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# VULNERABILITY ANALYSIS BY THE DEVELOPMENT OF FRAGILITY CURVES

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**ABSTRACT :** *Earthquake vulnerability analysis is a fertile area of research which needs more input from seismologists and engineers. This paper focuses on the generation of fragility curves for a five-story reinforced concrete (RC) flat-slab building structure in the central United States. Fragility curve is a statistical tool representing the probability of exceeding a given damage state to the earthquake intensity. For the development of fragility curves asset of earthquake records selected from PEER data base .Inelastic time history analysis was performed to anlyse the structure subjected to the earthquake records in terms of spectral acceleration in ETABS V 9.7.3. To improve the seismic performance of the structure retrofitting was done by the addition of shear walls. Then fragility curves were also developed for retrofitted structure. The fragility curves developed from this study were used to compare the seismic performance of retrofitted and unretrofitted structure.*

***Keywords -*** *Fragility Curves, PEER Data Base, Flat Slab Structure, Time History Analysis, Spectral Acceleration, Damage State*

## I. INTRODUCTION

Some destructive earthquakes occur periodically in different countries in the world. This leads to damage of many vulnerable buildings and loss of lives in each year. Therefore, evaluation of seismic vulnerability of buildings before the occurrence of an earthquake is essential step in preventing financial costs and loss of lives due to earthquakes. Developing fragility curves is a helpful tool to accomplishing this goal. As being one of the special reinforced concrete structural forms, flat-slab systems need further attention. They possess many advantages in terms of architectural flexibility, use of space, easier formwork and shorter construction time. However the structural efficiency of the flat-slab construction is hindered by its poor performance under earthquake loading. This undesirable behaviour has originated from the insufficient lateral resistance due to the absence of deep beams or shear walls in the flat-slab system. This gives rise to excessive deformations that cause damage in non-structural members even when subjected to earthquakes of moderate intensity. Flat-slab type of construction is in widespread use in U.S, which is one of the earthquake vulnerable regions of the world. Hence it becomes even more important to investigate the vulnerability of this special structural form.

The main ojectives of this study were to evaluate the seismic vulnerability of a flat slab structure by the development of fragility curves, to determine the improvement in the seismic performance of the structure for the addition of shear walls and to compare fragility curves of unretrofitted and retrofitted structure.

***Mary Beth et al.,*** (2006) [4] conducted an assessment of seismic fragility for a reinforced concrete frame structures representative of 1980’s construction in central U.S. The paper presents the performance of unretrofitted structure and retrofitted structure in terms of fragility relationships that relate the probability of exceeding a performance level to the earthquake intensity.

***Erbiric,M et al.,*** (2003) [2] conducted a study on flat slab structures .The main focus was on the derivation of fragility curves using medium rise flat slab buildings with masonry infill walls. The case study building was modelled as a 2D frame with lumped masses. Spectral displacement was used as the hazard parameter for the development of curves.

***Lombard*** (2007) [3] conducted a study on rehabilitation of structures by addition of shear walls. The research shows that with the infilling process, the response of panels and the overall structure was changed. The infilling process tends to stiffen the structure such that the base shear can increase. The overturning effects and base shear are concentrated at the stiffer infill locations. Therefore, strengthening of the foundation is typically required at these locations.

***Jirsa*** (2000) [2] tested one-story infill walls using four specimens. In their experiment, they used three one-bay, single-story, non-ductile RC frames that were designed to represent 1999’s construction techniques.

These included wide spacing in the column shear reinforcement and compression splices that were inadequate to develop the required tensile yield strength. In their experiment, the first three walls varied in their opening locations. Longitudinal reinforcement was added adjacent to the existing columns to improve the continuity of the steel in the fourth specimen. The first three experiments had brittles failures due to the deficient column lap splices, even though the infill strengthened the frame.

## II. BUILDING CONFIGURATION

The case study building is a medium rise RC flat slab building. The building is located in Mid American Region. The plan and elevation of the building is shown in Fig.1.

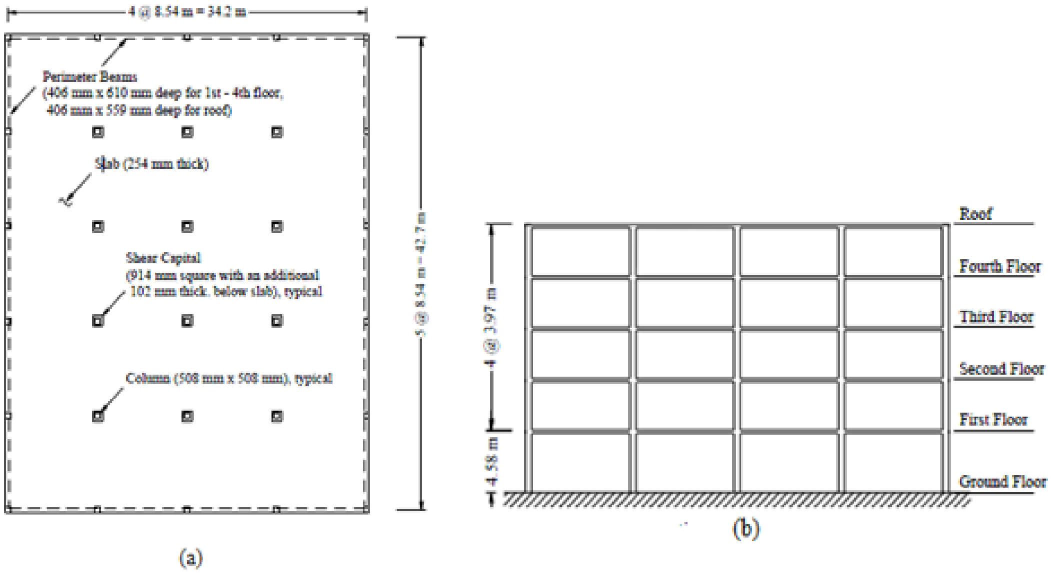


Fig.1 Five story flat-slab building

(a) Elevation (b) Plan

The informations regarding the size of building and variables used for analysis are shown in Table 1 and Table2.

Table 1 Building Description data

| | | |
|---|---|---|
| 1 | Use of building | Office |
| 2 | Plan size | 34.2 ×42.7m |
| 3 | Building height | 20.46 |
| 4 | Number of storey's above ground level | 4 |
| 5 | Type of structure | RC frame |

Table 2 Variables for Analysis

| | | |
|---|---|---|
| 1 | Dead loads (unit weights) | |
| | ● Masonry | 19.8 $KN/m^3$ |
| | ● Concrete | 23.56 $KN/m^3$ |
| | ● Steel | 78.54 $KN/m^3$ |
| 2 | Imposed (live) loads | |
| | ● Floor loads | 2.4 $KN/m^2$ |
| | ● Roof loads (snow load) | 0.814 $KN/m^2$ |
| 3 | Wind loads | Not consider |
| 4 | Super imposed dead loads | |
| | Partition load | 0.958 $KN/m^2$ |
| | Cladding load | 0.719 $KN/m^2$(applied to each perimeter beam as udl) |
| 5 | Type of Building | Regular frames |
| 6 | Horizontal floor system | Flat slab |
| 7 | Grade of concrete | 4000psi |
| 8 | Grade of steel | A615G60(414 MPa) |

## III. GROUND MOTION DATA

Since the study focuses on the effect of the ground motion variability on the building's response, selection of ground motion is a critical step. The ground motion should be earthquake records chosen for study is of class C soft soil (ACI 318M 08).Table 3 provides the characteristics of the ground motion data chosen from PEER (Pacific Earthquake Engineering Research Centre) database for this study.

## IV. FRAGILITY CURVES

Eigen value analysis was performed to identify fundamental time period of the building and Response spectrum analysis was conducted to obtain the spectral acceleration values corresponding to the fundamental time period of the building for developing fragility curves. From the time history analysis we get interstory drift values corresponding to the 25 ground motions. Appendix B gives the interstory drift values for the 25 selected ground motions. The maximum interstory drift values from each of the 25 analysis output is further sorted out and plotted as shown in Fig.2. The median values of maximum building drift were calculated based on natural log of obtained interstory drift values and these values were used for the construction of fragility curves. To find the median value Eq. (1) is used.

Table 3 Selected ground motions for the study

| No. | EQ | STATION | Mag. | PGA(g) | PGV |
|---|---|---|---|---|---|
| 1 | North Ridge | Arleta fire station | 6.7 | 0.33 | 0.309 |
| | | Newhall fire station | | 0.69 | 0.818 |
| | | Sun valley | | 0.36 | 0.314 |
| | | Canoga park | | 0.26 | 0.138 |
| | | Rinaldi station | | 0.64 | 1.093 |
| 2 | Imperial valley | El centro diff. array | 6.53 | 0.43 | 0.553 |
| | | Calexico station | | 0.23 | 0.185 |
| | | El centro array#8 | | 0.54 | 0.578 |
| | | El centro array#4 | | 0.37 | 0.471 |
| | | El centro array#5 | | 0.45 | 0.771 |
| 3 | Loma Prietta | LGPC | 6.93 | 0.78 | 0.771 |
| | | Hollister city hall | | 0.23 | 0.418 |
| | | BRAN | | 0.53 | 0.497 |
| | | CDMG Capitola | | 0.48 | 0.345 |
| | | UCSC 15 | | 0.34 | 0.118 |
| 4 | Landers | SCE 23 cool water | 7.28 | 0.37 | 0.346 |
| | | Morongo Valley | | 0.16 | 0.186 |
| | | Ingle wood | | 0.04 | 0.115 |
| | | Westcovino | | 0.04 | 0.121 |
| | | Tustin –E Sycamore | | 0.041 | 0.098 |
| 5 | Cape Mendocino | CDMG | 7.01 | 1.34 | 0.904 |
| | | Myrtle and west | | 0.17 | 0.25 |
| | | Fortuna Blvd | | 0.12 | 0.246 |
| | | Petrolia | | 0.62 | 0.692 |
| | | Rio dell overpass | | 0.42 | 0.479 |

$$Y_M = e^{average \ \ln[(X_i)]} \quad (1)$$

Where

$Y_M$ =Medianresponse

$X_i$ = Response for a given ground motion record i

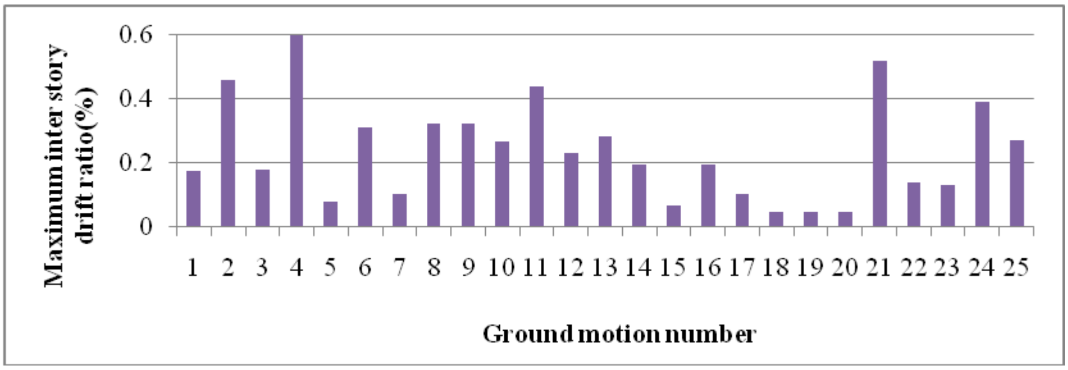


Fig.3 Bar chart showing maximum interstory drift ratio for each ground motion

FEMA 356 suggests two approaches for seismic evaluation: global-level and member-level using three performance levels (Immediate Occupancy, Life Safety and Collapse Prevention).In this study only global level evaluation was conducted. In the global-level evaluation the performance of the building is measured by the interstory drift. The advantage of this quantity is that it is easy to measure during the analysis and has physical meaning that is well-understood. Interstory drift values for different limit states have also been suggested by seismic codes and guidelines.Table 4 shows the global-level interstory drift limits for the three performance levels for concrete frame elements in FEMA 356(ASCE 2000)

Table 4 Drift limits for concrete frame elements in FEMA 356(ASCE 2000)

| **Structural performance levels** | **Drift (%)** |
|---|---|
| Immediate occupancy | 1 |
| Life safety | 2 |
| Collapse prevention | 4 |

Here spectral acceleration ($S_a$) is used as hazard parameter for fragility analysis. The spectral acceleration for a given ground motion record is the value corresponding to the fundamental time period of the structure and 5% damping.The desired fragility curves were developed using the Eq.(2).

$$P(LS/S_a) = 1 - \emptyset\left(\frac{\lambda_{CL} - \lambda_{D/S_a}}{\sqrt{\beta_{D/S_a}{}^2 + \beta_{CL}{}^2 + \beta_M{}^2}}\right) \tag{2}$$

Where,

$P(LS/S_a)$ = Probabilty of exceeding a limit state at a given ground motion intensity

$\emptyset$ = Standard normal cumulative distribution function

$\lambda_{CL}$ = ln (median drift capacity for a particular limit state)

$\lambda_{D/S_a}$ =ln(calculated median demand drift) where demand drift is obtained from bestfit power line)

$\beta_{D/S_a}$ = Uncertainty associated with the fitted power law equation used to estimate demand drift = $\sqrt{\ln(1+s^2)}$

$\beta_{CL}$ = Uncertainty associated with the drift capacity criteria, taken as 0.3 for this study

$s^2$ = Square of the standard error

$\beta_M$ = Uncertainty associated with analytical modelling of the structure, taken as 0.3 for this study

Values of $\lambda_{CL}$ for each limit states are as follws:-

$\lambda_{CL}$ = ln (median drift capacity for a particular limit state)

Median drift capacity for each limit state is as follows:-

Immediate occupancy - ln(1)

Life safety - ln(2)

Collapse prevention - ln(4)

Figure 10.1 provides the best power law equation between maximum interstory drift ratio and the corresponding spectral acceleration for the selected 25 ground motions. The best power law equation was determined by using Microsoft Excel. Values of $\left[\lambda_{D/S_a}\right]$ for spectral accelerations corresponding to the 25 ground motions are determined from Eq. (10.1).This equation is known as power law equation.

$$y = 0.316x^{0.444} \tag{3}$$

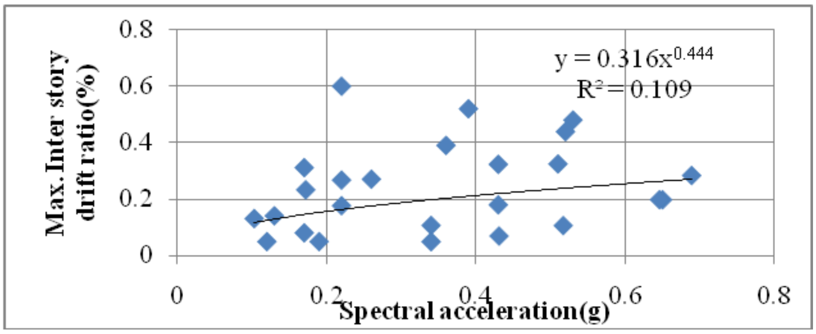


Fig.4 Development of power law equation for unretrofitted structure

The standard error (s) of this distribution was determined by using Microsoft Excel.

s = 0.178

$\beta_{D/S_a}$ = $\sqrt{\ln(1+s^2)}$ = 0.177

The fragility curves developed using FEMA global level performance criteria are shown in Fig.5.

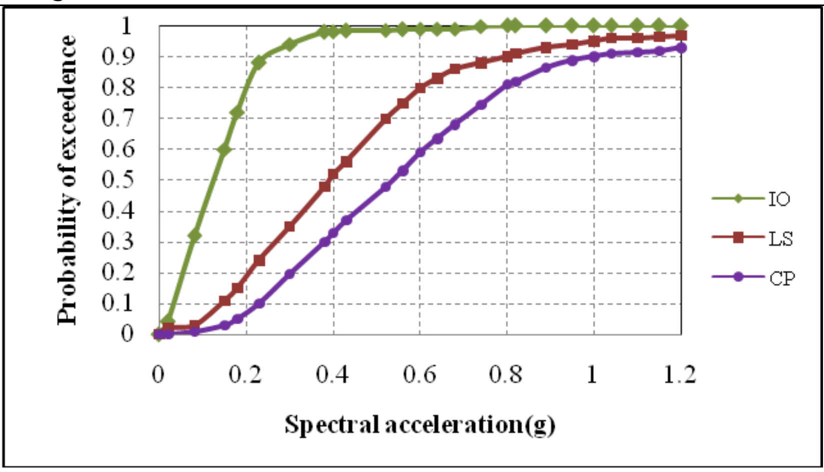


Fig.5: Global level fragility curves of unretrofitted structure

By pushover analysis of unretrofitted building it was determined that the addition of shear wall is the best retrofitting technique. So the structure was strengthened by adding shear walls to the two centre bays of the exterior frame.The shear walls are 406 mm thick. The reinforcement was designed using ACI 318-02 (ACI Comm. 318 2002). Two layers of #6 (US) reinforcing bars at 305 mm spacing were selected for the shear walls.

Then fragility curves were developed for retrofitted building by using same procedure as that of unrerofitted building.

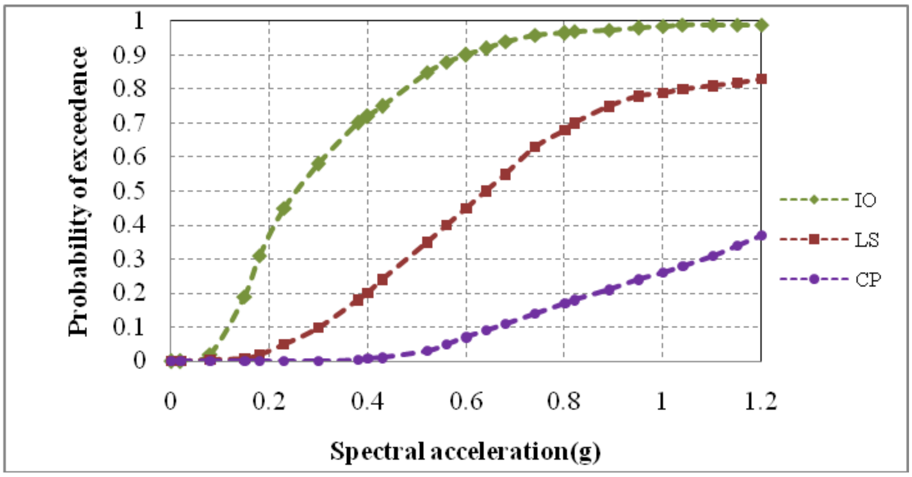


Fig.6 Global level fragility curves of retrofitted structure

## V. CONCLUSIONS

Fragility curves derived for the flat-slab structure reflect the inherent characteristics of this structural form. When compared with the curves of regular moment frames of similar structural class, it is observed that the fragility curves are more vulnerable to seismic hazard because of their insufficient lateral resistance and undesired performance at high levels of seismic demand. Retrofit technique was applied to the case study building to impact the major structural response parameters. Due to the addition of shear walls the seismic performance of the structure was enhanced based on the analytical results from both the nonlinear static and nonlinear dynamic analyses. Fragility curves using the FEMA global-level criteria were developed for both the unretrofitted and retrofitted case study buildings. Addition of shear walls reduced the probability of exceeding each limit state. The fragility curves developed for flat-slab system gets flatter as the limit state shifts from immediate occupancy to collapse prevention. This is due to the nature of the statistical distribution of the response data. The steep shape of the immediate occupancy limit state curve is because of the flexibility of the flat-slab structures and the infill panel stiffness and strength.

## REFERENCES

[1] Erbiric, M. (2000), "Fragility Curves for Reinforced Concrete Structures in Skopje (Macedonia) Region," *Soil Dynamics and Earthquake Engineering,* 19, 455-466.

[2] Jisra, J.O. and Kreger, M. (1989), "Recent Research on Repair and Strengthening of Reinforced Concrete Structures," *Proceedings,* ASCE Structures Congress, San Francisco, CA, 1, 679-688.

[3] Lombard, j., Humar, J.L. and Cheung, M.S. (2000), "Seismic Strengthening and Repair of Reinforced Concrete Shear Walls," *Proc., 12th world Conference on Earthquake Engineering,* Auckland, New Zealand (CD-Rom).

[4] Mary, Beth, Hueste, D. and Jong, Wha, Bai. (2007). "Seismic Retrofit of a Reinforced Concrete Flat Slab Structure: Part II- Seismic Fragility Analysis" *Engineering Structures,* 29, 1178-1188.

[5] Wen, Y.K. and Wu, C.L. (2001), "Uniform Hazard Ground Motions for Mild-America's Cities," *Earthquake Spectra,* 17, (2), 359-384.