Reliability Based Evaluation of Low-rise Reinforced Concrete Moment Frames Designed for Different Levels of Ductility

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Abstract

This study aims to assess reinforced concrete moment frames designed at varying ductility levels within a typical reinforced concrete structure, from a reliability perspective. The article explores the probabilistic methods for designing different ductility levels in the current Iranian Concrete Code, focusing on reliability. Specifically, a three-story concrete moment frame structure, designed to low, medium, and special ductility levels as per the Iranian code, is studied. The reliability analysis encompasses uncertainties in loading, dimensional parameters, evaluating structural performance functions such as floor drift and acceleration. The study utilizes horizontal earthquake components specified by the FEMA P-695 standard to analyze earthquake record uncertainties. Furthermore, a comparison of the reliability index and probability of failure for each performance function is used to assess failure uniformity. The findings reveal a maximum probability of failure in collapse damage state of approximately 9%, 5%, and 2% for low, medium, and special ductility frames, respectively.

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Keywords: Reliability, Seismic Evaluation, Moment Frame, Reinforced Concrete, Ductility

1.Introuduction

Despite the widespread use of concrete frames in construction, significant damage has been observed in these structures in some recent seismic events around the world, resulting in human and financial losses (for example, the Sarpol Zahab earthquake in 2016). Hence, numerous researchers have recently explored the seismic performance of reinforced concrete structures using diverse approaches. Reliability analysis is increasingly deemed the optimal method for evaluating the effectiveness of earthquake-resistant structural systems. This is due to its ability to consider the uncertainties in seismic loads and structural capacity. Lu et al. (1994) assessed the reliability of reinforced concrete beams designed according to ACI regulations. They examined a variety of beams in different positions and compared the reliability index for various modes. Their results emphasized the influence of live load and material strength on the reliability index [1]. Dymiotis et al. (1999) studied the reliability of reinforced concrete frames, assuming uncertainty in the structure's stiffness and capacity. Their approach includes accounting for both local member failure and overall structure failure. They utilized seismic table test results from small-scale models of reinforced concrete frames to statistically represent the structure's critical response [2]. Arafah examined the factors influencing the reliability of concrete beams, including concrete strength, cross-sectional dimensions, stress in the beam, and shear strength. These factors need to be considered in structural design [3]. The study by Dymiotis et al. (2002) compared bending frames with frames containing masonry infills. They found that in the ultimate limit state, the ductility of concrete was the primary determinant of failure probability. However, in the serviceability limit state, the shear resistance of building materials had a more significant impact [4].The analysis and design of structures using reliability theory have garnered substantial attention recently. Several studies have explored the reliability of structures, yielding noteworthy results. However, few research studies have been conducted on examining current regulations using reliability theories in concrete structures. For this purpose, in this research, by Considering the uncertainties mentioned in the probability space and the design of the structure based on the current regulation, the reliability of different bending concrete frames designed based on the regulation is investigated, and in this way, the effect of the uncertainties directly in regulations is studied.

2-**Methodogy**

In this study, the initial step involves analysing and designing 3D models using Etabs software. Subsequently, a 2D frame of each structure is modelled in Oppenses software [5]. After the completion of modelling and static analysis, a time history analysis is conducted. Lastly, the Oppenses software is connected to the RT software to carry out the reliability analysis.

For the seismic design of the structures, a very high seismic zone and type 3 soil were selected in accordance with regulation 2800 [6], with a base earthquake acceleration of 0.35. The study considered three frames of normal, medium, and special type on 3 floors to compare the ductility as per the lateral bearing system regulations for concrete bending frames. All buildings assumed the same residential use and gravity loading details. In total, three types of buildings with identical geometric conditions and loading were investigated. The dead and live loads of the structure floors were chosen as 600 and 200 kg/m2, respectively, following the sixth section of the national regulations [7]. Additionally, the dead and live loads of the roof were 500 and 150 kg/m2. The beam and column sections of each floor of the three-story building in three low, medium, and special ductility levels are designed. All three structures had similar frames in two directions with three openings of 5.5 meters in length, and the height of each floor was 3.2 meters.

3-Result and Discussion

3-1 Reliability index values for the limit state functions of drift and acceleration.

The reliability coefficient (β) obtained from earthquakes in normal, medium, and special bending frame models for damage levels from DS1 to DS4 are given in Tables 1, 2, and 3, respectively. In these tables, both functions of maximum drift and maximum acceleration have been considered. Among the analyses performed, none of the cases resulted in failure, and the probability of the failure level was zero.

Table 1: Reliability index values in low-ductility frame for drift and acceleration functions

Earthquake	DS1		DS2		DS3		DS4	
	Acc.	Drift	Acc.	Drift	Acc.	Drift	Acc.	Drift
Manjil	-2.32	-2.32	-2.32	-2.32	-0.82	2.35	0.73	inf
Imperial Valley	-2.19	-2.19	-2.19	inf	inf	inf	inf	inf
Northridge	-2.19	-2.19	-2.19	-2.19	2.02	inf	2.20	inf
Kobe	-2.28	-2.28	-2.28	-2.28	0.37	0.98	0.99	1.40
Landers	-2.19	-2.19	-2.19	-2.10	2.57	inf	inf	inf
Duzce	-2.19	-2.19	-2.19	-2.19	1.33	inf	1.83	inf

Table 2: Reliability index values in medium-ductility frame for drift and acceleration functions

Earthquake	DS1		DS2		DS3		DS4	
	Acc.	Drift	Acc.	Drift	Acc.	Drift	Acc.	Drift
Manjil	-2.19	-2.19	-2.19	-2.19	-0.29	2.69	1.09	inf
Imperial Valley	-2.26	-2.19	-2.26	inf	inf	inf	inf	inf
Northridge	-2.22	-1.98	-1.59	-1.98	2.09	inf	2.67	inf
Kobe	-2.26	-2.26	-2.26	-2.26	0.58	1.11	1.21	1.62
Landers	-2.08	-2.08	-2.08	-2.08	inf	inf	inf	inf
Duzce	-2.19	-2.19	-2.19	-2.19	1.61	inf	2.69	inf

Table 3: Reliability index values in special-ductility frame for drift and acceleration functions

Earthquake	DS1		DS2		DS3		DS4	
	Acc.	Drift	Acc.	Drift	Acc.	Drift	Acc.	Drift
Manjil	-2.19	-2.19	-2.19	-2.19	-0.29	inf	inf	inf
Imperial Valley	-2.26	-1.96	-2.26	inf	inf	inf	inf	inf
Northridge	-1.65	-1.65	-1.51	-1.65	2.68	inf	2.67	inf
Kobe	-2.26	-2.26	-2.26	-2.25	0.82	1.31	1.45	1.69
Landers	-1.94	-1.94	-1.94	-1.94	inf	inf	inf	inf
Duzce	-2.19	-2.19	-2.19	-2.19	inf	inf	inf	inf

It is evident that failure at lower levels occurs earlier due to the lower limit values of acceleration and drift in performance functions when changing the model and characteristics of the earthquake record. Therefore, lower failure levels are less reliable and more likely to occur. In other words, the possibility of the structure reaching the limit values of drift and acceleration is lower at higher levels of structural failure, resulting in a lower probability of failure. Moreover, by comparing the values of normal, medium, and special frames in each earthquake, it can be seen that the highest β values are related to the special frame, which is due to the greater plasticity of this frame. Therefore, the bending frame with high ductility has a lower probability of failure.

3-2 failure probability diagram in functional function of maximum acceleration and drift

To further illustrate the difference in failure rates due to acceleration and drift, the average failure probability of all models is depicted in the two bar graphs of Figures 1 and 2.

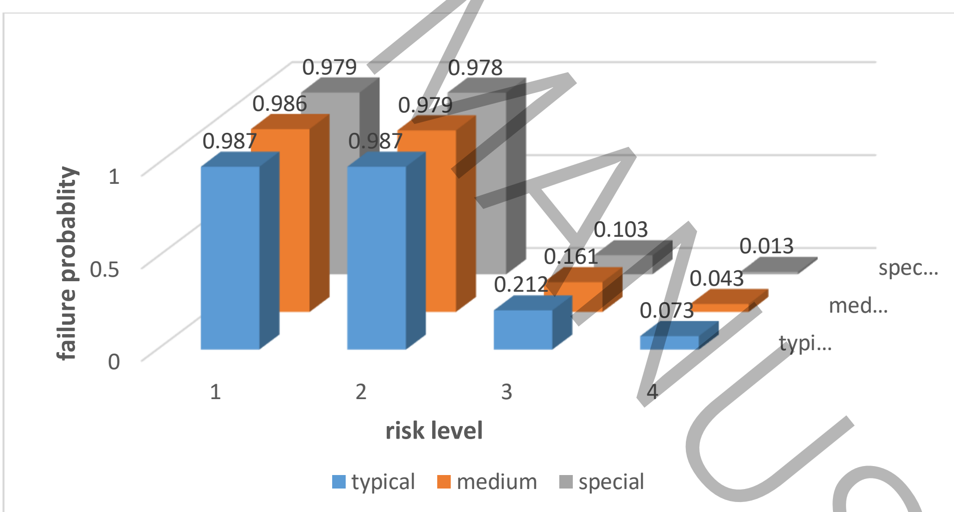

Figure 1: The average failure probability at different risk levels according to the maximum acceleration performance function

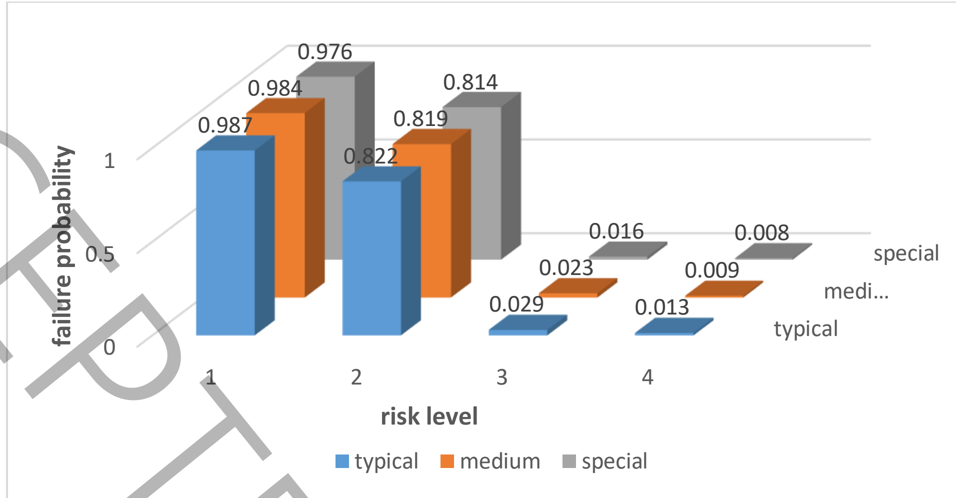

Figure 2: The average probability of failure at different risk levels according to the maximum drift performance function

4-Conclusions.

• In low, medium, and special-ductility moment frames in areas with the same seismicity, it can be observed that the average probability index of frame failure due to drift at the collapse risk level was 1.3, 0.087, and 0.075%, respectively. It is evident that low-ductility frames have a higher probability of failure than medium and special ones, while the probability of failure of the medium moment frame is higher than the special frame. This is attributed to the superior reinforcement of concrete components, resulting in the special frame being more flexible than the medium one, and the medium frame being more flexible than the low-ductility frame

• The examination of results in the series system, i.e., the probability of simultaneous occurrence of collapse due to acceleration or drift, indicates that the probability of occurrence decreases with the increase of the failure level. For example, the upper limit of failure probability of low, medium, and special-ductility moment frames at the level of collapse risk were 8.6, 1.1, and 0.2%, respectively. Since the probability of series failure occurs based on the occurrence of each of the limiting values of acceleration or drift, the probability of series occurrence is higher than the probability of each of the functional functions.

• The probability of failure due to acceleration in low, medium, and special-ductility frames at the severe risk level (level 3) were 21%, 16%, and 10% respectively. The probability of failure due to drift in low, medium, and special-ductility momentframes at the same risk level were 8.2%, 2.2%, and 5.1% respectively. Comparing the probabilities of failure due to acceleration and drift shows that the non-structural failure probability, i.e., the effect of acceleration, is much higher than the structural collapse probability due to drift.

5-References

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