Abstract

According to the importance of fragility curves in seismic evaluation of buildings, fragility curves for a number of R/C frame buildings have been developed through a series of nonlinear time history analysis for 3-, 5-, or 7-story buildings in the current study. A number of accelerograms with different values of peak ground acceleration (PGA) besides different frequency contents for each building to create a rather huge statistical data in order to extend reliable fragility curves are applied. The damage index of "plastic hinge rotation" will also be applied. Numerical results confirm the reliability and validity of developing fragility curves for R/C frames.

Keywords: Seismic Fragility, R/C Frame, Plastic Hinge Rotation, Non-Linear Time History Analysis.

1. Introduction

Estimation of damage and loss is one fundamental prerequisite for every earthquake hazard reduction program in all earthquake prone countries. However, very little data is available on earthquake information and the relationships between level of damage and loss in different buildings. Many of the developed fragility curves are based on actual data obtained from buildings damaged from past earthquakes which does not necessarily include all types of existing buildings in several countries. Therefore, developing fragility curves through computational methods is of high importance particularly for areas lacking a rich data base of earthquake. So far, many researchers have attempted to develop and extend fragility curves for the existing buildings using actual data or different types of analyses including non-linear time history analysis or Push over analysis. Recently, M.S. Kircil et al. (2006 [1]) have developed fragility curves for R/C frame buildings with different structure high in Istanbul which have been designed according to Turkish Seismic Design Codes (1975 versio) based on numerical simulations in proportion to the number of stories in buildings. They developed 3-, 5-, and 7-story buildings and then performed incremental and ascending dynamic analysis for sample buildings using 12 artificial ground motions to determine the capacity of yielding and collapse in two of buildings. Based on building's capacity, fragility curves were developed in terms of acceleration of elastic range, the peak ground acceleration, and elastic displacement spectrum for areas of yielding and collapse damage assuming a log-normal distribution. To examine the effect of the number of building stories on fragility parameters, a regression analysis has been performed. It was observed that fragility parameters vary considerably with the numbers of building stories. Finally, using the created fragility curves in statistical methods, they estimated the proportion of inter-story drift and the maximum displacement spectrum values which fulfill the conditions of "CP" and "IO" performance level.

In addition, G. Ariaga [2] introduced fragility curves of R/C frame with different number of stories more than 10 based on inter-drift story using RAM perform software to non-linear dynamic analysis. Recently, Aziminejad [3] developed fragility curves for single story concrete copper buildings with shear walls based on story drift and plastic hinge rotation.

It was observed that despite existence of several publications relating to fragility curves, only few of them have focused their attention on concrete buildings and particularly moment frames. However, moment frame buildings are the most popular concrete buildings in Iran. Moreover, developing fragility curves for such buildings is necessary for assessing the risk and structural program of the country. In a recent study, the authors have applied the same method as Kircil and Polat and also Azirninejad, Moghaddam for developing fragility curves for a group of R/C frame buildings.
2. Developing Fragility Curves by Using Nonlinear Dynamic Time History Analysis

To develop fragility curves for any kind of building based on nonlinear dynamic time history analysis (NLTHA), it is necessary to consider the following steps:

1) Considering multiple buildings as specimen and various kinds of soil as their construction site.
2) Calibrating the intended buildings on the basis of the nonlinear behavior of its materials and their deterioration properties.
3) Selecting various accelerograms recorded from previous earthquakes on the basis of their frequency content and in respect to the soil type of the site, and then scaling them in accordance to various PGA amounts.
4) Considering a proper damage scale for the building materials or the frames used, such as “inter story drift (ISD)”, “plastic hinge rotation (PHR)”, and “axial plastic deformation (APD)”.
5) Considering a number of acceptance criteria suitable for breaking points in accordance to different building design codes.
6) Carrying out a nonlinear dynamic time history analysis (NLTHA) for each building regarding different levels of PGA.
7) Choosing a proper probability-density function.
8) Presenting fragility curves and tables.

3. Introducing Models of The Buildings under Study

Regarding the fact that R/C frame buildings are the most prevalent multi story buildings in Iran and that the development of fragility curves of this country is almost new, these buildings are first examined to develop fragility curves. For this purpose, the complex including one 3-, 5-, and 7-story building with the same plan is considered. Accordingly, majority of the existing buildings in Iran are designed based on version 2 of Iranian Standard 2800 (Iranian Code of Practice for Seismic Resistant Design of Buildings) [4], which are similar to UBC-97. This version of that standard has been applied to design the buildings as specimens. To calculate the lateral force coefficients in all states, the B soil condition has been used since the majority of existing constructions in Tehran occur on such soil. The plan of the considered buildings and the selected frames for analysis are depicted in Fig.1.
4. The Applied Software

To carry out a NLTHA and evaluate the buildings considered, the building frames are calibrated through SeismoStruct V6 software [5]. The non-linear and inelastic behavior of various structural members including beams, columns and bracing elements are introduced to the software based on FEMA 306 guide [6].

5. Damage Index and The Applied Performance Levels

To develop fragility curves, it is necessary to use a number of reasonable damage indices for each structural elements. In beams and columns, researchers have widely used plastic hinge rotation; however, partial axial deformation or inter-story drift are considered as the suitable indices in bracing elements. In the current study, the plastic hinge rotation is used as a damage index for fragility assessment of the frames. In addition, three levels of low, moderate and extensive can be considered as the general damage of a building which is usually regarded as PL of a building prone to earthquake (i.e., a special hazard level). In FEMA 306, these three PLs are called Immediate Occupancy (IQ), Life Safety (LF), and Collapse Provision (CP), respectively; which have been applied in the current study. Therefore, exceeding the selected damage index from the corresponding amount based on each of these 3 PLs will lead to system fragility in that special PL. To deform the axial plastic, elements of the three levels are obtained based on the values presented in Tables 5-7 from FEMA 306 depending on cross section and the allowed axial plastic deformation.

6. Non-Linear Time History Analysis (NLTHA)

For NLTHA in various types of buildings, 6 accelerograms recorded on soil type B have been used all of which have PGA of about 35g (i.e., the maximum amount of PGA recorded in Codes and Regulations). The accelerograms used are scaled to 7 different PGA levels from (.1g) to (.7g) to create 42 states of time history analysis for each kind of buildings. The characteristics of these accelerograms are presented in Table 1.
Table 1 - Characteristics of the accelerograms used

<table>
<thead>
<tr>
<th>NO.</th>
<th>Event</th>
<th>PGA(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kocaeli, Turkey, 1999.8.17</td>
<td>.375</td>
</tr>
<tr>
<td>2</td>
<td>Loma Prieta 1989.10.18</td>
<td>.357</td>
</tr>
<tr>
<td>3</td>
<td>El Centro 1950.5.18</td>
<td>.319</td>
</tr>
<tr>
<td>4</td>
<td>Northridge 1995.01.17</td>
<td>.363</td>
</tr>
<tr>
<td>5</td>
<td>San Fernando 1971.2.</td>
<td>.365</td>
</tr>
<tr>
<td>6</td>
<td>Duzce, Turkey 1999.11.12</td>
<td>.426</td>
</tr>
</tbody>
</table>

7. Fragility Calculations

Developing and expanding fragility curves by using PGA amounts as changing parameter is prevalent. Based on numerical results of NLTHA, the maximum amounts of plastic hinge rotation of the elements are obtained. This parameter is used as a damage index to develop fragility functions. Accordingly, fragility function is defined as follows:

\[
\text{Fragility} = P[\text{EDP} > \text{AC} | \text{IM}]
\]  

(1)

In equation 1, IM the severity criterion which is the amount of PGA and EDP is engineering demand parameter considered similar to damage index in the present study and AC is the acceptance criterion which is considered as the PL mentioned in section 5. The probability function given in equation 1 can be obtained as follows:

\[
P = P[\text{EDP} > \text{AC}] = 1 - P[\text{EDP} < \text{AC}] = 1 - \phi\left(\frac{\text{AC} - \text{IM}}{\text{6}}\right)
\]  

(2)

Though some researchers have suggested using log-normal probability density function, many other researchers argue that using a log-normal density function can also produce satisfactory results (Suppasri et al., [7]; Altug Erberik [8]). Accordingly, a normal or Gaussian probability density function is assumed for EDP used. In order to calculate the probability of exceeding from a certain limit, standard deviation and mean deviation of EDP are calculated for a total of 6 earthquakes. Then, using cumulative distribution function of normal distribution, we calculate the probability of exceeding in each EDP from the certain limit.

8. Creation and Presentation of Fragility Curves

The numerical results obtained from NLTHA and equation 6 have been used to develop the fragility curves for each frame. Fragility curves can be plotted using the fragility data. Fragility curves for 3-story frames for three PLs are depicted in Fig.2.

![Fragility curves for 3-story frames](image)

Fig 2- Fragility curves for 3-story frames

Having a look at Fig.2, one can observe that in 3-story frames:
- Fragility curves in Performance level of IQ initiating in a space between .1g and .2g (based on type of frame) reaches an amount of about 1 in a space between .4g and .5 g.
- Fragility curves in performance level of LS initiating in a space between .2g and .35g (based on type of frame) reaches an amount of .8g or more about PGA amount (i.e., .7g).
- Fragility curves in performance level of CP (based on type of frame) initiating in a space between .3g and .4g, reaches an amount of .7 or more about PGA amount (i.e., .7g). However, fragility amount in this PL cannot exceed .95 for the maximum PGA amount (.7g).

Fragility curves for 5-story frames are depicted for three levels of PL in Fig.3.

![Fragility curves for 5-story frame](image)

**Fig 3- Fragility curves for 5-story frame**

Based on the fragility curves shown in Fig.3, one can express the following regarding the 5-story frames:
- Fragility curves in performance level of IQ initiate from .1g and reach to the amount of almost 1 in a space between .4g and .5g.
- Fragility curves in performance level of LS initiate in a space between .2g and .35g and reach to amount of .7 or more about the amount of PGA (.7g).
- Fragility curves in performance level of CP initiate from .25g and reach to 0/5g or more to 0/7 g GP; however, fragility amounts in this performance level cannot exceed 0/95 for the biggest amount of GPA (i.e., 0/7g).

Fragility curves for 7-story frames with various numbers of extended bay for the performance levels of PL are depicted in Fig. 4.

![Fragility curves for 7-story frames](image)

**Fig 4- Fragility curves for 7-story frames**

From Fig.4 the following conclusions can be made:
- Fragility curves in performance level of IQ initiate from .1g and reach to an amount of .95 or more in a space between .4g and .5g.
Fragility curves in performance level of LS initiate in a space between .25g and .4g and reach to the amount of .6 or more in PGA (i.e., .7); however, fragility amount in this performance level cannot exceed .95 for the biggest amount of PGA (i.e., .7g).

Fragility curves in performance level of CP initiate from .2g and reach the amount of .45 or more about .7g GPA; however, fragility amount in this performance level cannot exceed .85 for the biggest amount of GPA (i.e., .7g).

9. Conclusion

Based on extended fragility curves for R/C frame buildings with multiple stories by using non-linear time history analysis and considering plastic hinge rotation of structural elements as the damage index, the following conclusions are made:
1) The number of frame stories does not considerably affect their fragility amount in various Performance Levels.
2) In general, for PGA amounts of 0/5 or more, changes in fragility amounts is less than corresponding changes with PGA amounts of less than 0/5g.

Among various damage index, the index of "plastic hinge rotation" are more reliable for extending fragility curves for R/C frame buildings. Finally, it should be taken into consideration that the current study was performed on regular buildings. To find more general results a study should be performed on more irregular buildings.

References