

PAPER • OPEN ACCESS

Method of determining seismic action of existing structures for different continuing seismic service life

To cite this article: Shaoge Cheng *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **218** 012089

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the [collection](#) - download the first chapter of every title for free.

Method of determining seismic action of existing structures for different continuing seismic service life

Shaoge Cheng¹, Kui Sun^{1*}, Tiehua Shi¹ and Yixiu Zhu¹

¹ Institute of earthquake engineering, China Academy of Building Research, Beijing, 100013, China

*E-mail: sunkui@cabrtech.com

Abstract. This paper introduces a method of determining the seismic action for existing structure. The method incorporates the influence of seismic hazard and the continuous seismic service life. According to the more commonly assumed magnitude distribution, attenuation laws and the earthquake record, the relation of seismic hazard to seismic action is studied. The results are in terms of a modification factors of seismic action versus design reference period (i.e., 50 years). Under the principle of all the seismic action of each fortification level have the same exceeding probability, the calculation formulas is proposed to calculate exceeding probability of seismic action, while the exceeding probability based on the continuous seismic service life is converted to the well-matched exceed probability based on the design reference period (i.e., 50 years). At last, the modification factors of seismic action for existing structure with different continuous seismic service life are given in this paper.

1. Introduction

The continuous seismic service life refers to the period that the existing structure continues to be used after the seismic appraisal. During this period, the structure can be used as intended function or to be unsafe without re-appraisal and corresponding reinforcement[1]. The continuous seismic service life is an important parameter for determining the seismic action of existing structure. For new structure, the continuous seismic service life is the design reference period (i.e., 50 years). With the needs of social and economic development, the seismic appraisal and strengthening have maintained a rapid development in china. Domestic and foreign scholars have done a lot of research on the ground motion parameters for design working life. Some of the researchers studied the ground motion parameters for continuous seismic service life. For instance, Cornell C A presented a seismic risk analysis method[2]. Gao et al. think that seismic intensity and seismic action fit extreme value type III and II, based on statistical fitting of probability distribution of seismic intensity and seismic action in China[3]. Xie et al. recommended to demarcate importance and ground motion parameters of buildings by the service period[4]. Vision 2000 presented earthquake return periods and exceeding probability corresponding to seismic fortification level[5], and the NZBC (1992) lists the factors related to design reference period[6]. Zhou et al. adopted seismic intensity to analyze modification factor of seismic action[7]. The relation of seismic intensity to seismic action for different continuous seismic service life was pointed out (see Zhou et al., 2002[8]; Sun et al., 2003[9]; Wu et al., 2003[10]; Ding et al., 2005[11]). However, the seismic action used in the derivation formula took no account of the probability discrepancy of between seismic peak acceleration and seismic intensity. Besides, the probability distribution of seismic action was poorly conceived.



Both the determination of seismic action related to continuous seismic service life and the precautionary criterion. Adopt Homogeneous Poisson Process to establish earthquake generation model, after giving full consideration to the seismic fortification and continuous seismic service life, the modification factors of seismic action of structure for three fortification levels are given in this paper. Also, at the regulating process, the modification factors has the same statistical levels as the current seismic code[1].

2. The probability distribution of seismic action

The reference [11] recommended the relationship between peak-ground acceleration, A , and earthquake magnitude, M , and focal distance, R :

$$A = b_1 e^{b_2 M} R^{-b_3} \quad (1)$$

where: b_1 , b_2 , b_3 are semiempirical constants.

Given that an earthquake occurs at focal distance $R = r$, the probability that A , the peak-ground acceleration, is greater than any number \tilde{A} is, using equation (2):

$$P(A \geq \tilde{A} | R = r) = P(b_1 e^{b_2 M} R^{-b_3} \geq \tilde{A} | R = r) = 1 - F_M \left(\frac{\ln(\tilde{A} / b_1 r^{-b_3})}{b_2} \right) \quad (2)$$

where: F_M is the cumulative distribution function of earthquake magnitudes.

The functional relationship between number n_m , and magnitude, m has been widely verified by Richter[12]:

$$\log_{10} n_m = a - bm \quad (3)$$

where: n_m is the frequency that magnitude greater than m , a , b are semiempirical constants.
implies

$$1 - F_M(m) = e^{-\beta(m-m_0)} ; m \geq m_0 \quad (4)$$

where: $\beta = b \ln 10$, m_0 is some magnitude so enough that can be ignored for engineering.

Substituting equation (4) into equation (2):

$$P(A \geq \tilde{A} | R = r) = \exp \left(-\beta \left(\ln(\tilde{A} / b_1 r^{-b_3}) / b_2 \right) - m_0 \right) \quad (5)$$

In order to consider the influence of all possible values of the focal distance and their relative likelihoods, integrate variables focal distance, The cumulative distribution of A :

$$1 - F_A(\tilde{A}) = P(A \geq \tilde{A}) = \int_{d_0}^{r_{\max}} P(A \geq \tilde{A} | R = r) f_R(r) dr \quad (6)$$

where: d_0 is focal distance when the focal point is located in the middle of the seismic belt.

r_{\max} is focal distance when the focal point is located in the end of the seismic belt.

$f_R(r)$ is the probability density function of R , the uncertain focal distance. It can be obtained by cumulative probability distribution of the uncertain focal distance:

$$F_R(r) = P(R \leq r) = \frac{(r^2 - d_0^2)^{1/2}}{l/2} ; d_0 \leq r \leq r_{\max} \quad (7)$$

where: l is the Length of fault.

Therefore

$$f_R(r) = \frac{dF_R(r)}{dr} = \frac{2r}{l(r^2 - d_0^2)^{1/2}} ; \quad d_0 \leq r \leq r_{\max} \quad (8)$$

Substituting equation (8) into equation (6), the cumulative distribution function of A , the peak-ground acceleration

$$1 - F_A(\tilde{A}) = P(A \geq \tilde{A}) = \frac{1}{l} CG \tilde{A}^{-\beta/b_2} ; \quad \tilde{A} \geq b_1 e^{b_2 m_0} d^{-b_3} \quad (9)$$

where: $C = e^{\beta m_0} b_1^{\beta/b_2}$, $G = \frac{2\pi}{(2r_0)^\gamma} \Gamma(\gamma) \left[\Gamma\left(\frac{\gamma+1}{2}\right)^2 \right]^{-1}$, $\gamma = \beta \frac{b_3}{b_2} - 1$.

Adopt the common assumption that the occurrences of earthquake follow a Homogeneous Poisson process[12]. The earthquake with average occurrence rate of v per year and \tilde{N} , the number of earthquake of interest in a time interval of length t years were embodied by Poisson distribution:

$$P_{\tilde{N}}(n) = P(\tilde{N} = n) = \frac{e^{-vt} (vt)^n}{n!} \quad (10)$$

Thus the number of times N that the peak-ground acceleration will exceed \tilde{A} in an interval of length t is

$$P_N(n) = P(N = n) = \frac{e^{-P_A vt} (P_A vt)^n}{n!} \quad (11)$$

where: $P_A = P(A \geq \tilde{A}) = \frac{1}{l} CG \tilde{A}^{-\beta/b_2}$ is the probability that A , the peak-ground acceleration, is greater than any number \tilde{A} .

If there is no event that the peak-ground acceleration exceed \tilde{A} in an interval, then

$$P_A(A_{\max}^t \leq \tilde{A}) = P(N = 0) = e^{-P_A vt} \quad (12)$$

Substituting equation (9) into equation (12), the cumulative distribution function of \tilde{A} , the max peak-ground acceleration:

$$F_{A_{\max}^{(\tilde{A})}} = e^{-P_A vt} = \exp(-vt CG \tilde{A}^{-\beta/b_2}) \quad \tilde{A} \geq b_1 e^{b_2 m_0} d^{-b_3} \quad (13)$$

It should be noticed index of \tilde{A} negative values. The conclusion is that the max peak-ground acceleration has a distribution of Type II extreme value type.

3. Modification factors of seismic action based on continuous seismic service life

The equal exceeding probability principle is that the seismic action for existing structure in continuous seismic service life and new structure in design reference period (i.e., 50 years) are the same equal exceeding probability. It's carried out to determine the exceeding probability based on the continuous seismic service life is converted to the well-matched exceed probability based on the design reference period. The functional conversion relationship of equal exceeding probability principle

$$p_{i/T(50)} = 1 - (1 - p_{i/T})^{50/T} \quad (14)$$

where: $p_{i/T}$ is the exceed probability of fortification level i in T year.

$i=1, 2, 3$, are fortification levels for frequently earthquake, design earthquake and rarely earthquake. The exceed probability of three fortification levels are 63.2%, 10% and 2% respectively.

$p_{i/T(50)}$ is equal exceeding probability which was converted to the well-matched the exceed probability in T years of fortification level i .

Given that a continuous seismic service life, T years, and fortification level i , the seismic action, $A_{i/T}$ is, using equation (13),

$$A_{i/T} = \left[-\frac{\ln(1 - P_{i/T(50)})}{vCG} \right]^{-b_2/\beta} \quad (15)$$

So that, the seismic action modification factors, μ_T , for continuous seismic service life, T years, using equation (14) and (15),

$$\mu_T = \frac{A_{i/T}}{A_{i/50}} = \frac{\left(-\ln(1 - p_{i/T}) \right)^{1/K}}{\left(-\ln(1 - p_{i/50}) \right)^{1/K}} = \left(\frac{T}{50} \right)^{-1/K} \quad (16)$$

where: $K = \beta / b_2$ is shape parameter. β , b_2 is given in equation (1) and (4).

Notice that equation (16) dose not contain fortification level coefficients. It means that the seismic action modification factors were same for different fortification levels with same continuous seismic service life. The shape parameter K is given by equation (13) or current seismic design code. The shape parameter adopted by the code for seismic design of building (GB50011-2010) is -2.14. In accordance with equation (16), the modification factors can be calculate for different continuous seismic service life. The modification factors corresponding to continuous seismic service life are shown in Table 1.

Table 1. Modification factors of seismic action.

The continuing seismic service life (yrs)	The modification factors
30	0.8
40	0.9
50	1.0

4. Conclusions

A quantitative method of calculating the modification factors for different continuous seismic service life has the advantage that consistent estimates of these risks can be prepared for various fortification levels. Under the equal exceeding probability principle, the following conclusions are drawn from this study. (1) The probability distribution of seismic action was embodied by Extreme Value Type II. (2) The modification factors of seismic action were 0.8, 0.9 and 1.0 for the continuous seismic service life were 30, 40, 50 yrs. (3) The seismic action modification factors were same for different fortification levels with same continuous seismic service life.

Acknowledgments

This work was financially supported by the National Key Research and Development Project (Project No.2016YFC0700700).

References

- [1] MOHURD. (2008) GB50023-2009 Standard for seismic appraisal of buildings. China Building Industry Press, Beijing.

- [2] Cornell C A. (1968) Engineering seismic risk analysis. *Bulletin of the Seismological Society of America.*, 58:1583-1606.
- [3] Gao X, Bao A. (1985) Probabilistic model and its statistical parameters for seismic load. *Earthquake Engineering and Engineering Dynamics.*, 5: 13-32.
- [4] Xie Lili, Ma Yuhong, LIU Zengwu. (2001) Seismic design levels of building structures with different importance factors in consideration of earthquake environment. In: *The first national modern structural engineering Conference*. Tianjin. pp. 7-12.
- [5] Version 2000 Committee. (2000) California Office of Emergency Services. *Performance Based Seismic Engineering of Buildings*. Structural Engineering Association of California, California.
- [6] BIA. (1992) *The New Zealand Building Code Handbook and Approved Documents*. Building Industry Authority, Wellington.
- [7] Zhou X L, Li Y M. (2012) Study on Ground Motion Parameters of Seismic Appraisal for Existing Structures Based on Residual Service Life. *Advanced Materials Research.*, 368-373:2303-2308.
- [8] Zhou X, Zeng D, Gao X. (2002) Simplified method for evaluating seismic design intensities structures with various service periods. *Building Structure.*, 32: 37-42.
- [9] Sun B, Niu D, Dong Z. (2003) Research on earthquake action for seismic assessment of existing structures. *Journal of Xian University of Architecture & Technology: Natural Science Edition.*, 35 : 312-316.
- [10] Wu J, Bai X, Sun J. (2003) Determination of earthquake action under different design seismic service life. *Earthquake Resistant Engineering.*, 25: 36-39.
- [11] Esteva L, Rosenblueth E. (1964) Spectra of earthquakes at moderate and large distances. *Soc. Mex. de Ing.*, 11:1-18.
- [12] Richter C. (1959) Seismic regionalization. *Bulletin of the Seismological Society of America.*, 49:123-162.