF A SINGLE STRUCTURE

4.1. Initial cost

Several studies regarding initial cost in terms of base shear coefficients are found in the literature, we adopt here an expression from García-Pérez J. (2005) given by

$$u = \begin{cases} C & if \;\; c \le c_0 \\ [1 + \alpha_2 (c - c_0)^{\alpha_3}]C & if \;\; c > c_0 \end{cases} \tag{4.1}$$

C is the cost that the construction would have if it were not designed to resist earthquakes. α_2 is a coefficient that increases as the cost of the structure increases relative to that of the entire building, and α_3 is approximately 1.2 for low-rise buildings on bearing walls (type 1) and usually increases up to 1.8 as we go to other structural solutions and increasing slenderness ratios (type 2), c is the design base shear coefficient, c_0 is the lateral resistance of the structure. Table 4.1 shows values for the two types of structures used in this study.

Table 4.1 Values used in initial cost functions.

Structural type	α_2	c_0	α_3
1	0.5	0.1	1.2
2	0.6	0.05	1.8

4.2. Expected losses

Let us consider an initially intact building, let D_z represent the direct material loss due to damage to the building itself, when subjected to an intensity z, and let $\zeta = z/c$ .It has been found empirically that when $1 \le \zeta \le 7$, D_z can be put in the form $\delta\zeta^{1.6}u$, where δ is a coefficient depending on the type of the structure. When ζ tends to zero, D_z should tend to zero. This comes from a common observation that very small earthquakes do not cause damage, regardless of how many, and when ζ tends to infinity, $D_z u$ must tend to 1. Furthermore, D_z must be a monotonically increasing function of ζ and should be consistent with empirical data in the range for which they were obtained. We will take $D_z = u\xi(\zeta)$. The function $\xi(\zeta)$ must increase with z, thereby decreasing as c increases so that $\lim_{z\to 0} \xi = 0$ and $\lim_{z\to\infty} \xi = 1$. Furthermore, it must tend very fast to zero when z tends to zero because we know that earthquakes of low intensity do not cause any damage. We take
$\xi(\zeta)$: $\xi(\zeta) = 0.025\zeta^6 - 0.015\zeta^9 \;\; if \; \zeta \le 1$ and $\xi(\zeta) = (0.188 + \zeta^{1.8})/(117.8 + \zeta^{1.8}) \;\; if \;\; \zeta > 1$
In addition to the direct material loss D_z, there are noneconomic losses. These must be insignificant when $\xi(\zeta)$ is small and should exceed $u\xi(\zeta)$ when it is large. But they should tend to a finite limit when ζ tends to infinity. We must include all the seismic losses caused by an earthquake of intensity z by letting this loss be

$$L_z = u\xi(z/c)[1 + b\xi(z/c)] \tag{4.2}$$

where b is a coefficient usually greater than 1 that depends on the intended use of the building.

If the earthquake arrival times constitute a multiple Poisson process, and we assume that the original condition is restored to the structure after each earthquake, and the expected cost of damage and failure per unit time is (Rosenblueth E. 1976)

$$d_0 = \int_0^{\infty} -\frac{d\lambda}{dz} L_z d_z \tag{4.3}$$

which is constant with time t, then the expected present value of all seismic losses becomes

$$v = \int_0^\infty d_0\, e^{-\gamma t}\, dt \tag{4.4}$$

and after substituting all variables

$$v = \int_0^\infty dv_z = \frac{\alpha_4 \alpha_5 u}{\gamma} \int_0^{z_1} \frac{\xi(z/c)[1+b\xi(z/c)]}{z^{\alpha_5+1}} dz + \frac{u\eta\xi(z_2/c)[1+b\xi(z_2/c)]}{\gamma} \tag{4.5}$$

It is convenient to write $\zeta = z/c$ in equation 4.5 and integrate with respect to ζ rather than with respect to z. We get then

$$v = \frac{u}{\gamma}\left\{\frac{\alpha_4\alpha_5}{c^{\alpha_5}} \int_0^{\zeta_1} \frac{\xi(\zeta)[1+b\xi(\zeta)]}{\zeta^{\alpha_5+1}} d\zeta + \eta\xi(\zeta_2)[1+b\xi(\zeta_2)]\right\} \tag{4.6}$$

where $\zeta_1$and ζ_2 stand for z_1/c and z_2/c, respectively. Thus, the expression to be minimized is the present value of the total cost comprised by equations 4.1 and 4.6.

5. UNCERTAINTIES

We now take into account the effect on spectral ordinates of uncertainties in some parameters. We treat the initial cost of a structure u as deterministic, since c, the base shear coefficient, is chosen by the designer or fixed by a code. We also treat α_4, α_5, β, and β' as deterministic. All other quantities in equation 4.6 are uncertain, thus we assign them lognormal distributions with standard deviations and modes as shown in table 5.1.

Table 5.1 Standard deviations and modes for variables used in the analysis

Variable	Site	Mode	σ
α_4	I	0.0005	0
	II	0.008	0
α_5	I, II	3.3	0
γ	I,II	0.0686	0
η	I,II	0.02	0.2
b_A	I,II	------	1
b_B	I,II	12	1
c	I,II	------	0.4
z_1	I	0.2	0.5
	II	0.8	0.5
z_2	I	0.4	0.5
	II	1	0.5

The expected value of a linear function of a power of a random function, for example, X^m, where m is any real number, is computed as the function's median times $\exp(m^2\sigma_{lnX}^2/2)$. In the case of nonlinear functions, the two-point estimates method developed by Rosenblueth (1981) is used. In the following $\hat{c}$ represents the mode of c and $\zeta^{++} = z^+/c^+$, $\zeta^{-+} = z^-/c^+$ and so on. Thus, the total expected costs for structures is computed as

$$\bar{v} = u(1 + I_1 + I_2) \tag{5.1}$$

where

$$I_i = \frac{\alpha_4\alpha_5}{4\gamma\hat{c}^{\alpha_5}}\{3.32(I_i^{++} + I_i^{\mp}) + 0.3(I_i^{+-} + I_i^{--}) + A_i\} \quad (5.2)$$

For i=1,2 $I_1^{++} = \int_0^{\zeta^{++}}[\xi(\zeta)/\zeta^{\alpha_5+1}]d\zeta$ and $I_2^{++} = 19.78\int_0^{\zeta^{++}}[\zeta^2(\zeta)/\zeta^{\alpha_5+1}]d\zeta$, etc.
and for A_i:
$A_1 = 0.01[\xi(\zeta_2^+) + \xi(\zeta_2^-)]$ and $A_2 = 0.1978[\xi^2(\zeta_2^+) + \xi^2(\zeta_2^-)]$.

6. NON-POISSON ARRIVALS OF EARTHQUAKES

The assumption that arrival times of all earthquakes at the site of interest constitute a multiple Poisson process is adequate when nothing is known about arrival times other than the magnitude exceedance rates, or when significant earthquakes can arrive from a number of independent sources. However, when significant earthquakes are originated in a single source and there is an idea of the recurrence period of the characteristic earthquake, one should take into account the non-Poisson nature of their arrival times.

7. SLIP-PREDICTABLE MODEL FOR CHARACTERISTIC EARTHQUAKES

Based on a physically founded mathematical model (Hong HP. and Rosenblueth E. 1988) and on data from real earthquakes (Jara JM. and Rosenblueth E. 1988), we may assume that the magnitude of characteristic earthquakes conforms to a slip-predictable model (Shimazaki K. and Nakata T. 1980; Kiremidjian A. and Anagnos T. 1984). If t denotes the time of the last characteristic earthquake, we can write

$$M_2 = \begin{cases} M_r & if \quad t \leq t_r \\ M_r + F\, ln(t/t_r) & if \quad t \geq t_r \end{cases} \quad (7.1)$$

For Mexican subduction earthquakes the threshold magnitude of the characteristic earthquake, the corresponding recurrence time, and the constant F are respectively (Jara JM. and Rosenblueth E. 1988): $M_r = 7.4$, $t_r = 26.7$, and $F = 1.43$.

8. VARIATION OF SEISMIC DESIGN PARAMETERS

8.1 Sites under study and methodology

We consider two sites, one at the near-field which we call II, and one at a far distance from the focus which we call I. Locations of the two sites are shown in figure 3. Now, in order to compute the increment on the spectral ordinates for important structures, we will follow a methodology developed in García-Pérez J. et al (2005). Thus, we assume that the increment is given exclusively in both noneconomic and indirect economic losses, but not in the material damage suffered by the building itself. We find first the value of c, which at site I minimizes the total cost given by the sum of the initial cost and those due to damage and failure. This c applies to ordinary structures (group B). Now we compute the factor by which we must multiply variable b to increase the computed optimum coefficient to 1.5c (important structures or group A), such that the increment factor at site I is 1.5. We assume that the value of 1.5 is optimum at this site, according to the Mexican code. Now we go to site II and compute the optimum design coefficient, assuming that b_A and b_B (values of b for structures of group A and B, respectively) are the same as those at site I. The ratio c_A/c_B gives us the increment factor at site II.

Incremental factors computed for the two sites and two types of structures, considering both deterministic parameters (D) and parameters with uncertainties (ND) are presented in table 8.1. The incremental factors at the near-field are smaller than those at far distances. Saturation of ground motion intensities influences these results. These conclusions are merely comparative, and based on the assumption that the incremental factor of 1.5 is near the optimum at site I, according to engineering judgment.

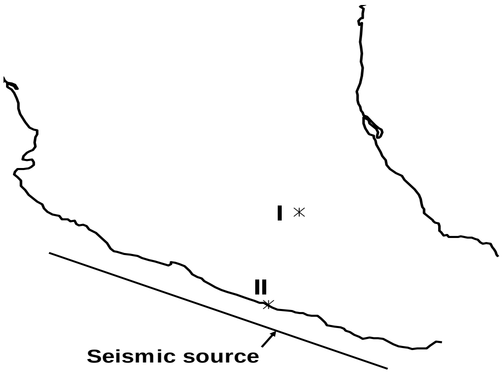

Figure 3 Sites under study

Table 8.1 Variations of incremental factor for important structures

Structural type	Site I	Site II
D_1	1.5	1.37
D_2	1.5	1.36
ND_1	1.5	1.46
ND_2	1.5	1.45

9. CONCLUDING REMARKS

We have computed the variations of seismic design coefficients for important structures, for a site in the near-field, accepting that a factor based in engineering judgment is adequate for a site distant from the seismic source. Different concepts were taken into account such as peak ground saturation, initial costs of structures and uncertainties in some variables. The results show that the incremental factor decreases for the site in the near-field, and its increment is appreciable when uncertainties in some variables are considered.

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