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Seismic Performance of Reinforced Concrete Structures at Different Damage Levels

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***Abstract*: Performance ofreinforced concrete structures fora broad range of seismic events is a matter of importance. Assessment of the performance of a structure is done by considering various deformations and damage levels. This study represents a plan or a process in performance-based design to evaluate the behaviour or the performance level as an acceptance criterion of a reinforced concrete structure for seismic events, considering the likelihood of occurrence of a major seismic event pertaining to its place based on the past records of earthquakes and their probabilistic seismic hazards. Story drift ratios were considered as a design parameter corresponding to the different performance levels established by FEMA 356 (2000). The prescribed acceptance criteria for different performance levels gives an understanding of damages to be incurred by a reinforced concrete structure under a particular magnitude of earthquake considering its design lifetime. This helps in designing the structure for a particular seismic event at the desired level of performance encompassing the economies involved in its design.**

Keywords—Drift ratio, FEMA 356 (2000), performance-based design, performance level, probabilistic seismic hazard.

I. Introduction

Structures are designed as earthquake resistant conforming to the code IS 1893:2016[1]prescribes a force based method of designing the structures. The compliance of the codes for the design as earthquake resistant does not ensure explicitly the capability of a structure or the performancefor an extreme seismic event. The performances levels appropriate for a building structure are determined not only in terms of structural technologies but by the demands of its owners, users, and society Y Aoki et al. (2000)[2].

National Institute of Disaster Management of India in its report 'An Earthquake Preparedness Guide'[3] has described some important facts pertaining to economies of earthquake resistant features of the structures which are:

1. The extra cost of earthquake resistant features in severe earthquake zones for reinforced concrete buildings (4-8 storeys) would be 5-6%.

2. Retrofitting of buildings not initially designed for earthquakes will costs 2-3 times as much as the extra costs of the earthquake resistant features in the new buildings.

These facts emphasize the importance of earthquake resistant features. But having incorporated these earthquake resistant features does not always ensure the desired performance, the structure might perform well or its performance will not be up to the desired expectations. As a result, the performance capability of a reinforced concrete structure designed by conforming to the codes remains a mystery.

II. Performance-based Design

K. Yamawaki et al. (2000)[4] described thatsince the 1995 Kobe Earthquake,the clients and the society have necessitated clarifying various performances, especially seismic ones related to buildings.This resulted in formulating, a methodology for a performance-based design wherein seismic performances are to be clearly defined and expressed.Seismic Performance Menus were proposed for various performance levels and probable damagesK. Yamawaki et al. (2000) [4]. Researchers have proposed various methodologies were proposed for the performance of both structural and non-structural components. The performances in this study were prescribed for lateral load resisting system of a reinforced concrete structure.

M. Nino et al. (2004)[5] described that the evaluation of the performance of structures during recent destructive earthquakes around the world has shown that current seismic design codes do not always provide adequate safety levels like the application of their design provisions does not guarantee the performance levels that the structures were expected to reach under design seismic demands. The difference between the design procedures which uses the performance-based design philosophy and the previous approaches was the use of specific design objectives and limit states which were based on indices that represent the structural performance in a better way.

FEMA 356 (2000) [6] defines different damage levels such as immediate occupancy (IO), life safety (LS) and collapse prevention (CP). In the IO level,the damage after an seismic event resulting in state of structural elements consisting ofminor hairline cracking, yielding at certain locations, spalling will be minor, flexural cracks in beams and columns, and formation of shear cracks at joints. In the LS level, there will be comprehensive damage to the beams, shear cracks in ductile columns, formation of hinges in ductile elements, short columns confront damages. In the CP level, there will be extensive cracking, spalling in columns and beams, formationof hinge in ductile elements, joint damage will be severe and buckling of reinforcement.

III. Performance Levels as an Acceptance Criterion

The performance levels of a structure under a seismic action can be assessed based on deformations like cracks, strains, drift ratio, roof displacement etc. But certain deformations cannot be assessed until a seismic event has caused them to occur rendering a few deformations that can be used as acceptance level of damage which could be used to assess the performance of a structure before a seismic event using nonlinear methods of analysis.

Drift ratios were considered as target performance levels as inY. Aoki et al.(2000)[2] andK. Yamawaki et al. (2000) [4]. For the present study, drift ratios are considered as target performance levels as proposed in Y. Aoki et al.(2000)[2] for different damage levels as given in Table 1.

TABLE 1
Building performance and its drift ratio

Performance of Building	Drift ratio
Concrete crack	1/200
Damage on Secondary elements	1/100
Failure of structural elements	1/50
Collapse of building	1/30

IV. Selection of a Region

The structure has to be evaluated for its performance to seismic events based on the empirical data about the past earthquakes and considering the seismic hazard analysis of the place where it should be built. Seismic hazard analysis is done based on respctive methodologies resulting in the probabilities of occurrence of next seismic event involving the study of plate tectonism, division of the area of study into seismotectonic units as employed inM. L. Sharma and S. Malilk (2006)[7] andM. L. Sharma and R. Kumar (2008)[8].

M. L. Sharma and R. Kumar (2008)[8] describes that the assessment of seismic hazard is the first and fundamental step in the mitigation process, which reduces the disastrous economic and social effects of earthquakes. Return periods of the damaging earthquakes and seismicity rate are important to assess the seismic potential of aregion. The seismic potential of a region is the probability of occurrence of an maximum magnitude M_{max}earthquake in future and the knowledge of probabilities of occurrence of earthquakes is of use in designing earthquake resistant structures M. L. Sharma and S. Malik(2006)[7].

In this context, a report by Building Materials and Technological Promotion Council, India [9] is referred to and it states:

1. 59% of the land of the country is vulnerable to earthquakes.

2. 10.9% ofthe land is liable to severe earthquakes (Intensity of MSK IX or more).

3. 17.3% ofthe land is liable to MSK VIII (similar to Latur / Uttarkashi).

4. 30.4% of the land of the country is liable to MSK VII (similar to Jabalpur earthquake).

Most of the earthquakes are confined to the Indo-Australian and Eurasian plate boundary forming orogenic belt where the two continental plated collide and push towards to form large mountain ranges. The north-eastern part of the country is susceptible to more number of earthquakes and is under seismic zone V according to IS 1893:2016[1], which is rendered as highly active seismic zones. The magnitude of earthquakes in this region ranges from 5-6, 6-7, 7-8 and more than magnitude 8.

The probabilistic seismic hazard analysis of the North-East part of India has been carried out inM. L. Sharma and S Malik (2006) [7]and the data provided in it is utilized to frame the target performance levels. For the seismic hazard estimation,M. L. Sharma and S Malik (2006) [7]have used the earthquake database from 1762 to 2001, as provided by Indian Meteorological Department (IMD). The entire North-East region was considered and it was divided intoseismogenic zones SZ-I to SZ-X and are further subdivided into major and subdivision.

The Shillong Massif Zone is divided into three zones i.e. SZ-III, SZ-IV and SZ-V[7]. Among them, SZ-IV has maximum magnitude of earthquakesfor 10% and 20% exceedance values in terms of maximum probable magnitudesas reported by M. L. Sharma and S. Malik (2006) [7]. Hence SZ-IV region is considered for performance

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evaluation of the structure and the corresponding probabilities of occurrence of a different magnitude of earthquakes are considered as represented in Table 2, Table 3 and Table 4.

TABLE 2
THE MAGNITUDE OF ANEARTHQUAKE AND ITS RETURN PERIOD

Magnitude of Earthquake	Return Period (Years)
5	5
6	10
7	20
8	100

TABLE 3
THE MAGNITUDE OF AN EARTHQUAKE AND ITS PROBABILITY OF OCCURRENCE FOR 50 YEARS

Magnitude of Earthquake	Return Period (Years)
5	100
6	100
7	80
8	20

TABLE 4
THE MAGNITUDE OF AN EARTHQUAKE AND ITS PROBABILITY OF OCCURRENCE FOR 100 YEARS

Magnitude of Earthquake	Return Period (Years)
5	100
6	100
7	100
8	60

Considering the performance levels as Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) from FEMA 356 (2000) [6], the drift ratios from the Table 1 and the probabilities of occurrence of different magnitudes of earthquakes for Shillong Massif Zone under the seismogenic zone SZ-IV as described by M. L. Sharma and Shipra Malik [7] for the return period of 50 years as given in the Table 3, a performance menu has been proposed for a reinforced concrete structure as shown in Table 5.

TABLE 5
PROPOSED SEISMIC PERFORMANCE MENU

Magnitude of Earthquake	Performance Level IO	LS	CP
8	1/100	1/50	1/30
7	1/200	1/100	1/50
6	1/200	1/100	1/50
5	1/200	1/100	1/50

Thus the proposed seismic performance menu forms the basis for designing the reinforced concrete structures.

V. CONCLUSION

The performance-based design encompasses the performancelevels which are expected (performance demand) from a reinforced concrete structure during the respective seismic event. The performance levels are processed considering the target performance and the prescriptive criteria of the codes in designing the elements of the structure with mutual agreement between the designer and the designs. This process of defining the performance targets with respective damage levels gives an understanding of the capacity of the structures and helps in mitigating post-earthquake consequences. Although the performance menu does not encompass integrated performance requirements. The performance-based design responding to the performance levels delineate the initial, life cycle costof the structure and itsassociated risk management.

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