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Review on Seismic Design of Steel Structure

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Abstract— **Seismic design codes recommended the Force-Based Design method for the design of steel buildings. During intense seismic events, the FBD method employed capacity design principles to confine inelastic behavior primarily within beams in Steel Special Moment Resisting Frames, braces in Special Concentrically Braced Frames, and links in Eccentrically Braced Frames. Therefore, in line with the strength hierarchy required in capacity design, seismic design codes recommended guidelines/procedures for the design of capacity-protected components in SMRFs, SCBF and in EBF. This review paper synthesized findings from a comprehensive analysis of seismic design considerations for steel buildings and their components. Drawing upon multiple studies, it examined seismic performance evaluations of buildings in earthquake-prone regions, comparing design provisions of different codes. Ductility and capacity design approaches arises as a vital angles for steel structures, highlighting differences in design philosophies among seismic design codes. Various type of structural systems and key factors such as column-to-beam strength ratio and panel zone design variations were scrutinized for their influence on seismic behavior and structural performance subjected to earthquake forces.**

Keywords— Column to beam strength ratio, Panel zone, Special Moment Resisting Frames, Special concentrically braced frames, Eccentrically braced frame.

I. INTRODUCTION

The seismic resilience of buildings is crucial in regions prone to earthquakes, requiring careful design techniques as described in seismic design codes. These codes prioritize the establishment of specific structural mechanisms, such as the beam-sway mechanism, to increase energy dissipation and lateral displacement capacity. Optimizing link behaviour, ensuring ductility, and enhancing overall seismic performance. Recommendations for designing capacity-protected elements, like Panel zone and columns are provided, alongside procedures for estimating demands and capacities. International design specifications, such as AISC, Euro-codes, British and Indian, offer comprehensive guidelines, reflecting advancements in engineering knowledge and past earthquake experiences [1]. The seismic energy dissipation capacity of SMRFs is heavily dependent on the flexural yielding of the beam ends and to a lesser on the yielding of the columns and the panel zones [11]. SCBFs emerge as effective seismic load-resisting systems, leveraging truss action to minimize damage during moderate seismic events [9]. The design of EBFs integrates features of moment resisting and concentrically braced frames, aiming for high elastic stiffness and controlled plastic deformations during earthquakes [5]. The study explores into various design approaches, including SCWB frames, proposing multi-objective seismic design methods to achieve desired mechanisms while optimizing structural weight and member strengths [3][7][8]. Additionally, scrutiny of seismic design codes, behaviour factor provisions considers factors like reserve strength, redundancy, and ductility [4]. Finally, a comparative analysis of seismic design provisions among major country codes underscores the importance of understanding diverse code requirements for effective earthquake analysis and design.

II. LITERATURE REVIEW

Employing a variety of computer programs, including numerous studies undertaken significant amounts of research on the behaviour of steel structures and their individual components such as.

1. Anupoju Rajeev, Naveen Kumar Meena and Kumar Pallav [1]

The study investigated the seismic performance evaluation of buildings in seismic-prone areas in India, focusing on the design provisions of Indian, British, and European codes for multi-storey rigid joint space frame buildings. The study compared the seismic performance of buildings designed for the Indian code provisions for both cases, revealing significant differences in design parameters and safety factors among the codes. The results showed that the Indian code was a safer design methodology with higher reserve strength and a reasonably good displacement capacity before

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reaching the Collapse Prevention performance limit. The study also found that the European code tended to have a more conservative design approach compared to the Indian and British codes. Overall, the study offered valuable insights into the seismic design provisions of these codes, highlighting differences in design philosophies and safety considerations.

2. Chia-Ming Uang and Michel Bruneau [2]

The research provides an extensive review of seismic design requirements for steel structures, highlighting their evolution and the crucial role of ductility and capacity design. It explores past seismic events, innovative systems, and unresolved design issues, high lighting the need for further research to boost seismic performance. The study also compares seismic design approaches globally, drawing lessons from events like the 1994 Northridge earthquake and the rebuilding of Christchurch, New Zealand. The document identifies inconsistencies in current design practices and calls for research to address these unresolved issues, promote innovation, and unify design standards across seismic force-resisting systems.

3. Nattapat Wongpakdee1 and Sutat Leelataviwat, Ph.D [3]

The paper investigated the influence of column strength and stiffness on the inelastic behaviour of strong-column-weak-beam (SCWB) frames. A parametric approach was employed to analyse the response of SCWB frames with different distributions of beam and column plastic strengths. The study revealed that the relative plastic flexural strengths of the beams and column bases significantly affected the response of SCWB frames, especially in the inelastic range of deformation. The work ratio was identified as a crucial parameter for achieving desirable SCWB behaviour. The study concluded that relying only on column-to-beam strength requirements might not be sufficient to ensure desirable SCWB behaviour. It emphasized the need for an additional global parameter, such as the work ratio, in seismic design. Studies recommended optimal ranges between approximately 0.20 and 0.25 for uniform inter-story drifts and desirable SCWB behaviour, respectively.

4. Djamal Yahmi ,Taïeb Branci ,Abdelhamid Bouchaïr and Eric Fournely [4]

Nonlinear static pushover analysis was used to evaluate behaviour factors (BF) of steel moment-resisting frames in this study. Additionally, it is discovered that existing seismic design codes like EC8 do not accurately define failure modes and ultimate limit states for BF values. SAP2000 software was used to model SMRFs of different stories and bays to examine the influence of structural performance limits, capacity factors, and other parameters on BF. Moreover, key parameters responsible for qualification of BF were revealed through the findings. Finally, there are many implications that are relevant to the design and construction of steel structures with respect to this study, these include: identification of behaviour factors for effective seismic design; adjustments in design practices; better understanding of structural behaviour and recommendations for designing criteria amongst others. Therefore, accurate evaluation and consideration of behaviour factors is critical in ensuring earthquake resilience and safety.

5. Sina Kazemzadeh Azad, Cem Topkaya [5]

This paper presents a comprehensive review of steel EBFs, focusing on their performance in the seismic region, design considerations and optimization techniques. The capacity design approach for EBFs focused on optimizing link behaviour, ensuring ductility, and enhancing seismic performance. The design concentrated on link segment yielding, it also gave priority to link size design based on anticipated demands and capacities as well as designed other structural members to resist loads generated by yielded links. The stiffness of EBF systems could be adjusted by altering link lengths, balancing stiffness, strength,and ductility. Design methods, including plastic and allowable stress design approaches were utilized. Elastic Analysis is used to ensure that the structure meets performance criteria under elastic and inelastic conditions. The general conclusion emphasizes significant points from research on EBFs, energy dissipation roles, seismic performance, design implications and future research needs.

6. Mehmet Tuna, Cem Topkaya [6]

The study examines panel zone design variations for AISC360, Euro-code 3 and FEMA-355D. The research uses numerical analysis to quantify the deformation demands of a panel zone under factors as beam depth, axial load, panel zone thickness, and seismic hazard. This is because AISC360 and Euro code 3 designs have much higher level of panel zone yielding while FEMA-355D has less so. In addition to that, the research highlights how deformation demand varies with changing variables such as beam depth, axial load, panel zone thicknesses and seismic hazards. This information can be utilized by engineers to optimize their panel zones design with an aim of attaining better ductility and energy dissipation in steel moment resisting frames that are designed according to different specifications.

7. Arash E. Zaghi, Siavash Soroushian, Ahmad Itani, E. Manos Maragakis Gokhan Pekcan Masoud and Mehrraouf [7]

CBSR was the major focus of the seismic behaviour study of steel moment resisting frames (MRFs). The study evaluated 3-, 9-, and 20-story structures through which CBSRs were analyzed. Member ductility demands, inter-story drifts, and floor acceleration amplifications were assessed. It was noted that frames with large CBSRs experienced column yielding due to higher vibration modes, even when CBSRs exceeded 2.0. CBSR values significantly influenced column and beam yielding, with larger CBSRs reducing column yielding without compromising seismic

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performance. Inter-story drifts for instance were found to be CBSR-sensitive hence smaller drifts in lower stories & larger drifts in upper stories. Surprisingly, floor acceleration amplification remained independent of CBSR, suggesting that larger strength factors mitigated the risk of exceeding an amplification of 1.0.The paper advised increasing the value of CBSR while maintaining column stiffness as this would help restrict column yielding. Additionally, it suggested the strategic use of weaker beams or stronger columns at higher levels to prevent column yielding.

8. Se Woon Choi, Yousok Kim, Jaehong Lee, Kappyo Hong, Hyo Seon Park [8]

This paper propose a method for multi-dimensional seismic design using nonlinear static analysis that will be used to determine CBSR in SMRFs. The design approach, which is aimed at minimizing two objective functions such as: structural weight and column-to-beam strength ratio while satisfying constraints. This study uses two moment resisting example structures to identify a common tendency between optimal strength ratios and structural weights The strength ratios of the 3-story and 9-story examples are found to be in the range of 1.01–1.86 and 1.01–1.92, respectively, which are greater than the value of 1.0 suggested in ANSI/AISC 341-05. . The study also found that the optimal strength ratios for joints at external columns decreased considerably as the structural weights increased, whereas the variation of strength ratios for joints at the internal columns was not considerable. The paper recommends that strength ratios be determined with the consideration of locations (internal and external) of the joints for a more economical design.

9. Eric J. Lumpkin, Po-Chien Hsiao, Charles W. Roeder , Dawn E. Lehman b, Ching-Yi Tsai, An-Chien Wu, Chih-Yu Wei, Keh-Chyuan Tsai [9]

This study seeks to assess the seismic behaviour of special concentrically braced frames (SCBF) through experimental testing and analytical research. It provided an overview of SCBF systems, with emphasis their stiffness, strength and cost-effectiveness in resisting lateral loads especially seismic forces. The research used two three story SCBF specimens with different brace configurations to conduct experiments that would evaluate a new design approach for mid span gusset plate connections and also develop advanced design recommendations. Wide flange braces and HSS braces have different buckling deformations and connection damage mechanisms as observed from the tests carried out, the behaviour of wide flange braces is however more prone to buckling deformations than that of HSS braces, which had more connection damages. The analytical model verified the experimental results while providing insights about local behaviours such as brace deformations or even gusset plate damage. To improve the ductility of SCBF systems and prevent undesirable failure modes balanced design equations were introduced in this investigation.

10. J. M. Castro F. J. Dávila-Arbona & A. Y. Elghazouli [10]

This study looked into different approaches in the design of panel zones in steel moment frames. It focused on enhancing seismic resilience Again, a significant paradigm shift was identified that emphasized the injection of energy dissipation considerations mainly affecting lateral stiffness as well as overall frame strength. The document compared Euro-code 3, FEMA 350 and AISC 341-05 approaches to highlight their weaknesses and strengths over the years. The most important thing considered was to adopt a balanced design approach managing inelastic behaviour and rotational demand within these panel areas with care. These key factors included: panel zone strength, energy dissipation, a balanced design approach, inelastic response, avoidance of excessive distortional demands etc. All these issues aimed at making optimum designs for panel zones so as to make the seismic performance of steel moment frames better than ever before.

11. Ricardo A. Medina, and Helmut Krawinkler [11]

This paper carries out an in-depth analysis of the demands on column strength in seismic conditions for moment-resisting frames. The study classifies these demands into those that are global, such as story shear forces and overturning moments, and those that are local like column moments, emphasizing that axial forces play a central role in columns. These factors greatly affect moment capacity, shear capacity, ductility, and overall stability during strong earthquakes. The study shows that evaluating shear requirements is difficult due to differences between dynamic and static load patterns particularly at the top levels of buildings. Using predefined stress distributions like the parabolic variation may result to possible under estimation which highlights some short comings of higher mode effects capture as well as dynamic redistribution. In this regard, it may be necessary to adjust for amplification values when designing columns for both steel and reinforced concrete structures based on pushover analyses so as to ensure safety against collapse caused by lateral loads. They concluded that increasing reinforcement percentage in columns increases the performance which results in decrease in roof displacement, this also increases the base shear. By changing reinforcement percentage in beams of 1st story, a major affect was seen in base shear.

III. FINDINGS OF PAPER

The collective findings from the papers underline the complexity and importance of seismic design considerations in various structural systems.

1. Study illustrate significant variation in the design philosophies and safety considerations of various seismic design codes, compared with the Indian code often displaying better displacement capacity and reserve strength.
2. Study illustrate significant variation in the design philosophies and safety considerations of various

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seismic design codes, compared with the Indian code often displaying better displacement capacity and reserve strength.

3. Study illustrate significant variation in the design philosophies and safety considerations of various seismic design codes, compared with the Indian code often displaying better displacement capacity and reserve strength.

Overall, the findings highlight the necessity of balanced design approaches, careful management of inelastic behaviour, and consideration of local behaviours to improve seismic resilience and safety in structural systems subjected to earthquake forces.

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