

Life-cycle seismic insurance model for multi-story RC frames based stochastic big-data analysis

Zhu Jian^{1,2, a}, Zhao Junhai^{1, b}

¹ School of Civil Engineering, Chang An University, Xi An, China

²School of Civil & Hydraulic Engineering, Ningxia University, Yin Chuan, China

^a zhujian@nxu.edu.cn, ^b zhaojh@cha.edu.cn

Keywords: Life-cycle seismic insurance model; Stochastic ground motion; Multi-story RC frames; Stochastic big-data simulation; Seismic insurance premium.

Abstract. The estimation of annual average seismic insurance premium in life service period for multi-story reinforced concrete (RC) frames based stochastic parameters models is the focus of the research. An innovative seismic analysis methodology is adopted for seismic loss estimation of buildings. The damage of the structural and nonstructural which connected into response of the inter-story drift ratio and peak diaphragm acceleration under a given stochastic motions use nonlinear incremental dynamic analysis to estimate damage of buildings in a detailed. Description of the uncertainty of all parameters in research through random big-data probability distributions to reach quantification of the life-cycle seismic losses expected value. Moreover, the study is also to give the expected suggested insurance premium of RC structures in selected region based Monte-Carlo stochastic simulation in its service lifetime.

Introduction

High seismic intensity regions and coastal regions are more vulnerability to natural disasters due to particular geographic location. Although it is not possible to completely avoid damage due to suddenly occurrence of disasters. It is however still possible to minimize their devastating effects by enhancing resilience in communities, that is, by reducing (1) system failure probability, (2) consequences of system failures, and (3) fee and time to recovery. At present for better approach above targets, many researchers further push the research performance-based earthquake engineering (PBEE) forward a great step over the entire life-cycle of the buildings. In this paper, life cycle cost is introduced in the field of constructions as a complex investment appraisal tool incorporating structural performance criteria[1]. An innovative method is considered for multi-story reinforced concrete buildings in China. Simple probabilistic insurance model is also reviewed based on advanced stochastic sampling concepts. This analysis aims to identify the importance of the various seismic loss risk-factors towards the overall performance of the inhabitant structural system.

Life-cycle cost estimation

The total cost C_{TOT} of a building may refer either to the design life period of a new structure or to the remaining life period of an existing or retrofitted structure. This cost can be expressed as a function of time and the design vectors s as follows

$$C_{TOT} = C_{IN}(s) + C_{LS}(t, s) \quad (1)$$

Where $C_{IN}(s)$ is the initial cost of a new or retrofitted structure, $C_{LS}(t, s)$ is the present value of the limit state cost, s is the design vector corresponding to the design loads, resistance and material properties with relation to the performance of the structural system, while t is the time period. The limit state cost refers to the potential damage cost from earthquakes that may occur during the life of the structure. It accounts for the cost of repair, the cost of loss of contents, the cost of injury recovery or human fatality and other direct or indirect economic losses related to loss of contents, rental and income after an earthquake.

Damage may be quantified by using several damage indices (DIs) whose values can be related to particular structural damage states. Damage refers not only to structural damage but also to non-structural damage. The latter including the case of architectural damage, mechanical, electrical and plumbing damage and also the damage of furniture, equipment and other contents.

The maximum inter-story drift ratio (ISD%) has been considered as the structural damage response parameter based a great deal of post research[2]. The peak diaphragm acceleration (PDA) is also chosen as the most appropriate intensity measure associated with the loss of contents like furniture and equipment[3]. The relation of the limit state with the values of the ISD and PDA(see Table 1).

Table 1. Limit State Drift Ratio And PDA For RC Frames

Limit States	$q_{isd} \%$	PDA(g)
(I) None-N	$q \leq 0.10$	$a \leq 0.05$
(II) Slight Damage-S	$0.10 < q \leq 0.20$	$0.05 < a \leq 0.10$
(III) Light Damage I-L I	$0.20 < q \leq 0.28$	$0.10 < a \leq 0.16$
(IV) Light Damage II-L II	$0.28 < q \leq 0.40$	$0.16 < a \leq 0.20$
(V) Moderate Damage I-MI	$0.40 < q \leq 0.55$	$0.20 < a \leq 0.30$
(VI) Moderate Damage II-M II	$0.55 < q \leq 0.90$	$0.30 < a \leq 0.50$
(VII) Heavy Damage-H	$0.90 < q \leq 1.70$	$0.50 < a \leq 0.75$
(VIII) Major/Collapse-Ma/C	$q > 1.70$	$a > 0.75$

The limit state cost (C_{LS}) for the i th limit state can be expressed as follows:

$$C_{LS}^i = C_{dam}^i + C_{con}^i + C_{ren}^i + C_{inc}^i + C_{inj}^i + C_{fat}^i \quad (2)$$

$$C_{LS}^i = C_{con}^{i,q} + C_{con}^{i,a} \quad (3)$$

Where C_{dam}^i is the damage repair cost, $C_{con}^{i,q}$ is the loss of the contents cost due to structural damage while $C_{con}^{i,a}$ is the loss of contents cost due to non-structural damage. C_{ren}^i is the loss of rental cost, C_{inc}^i is the income loss cost, C_{inj}^i is the cost of injuries and C_{fat}^i is the cost of human fatality. A more detailed description of the different cost evaluation for each limit state cost can be found(see Table 2).

Table 2. Limit State Costs-calculation formula

Cost Category	Calculation Formula	Basic Cost
Damage/repair	Replacement cost \times FA \times DI	1200¥/m ²
Loss of machine & contents	Unit cost \times FA \times DI	3300¥/m ²
Rental	Rental rate \times FA \times LF	30¥/mo/m ²
Income	Rental rate \times FA \times LF	2000¥/ye/m ²
Minor Injury	MI per cost \times FA \times OR \times rate	2000¥/per
Serious Injury	SI per cost \times FA \times OR \times rate	2×10^5 ¥/per
Human fatality	HF per cost \times FA \times OR \times rate	5×10^5 ¥/per

*FA=floor area, DI=damage index, LF=loss function, OR=occupancy rate, MI=minor injury, SI=serious injury, HF=human fatality.

Moreover, Wen and Kang proposed the further formula for the limit state cost considering N limit states[4].The steps of the life-cycle cost analysis are presented in the flowchart(see Fig. 1).

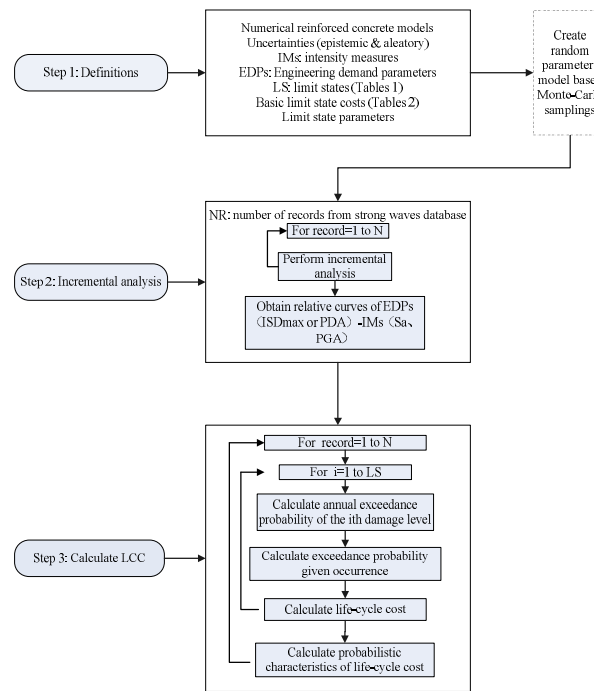


Fig. 1. Framework of life-cycle loss estimation

Modeling of uncertainties and numerical simulation

For the calculate example, the six storey reinforced concrete building used in this research. The structure corresponds to towns' and villages' RC frames wide used in Western China comply with the China seismic code (GB50011-2010) [5]. For the analysis a three dimensional fiber model is created(see Fig. 2).

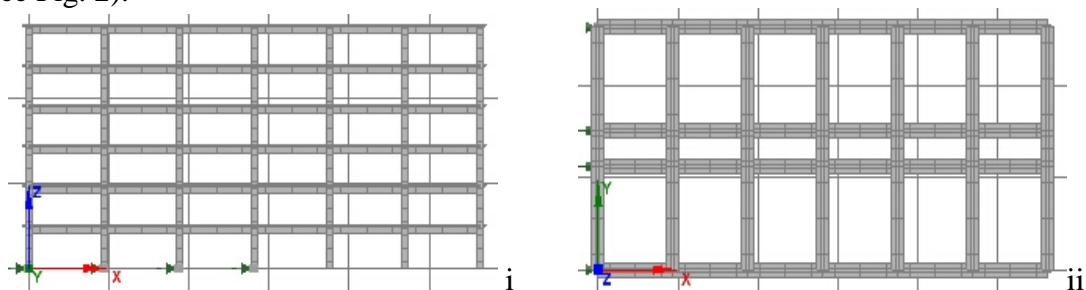


Fig 2. Finite element model of the RC buildings(i: front view, ii: top view)

The structural layout of the building represents six bay in longitudinal direction with 6-8m span lengths and three bay in transverse direction with 6-2.5-6m span lengths respectively. The storey height is 3.3m. The column elements size is 0.6m×0.6m and reinforcement ratio is 1.74%. The beam size is 0.3m×0.6m and reinforcement ratio is 1.40%(see Fig 3). The gap between hooping is also require the code of China.

In this work, finite RC buildings have been considered by influence of various sources of uncertainties in the process of life-cycle cost estimation. Steel of class with yield stress of 335-400 Mpa and modulus of elasticity equal to 210 Gpa has been considered, while concrete of cubic strength of 20-25 Mpa and modulus of elasticity equal to 30 Gpa. The slab thickness is equal to 12cm, while in addition to the self weight of the beams and the slabs, a distributed permanent load of 2 kN/m^2 due to floor- finishing partitions and live load of 1.5 kN/m^2 .

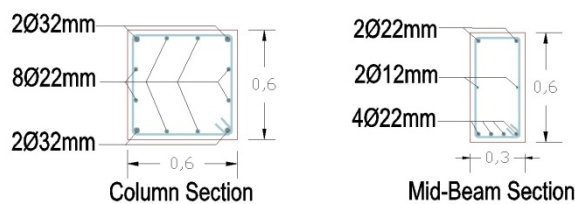


Fig 3. Detailed drawings of frame' section

In the research the hazard levels are defined in accordance to the hazard curve transferred from China seismic code and of the city of Yinchuan, western of China(latitude(N)38.4°,longitude(W)106.2°) because of high seismic hazardous of local region. Seven hazard levels (HL: 72/50, 38/50, 25/50, 16/50, 10/50, 5/50, 2/50) corresponding to the different annual probability of exceedance and maximum inter-storey drift ratio (ISD) and Peak diaphragm acceleration (PDA) in local area are calculated. Therefore, the maximum DIs calculated at each hazard level have an annual exceedance probability equal to that of the current HL.

Incremental dynamic analysis nonlinear procedure has been chosen for detect structural seismic vulnerability including structural damage and non-structural damage. For implementation of the IDA, multiple nonlinear analyses have to be performed in order to assess it's performance in all eight hazard levels. So we set suggested 7 damage limit states in calculation on the base of post research. And emphasis of limit state is been located in light damage and moderate damage corresponding to the damage ratio between 5%-20% based structural damage condition[6]. At the same time nonstructural damage also can be classify with 7 hazard level or limit state using peak ground acceleration. Damage scale indicators in IDA is decided through 7 scale factor for each of the 50 ground motions and of 7 hazard levels (see Fig. 4 and Table 3).

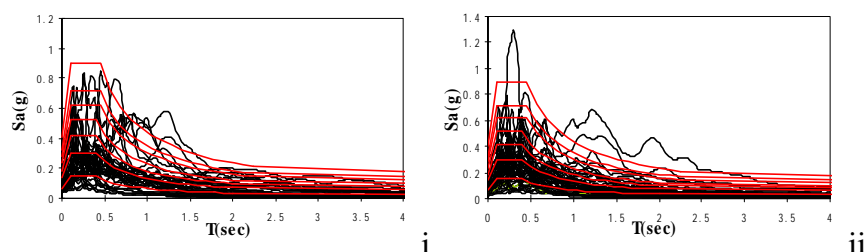


Fig. 4. Response spectrum (I: longitude, II: Transverse) of selected waves with 7 HL (red curves)

Table 3. Experimental and calculated data

No.	Hazard Level (HL)	Limit State (LS)	P_i^{DI} %	Scale factors
1	72/50	Slight damage	1.81	1.3
2	60/50	Light damage I	0.379	2.7
3	38/50	Light damage II	0.227	3.7
4	25/50	Moderate damage I	0.139	4.7
5	16/50	Moderate damage II	0.107	6.2
6	10/50	Heavy damage	0.0626	7.2
7	5/50	Major damage	0.0404	9.0

LCC analysis and conclusion

In the seismic assessment of structures a wide range stochastic man-made waves and seven HL level are considered in order to take into account the uncertainties. The main objective of a IDA method is to define a curve through a relation between the seismic intensity level and the corresponding maximum response of the structural system. The intensity level and the structural response are

described through an intensity measure (IM) and an engineering demand parameters (EDP) which refers also as damage index (DI). Incremental analysis are implemented through the following steps in this research: (i) Construct the local typical digital finite element model for performing nonlinear dynamic analyses; (ii) select a group of stochastic man-made waves fitted with local response spectrum; (iii) select a proper intensity measure and an engineering demand parameter; (iv) employ an appropriate algorithm for selecting the record scaling factor in order to obtain the IM-EDP curve by performing the least required nonlinear dynamic analyses and (v) employ a summarization technique for exploiting the multiple waves results. In this work, the $S_a(T_1, 5\%)$ for damping equal to 5% is selected as IM indicator, since it is the most commonly used intensity measure in practice for the analysis of buildings. At the same time, two kind of damage index: the maximum inter-storey drift and PDA are chosen as EDPs, which are based on the maximum deformation of different damage limit states.

For example actual physical damage calculation process of RC frames using IDA with Friuli Italy-02 (1976) earthquake record is explained next carefully. The IM scale factor increase from 1 to 9 in IDA analysis. The whole damage results of maximum inter-storey drift ratio and PDA of every storey. That means all kind of seismic intensity waves have impacted on buildings in life-cycle period. So the structural and non-structural damage of every floor of buildings can be calculated from the two EDPs parameters. The maximum ISD% of whole structure locates in second floor and the peak diaphragm acceleration (PDA) in the top floor at the same time. So that mean the most structural damage lie in second floor and the severe non-structural damage in top storey. The tendency of the seismic vulnerability changed more obvious than ever(see Fig. 5).

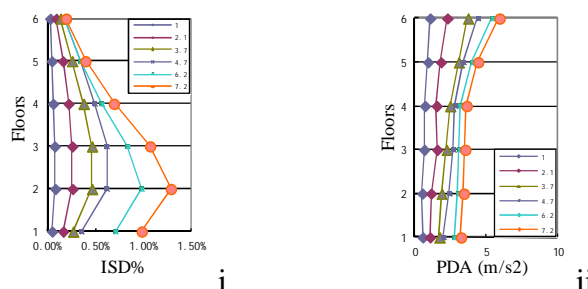


Fig.5 The Maximum inter-storey drift ratio and Peak Diaphragm acceleration (i: ISD%; ii: PDA)

The life-cycle seismic cost can be obtained finally through incremental dynamic analyses based above equations in research[7]. More efficient consist of LCC results can be found after stochastic big-data analysis (see Fig. 6 and Table 3).

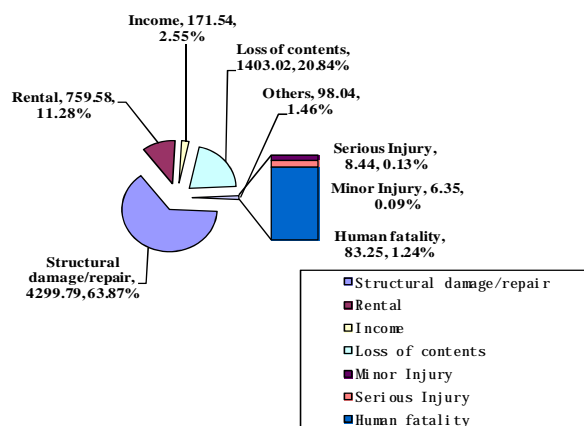


Fig.6 Consist of LCC probability median values in Yinchuan region

After study local statistics data of construction engineering in Yinchuan which located in high seismic hazardous region of western China. In this research 2500 ¥/m² is considered as C_{IN} , meantime $\pm 10\%$ variance is also included.

Table 4. SLCC Of statistics characteristics comparison

Constitute	Average ¥	Median ¥	CoV %
C_{dam}^i	4060.44	4299.79	2.61%
C_{ren}^i	730.52	759.58	8.16%
C_{inc}^i	166.15	171.54	10.43%
$C_{con}^{i,q}$	1196.27	1403.02	0.77%
C_{inj}^i	24.06	14.79	5.22%
C_{fat}^i	136.66	83.25	6.08%
C_{tot}	6314.21	6731.98	1.23%

The statistics median construction area of typical sample RC building is 3650m². The annual average LCC is 1.73 ¥/m² after calculation using above procedure, and annual median LCC is 1.84 ¥/m². There will add up additional reasonable 50% fee if insurance companies will establish catastrophe insurance in the near future. The final insurance premium per people is about 90.8-96.8 ¥ annually in considering of local life endurance in this research on base of average living space per person equal 35 m². The result is considered in acceptable level for local inhabitant in Yinchuan city of western China as research sample region finally.

Acknowledgements

This work was financially supported by the National Natural Science Foundation of China (51468050) and the Shanxi Province Post-doctoral Science Foundation.

References

- [1] Christine A. Goulet et. al: Evaluation of the seismic performance of a code-conforming reinforced-concrete frame building—from seismic hazard to collapse safety and economic losses, *Earthquake Engng. & Struct. Dyn.*,36:1973–1997,2007.
- [2] Ramirez, C. M et al.: Expected earthquake damage and repair costs in reinforced concrete frame buildings. *Earthquake Engng.&Struct. Dyn.*,41(11):1455 – 1475,2012.
- M.A. Green: *High Efficiency Silicon Solar Cells* (Trans Tech Publications, Switzerland 1987).
- [3] Ghobarah A., "On drift limits associated with different damage levels,"Proceedings of the international workshop on performance-based seismic design, June 28-July 1,2004.
- [4] Wen YK. Kang YJ.: Minimum building life-cycle cost design criteria II: application," *J.Struct Eng*,127(3):338-346,2001.
- [5] Ministry of Construction P.R.China, in:Code for seismic design of buildings (GB50011-2010), China Construction Press Publication, Beijing, 2010.
- [6] Federal Emergency Management Agency. : *FEMA 227:A benefit-cost model for the seismic rehabilitation of buildings*, Washington, DC: Building Seismic Safety Council, pp. 102-135,1992.
- [7] Lagaros, ND and Mitropoulou, CC: The effect of uncertainties in seismic loss estimation of steel and reinforced concrete composite buildings, *Structure and Infrastructure Engineering*, Vol. 9, No. 21, 546-556,2013.