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Review on Fragility Analysis of Building Structure in Seismic Prone Area

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***Abstract:** In general, using a steel bracing system is the most effective choice for enhancing the resistance of reinforced concrete frames to lateral loads. Steel bracing offers notable advantages over other methods, including greater strength and stiffness, cost-effectiveness, a smaller footprint, and minimal additional weight on existing structures. Both empirical and analytical fragility curves have been taken into account. Strengthening seismically deficient reinforced concrete frames with steel bracing systems is a practical solution for improving earthquake resilience. Nearly all structural analysis software, such as ETABS and SAP2000, supports linear and nonlinear static analysis for high-rise structures. Key parameters include fragility curves, the P-Δ effect, base shear, lateral displacement, axial force, and story drift, among others. The findings showed that bracing systems significantly reduce lateral displacement in frames. Fragility curves were developed based on peak ground acceleration (PGA) for various limit states—slight, moderate, major, and collapse-assuming a lognormal distribution. This study aims to develop analytical fragility curves for high-rise building structures.*

***Keywords:** Fragility analysis, steel bracing, Reinforced concrete frame, Fragility curve, Lateral Displacement, Storey Drift, Performance levels*

I. INTRODUCTION

Estimating damage is a critical component of any earthquake risk reduction program in seismically active regions. However, there is limited data on the relationship between earthquake characteristics and the damage levels in different building types. Most existing fragility curves, which estimate structural vulnerability, are based on data from buildings damaged in past earthquakes; however, these datasets may not comprehensively represent all types of structures found across various countries. To address this, many researchers have developed fragility curves for existing buildings using either empirical data or analytical methods like Push Over analysis. In recent decades, seismic vulnerability and the effectiveness of retrofitting techniques for different structures—such as buildings and bridges etc. are commonly assessed through probabilistic seismic analysis using fragility curves. Simply put, seismic fragility represents the likelihood that a structure or its components will experience a certain damage level during earthquakes of specified intensity. Thus, fragility curves enable probabilistic assessments of damage outcomes under different seismic events.

A. Type of Bracing

There are two types of bracing systems

1) *Concentric Bracing System:* Steel braces are typically arranged in vertical spans, which adds significant stiffness to the structure without much additional weight. Concentric bracings boost the frame's lateral stiffness, thereby raising the natural frequency and generally reducing lateral floor drift. However, this added stiffness can also lead to higher inertia forces during an earthquake. While the bracings help reduce bending moments and shear forces in the columns, they also increase the axial compression in the columns they're connected to.
2) *Eccentric Bracing:* To decrease the system's lateral stiffness and enhance its energy dissipation capacity, the flexural stiffness of the beams and columns which largely determines lateral stiffness can be reduced. During an earthquake, the vertical component of bracing forces introduces a lateral concentrated load on the beams at the connections with the eccentric braces.

II. LITERATURE REVIEW

A. Bracing System

Akbri, Aboutalebi and Maheri[1] discussed on Seismic fragility Assessment of Steel X-braced analysis SAP2000. He conducts research on 4-story, 8-story, and 12-story steel-braced reinforced concrete (RC) frames, which represent typical low-rise, mid-rise, and high-rise buildings, respectively. His findings on the fragility curves for braced frames are compared to those of unbraced moment-resisting frames.

His work shows that steel-braced RC dual systems, combining braced frames with moment-resisting frames and designed to resist a specified base shear, exhibit better performance (i.e., lower probability of damage) and greater load-bearing capacities than equivalent unbraced RC frames. Additionally, a system configuration with stronger bracing and a weaker frame structure lowers the overall damage likelihood of the dual system.

In terms of frame height, chevron bracing tends to perform better under extensive and complete damage states than X-bracing. He assesses the seismic vulnerability of steel X-braced and chevron-braced RC frames by developing analytical fragility curves. His study examines multiple parameters, including frame height, P-Δ effects, the fraction of base shear the bracing system is designed to handle, and the type of bracing used. His research also includes nonlinear time history analysis.

Bhojkar and Bagade[2] studied seismic evaluation of high-rise structure by using steel bracing system. He conducted a seismic analysis on a ten-story reinforced concrete (RC) building with various bracing types, using STAAD-PRO. His findings show that incorporating X-type steel bracing notably enhances the building's structural stiffness, leading to a considerable reduction in maximum inter-story drift. This bracing system not only boosts lateral stiffness and strength capacity but also increases the building’s displacement capacity. Additionally, he observed that adding steel bracing has minimal impact on the building's overall weight. The X-type bracing system effectively reduces lateral displacement by up to 65%, while generating the highest axial force, which reaches approximately 22%.

Mishra, Sharma and Garg [3] discussed on analysis of RC building frames for seismic forces using different types of bracing systems. Bracing systems are highly effective and robust lateral load-resisting mechanisms. A G+10 story building frame was analyzed under seismic loading to evaluate various bracing systems using STAAD-Pro software. Different types of bracing—X Bracing, V Bracing, K Bracing, Inverted V Bracing, and Inverted K Bracing—were compared to a bare frame model to assess their effectiveness in reducing lateral displacement and member forces. Steel bracing is advantageous for resisting seismic forces, as it can reduce lateral displacement by up to 80% compared to an unbraced frame.

Additionally, steel bracing significantly decreases the forces acting on members, making it an efficient choice for controlling story drift, which can be reduced by up to 56% compared to unbraced structures. This indicates that the stiffness of the building is enhanced when bracing is incorporated.

Sarokolal, Faghihmaleki & Gholampour[4] discussed on fragility curve assessment of collapse and yielding limit state for steel buildings with X-brace. Three samples of Steel Moment Frames with X-bracing, each with three, eight, and twelve stories, were analyzed using Incremental Dynamic Analysis (IDA) in the SeismoStruct software. Fragility curves were generated based on Peak Ground Acceleration (PGA) for areas prone to yielding and collapse, assuming a log-normal distribution. Yielding was found to occur at lower efficiency, with a steeper curve slope, indicating a quicker onset of yielding in the structures. Conversely, collapse efficiency was higher, and the curve was more gradual. Comparing the collapse fragility curves across the three structures, it was observed that as building height increased, the likelihood of collapse and the probability of extensive damage also rose. For yielding states, shorter buildings demonstrated faster yielding due to their lower capacity compared to taller buildings. Using bracing members as resistive components increased the structures' safety margin against collapse.

Chavan & Jadhav [5] discussed seismic response of RC building with different arrangement of steel bracing system. A seismic analysis was conducted on a reinforced concrete (RC) building with various bracing types, including diagonal, V, inverted V, and X configurations.

The study focused on a seven-story (G+6) structure located in seismic zone III. The building models were analyzed using equivalent static analysis per the IS 1893:2002 standards, employing STAAD-PRO V8i software. Results indicated that lateral displacement decreased by 50% to 56% when using the X-type steel bracing system, with this configuration providing the greatest reduction in maximum displacement. Additionally, the inclusion of steel bracing led to an increase in base shear, especially evident under Non-Linear Time History Analysis.

Majd, Hosseini Moein Amini[6] discussed on development fragility curves for steel building with X-bracing by nonlinear time history analyses. He presented regular structural models in both plan and elevation to minimize torsional effects. These models included a set with a 2-by-4-bay layout and another with a 4-by-6-bay layout, each featuring 3, 5, or 7 stories. To assess potential damage, he applied two indices: "Inter-story Drifts" and "Axial Plastic Deformation of Bracing Elements." Using nonlinear dynamic analysis through RAM PERFORM software, he generated fragility curves for steel moment frames with story heights up to ten, primarily based on inter-story drift values. Of the two indices, "Axial Plastic Deformation" (APD) of bracing elements proved more reliable for developing fragility curves for steel structures.

B. Case study of Eccentric Steel Bracing System

Ozel and Guneyisi[7] presented a case study Effects of eccentric steel bracing systems on seismic fragility curves of mid-rise R/C buildings. A six-story mid-rise reinforced concrete building was selected for analysis, utilizing D, K, and V-type eccentric bracing systems. Each bracing system was applied with four distinct spatial distributions within the structure. Nonlinear time history analysis was performed to evaluate the building's response under a set of earthquake accelerations, defined by peak ground accelerations (PGA), and to monitor four performance limit states: slight, moderate, major, and collapse. Fragility curves for these limit states were developed in terms of PGA, assuming a lognormal distribution. Seismic reliability was assessed by comparing the median PGA values of the fragility curves for the original building with those after retrofitting. Nonlinear time history analysis was conducted using SAP2000. The retrofit with steel braces significantly improved the fragility curves, reducing vulnerability by as much as 1.8 times (for the V1 braced frame) in terms of median PGA values. The eccentric steel brace distribution had a slight effect on the seismic reliability of the braced frames. Reduction curves were proposed to derive post-retrofit fragility curves based on the available fragility curves of the existing structures.

C. Fragility Analysis

Kircil and Polat[8] discussed on fragility analysis of mid-rise R/C frame buildings. He analyzed mid-rise buildings with 3, 5, and 7 stories and developed fragility curves based on their capacities. These curves were expressed in terms of elastic pseudo spectral acceleration, peak ground acceleration (PGA), and elastic spectral displacement for yielding and collapse damage levels, using a lognormal distribution. He examined existing buildings constructed under the influence of twelve artificial ground motions, focusing on the relationship between spectral acceleration (Sa), PGA, and spectral displacement (Sd) concerning different story counts. Using the constructed fragility curves and statistical methods, he estimated the maximum allowable inter-story drift ratios and spectral displacement values that meet the immediate occupancy and collapse prevention performance level requirements based on the number of stories in the buildings

Erberik and Elnashai[9] discussed fragility analysis of flat-slab structure. He presented the derivation of fragility curves for medium-rise flat-slab buildings with masonry infill walls, utilizing inelastic response-history analysis on a random sample of structures subjected to a suite of records scaled by displacement spectral ordinates while monitoring four performance limit states. The fragility curves developed from this study were compared to those derived for moment-resisting reinforced concrete (RC) frames. Analysis of three, five, and seven-story buildings indicated minimal differences in the inelastic dynamic analysis results. The comparison between flat-slab and moment-resisting buildings showed that the earthquake losses for the flat-slab structures were comparable to those of the moment-resisting frames.

Shinozuka, Honorary, Feng, Lee & Naganuma[10] discussed Statistical Analysis of fragility curves. Both empirical and analytical fragility curves were examined, with the empirical curves based on bridge damage data from the 1995 Hyogo-ken Nanbu (Kobe) earthquake. The presentation included methods for assessing the goodness of fit for these fragility curves and estimating the confidence intervals for the two parameters (median and log-standard deviation) of the distribution. Statistical procedures were introduced to evaluate the goodness-of-fit hypothesis and to estimate the confidence intervals for the parameters of the lognormal distribution. Bilgin[11] discussed Fragility-based assessment of public buildings in Turkey. He presented the study focuses on assessing the seismic fragility of reinforced concrete public buildings using representative template designs. Nonlinear static analyses are conducted in two primary directions to determine the lateral stiffness, strength, and displacement capacities of these designs. The research investigates the vulnerability of existing RC public buildings with template designs in the Turkish building stock. It is found that as seismic demand increases, the probability of damage across all states also rises. The number of stories significantly influences the likelihood of exceeding moderate and severe damage limit states. Additionally, the proximity of damage probabilities between the Life Safety (LS) and Collapse Prevention (CP) levels is particularly notable for 4- and 5-story buildings.

Lallemant, Kiremidjian and Burton[12] presented Statistical procedures for developing earthquake damage fragility curves. He presented The synthesis of commonly used methods for fitting fragility curves reveals significant limitations in many of them. Novel approaches are introduced for developing parametric fragility curves, including generalized linear models and cumulative link models, as well as non-parametric curves through generalized additive models and Gaussian kernel smoothing. The presentation covers various techniques for establishing relationships between earthquake damage and ground motion intensity. It critically examines the frequently used maximum likelihood (ML) and least-squares methods for fitting lognormal cumulative distribution function (CDF) fragility curves, highlighting some fundamental shortcomings of these approaches. Additionally, when creating empirical fragility curves from observed damage data, it is rare to have actual ground motion recordings available at all relevant sites.

Marco Vona[13] discussed Fragility Curves of Existing RC Buildings Based on Specific Structural Performance Levels. He outlined a procedure for developing analytical fragility curves for Moment Resisting Frame Reinforced Concrete buildings. The seismic capacity of selected models representing existing RC buildings was assessed through nonlinear dynamic simulations. The seismic response was analyzed using various peak and integral intensity measures, along with different response parameters such as ductility demands and Inter-storey Drift Ratio (IDR). The fragility curves presented are tailored to address seismic risk mitigation needs at various territorial scales. The buildings investigated are classified as low-engineered, pre-seismic code, or governed by older seismic codes. Previous studies often relied on numerical analyses, primarily using push-over methods, which are generally less accurate than the Nonlinear Dynamic Analyses (NDLAs) employed in this research. Based on the NDLAs, specific limits have been established for each building type analyzed, and distinct relationships between damage levels and damage states have been defined for each type considered.

Yue li, M.ASCE & Van De Lindt[14] discussed Collapse Fragility of Steel Structures Subjected to Earthquake Mainshock-Aftershock Sequences. He investigated the collapse probability of steel buildings that have been damaged by a mainshock during aftershocks, which is a crucial component in developing a framework for integrating aftershock seismic hazards into performance-based engineering (PBE). He presented data from NEEShub. To assess the impact of damage states from mainshocks on structural collapse capacity, three approaches were used to generate collapse fragility for the steel buildings experiencing a specific level of damage. The findings indicated that the structural collapse capacity can be significantly reduced after a high-intensity mainshock, making it likely for the structure to collapse even with a minor subsequent aftershock. Additionally, different mainshocks had a notable effect on the structural collapse fragility when substantial damage was inflicted by the mainshock.

D. Nonlinear static (Pushover Analysis)

Amini, Majd & hosseini[15] discussed on A Study on the Effect of Bracing Arrangement in the Seismic Behavior Buildings with Various Concentric Bracings by Nonlinear Static and Dynamic Analyses. In this study, regular multi-story steel buildings were analyzed with three types of bracing—X, V, and chevron—positioned in either 'two adjacent bays' or 'two non-adjacent bays' along the building height to investigate their seismic behaviors. The buildings were designed according to code and assessed using both pushover and nonlinear time history analyses, with their performances compared against standard Performance Levels (PLs). The bracing configuration significantly influences the seismic response of steel Concentrically Braced Frame (CBF) buildings. A set of 3, 5, and 7-story steel structures was evaluated using RAM PERFORM-3D software. Results showed that chevron bracing provided greater stiffness compared to the other two types, while X and V bracing exhibited similar stiffness levels. Furthermore, the ultimate resistance of chevron bracing was approximately 50% higher than that of X bracing, suggesting that applying the same response modification factor for all types of concentric bracing may be inappropriate, indicating a need for revisions in design codes.

Rota, penna and magenes[16]] discussed A methodology for deriving analytical fragility curves for masonry buildings based on stochastic nonlinear analyses. His methodology is based on nonlinear stochastic analyses of building prototypes. Nonlinear static (pushover) analyses are utilized to define the probability distributions for each damage state, while nonlinear dynamic analyses help determine the probability density function of displacement demand for various levels of ground motion. By convolving the complementary cumulative distribution of demand with the probability density function of each damage state, fragility curves can be derived. He presented a three-storey masonry building characterized by strong connections between orthogonal walls and between walls and floors, along with rigid diaphragms, resulting in behavior primarily influenced by in-plane mechanisms. Additionally, he examined a building with inadequate connections and no specific devices to prevent local collapse (e.g., tie rods or tie beams), highlighting the need to incorporate such local failure modes into the assessment procedure.

III. CONCLUSION

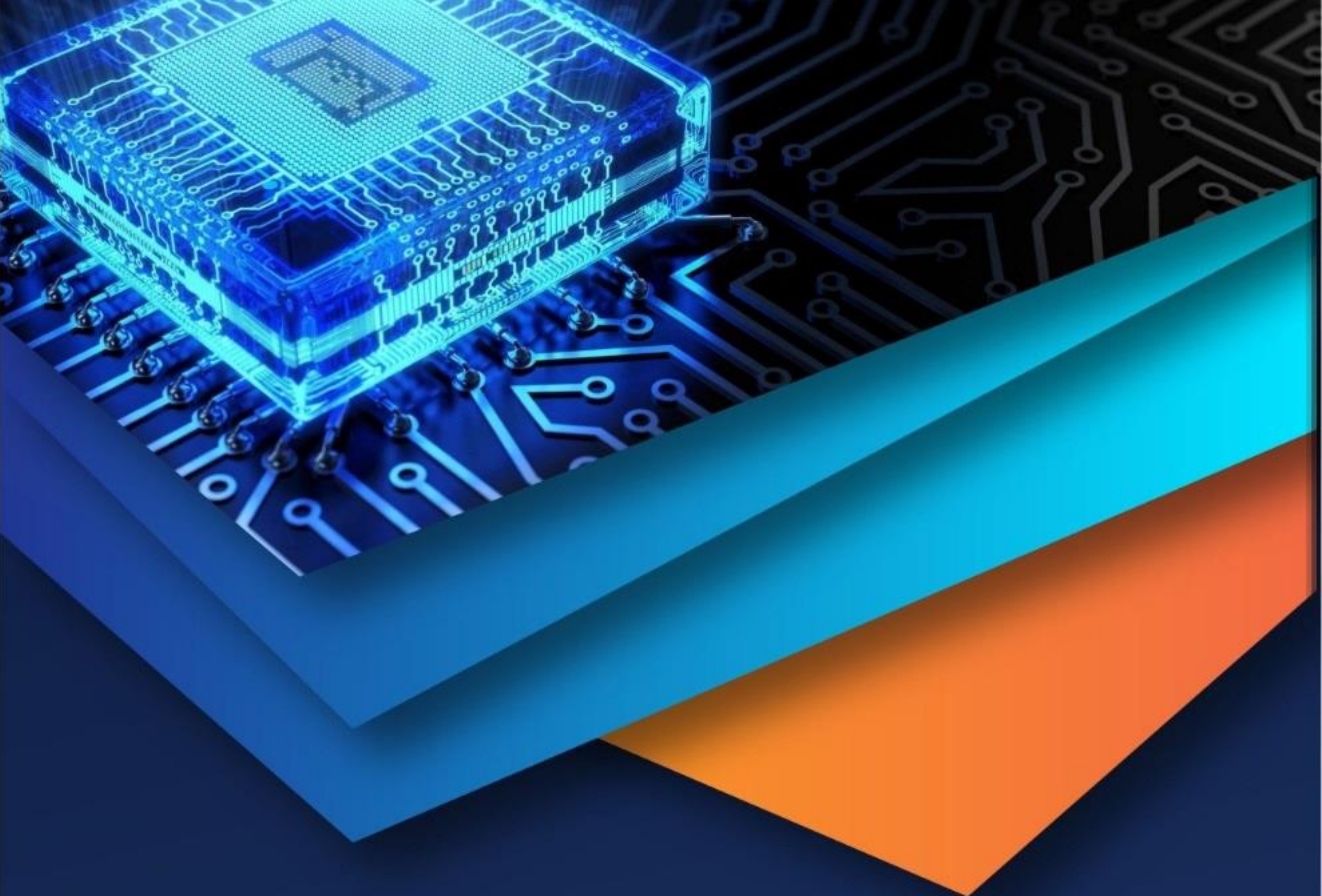
From the literature study based on fragility analysis of RC structure following conclusions are made:

1) Steel-braced reinforced concrete (RC) dual systems designed to withstand base shear exhibit improved performance and greater capacity than unbraced RC frames. Stronger bracing combined with a weaker frame reduces potential damage in dual systems.
2) Fragility curves are used to evaluate frames with and without P-Δ (P-delta) effects, indicating an increase in damage probability and a greater impact in taller frames.
3) The base shear capacity of steel-braced buildings is greater compared to buildings without steel bracing, signifying an increase in building stiffness.
4) The stiffness of the building is increased with the addition of steel bracing.

5) Analytical results generally supplement empirical procedures, which are calibrated based on observed behaviour and damage data gathered after earthquakes.
6) Buildings with taller columns exhibit more rapid yielding and collapse under P-Δ effects, especially as the height of the building stories increases.
7) Fragility curves show that shorter structures yield more quickly, displaying lower capacity than taller structures in the yielding state.
8) The intensity measure for masonry buildings, as well as validation of the capacity spectrum method—commonly used for developing fragility functions—requires extensive use of incremental nonlinear analysis (IDA).
9) Developing seismic fragility functions can be achieved through a hybrid method.
10) Structural collapse capacity diminishes when a building experiences a high-intensity mainshock, with a small aftershock following the mainshock potentially causing collapse.
11) Soil-structure interaction, aging effects, cumulative damage, and multiple hazards are additional considerations that can be incorporated into analyses.

REFERENCES

[1] R. Akbari 1, M.H. Aboutalebi2 and M.R. Maheri3, “Seismic fragility assessment of steel X-braced and chevron-braced RC frames", Asian journal of civil engineering (BHRC) Vol,16,Pages-13-27(2015)
[2] Nitin Bhojkar, Mahesh Bagade "Seismic evaluation of structure by using steel bracing system "IJISET, Vol.2, issue 3(2015)
[3] Liela kalani Sarokolayi, Hadi Faghihmaleki, Siroos Gholampour, "Fragility Curve assessment of collapse and limit state for steel building with X-brace", ACEE-Volume01[3],136-145, Iran
[4] Jong-Wha Bai, Paolo Gardoni, Mary Beth D.Hueste "Story-specific demand models and seismic fragility estimates for multi-story buildings", Structural safety 33(2011)96-107
[5] Sekiguchi I. Seismic strengthening of an existing steel reinforced concrete city office building in Shizuoka Proceedings of the 9th World Conference on Earthquake Engineering, Japan, III(1998).
[6] Kircil, M.S; Polat, Z. (2006 - July). Fragility analysis of mid rise R/C frame buildings, Engineering Structures, Vol. 28, No. 9, pp1335-1345
[7] M.Rota A.Penna,G. Magenes "A methodology for deriving analytical fragility curves for masonary buildings based on stochastic nonlinear analyses”, vol 32 (2010), pages 1312-1323. 1
[8] A.Moein Amini & M,Majd, M, Hosseini, "A study on the effect of bracing arrangement in the Seismic behaviour building with various concentric bracing by nonlinear static and dynamic analyses", 15 WCEE, lisboa 2012
[9] Krishnaraj R. Chavan, H.S.Jadhav, "seismic response of RC building with different arrangement of steel bracing system"IJERA, Vol.4,July 2014
[10] Badoux M, Jirsa O. Steel bracing of RC frames for seismic retrofitting, Journal of Structural Engineering Engineering Vol-(ASCE), 116(1990) 55-74.
[11] Bush TD, Jones EA, Jirsa JO. Behaviour of RC frame strengthened using structural steel bracing, Journal of Structural Engineering (ASCE), 117(1991),1115-26
[12] Rishi Mishra, Dr. Abhay Sharma, Dr. Vivek Grag, “Analysis of RC building frames for seismic forces using different types of bracing systems", IJERT Journal vol-3,july-2014
[13] M. Altug Erberik, Amr S. Elnashai, “Fragility analysis of flat-slab structure", engineering Structural 26(2004), No.937-948
[14] M.Majd, M.Hosseini, A.Moein Amini, “Developing fragility curves for steel building with X-bracing by nonlinear time history analyses ", 15 WCEE lisboa 2012
[15] Pierluigi Olmati, Francesco Petrini Konstantinos Gkoumas, "Fragility analysis for the performance -based design of cladding wall panels subjected to blast load", Engineering structures 78(2014)112-120
[16] Adil Emre Ozel, Esra Mete Guneyisi, "Effects of eccentric steel bracing systems on seismic fragility curves of mid-rise R/C building: A case study", Structure Safety, 33, (2011)82-95
[17] Murat Serdar kircil, Zekeriya Poiat “Fragility analysis of mid-rise R/C frame buildings", Engineering structure 28(2006)1335-1345
[18] Jong-su jeon, Laura N.Lowes, Reginald Desroches, Ioannis Brilakis "fragility curves for non-ductile reinforced concrete frames that the exahibit different component response mechanisms", Engineering structure 28(2006)1335-1345
[19] Huseyin Bilgin “A Case Studyagility-based assessment of public building in turkey” Engineering structure 56(2013)1283-1294
[20] Masanobu Shinozuka, Honorary Member, M.Q> Fenq, Associate Member, ASCE,jongheon Lee, Toshihiko Naganuma, “Statistical analysis of fragility curves"j. eng. mech126 (2000) pg 1124-1231
[21] Yue Li, M.ASCE, Ruiqiang Song, S>M>ASCE< and W>Van DE Lindt, M.ASCE "Collapse fragility of steel structure subject to earthquake mainshock-aftershock sequences", j.struct. eng. 2014.140
[22] Jian Zhang, Tadeh Zirakian, "Probabilistic assessment of structures with SPSW systems and LYP steel infill plantes using fragility function method", " Engineering structure 85(2015)195-205
[23] S.D Fotopoulou, K.D.pitilakis, "Fragility curves for reinforced concrete building to seismically triggered slow- moving slides", soil dynamics and earthquake engineering, 48(2013) Pages-143-161
[24] David Lallemant, Ame Kiremidjian and Henry Burton, “Statical procedures for developing earthquake damage fragility curves", earthquake engng struct.dyn .(2015)
[25] Stefan Reese, Brendon A. Bradliey, Jochen Bind Jochen Bind, Grareme Smart, William Power, James Sturman, "empirical building fragilities from observrd damages in the 2009 south pacific tsunami”, earth-science 107(2011)156-173
[26] Marco Vona, “Fragility curves of existing Rc building based on specific structural performance levels”. open journal of civil engineering,2014,4,120-134
[27] Badoux M, Jirsa O. Steel bracing of RC frames for seismic retrofitting, Journal of Structural Engineering (ASCE), 116(1990) 55–7



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