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DAMAGES ASSESSMENT OF REINFORCED CONCRETE BRIDGES UNDER THE GROUND MOTIONS - A PROBABILISTIC APPROACH

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Abstract

Bridges are important structures for urban civilization. The catastrophic damage to bridges during an earthquakes cause sudden disruption to human livelihood. For making bridges resilient to earthquakes proper damage assessment technique is inevitable. The present study has been carried out to evaluate damage of Reinforced Concrete Bridge under the seismic loadings using a probabilistic approach. Nine earthquakes were considered for seismic vulnerability assessment. From the obtained results, different damage states were discussed based on intensity measures using Incremental Dynamic Analysis (IDA) and Fragility Analysis. This study may be used as a viable tool for health monitoring, vulnerability assessment and formulating retrofit strategies of the reinforced concrete bridges under the seismic loadings.

Keywords: Reinforced Concrete Bridge; Damage Index; Incremental Dynamic Analysis; Cumulative Energy Dissipation; Fragility Analysis.

1. INTRODUCTION

During earthquakes, significant damage occurs in structures resulting in adverse effect on human life. There are many studies available which indicates, the collapse of bridges during earthquakes, leads to loss of properties and lives (Moehle and Eberhard, 2000). The impact of such disaster depends upon the stability of the structure subjected to earthquake(s). Hence, seismic evaluations of structures are the prime concern of structural engineer. Bridges are important structures used for mobility of goods and people worldwide. A few studies are available to assess the performance of bridges. One such study focuses on developing methodologies for bridge-column modeling under cyclic loads and proposes the damage model for damage state prediction (Berry and Eberhard, 2007). On a concrete box girder bridge, a statistical and probabilistic study was conducted to determine whether modeling and analytical characteristics have a persuasive impact on the behavior of different bridge components under seismic loading (Soleimani, 2021). On the basis of the deformation capacity of the structures, a seismic design philosophy was presented, and the phrase performance-based design was introduced (Priestley et al., 2007). Study has been done on the multi-span bridges considering seismic energy dissipation and comparative study between the isolated systems to control the response of existing bridge (Contin and Mardegan, 2016). Using the geometry and material parameters of bridges, another study established the tools to improve the seismic assessment of RC bridges. As geometric variables, height of pier and length of bridges were examined. The relationship between the vibration period and the geometric features of the bridge were also studied (Zelaschi et al., 2016). Assessed

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the bridge's response under near-source site conditions by considering nearby ground excitations (Rodriguez-Marek and Cofer, 2007). The process of nonlinear analysis of bridge to estimate seismic demand on vital bridge components and systems is highlighted (Aviram et al., 2008). Some of the studies are done on pier of bridge to observe the effect of corrosion (Lavorato et al., 2020). A probabilistic analysis was conducted using design data such as the diameter and height of the pier, the concrete's characteristic strength, and longitudinal bars. Which impact the seismic response of reinforced concrete bridges and the proposed probabilistic multi-parameter seismic demand model (Wang et al., 2014). Seismic damage assessment criterion for the health monitoring has seldom been performed for bridges. Numerous database are exists for Fragility curves such as ATC-13,1985 (ATC-13, 1985). Although there are few literatures available on the fragility analysis of RC bridges, the parameters offered for damage evaluation in those studies are confusing and must be reconsidered. Consequently, this study is structured so that crystal clear criteria for the evaluation of damage to an RC bridge may be created. In the present study, a RCC bridge is modeled in SAP2000. In order to obtain fragility curves, incremental dynamic analysis (IDA) using nine earthquakes has been performed (Porter, 2000; Vamvatsikos and Cornell, 2002).

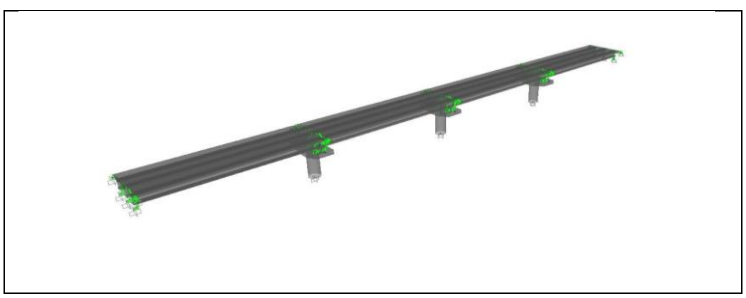
2. DESCRIPTION OF BRIDGE

Description of finite element model of a simply supported bridge of four spans is given in Table 1 and the model is shown in Figure 1.

Table 1: Bridge details

Span length	27 m
Longitudinal length	108 m
Width	7.5 m
Clear height of bridge	6.2 m
Number of I-girders in each span	3
Thickness of deck slab	0.25 m
Column diameter	2 m

Figure 1: Bridge Model



Substructure consists of one Pier having diameter of 2m. Each pier is modeled with fiber-section frame element and with flexure (P-M2-M3) hinge under the lateral load. Material non linearity is assigned using Mander model (Mander et al., 1988). M-35 concrete and

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longitudinal bars of Fe-415 grade steel (36 bars) of diameter 32 mm are used in modeling. Hinges are assigned at the base of column. For defining the hinges, moment curvature analysis is obtained from section designer in SAP2000. Performance criteria of hinges are defined according to FEMA-356 (FEMA-356, 2000) & ATC-40 (ATC-40, 1996). Yield rotation and ultimate rotation capacity are calculated by the formula given in EUROCODE-8-PART-3(CEN 2004) (Eurocode-8-Part 3, 2004).

2.1 Bearing Modeling

Each bearing modeled as a rigid link and connected to the top of the pier cap and superstructure.

2.2 Gap Modeling

In the SAP2000 , the gap element modeled as “compression-only” is used to counter the pounding effect (Muthukumar, 2003).

3. NORMALIZATION AND SCALING OF GROUND MOTIONS

Nine different earthquakes are considered for the IDA. The details of ground motions are presented in Table 2. Scaling of ground motions is done according to FEMA P695 (2009) (FEMA, 2009).

4. RESULT AND DISCUSSION

In this study, analysis of a RCC bridge is conducted using SAP 2000 for its seismic vulnerability assessment. From the obtained results, IDA curves and fragility curves are plotted and presented in Figure 2, 3 and 4. For damage assessment, Park and Ang model and its different damage states (slight, moderate, extensive and collapse damage states) are used in this study (Park and Ang, 1985).

Table 2: Selected ground motions

Earthquake Name	Station Name	Magnitude	Rjb (km)	Arias Intensity (m/sec)	PGA(g)
Imperial Valley-06	El Centro Array #8	6.53	3.86	1.6	0.610143
Loma Prieta	Saratoga - Aloha Ave	6.93	7.58	1.5	0.514455
Cape Mendocino	Petrolia	7.01	0	3.8	0.590789
Northridge-01	Pacoima Dam (downstr)	6.69	4.92	0.9	0.415789
Kobe_ Japan	Takarazuka	6.9	0	3.9	0.697348
Chi-Chi_ Taiwan	TCU101	7.62	2.11	1	0.2119
San Simeon_ CA	Templeton - 1-story Hospital	6.52	5.07	1.9	0.435199
Montenegro_ Yugoslavia	Ulcinj - Hotel Albatros	7.1	1.52	0.7	0.183279
Darfield_ New Zealand	TPLC	7	6.11	1.5	0.299726

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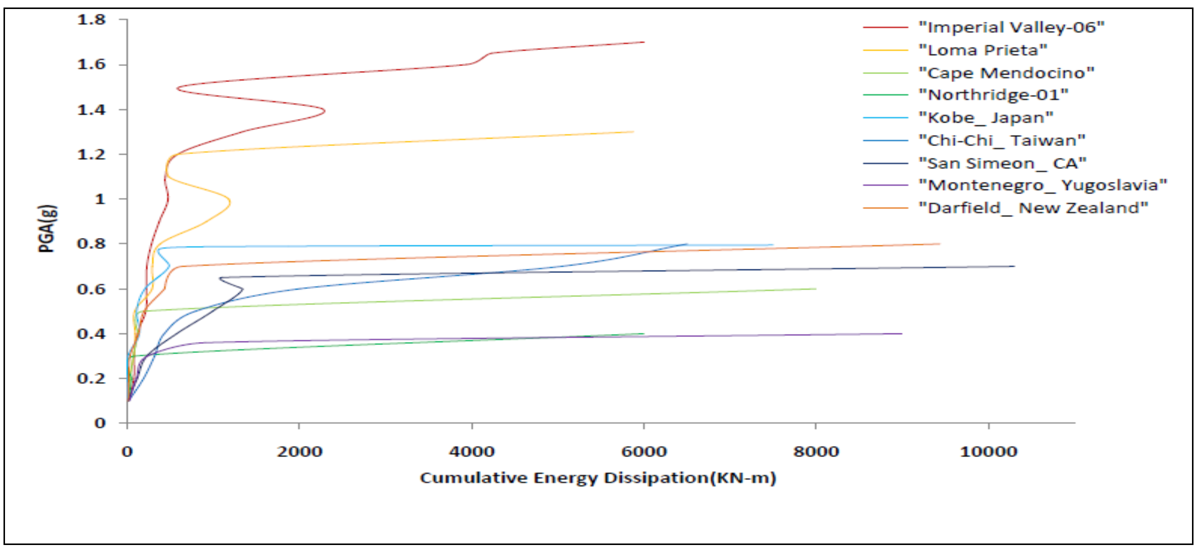
In Figure 2, IDA curves are plotted against IM (PGA) Cumulative Energy Dissipation. In the range between 0.36g to 0.8g, cumulative energy dissipation is high due to vulnerable source site condition, resulting in sudden collapse of structure from the range of slight damage state. It is further observed from IDA plot, that the minimum of all maximum cumulative energy dissipation for the very first yield is nearly 438 kN-m. The corresponding top displacement of pier is 62 mm. Similarly, from all IDA curves, maximum value for cumulative energy dissipation is 10300 kN-m and corresponding maximum top displacement of pier is 530 mm.

In the Figure 3, the damage index is plotted against PGA. The values of damage index for slight, extensive and collapsed damage states are 0.08, 0.48 and 0.88 respectively. Further, yielding region is lying between 0.36g to 1.6. Below this there is elastic region, and above, there is failure region. The mean curve is plotted by taking the average value of damage indices at different PGA of all the nine records. Upper bound curve is at 70% upper deviation and lower bound curve is at 30% lower deviation from the mean curve. All Structural responses of bridge are lying between upper and lower bound curves.

Figure 2: IDA curve for cumulative damage energy dissipation



In Figure 4, the fragility curve is plotted for IM (PGA) considering average values of DI for each damage states. For development of fragility curves, lognormal distribution is used. The mean value of PGA for slight, extensive and collapse states are 0.542g, 1.233g and 1.833g respectively.

Actual and predicted damage curves are plotted in Figure 5. To plot the actual damage curve, 'n' number of PGA values (PGA_d) corresponding to different level of damages in the bridge are sorted from smallest to largest and plotted on X-axis. On the Y axis, probability of damage (P_d) corresponding to each PGA_d is plotted. The P_d corresponding to each PGA_d out of 'n' number of PGA_d is 1/n. This probability value is cumulatively added to the previous value. For illustration, the P_d corresponding to first PGA_d is X (=1/n).

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The P_d corresponding to second PGA_d is Y (= X + 1/n), the P_d corresponding to third PGA_d is Z (=Y + 1/n) and so on till the P_d corresponding to n^{th} PGA_d becomes 1. The curve thus plotted is categorized in three damage states (i) Slight Damage (ii) Extensive Damage (iii) Collapse. This plot depicts some interesting features regarding the damage performance of the bridge. There is a sudden upward deflection of the curve while transitioning from slight damage state to the extensive damage state, due to high cumulative energy dissipation caused by source effect of ground motion. For plotting the predicted damage curve, a lognormal distribution is considered.

Figure 3: DIs against PGA.

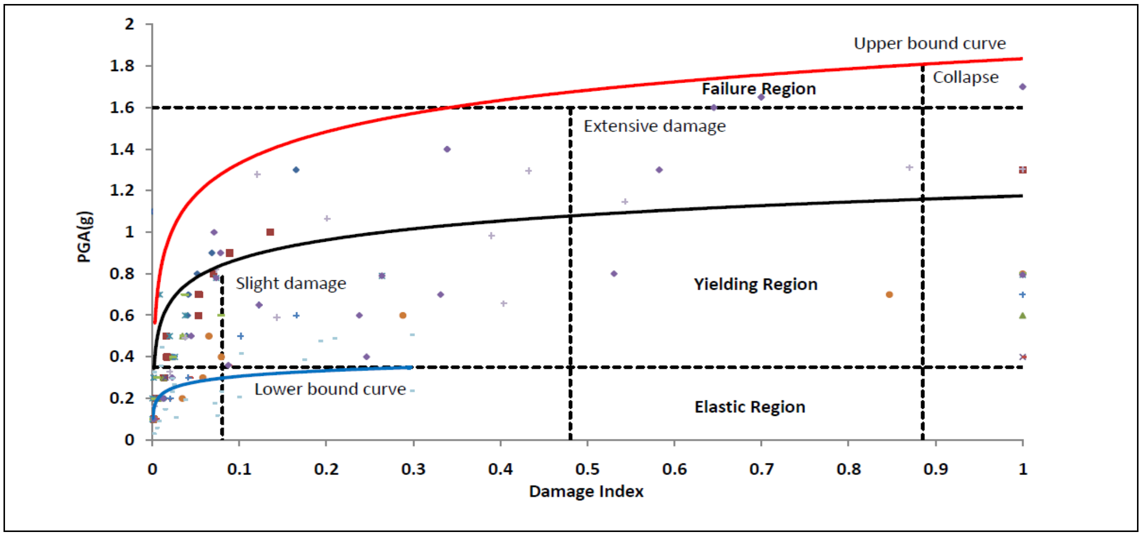

Figure 4: Fragility curve for IMs.

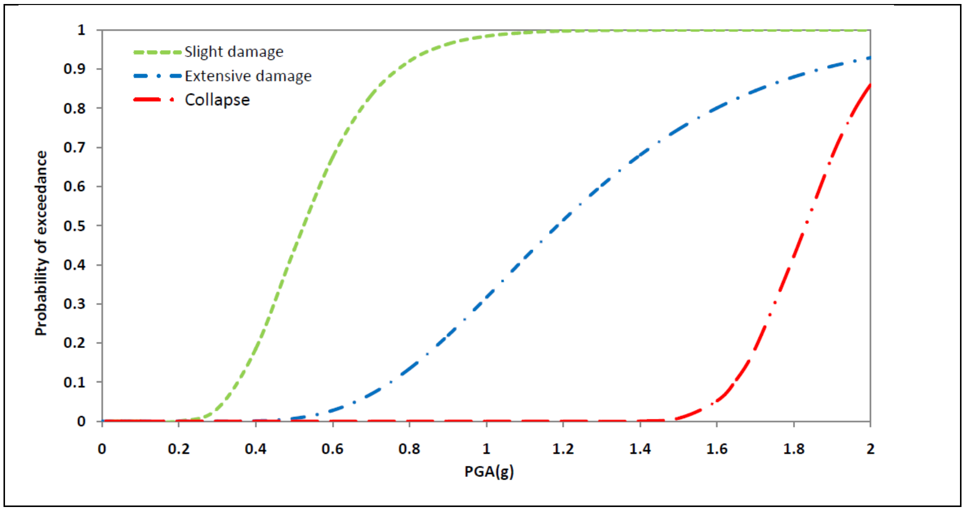

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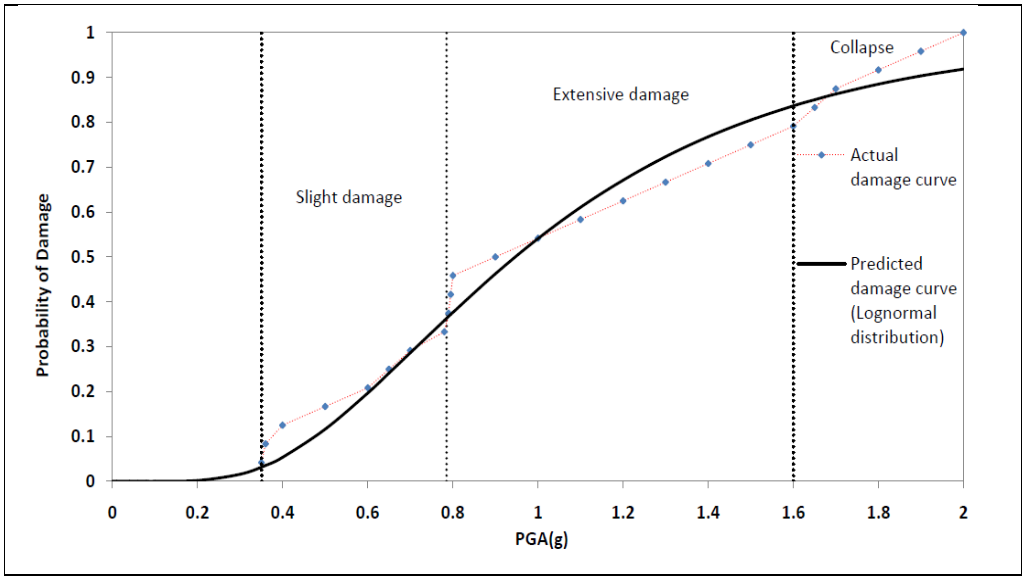
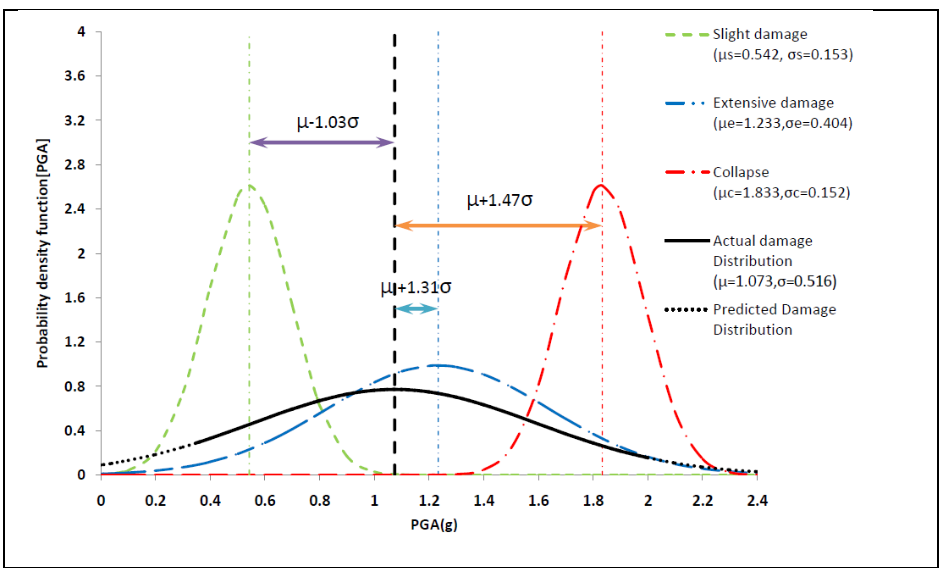
Figure 5: Predicted damage plotted against PGA



As depicted in Figure 6, mean of normal distribution function for Slight, Extensive and Collapse damage states deviate by -1.03σ, +1.31σ and +1.47σ respectively from the mean of predicted damage distribution, where σ is standard deviation of actual damage distribution.

Figure 6: Probability density functions plotted against IMs



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5. CONCLUSION

This study is conducted on a reinforced concrete bridge for its seismic vulnerability assessment with the help of fragility curves, normal distribution, lognormal distribution, cumulative energy dissipation and damage index. An analytical approach using SAP2000 is adopted for performing the damage assessment analyses. Following are the main conclusions of the study:

It is found from the IDA curves, that energy dissipation at first yielding is 438 kN-m and corresponding yield displacement at the top of the pier is 62 mm, while the maximum cumulative energy dissipation is observed about 10300 kN-m for collapse state.

It is observed that the structural responses of the bridge lie between 30th and 70th percentile from the mean response of the bridge. The mean value of PGA for slight, extensive and collapse state is observed to be 0.542g, 1.233g and 1.833g respectively.

The study shows prediction of damage for different damage states against different PGA levels. The study also shows that to what extent the mean of normal distribution function of slight damage, extensive damage and collapse states deviate from the mean of predicted damage, in terms of standard deviation (σ) of actual PGA_d. The Probability of all defined damage states lie in confidence interval of actual damage distribution.

The parameters related to source to site conditions, used while selecting ground motions are observed to be playing a key role in the damage assessment study of the RC bridge. Therefore it requires precision in selection of ground motions and its parameters.

Above study may be used as a viable tool for health monitoring, vulnerability assessment and formulating retrofit strategies of the reinforced concrete bridges under the seismic loadings.

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