8th International Conference on Seismology & Earthquake Engineering
11-13 Nov. 2019, Tehran, Iran

INFLUENCE OF REDUCED SEISMIC HAZARD LEVEL IN REHABILIATION CONSIDERING REMAINING LIFE SPAN

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Keywords: Seismic hazard level; Remaining building life span; Existing building; Probable of limit state

ABSTRACT

In the seismic evaluation and retrofit methodology proposed by FEMA 356 and seismic rehabilitation of existing buildings No.360, the selected seismic hazard level is a 475-year return period earthquake with a probability of occurrence 10% in 50 years expected remaining lifespan for an existing building, While expected remaining existing building life span is much less than 50 years. Hence, reducing the seismic hazard level is used to enable cost-effective seismic evaluation and retrofit of the existing building. The current study base on the equivalence of probability of exceedance between existing and new building recommend seismic hazard reduction factors. Then, the existing building is retrofitted for the reduced seismic hazard level. A validation procedure is proposed to investigate the objective performance of a nonlinear SDOF system based on using the probability of a limit state. The limit state probability is a probability that a specific limit state occurs during the building lifespan. The results show that considering reduced seismic hazard level according to the remaining building lifespan can be permitted in conjunction with appropriate lower bounds of the remaining building lifespans.

1. INTRODUCTION

Retrofitting the existing buildings sometimes is very expensive. It may be costs as much as building a new one. Cost-benefit considerations are needed in seismic codes for existing buildings to avoid the inefficient allocation of resources.

Proportional cost limits for retrofitting can be efficiently determined by the risk-based rules introduced in Swiss Pre-standard SIA 2018 (SSEA, 2004). The framework is based on the probabilistic seismic hazard assessment elaborated by the Swiss Seismological Service, and the main parameters of this assessment are the compliance factor, the occupancy, and the remaining useful life of the existing structure (Jamali et al., 2012) and (Wenk, 2014). The compliance factor as a ratio of seismic demand overcapacity has the main influence. Pre-standard SIA 2018 considering both life-safety and cost-effectiveness, set a minimum compliance factor that must be preserved in order to maintain life safety standards. (Wenk and Beyer, 2014). Based on equal probabilities of exceedance within different remaining building lifespans, seismic hazard reduction factors have been recommended to enable cost-effective seismic evaluation and retrofit of an existing building (Park, 2019).

The current study base on the equivalence of probability of exceedance between existing and new building in their remaining building lifespan (RBL) calculate the seismic hazard reduction factors for 4 seismicity zones of Iran, one of low to very high seismicity regions. In addition, a validation procedure is proposed to investigate the equivalence of performance between an existing building and a new building.

2. SEISMIC HAZARD REDUCTION FACTORS BASED ON REMAINING BUILDING LIFESPAN

In many seismic design codes, seismic hazards are defined as the probability of exceedance in 50 years, which is the expected lifespan of the buildings. However, existing buildings have remaining building lifespan shorter than 50 years. Therefore, the seismic hazard level for evaluation and retrofit of an existing building can be reduced according to the RBL as given in the following.

$$P_E = 1 - (1 - \lambda_{exist})^{L_{exist}} = 1 - (1 - \lambda_{new})^{L_{new}} \qquad (1)$$

Where L_{exist} is the expected remaining building lifespan for an existing building and L_{new} is the expected whole building lifespan for a corresponding new building. Also, λ_{exist} is the annual rate of exceedance of the seismic hazard level applied to the evaluation and retrofit of the existing building, and λ_{new} is the annual rate of exceedance applied to design of the corresponding new building. Therefore the annual rate of an existing building given the RBL can be computed in the following.

$$\lambda_{exist} = 1 - (1 - \lambda_{new})^{L_{new}/L_{exist}} \qquad (2)$$

The seismic hazard reduction factors are listed up in Table 1 for 475 years return period for 4 seismicity zone of Iran, and each zone contains 4 cities.

Table 1. Seismic Hazard Reduction Factor for four different seismicity zones in Iran

		Rh														
		λ=0.0021049			**λ=0.0026305**			**λ=0.0035058**			**λ=0.0052541**			**λ=0.01048**		
Seismicity zones	L_{exist}/L_{new}:	**1**			**0.8**			**0.6**			**0.4**			**0.2**		
Very High	Tehran	0.78	0.78	1.00	0.78	0.69	0.88	0.78	0.59	0.75	0.78	0.45	0.58	0.78	0.28	0.36
	Boroujerd	0.47	0.47	1.00	0.47	0.42	0.90	0.47	0.37	0.78	0.47	0.29	0.63	0.47	0.20	0.42
	Tabriz	1.14	1.14	1.00	1.14	1.02	0.89	1.14	0.86	0.76	1.14	0.68	0.60	1.14	0.43	0.38
	Qazvin	0.59	0.59	1.00	0.59	0.52	0.89	0.59	0.45	0.76	0.59	0.36	0.61	0.59	0.24	0.41
High	Ardabil	0.37	0.37	1.00	0.37	0.33	0.90	0.37	0.29	0.78	0.37	0.24	0.64	0.37	0.16	0.44
	Mashhad	0.36	0.36	1.00	0.36	0.32	0.89	0.36	0.28	0.76	0.36	0.22	0.61	0.36	0.14	0.40
	Bam	0.47	0.47	1.00	0.47	0.42	0.90	0.47	0.37	0.79	0.47	0.30	0.64	0.47	0.20	0.42
	Bandar abbas	0.65	0.65	1.00	0.65	0.58	0.90	0.65	0.49	0.76	0.65	0.39	0.60	0.65	0.26	0.40
Moderate	Esfahan	0.25	0.25	1.00	0.25	0.22	0.88	0.25	0.19	0.74	0.25	0.15	0.59	**0.25**	**0.10**	**0.40**
	Ahvaz	0.44	0.44	1.00	0.44	0.39	0.89	0.44	0.33	0.76	0.44	0.27	0.61	0.44	0.17	0.38
	Ilam	0.46	0.46	1.00	0.46	0.42	0.90	0.46	0.36	0.79	0.46	0.30	0.64	0.46	0.21	0.45
	Yazd	0.27	0.27	1.00	0.27	0.24	0.90	0.27	0.21	0.77	0.27	0.16	0.61	0.27	0.11	0.40
Low	Abadan	0.13	0.13	1.00	0.13	0.12	0.89	0.13	0.10	0.76	0.13	0.08	0.61	0.13	0.05	0.41
	Arvandkenar	0.12	0.12	1.00	0.12	0.11	0.89	0.12	0.09	0.75	0.12	0.07	0.59	0.12	0.05	0.39
	Khoramshahr	0.25	0.25	1.00	0.25	0.22	0.90	0.25	0.19	0.77	0.25	0.16	0.63	0.25	0.11	0.44
	Bandarmahshahr	0.12	0.12	1.00	0.12	0.11	0.89	0.12	0.09	0.75	0.12	0.07	0.60	0.12	0.05	0.40

For instance, the seismic hazard reduction factor is 0.4 at building lifespan ratio equal to 0.2 for 475 years return period in Esfahan, which means that an existing building with 10-year RBL can be retrofitted against 40% of design earthquake for a new building with 50-year RBL.

3. DESCRIPTION OF THE MODEL

The seismic hazard reduction factor proposed in this study is applied to existing buildings retrofitted for unreduced and reduced design earthquakes. The structural behavior of existing buildings subjected to ground motion is idealized with an inelastic SDOF system with a trilinear envelope curve proposed by (Park 2019). The SDOF model has been retrofitted with 2 different strategies as follows, enhancing ductility capacity and increasing the strength of the model. Both strategies are plotted in Figure 1.

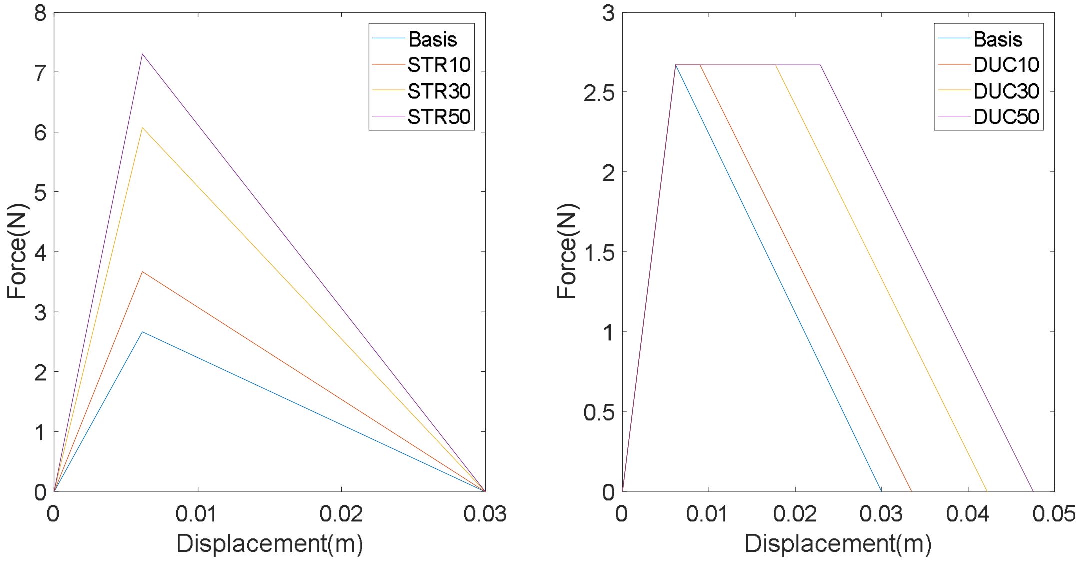

Figure 1. Force-Displacement relationship for basis SDOF systems with and without retrofitting (T=0.3s)

Retrofitting the existing building executed for 50, 30, and 10 years RBL. For instance, STR30 means the existing building with 30 years RBL is retrofitting with consideration of reduced seismic hazard level for 30 years RBL.

In this study, the objective performance level is LS2, which is approximately equal to life safety. Also, the behavior of the structure is being studied in LS1, which related to elastic limit and immediate occupancy, and LS3 that is related to the collapse prevention. The mentioned performance levels are corresponding to the ductility ratio μ_1 , μ_2 and μ_3 as illustrated in Figure 2.

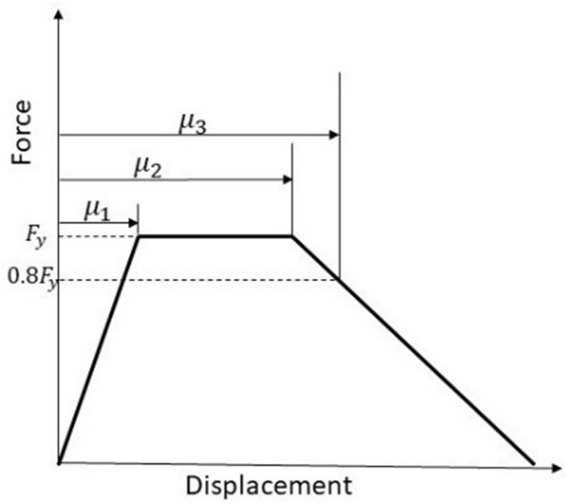

Figure 2. Objective performance.

The characteristics of retrofitted SDOF system are calculated by Equation (3) as in ASCE 41-17.

$$\delta_t = C_1.C_2.\delta_a.\frac{T_e^2}{4\pi^2}g \tag{3}$$

Sa is response spectrum acceleration at the effective fundamental period and damping ratio of the building in the direction under consideration, g is the acceleration of gravity, C1 is the modification factor to relate expected maximum inelastic displacements to displacements calculated for the linear elastic response, C2 is modification factor to represent the effect of pinched hysteresis shape, cyclic stiffness degradation, and strength deterioration on the maximum displacement response. Since the model is single-degree-of-freedom, so the modification factor to relate spectral displacement of an equivalent single-degree-of-freedom system to the roof displacement of the building multiple-degree-of-freedom system is not required.

The characteristics of the retrofitted SDOF system against the reduced seismic hazard level are listed up in Table 2.

Table 2. Components of the retrofitted SDOF systems

Parameter	Retrofitting strategies	Enhancing ductility			Strengthening		
	Designation	DUC10	DUC30	DUC50	STR10	STR30	STR50
	target remaining lifespan	10	30	50	10	30	50
Increased ductility capacity		1.45	2.88	3.72	1	1	1
Added strength ratio (Fd/Fu)		0	0	0	0.38	1.28	1.74

Fu: initial strength of existing buildings before retrofit

The increased ductility demand is 3.72 for retrofitting SDOF system with 50 years RBL while it drops about 60% for increased ductility demand for retrofitting SDOF system with 10-year RBL. The same results are observed in strengthening strategy, which added strength ratio decreased approximately 80% from building with 50 years RBL to 10 years RBL. The fragility curves with and without retrofitting extracted from (PARK, 2019) are plotted in Figure 3.

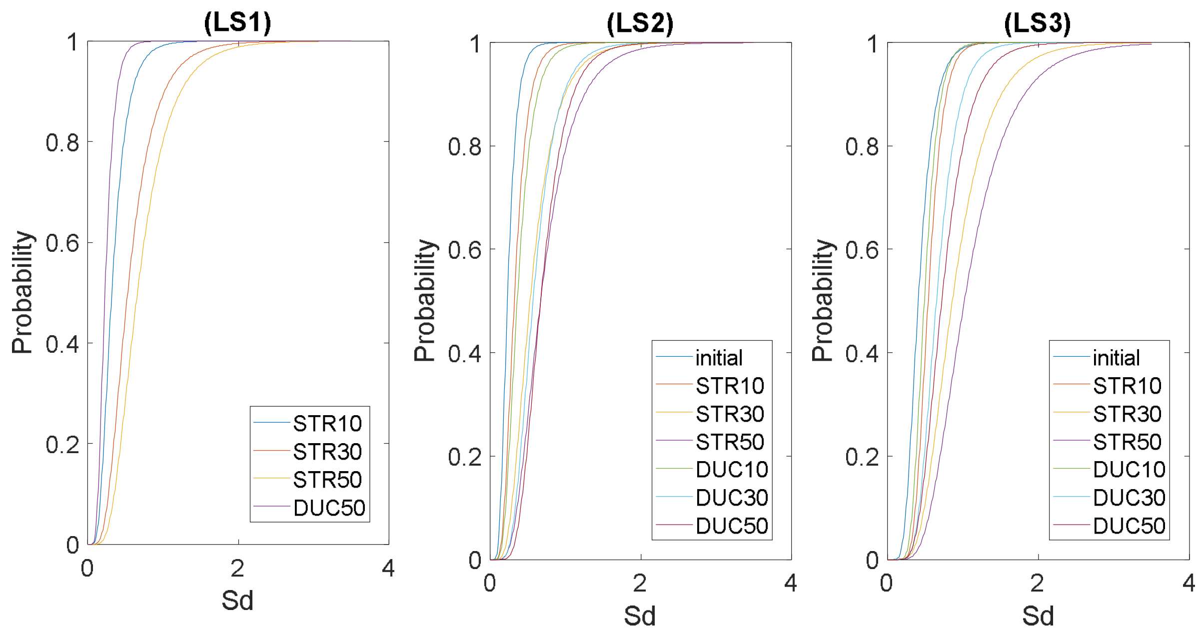

Figure 3. Seismic fragility curve.

However, fragility curves are not enough to investigate the equivalence in seismic performance for two different remaining building lifespans. Hence, the validation of equivalence between existing and corresponding new building investigate in terms of limit state probability, of which definition and evaluation procedure is proposed in the next section.

4. LIMIT STATE PROBABILITY

The limit state probability consists of integral convolution of fragility curves to probability density function (PDF) of the maximum intensity measure that occur during a remaining building lifespan.

The PDF of maximum intensity measure can be derived by differentiating the probability of non-exceedance in corresponding RBL in Equation (4).

$$P_{NE} = [1 - f(Sa)]^{L_{exist}} \quad (4)$$

P_{NE} is the probability of non-exceedance and $f(.)$ is the inverse seismic hazard function, which yields the annual rate of exceedance of the seismic hazard level corresponding to a given spectral acceleration.

The PDF of maximum intensity measure for 50, 30, and 10 years remaining building lifespan in Esfahan is plotted in Figure 4.

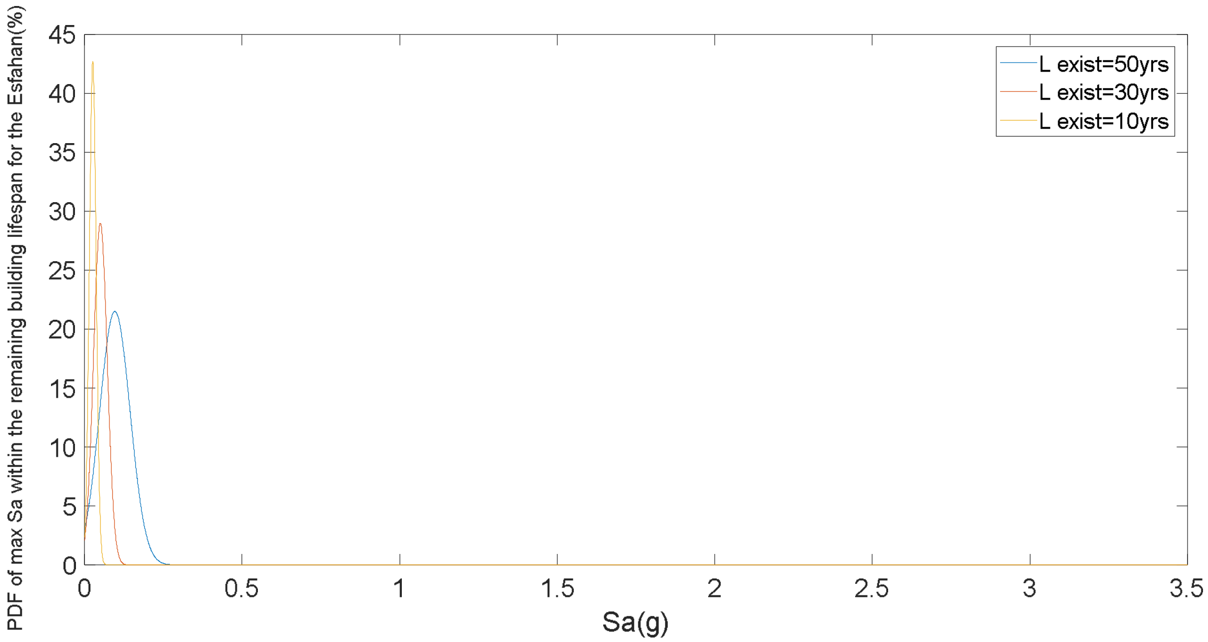

Figure 4. PDFs of the maximum Sa within the remaining building lifespan for the Esfahan seismic hazard curve of Iran.

As a result, the limit state probability given the building lifespan is computed as follows:

$$P_{LS}(L_{exist}) = \int_0^{\infty} \left\{ \frac{dP_{NE}(x, L_{exist})}{dx} \times P(D > C|IM = x) \right\} dx \quad (5)$$

Where $P_{LS}(L_{exist})$ the limit state probability for a given building lifespan L_{exist} and P is the fragility function of the limit state.

The PDFs of the limit state probability for 3 limit states are plotted in Figure 5.

As it is noticeable, the strengthening strategy is more suitable for LS1 and LS3 limit states since it doesn't relate to the plasticity behavior of the structure. In converse, enhancing ductility is more appropriate for LS2 because, in the same intensities, the probability of exceedance is lower than strengthening strategy.

Generally, the probability of exceedance for Esfahan is much more in comparison with the same case (PARK, 2019).

The results show that as much as the remaining building life span decrease, the probability of exceedance goes lower, but at some level, lower than 10 years is a too-short lifespan to spend retrofitting cost on.

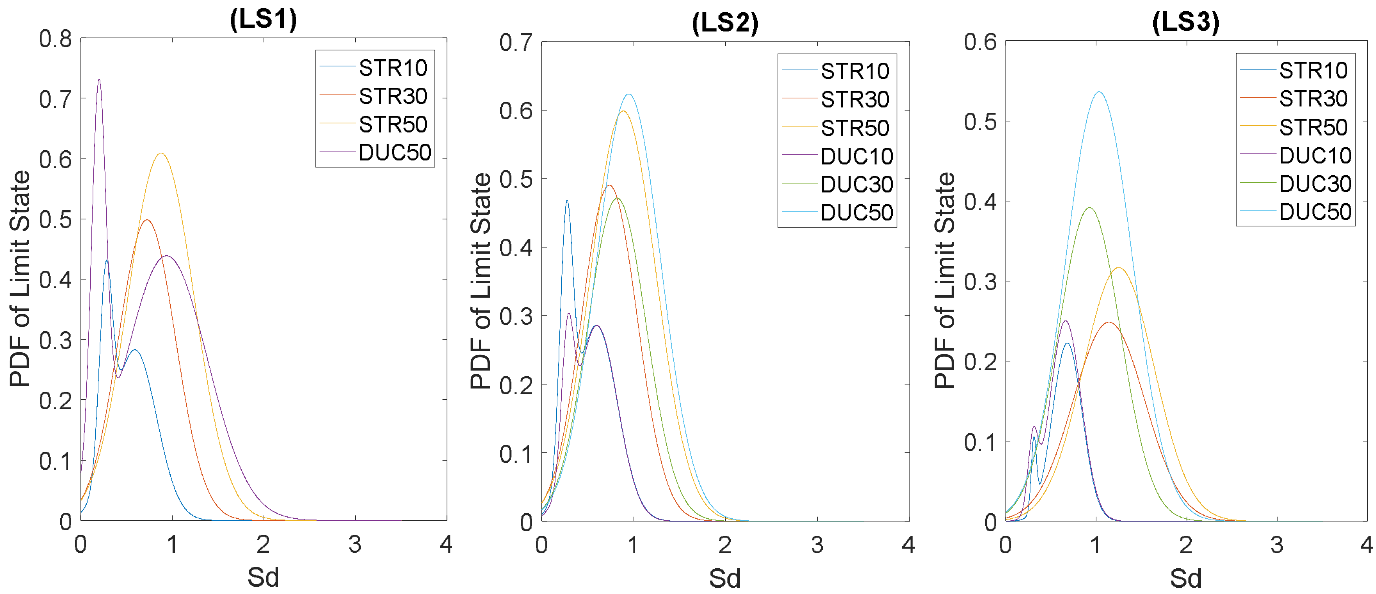

Figure 5. Probability density of exceeding specific limit state.

5. CONCLUSIONS

Seismic hazard reduction factors can be an appropriate method in conjunction with cost-effective seismic evaluation and retrofit of the existing building. The seismic hazard coefficient factors were proposed for 4 different seismicity zones of Iran, one of low to very high seismicity regions. Then a case study in Esfahan with moderate seismicity level has been chosen to assess the influence of reducing the seismic hazard level on the increasing ductility demand and added strength ratio demand in retrofitting the existing building. The results show that the demand decreases by about 50% according to 10 years remaining building lifespan.

The current study proposes the probability of a limit state to investigate the validation of the mentioned method. The probability of a limit state is determined by multiplying the probability density function of the maximum intensity measure within the remaining building lifespan to the fragility curve. To sum up, considering reduced seismic hazard level according to the remaining building lifespan can be permitted in conjunction with appropriate lower bounds of the remaining building lifespans.

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