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Original Research Article

Reliability of Iranian Existing Residential Reinforced Concrete Structures in Seismic Events

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Abstract

Structures failure prevention plays a vital role in saving the lives of citizens. The Iranian Code of Practice for the seismic-resistant design of buildings, Standard No. 2800, is one of the most critical and influential Iranian codes that are revised and edited regularly. Hence, this question arises: how will these regulations affect structures' performance in future events? In this study, the performance of structures designed based on the third and fourth editions of standard No. 2800 is evaluated in operational (OP), immediate occupancy (IO), life safety (LS), and collapse prevention (CP) performance levels. The performance of structures is evaluated via two probabilistic approaches. Structural nonlinear analysis uses incremental dynamic analysis based on conditional mean spectrum-compatible records. The evaluations are carried out on three, five, and eight floors (three and five spans) intermediate moment resisting reinforced concrete structures. The results show that the seismic performance of structures in the later edition has improved compared to the previous one. However, the structures of both editions are safe at performance levels of OP, IO, and LS with a confidence level greater than 99%; the confidence level of CP performance level decreases with increasing height of structures so that the reliability of the fourth edition 8-story structures and third edition 5-story and 8-story structures is less than 90%. Therefore, it seems necessary to consider CP performance levels in seismic evaluations.

Keywords: Reliability index performance levels; Confidence level; Incremental dynamic analysis (IDA).

1. Introduction

Assessing the reliability and seismic risk of structures plays a vital role in ensuring the safety of residents. Jara et al. assessed the seismic response and reliability index of reinforced concrete (RC) buildings in Mexico City, highlighting the effectiveness of passive control systems in reducing seismic risk [1]. Zhang et al. examined the reliability of RC structures in progressive collapse, finding that the reliability of frames under side column loss is lower than under other conditions [2]. Okada provided an overview of the development and status of seismic evaluation in existing RC buildings in Japan [3]. Jung and Lee proposed a methodology for evaluating the seismic risk of reinforced concrete buildings in Korea [4].

Iran is a seismic-prone country located in the Alpine-Himalayan orogenic belt and has experienced numerous catastrophic earthquakes with tens of thousands of casualties throughout history [5-8]. These experiences enforce earthquake risk mitigation criteria in all relevant aspects to prevent or reduce such losses [9]. Iranian Code of Practice for the seismic resistant design of buildings, Standard No. 2800, was first introduced in 1987 by Iran Building and Housing Research Center [10]. Standard No. 2800 has undergone three major revisions in 1999, 2005, and 2015 [11-13]. These significant changes raise the critical question of the role of regulation in building enhancement. In addition, what is the difference between buildings designed under the new and previous editions of the Code? Answering these questions, several studies investigate the seismic performance of reinforced concrete (RC) buildings designed based on different versions of the design codes. Mahmoudi Sahebi and Ghobadi [14] evaluated the service performance level of high-importance RC frames using static pushover analysis. The structures are designed according to standard No. 2800, third edition. They showed that buildings are vulnerable to earthquake excitations.

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Tasnimi and Kazemi [15], using nonlinear static and time history analysis methods, indicated that the moment-resisting RC structures designed based on the third edition of the standard No. 2800 are conservatively safe in Life Safety (LS) performance level. Mohammadi et al. [16] investigated near-fault effects on the demand for RC buildings in linear and nonlinear analysis. They showed that the design spectrum of the fourth edition of standard No. 2800 is incompatible with near-fault spectra and underestimates demands in the long-period range. Pazuki and Tasnimi [17] evaluated the performance levels of Immediate Occupancy (IO), LS, and Collapse Prevention (CP) for RC structures designed according to the standard no. 2800 (fourth edition), using the Park-Ang damage index. They showed that this damage index needs to be investigated at the CP level. Hoseini et al. [18] have conducted a detailed assessment of collapse risk on a set of intermediate moment resisting RC buildings designed according to Iranian codes (including standard No. 2800, fourth edition) and showed that the probability of instability increases with the height of the buildings. Sadeghpour and Ozay [19] evaluated the design reliability and seismic performance factors provided in Standard No. 2800-99 (second edition) and Standard No. 2800-05 (third edition) for RC structures. Their results showed that the structural systems designed based on Standard No. 2800-05 fulfill the requirements for moderately intense earthquakes. However, the vulnerability of certain building stocks designed based on the second edition is observed, and the life safety performance level is challenged. Rezaei and Massumi [20] studied the seismic performance of a multi-story reinforced concrete frame building designed according to the fourth edition of the Iranian seismic Code (standard No. 2800-15). The performance has been evaluated based on member and global-level criteria. Their results show that the building frames designed by standard No 2800-15 satisfy the intended code requirements and meet the inter-story drift and maximum plastic rotation demands suggested by Instruction for Seismic Rehabilitation of Existing Buildings (No. 360) [21]. Rahbari and Tasnimi [22] investigated the design criteria of the Iranian seismic code (3rd and 4th editions) using nonlinear static and dynamic analyses to make the design results more compatible with the performance levels. They indicated that in the fourth edition of Standard No. 2800, the demand capacity ratio of bending in the upper stories of the frame increases, while there is no significant change in the lower stories. Also, they showed that a reduction in drift criteria limitations leads to a reduction in the total structure damage index. Therefore, a comprehensive evaluation of the behavior of structures at different performance levels and risk assessment can help to understand the exact impact of regulations on structural safety.

In this research, based on the reliability index, we evaluate the effect of criteria of standard No. 2800, version 3 and 4, on the seismic performance of twelve intermediate moment resisting RC frames of 3, 5 and 8 stories (three and five-span), at different performance and hazard levels, including Operational Performance (OP) in the hazard of 99.5% probability of exceedance in 50 years (service level earthquake), IO performance in the hazard of 50% probability of exceedance in 50 years, LS performance in the hazard of 10% probability of exceedance in 50 years (design level earthquake) and CP performance in the hazard of 2% probability of exceedance in 50 years. Incremental Dynamic Analysis (IDA) is used to perform nonlinear structural analysis.

2. Structure loading and design

Twelve intermediate moments resisting RC frames of 3, 5, and 8 stories (three and five-spans) are designed in a very high seismicity zone in Tehran metropolitan based on the third and fourth editions of the Iranian Seismic Code [8-9]. Gravity loads are supposed to resemble common residential buildings in Iran [23-26]. Structures are assumed to be on soil type II (Average shear wave velocity of 360-750 m/s) according to Standard No. 2800 requirements. Story height in all structures is 3 meters. All farms have two equal side spans of 4m and a middle span of 5m length. Each frame is assumed to be part of the lateral load-resisting system of a building. The rigid diaphragm is assigned to all frames. The structures are symmetric in plan and regular in elevation. Materials properties are shown in Table 1.

Table 1. Material characteristics of RC structures

parameter	notation	unit	value
concrete compressive strength	f_c	MPa	25
longitudinal bars yielding strength	f_y	MPa	400
shear bars yielding strength	f_{ys}	MPa	300
concrete elasticity modulus	E_C	MPa	2.5×10^4
steel elasticity modulus	E_S	MPa	2.1×10^5

The plan and elevation view of the structures are shown in Figure 1. Elements marked with underlines show the third edition design. Fundamental periods of structures and cross-sections for all members are shown in Tables 2, 3, and 4, respectively.

Table 2 shows that the analytical fundamental period of structures with the same height is different in various editions of Standard No. 2800. Differences in the fundamental periods of the third and fourth editions structures are due to the change in design spectrum, structural behavior factors, and earthquake load coefficients in the design load combination. The beams' and columns' details are shown in Tables 3 and 4. The sections designed based on the fourth edition are greater in dimension, weight, and stiffness and smaller in the period than in the third edition. Period change in the 5 and 8-story structures is higher than in the 3-story structures.

3. Incremental Dynamic Analysis (IDA)

In this study, IDA was used for structural analysis. IDA curve is a drawing of the nonlinear dynamic response of structures under a scaled ground motion record [27]. Previous studies have shown that at least 12 different scale factors are required to calculate an IDA curve for a record [28]. Since the decency of the selected record, the IDA curve of one record alone cannot estimate the actual behavior of structures for other earthquakes. So, a suite of ground motion records is needed. The selection of ground motion records is an essential issue in IDA. Previous studies show that 20 earthquake records are required for middle-height structure analysis [29]. The selected records should assess the possibility of structural collapse in seismic zones in the maximum considered earthquake (MCE). We use the conditional mean spectrum (CMS) method for record selection [30]. This method considers regional characteristics, including magnitude, distance, and spectral shape, as dominant parameters in record selection. The CMS method incorporates the aleatory and epistemic uncertainties in earthquake events.

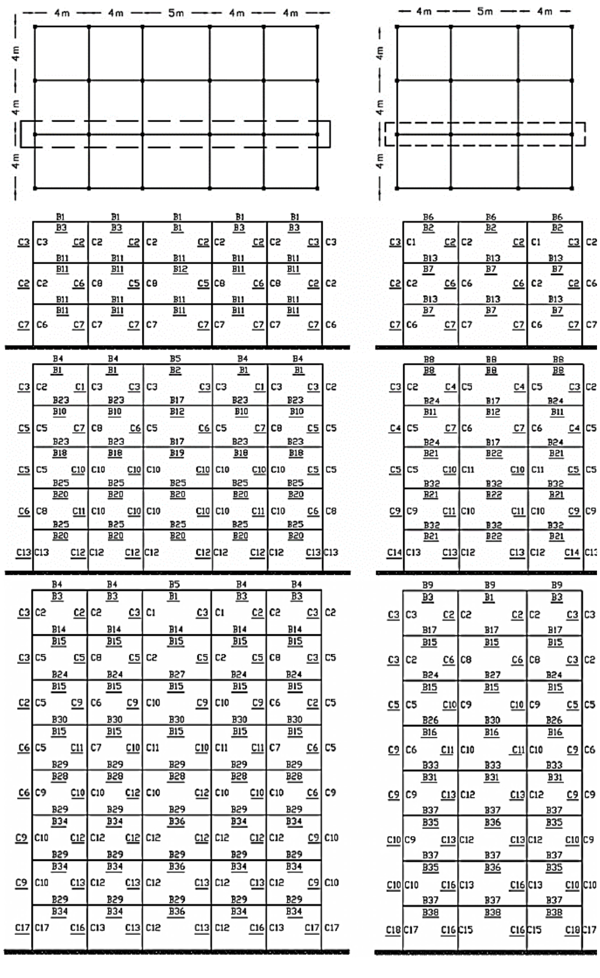

Figure 1. Plan and elevation of the structures with grouping beams and columns

Table 2. Fundamental periods of structures

Structure	Version 3	Version 4
3 story- 3 bay	**0.66**	**0.65**
3 story- 5 bay	**0.64**	**0.63**
5 story- 3 bay	**0.78**	**0.71**
5 story- 5 bay	**0.79**	**0.72**
8 story- 3 bay	**0.93**	**0.86**
8 story- 5 bay	**0.95**	**0.87**

Table 3. Beams details

Group	Width (cm)	Depth (cm)	top bars	bottom bars
B1	30	30	4Φ16, 1Φ10	1Φ12, 1Φ14
B2	30	30	3Φ20	2Φ14
B3	30	30	3Φ16, 1Φ12	3Φ10
B4	30	35	3Φ16	1Φ12, 1Φ14
B5	30	35	2Φ18, 1Φ16	1Φ12, 1Φ14
B6	.30	40	3Φ16	2Φ14
B7	30	40	3Φ22	2Φ16, 1Φ14
B8	35	30	4Φ18	2Φ14
B9	35	35	1Φ22, 1Φ20	2Φ14
B10	35	35	3Φ20, 1Φ16	2Φ18
B11	35	40	3Φ20, 1Φ14	2Φ18
B12	35	40	3Φ22	2Φ16
B13	35	45	2Φ20, 1Φ22	1Φ22, 1Φ14
B14	35	50	1Φ22, 1Φ20	3Φ14
B15	35	50	3Φ20, 1Φ18	2Φ18
B16	35	50	3Φ22, 1Φ10	4Φ16
B17	35	55	3Φ18	1Φ18, 1Φ14
B18	40	40	3Φ22, 1Φ14	4Φ16
B19	40	40	3Φ22, 1Φ16	2Φ18
B20	40	45	4Φ20, 1Φ12	4Φ16, 1Φ10
B21	40	45	4Φ20, 1Φ16	4Φ18
B22	40	45	4Φ20, 1Φ14	3Φ16
B23	40	45	3Φ20, 1Φ18	3Φ14
B24	40	45	3Φ20, 1Φ18	2Φ20, 1Φ12
B25	40	50	4Φ18	2Φ18
B26	40	50	3Φ20, 1Φ18	4Φ16
B27	40	50	3Φ16, 1Φ18	2Φ18
B28	40	55	3Φ22, 1Φ16	3Φ16, 1Φ12
B29	40	60	3Φ20, 1Φ12	4Φ14
B30	40	60	4Φ16, 1Φ10	4Φ14
B31	45	55	4Φ20, 1Φ10	4Φ18
B32	45	65	3Φ20, 1Φ14	4Φ16, 1Φ10
B33	50	50	3Φ22, 1Φ16	4Φ16, 1Φ14
B34	50	50	5Φ20	3Φ20, 1Φ18
B35	50	55	4Φ22	3Φ22
B36	50	55	4Φ22	2Φ20, 1Φ18
B37	50	60	3Φ20, 1Φ16	3Φ18
B38	50	65	3Φ20, 1Φ18	3Φ16, 1Φ20

Table 4. Columns details

Group	Dimensions	bars	Group	Dimensions	bars
C1	30X30	4Φ18	C10	40X40	8Φ18
C2	30X30	8Φ12	C11	40X40	8Φ20
C3	30X30	8Φ14	C12	45X45	8Φ18
C4	30X30	10Φ14	C13	45X45	8Φ20
C5	35X35	8Φ14	C14	45X45	8Φ22
C6	35X35	8Φ16	C15	45X45	14Φ16
C7	35X35	8Φ18	C16	50X50	8Φ20
C8	35X35	12Φ12	C17	50X50	8Φ22
C9	40X40	8Φ16	C18	50X50	12Φ20

Based on the probabilistic seismic hazard deaggregation result [31], we obtain the CMS and spectra of the records (Figure 2). The earthquakes' magnitude and peak ground-motion acceleration are from 4.5 to 7.5 (MW) and 0.05g to 1g, respectively (Table 5).

Another critical issue in IDA is selecting a suitable intensity measure (IM) and damage measure (DM) [32]. In this study, 5% damped first-mode spectral acceleration (Sa(T1, 5%)) and maximum inter-story drift ratio (θ_{max}) are selected as IM and DM, respectively.

IDARC2D (Version 7.0) [33] performs nonlinear time history analysis. The three-parameter Park hysteretic model, which comprises stiffness degradation, strength deterioration, non-symmetric response, slip-lock, and a tri-linear monotonic envelope, is used in this study. Values for hysteretic parameters (Stiffness degradation parameter (HC), Strength deterioration parameter (HBD, HBC), and slip-lock parameter (HS)) are used for intermediate moment resisting RC frames [34].

Table 5. Selected records for IDA (soil type II)

.4	.5	.6	.7	.8
Tabas	Dayhook	0.327	13.94	7.35
Manjil	Abbar	0.514	12.56	7.37
San	Pasadena	0.11	25.47	6.61
San	Lake	0.134	22.57	6.61
Kern	Taft	0.178	38.89	7.36
Morgan Hill	San Justo	0.081	31.88	6.19
Morgan Hill	Gilroy -	0.114	14.84	6.19
Hector	Twentynine	0.066	42.06	7.13
Sierra	LA - City	0.091	25.69	5.61
Loma Prieta	Anderson	0.244	20.26	6.93
Loma Prieta	Fremont -	0.106	39.51	6.93
Loma Prieta	Gilroy	0.126	18.33	6.93
Loma Prieta	Gilroy	0.17	18.33	6.93
Loma Prieta	Monterey	0.073	44.35	6.93
Northridge	Arcadia -	0.089	41.41	6.69
Northridge	Arcadia -	0.11	41.41	6.69
Northridge	Alhambra -	0.08	36.77	6.69
Northridge	N	0.271	12.51	6.69
Northridge	La	0.159	18.50	6.69
Northridge	LA - Chalon Rd	0.225	20.45	6.69

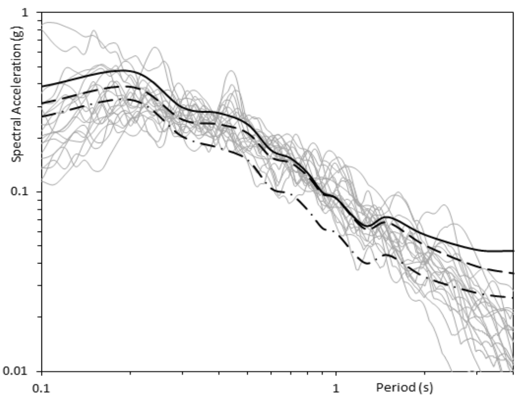

Figure 2. Regional design spectrum and spectra of selected records (CMS)

IDA curve is calculated for each record. Median (50%) and median plus or minus one standard deviation (e.g., 84% and 16%) are calculated for different structures [24]. Notably, each IDA curve was calculated based on at least 400 nonlinear time history analyses (20 records, each scaled by at least 20 different factors- 0.05 increment of spectral acceleration).

9. Performance evaluations

Based on the probabilistic framework of Yun et al. [35], performance analysis needs structural limit states to be defined for IDA curves. The confidence level estimation method and the desired performance objective are hired from FEMA-350 [32]. Four common performance levels are investigated in this study: OP with a hazard level of 99.5% probability of exceedance in 50 years (service level earthquake); IO with a hazard level of 50% probability of exceedance in 50 years; LS with hazard level 10% probability of exceedance in 50 years (design level earthquake); CP with hazard level 2% probability of exceedance in 50 years and that is defined according to criteria of standard No.2800 and FEMA-350. According to standard No.2800, drift ratios of 0.005 and 0.025 or 0.02 are selected for OP and LS performance levels, respectively. The assigned values to LS are different in the third and fourth editions. In the third edition, the value is chosen based on the fundamental period, such that for periods smaller than 0.7 seconds, it is 0.025, and for greater periods, it is 0.02.

Meanwhile, in the fourth edition, the values depend on the number of stories, such that for structures up to 5 stories, the value is 0.025, and for taller structures, the value is 0.02. Due to the silence of standard No. 2800, in this study, IO and CP limit states are defined according to FEMA guidelines [28]. According to the FEMA-350, the drift ratio of the IO limit state is considered as 0.01and the CP limit state drift ratio is defined as the minimum of two values: the point of IDA curve that the local tangent becomes less than 20% of the initial slope or maximum drift ratio of 10%. For illustration, the process is shown in Figure 3 for a 3-story- 3 bay structure. The values of the CP limit state are summarized in Table 6.

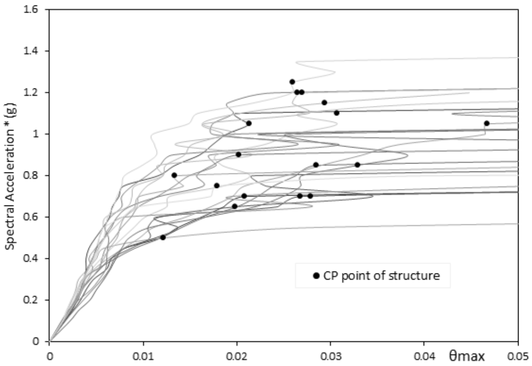

Figure 3. IDA of 3 story- 3 span structure and CP points based on FEMA-350

In Table 6, C ̂, β_CR, S_a^C ̂, and β_C are median capacity, standard deviation of displacement-based capacity, spectral acceleration corresponding to median capacity, and standard deviation of spectral acceleration, respectively. for example, θ_max^C ̂ is the median capacity of the maximum inter-story drift ratio

Table 6. Results of CP limit state based on FEMA-350

code	building	θ_{max}		$Sa_{T_1,5\%}$	
		$\hat{C}$	β_{CR}	$S_a^{\hat{C}}$	β_C
Third Edition	**3 story- 3 bay**	0.0278	0.378	0.896	0.280
	3 story- 5 bay	0.0328	0.455	0.807	0.366
	5 story- 3 bay	0.0306	0.500	0.580	0.304
	5 story- 5 bay	0.0306	0.396	0.576	0.458
	8 story- 3 bay	0.0300	0.519	0.465	0.426
	8 story- 5 bay	0.0295	0.513	0.371	0.420
Fourth Edition	**3 story- 3 bay**	0.0306	0.348	1.017	0.526
	3 story- 5 bay	0.0331	0.417	0.855	0.411
	5 story- 3 bay	0.0426	0.461	0.980	0.511
	5 story- 5 bay	0.0427	0.425	0.997	0.575
	8 story- 3 bay	0.0348	0.470	0.638	0.492
	8 story- 5 bay	0.0351	0.437	0.526	0.503

We evaluate Iranian residential reinforced concrete structures by applying existing relations described in the following section.

10. Structural reliability

In the probabilistic method, the performance is expressed as the annual rate of exceedance of a given limit state [24,31]. We use this method for reliability indices evaluation. The annual rate of exceedance of a structural limit state (or probability of failure) depends on the two parameters displacement-based seismic demand and structural capacity, as Eq. (1):

$$P_f = [D > C] \quad (1)$$

Where D and C are displacement-based seismic demand and structural capacity, respectively, the problem should be divided based on the total probability theory to calculate the probability of failure. So, each part can be solved separately, and the results are combined to form the failure probability by introducing two common variables based on structural damage and earthquake intensity. As mentioned, the first mode of spectral acceleration S_a (T1, 5%) is used as earthquake IM. The intensity of future earthquakes is calculated via the earthquake hazard function $H_{S_a}(S_a)$, which is defined as the annual rate of exceeding a given spectral acceleration (S_a). The earthquake hazard function is approximated by fitting the exponential model (straight line in logarithmic space) to data through two specified points in hazard curves [35-36]. This study uses spectral acceleration corresponding to 10% and 2% probability of exceedance in 50 years (475 and 2475-year return period) as two regression points. The regression process is shown in Figure 4. The earthquake hazard function is as Eq. (2):

$$H_{Sa}(S_a) = k_0(S_a)^{-k} \quad (2)$$

Where k and k0 are seismic hazard parameters that represent the slope and interception of the hazard curve, respectively, according to the hazard analysis of Yazdani et al., the seismic hazard parameters are presented in Table 7[31].

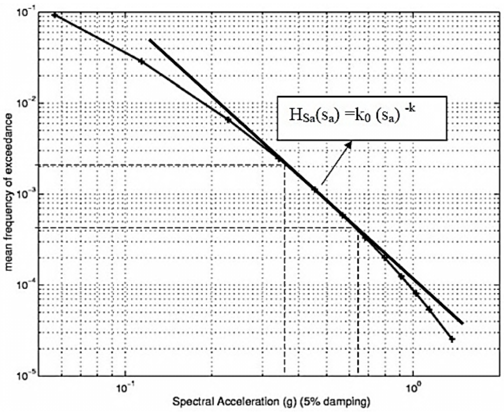

Figure 4. Regression process of hazard curve [28]

Table 7. Seismic hazard parameters

Structures	Third Edition		Fourth Edition	
	k_0	k	k_0	k
3 story- 3	2688.6	2.519	2688.6	2.519
3 story- 5	2688.6	2.519	2688.6	2.519
5 story- 3	992.27	2.468	1041.1	2.383
5 story- 5	992.27	2.468	1041.1	2.383
8 story- 3	180.16	2.275	345.19	2.297
8 story- 5	180.16	2.275	345.19	2.297

Structural capacity is defined based on IDA. The obtained earthquake IM can be related to the median of IDA curves as the power law. The power law is commonly used in the probabilistic assessment of nonlinear response in terms of different intensity measures [37]. The relation between the median of capacity and demand is as Eq. (3):

$$\hat{C} = a(x)^b \quad (3)$$

where a and b are the slope and interception of the IDA curve in logarithmic space, respectively (structural parameters), x is a spectral acceleration, and $\hat{C}$ is the median capacity. Table 8 shows a and b values for considered structures.

Now, spectral acceleration corresponding to median capacity ($S_a^{\hat{C}}$) is calculated as Eq. (4):

$$S_a^{\hat{C}} = \left(\hat{C}/a\right)^{1/b} \tag{4}$$

Table 8. structural parameters based on the power law method

Structure	Third Edition		Fourth Edition	
	a	b	a	b
3 story- 3 bay	0.031	1.356	0.023	1.326
3 story- 5 bay	0.035	1.404	0.027	1.261
5 story- 3 bay	0.050	1.353	0.034	1.348
5 story- 5 bay	0.057	1.330	0.032	1.323
8 story- 3 bay	0.036	0.851	0.045	1.191
8 story- 5 bay	0.038	0.846	0.050	1.214

The conditional standard deviation of demand given spectral acceleration (β_{D/S_a}) is assumed to be constant for all IMs. β_{D/S_a} is calculated as Eq. (5) [24] :

$$\beta_{D/Sa} = \sqrt{\frac{\Sigma\left(\ln(d_i) - \ln\left(a.s_{a,i}^{b}\right)\right)^2}{n-2}} \tag{5}$$

where d_i and $S_{a,i}$ indicate demand and spectral acceleration of the first structural mode for the ith record, respectively. n is the number of records. Finally, the resulting seismic hazard curve ($H_{Sa} - S_a$) and the IDA curve ($S_a - D$) are combined to form the drift hazard curve [284], which represents the annual rate of exceeding displacement-based demand (D) from the given damage index (d) as Eq. (6):

$$H_D(d) = \int P[D \geq d | S_a = x] \, |dH_{Sa}(x)| \tag{6}$$

Thereupon, combining the drift hazard and the displacement-based capacity curves in failure probability represents the annual rate of exceeding a limit state as Eq. (7):

$$P_{Pl} = \int P[C \leq d] |dH_D(d)| \tag{7}$$

Assuming log-normal distribution for parameters, Eq. (7) can be re-written as Eq. (8) [24]:

$$P_{Pl} = H\left(S_a^{\hat{c}}\right) \exp\left(\frac{1}{2}\frac{k^2}{b^2}\left(\beta_{D/Sa}^2 + \beta_{CR}^2\right)\right) \tag{8}$$

where $\hat{C}$ and β_{CR} are the median and standard deviation of displacement-based capacity, respectively; $S_a^{\hat{C}}$ is the spectral acceleration corresponding to median capacity and β_{D/S_a} is the standard deviation of displacement-based demand that is shown with β_{DR}. Regarding the approximations and limitations of knowledge in seismic demand, structural capacity, and seismic hazard, the estimations of the failure probability P_{Pl} also imply epistemic uncertainty. Considering the uncertainty, Eq. (8) is re-written as Eq. (9):

$$\bar{P}_{Pl} = \bar{H}\left(S_a^{\hat{c}}\right) \exp\left[\frac{1}{2}\frac{k^2}{b^2}\left(\beta_{DR}^2 + \beta_{DU}^2 + \beta_{CR}^2 + \beta_{CU}^2\right)\right] \tag{9}$$

where β_{DU} and β_{CU} represent epistemic uncertainty of displacement-based demand and capacity, respectively [25]; $\bar{H}(S_a^C)$ is the mean seismic hazard at spectral acceleration corresponding to median capacity defined as Eq. (10):

$$\bar{H}(S_a^C) = \hat{H}(S_a^C) \exp\left(\frac{1}{2}\beta_H^2\right) \tag{10}$$

where β_H is the standard deviation. β_H represents the epistemic uncertainty of the seismic hazard curve [25]. Ultimately, having the probability of failure, the reliability index of the structure is calculated as Eq. (11):

$$\beta = \Phi^{-1}(1 - P_{pl}) \tag{11}$$

Tables 9 and 10 show the results of the seismic reliability analysis for buildings designed based on Standard No. 2800, third and fourth editions, respectively. Reliability indices of third and fourth-edition structures are shown in Figure 5.

In Figure 5, the confidence coefficients for the four performance levels (OP, IO, LS, and CP) are shown separately.

Table 9. Uncertainty parameters and reliability index of structures based on Standard No.2800, third-edition

Performance	Structure	$S_a^{\hat{c}}$	β_{DR}	β_{DU}	β_{CR}	β_{CU}	k/b	β
OP	**3 story- 3 bay**	0.259	0.183	0.1	0.3	0.173	1.858	2.696
	3 story- 5 bay	0.250	0.213	0.1	0.3	0.173	1.795	2.667
	5 story- 3 bay	0.181	0.296	0.13	0.3	0.225	1.824	2.565
	5 story- 5 bay	0.161	0.266	0.13	0.3	0.225	1.855	2.469
	8 story- 3 bay	0.122	0.314	0.13	0.3	0.225	2.471	2.392
	8 story- 5 bay	0.120	0.389	0.13	0.3	0.225	2.614	2.279
IO	**3 story- 3 bay**	0.432	0.183	0.1	0.3	0.173	1.858	3.099
	3 story- 5 bay	0.410	0.213	0.1	0.3	0.173	1.795	3.061
	5 story- 3 bay	0.303	0.296	0.13	0.3	0.225	1.824	2.977
	5 story- 5 bay	0.271	0.266	0.13	0.3	0.225	1.855	2.899
	8 story- 3bay	0.273	0.314	0.13	0.3	0.225	2.471	2.923
	8 story- 5 bay	0.267	0.389	0.13	0.3	0.225	2.614	2.903
LS	**3 story- 3 bay**	0.849	0.183	0.125	0.3	0.216	1.858	3.563
	3 story- 5 bay	0.788	0.213	0.125	0.3	0.216	1.795	3.514
	5 story- 3 bay	0.505	0.296	0.165	0.3	0.285	1.824	3.325
	5 story- 5 bay	0.458	0.266	0.165	0.3	0.285	1.855	3.261
	8 story- 3 bay	0.549	0.314	0.165	0.3	0.285	2.471	3.423
	8 story- 5 bay	0.591	0.389	0.165	0.3	0.285	2.614	3.391
CP	**3 story- 3 bay**	0.896	0.376	0.15	0.378	0.259	1.972	3.490
	3 story- 5 bay	0.807	0.487	0.15	0.455	0.259	1.912	3.350
	5 story- 3 bay	0.580	0.266	0.2	0.500	0.346	1.549	3.392
	5 story- 5 bay	0.576	0.347	0.2	0.396	0.346	1.720	3.368
	8 story- 3 bay	0.465	0.288	0.2	0.520	0.346	1.506	3.409
	8 story- 5 bay	0.371	0.292	0.2	0.513	0.346	1.409	3.288

By increasing the number of stories and height of the structures, it is observed that the reliability indices decrease in all performance levels. The reason is that the decrease of the spectral acceleration corresponding to the capacity of each performance level increases the randomness uncertainty of seismic demand and epistemic uncertainty of demand and capacity [38].

Table 10. Uncertainty parameters and reliability index of structures based on Standard No. 2800, fourth-edition

Performance	Structure	$S_a^{\hat{c}}$	β_{DR}	β_{DU}	β_{CR}	β_{CU}	k/b	β
OP	3 story- 3 bay	0.321	0.158	0.1	0.3	0.173	1.900	2.871
	3 story- 5 bay	0.260	0.203	0.1	0.3	0.173	1.998	2.678
	5 story- 3 bay	0.239	0.198	0.13	0.3	0.225	1.768	2.685
	5 story- 5 bay	0.245	0.203	0.13	0.3	0.225	1.801	2.701
	8 story- 3 bay	0.158	0.403	0.13	0.3	0.225	1.928	2.479
	8 story- 5 bay	0.150	0.351	0.13	0.3	0.225	1.891	2.467
IO	3 story- 3 bay	0.541	0.158	0.1	0.3	0.173	1.900	3.265
	3 story- 5 bay	0.450	0.203	0.1	0.3	0.173	1.998	3.113
	5 story- 3 bay	0.399	0.198	0.13	0.3	0.225	1.768	3.071
	5 story- 5 bay	0.414	0.203	0.13	0.3	0.225	1.801	3.093
	8 story- 3 bay	0.298	0.403	0.13	0.3	0.225	1.928	3.076
	8 story- 5 bay	0.265	0.351	0.13	0.3	0.225	1.891	2.905
LS	3 story- 3 bay	1.080	0.158	0.125	0.3	0.216	1.900	3.719
	3 story- 5 bay	0.932	0.203	0.125	0.3	0.216	1.998	3.607
	5 story- 3 bay	0.788	0.198	0.168	0.3	0.285	1.768	3.509
	5 story- 5 bay	0.828	0.203	0.165	0.3	0.285	1.801	3.536
	8 story- 3 bay	0.507	0.403	0.165	0.3	0.285	1.928	3.296
	8 story- 5 bay	0.469	0.351	0.165	0.3	0.285	1.891	3.273
CP	3 story- 3 bay	1.017	0.179	0.15	0.348	0.259	1.873	3.653
	3 story- 5 bay	0.855	0.436	0.15	0.417	0.259	1.998	3.411
	5 story- 3 bay	0.980	0.303	0.2	0.461	0.346	1.732	3.561
	5 story- 5 bay	0.997	0.300	0.2	0.425	0.346	1.904	3.550
	8 story- 3 bay	0.638	0.427	0.2	0.470	0.346	1.492	3.454
	8 story- 5 bay	0.526	0.481	0.2	0.437	0.346	1.477	3.330

By increasing the number of stories and height of the structures, it is observed that the reliability indices decrease in all performance levels. The reason is that the decrease of the spectral acceleration corresponding to the capacity of each performance level increases the randomness uncertainty of seismic demand and epistemic uncertainty of demand and capacity [38].

Different performance levels have different importance for structures with different usage and occupancy. For example, if the structure is residential, the performance level of LS is significant for it. However, if the structure is a hospital, paying more attention to the OP and IO performance levels is necessary. It is important to know that each performance level is important, including maintaining the later performance levels. Therefore, CP performance level is important for all structures.

Comparing the OP and IO of the two editions shows that the reliability index of the fourth edition structures is more than the third one. It is worth noting that the reliability index values obtained for all the structures of both editions are greater than the minimum recommended value of the world's most authoritative regulations [39], which indicates the safety of structures designed according to the Iranian Code for these two performance levels.

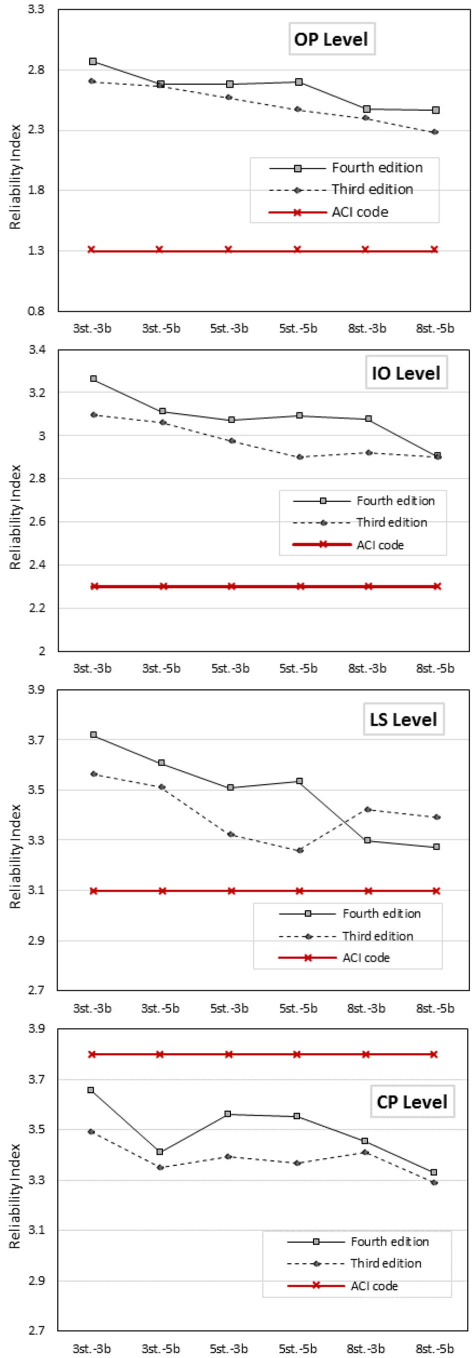

Figure 5. Comparison of Reliability indices of third and fourth-edition structures with the authentic regulations values

In assessing the LS (the loss of life is minimized while the stability of the building is maintained in standard NO.2800), it is observed that the 3 and 5-story structures of the fourth edition have better performance than the third edition. The reason is the greater spectral capacity and smaller uncertainty in the seismic demand. Also, in the case of 5-story structures, the limit state of this performance level increased from 0.02 in the third edition to 0.025 in the fourth edition, increasing the spectral capacity. Notably, the 8-story structures of the third edition have shown better performance than the fourth. There are two reasons. First, the spectral acceleration of the capacity of the third edition structures (resulting from a and b parameters) is larger than the fourth edition ones. Second, regarding the influence of seismic hazard parameters on β, the smaller k and k0 in 8-story structures of the third edition and identical approximation of βDR in both editions cause the role of hazard parameters in the reliability index to be more prominent. Finally, despite the differences in their values, the reliability indices of the LS level, 3.261 to 3.719, are higher than the minimum recommended value of the authentic regulations [39], so all the structures are safe at the LS level.

In the CP performance level, we encounter the missing data in IDA. Considering the effects of these data in reliability calculation is necessary [36-37]. In this case, the Cornell and Jalayer method calculates the reliability index [24]. The results show that the reliability index of the fourth edition is larger than the third edition. Table 6 shows that for the CP level, the structural capacity values, including θ^{C}_{max} and S^{C}_{a}, of the fourth edition are greater than the third one, i.e., the former parameters perform better. At the CP level, it is observed that the values of reliability indices are smaller than the proposed limits by the authentic codes [38]. Therefore, it can be said that the structures are unsafe at this performance level, and it is recommended to consider the criteria for controlling the CP level for designing the structures in standard No.2800.

11. Conclusions

In this study, structures designed according to the third and fourth editions of the Iranian seismic standard (No. 2800) are comprehensively evaluated using probabilistic methods considering various structural and seismic uncertainties. The reliability index was used to evaluate the performance of the structures. Seismic evaluation of the structures was carried out for OP, IO, LS, and CP performance levels. Fourth edition structures have larger structural sections and smaller periods. The CP level results showed that the third and fourth editions structures have θmax in the range of 0.0278-0.0328 and 0.0306-0.0427, respectively; also, they have spectral acceleration in the range of 0.391-0.896 and 0.526-1.017, respectively. These results show the improved performance of the new edition of standard No. 2800.

The survey reports that increasing the structure's height decreases the confidence level in CP performance level. So, it cannot satisfy FEMA-350 criteria for taller buildings, and structures are not sufficiently reliable at the CP performance level. Therefore, it is recommended to consider the requirements for controlling the CP level for designing the structures in standard No. 2800. Also, given that the CP level is a measure of mortality, it is suggested that seismic assessment and necessary retrofitting for existing buildings be performed at this performance level.

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