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ANALYSIS OF MULTISTOREY STEEL SETBACK BUILDING WITH STEEL PLATE SHEAR WALLS AND BRACINGS: A REVIEW

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ABSTRACT

This review paper explores the critical aspects of designing multistorey steel setback buildings with steel plate shear walls and bracings, focusing on their seismic performance. The investigation emphasizes the importance of effective lateral load-resisting systems to enhance the seismic resilience of steel frame buildings, reducing their vulnerability to collapse during earthquakes. Key studies highlight the necessity for specific design considerations for buildings with vertical and horizontal irregularities, as these irregularities significantly impact structural stability. The review also underscores the effectiveness of nonlinear dynamic analysis in predicting the dynamic response of irregular structures under severe seismic loads. Advanced seismic design approaches, incorporating both static and dynamic finite element methods, are discussed for their ability to address geometrical and material nonlinearities and ensure compliance with modern standards, such as Eurocode 8.

Keywords: multi-storey steel setback buildings, steel plate shear walls, bracings, seismic performance, lateral load-resisting systems

1. INTRODUCTION

1. General

For the past few decades global attention and interest has grown in the application of Steel Plate Shear Walls (SPSW) for building lateral load resisting systems. Advantages of using SPSWs in a building is lateral force resisting system compromise stable hysteretic characteristics, high plastic energy absorption capacity and enhanced stiffness, strength and ductility [1]. A significant number of experimental and analytical studies have been carried out to establish analysis and design methods for such lateral resisting systems; however, there is still a need for a general analysis and design methodology. As compared to the Reinforced cement concrete (RCC) the steel has got some important physical properties like the high strength per unit weight and ductility [2].

The high yield and ultimate strength result in slender sections. Being ductile the steel structures give sufficient advance warning before failure by way of excessive deformations. These properties of steel are of very much vital in case of the seismic resistant design [3]. Steel shear wall is a lateral load resisting system consisting of vertical steel plate infills connected to the surrounding beams and columns and installed in one or more bays along the full height of the structure to form a cantilever wall. Shear walls are vertical elements of the horizontal force resisting system. The main role of steel shear wall is to collect lateral forces of earthquake in a building and transfer those forces to the foundation. The web plates in steel shear walls are categorized according to their ability to resist buckling [4].

1.2 Purpose of erecting steel plate shear walls.

Shear wall systems are one of the most commonly used lateral load resisting in high rise building. Shear wall has high in plane stiffness and strength which can be used to simultaneously resist large horizontal loads and support gravity loads. Shear walls designed for resisting lateral loads of earthquakes and wind. Steel plate shear wall system has emerged as an efficient alternative to other lateral load resisting systems, such as reinforced concrete shear walls, various types of braced frames, etc [5]. SPSWs are preferred because of the various advantages they have over other systems, primarily, substantial ductility, and high initial stiffness, fast pace of construction, light weight, provides more space inside due to minimum thickness which is another advantage for architect and the reduction in seismic mass [6].

1.3 Modeling of steel plate shear walls

This is the most popular way of modeling thin, non-compact shear walls. It is purely based on the diagonal tension field action developed immediately after the buckling of the plate [7]. This type of modeling is recommended by the code of Canada, the CAN/CSA-S16-01 in the analysis and design procedure of the SPSWs. In the analysis software the steel plate in the wall panel is to be replaced by a series of truss members (struts) or the strips along the tension field. There are two ways of modeling by this method [8].

Generally, seismic upgrade and retrofit of such buildings to meet requirements of modern codes always pose a rather great effort to structural engineers. To help the owners clearly understand all retrofitting processes, it is very important for the engineers to know what are the seismic capacity and deficiencies of the existing RC-MRFs [11].

In order to evaluate their capacity and the deficiencies, it is necessary to assess their seismic performances. The criteria, usually used to represent the overall seismic performances of a building or building's components, have been defined in some codes or reference documents (i.e. EC8-3, FEMA 356 (2000)), depending on many aspects as seismic zones, types of the structures, seismic performances of the individual members, methods to evaluate, etc [12].

In addition, many other tasks are needed to be done such as collecting the data on site, testing the material properties, determining the strategies and retrofit processes for the structures. In those, selecting the retrofitting system might be the biggest concern for engineers due to its important effects on the success of the project. The retrofitting system means the direct intervention techniques on the structure. It may cause significant changes of the behaviour of structures in stiffness, strength, ductility or foundation system [13].

Aiming at giving general points of how to seismically retrofit RC-MRFs, this chapter first resents the main steps of retrofitting or upgrading the RC-MRFs, including criteria of seismic performances, seismic characteristics and analytical tools to assess the existing buildings. Retrofit strategies are then introduced with the main focuses on the technical solutions. Most of recent advanced retrofitting systems are then introduced to generalize the existing methods to retrofit and/or upgrade the RC-MRFs [14].

2. LITERATURE REVIEW

Ajamy, A., *et al* [1] investigated that constructional steel and composites materials have been widely used for structural applications and construction. The steel frames were employed frequently to construct the high-rise buildings to which major attention should be paid to resist against applied external loads. Earthquake is the most significant natural disaster making the steel frames vulnerable to failure. There has been a large number of records in the literature reporting the extensive structural damages and destruction due to high demand earthquakes. It has been documented that when buildings located in a region subject to seismic loads, some buildings collapse while some resist and remain undamaged which showed that they utilized a system providing them with a better seismic performance to stay resistant.

Anoj Surwase, *et al* [2] studied that it has been always a real need of constructing a structure resistant against seismic loads generated from earthquakes to increase safety and decrease the maintenance costs. Therefore, many attentions have been attracted to investigate the effects of various important parameters such as architectural design, structural materials and soil conditions on the seismic resistance of a building.

Ashvin G. Soni, *et al* [3] investigated that in recent decades, construction of the seismic-resistant steel frame buildings retrofitted with the proper lateral load-resisting systems providing ductile and elastic behavior under moderate earthquakes, despite being costly and uneconomic, was a great of interest. One of the major concerns that should be paid attention is the vertical irregularities of a building which is appealed in a structure in the form of varying column height in any floor resulting in the stiffness irregularity. Structures with irregular horizontal and vertical layouts are more vulnerable to collapse than regular structures.

Bhosle Ashwini Tanaji *et al* [4] investigated that besides, many public, commercial and institutional buildings have been designed with various irregularities in structural layout because of architectural and aesthetic requirements. Design of buildings with stiffness irregularities requires specific design considerations in comparison with that of regular buildings because of the various seismic demands. The structural elements can resist against a specific amount of plastic hinge rotation beyond which it may experience failure. In order to evaluate the structural behavior of a building subject to seismic loads, the linear static, nonlinear static (pushover), linear dynamic and nonlinear dynamic analyses can be employed.

Dr. S. A. Halkude *et al* [5] studied that it has been documented that the most accurate predictions of dynamic responses of irregular structures subject to severe dynamic loads can be obtained by the nonlinear dynamic analysis through which the plastic hinge development evaluated at the ends of the structural elements.

H. Gaur, *et al* [6] presented a method to investigate the seismic behavior of the multi-story setback building subject to strong ground motions at the preliminary stage of practical design. The accuracy of the method was evaluated by considering asymmetric tall buildings with a mass or stiffness irregularity. Dynamic responses of elastic multi- story building systems were obtained by analyzing simple (equivalent) single-story system. The behavior of the building was also investigated in the post elastic phase considering the stiffness-dependent strength of the various bents and discontinuities.

Hemal J shah *et al* [7] presented a seismic design approach for irregular space steel frames with respect to Eurocodes 8 and 3. The approach used an advanced static and dynamic finite element method considering geometrical and material nonlinearities as well as member and frame imperfections. The pushover analysis was performed by distributing the multimodal load along with the height of the building combining the first few modes. The nonlinear dynamic analysis was carried out, in the time domain, using accelerograms obtained from real earthquakes such that to be compatible with the elastic design spectrum of Eurocode 8.

Panigrahi *et al.* (2019) have made an experimental investigation on a realistic structure to study the effect of construction sequence. Building with three different height was considered to study the effect of beam and column with different structural parameters. The results obtained from the analysis showed that the construction sequence analysis was higher than conventional analysis in terms of shear force and bending moment. Hence, CSA method has to be adopted while analysing the structure to avoid failure of structural members.

K.S.L Nikhila *et al* [13] investigated that the abilities and efficiency of the proposed method were evaluated through two example problems; a seven- storey geometrically regular frame with in-plan eccentricities, and a six-storey frame with a setback.

Kannan R. *et al* [14] investigated the dynamic behavior of base-isolated multi-storey structures having high irregularity in the plan. In this regard, two types of dynamic analyses were adopted: a dynamic analysis with response spectrum and nonlinear dynamic analysis. The results were presented in the form of deformation, inter-story drift as different levels, and stresses with the focus on bending moment, and shear in the columns and beams and axial force.in columns.

Kiran Y. Naxane *et al.* [15] have carried out the work in G+4 multi-storey residential building for regular and irregular building as per IS 1893-2002 and IS 1893-2016 seismic load recommendations in zone III & IV. The scope behind the work was to learn how relevant Indian Standard codes are used for design of various building elements in Etabs. Both lateral loads are considered to act in the structure. For regular and irregular building, the analysis carried was equivalent static method. The results such as bending moment, shear force and storey displacement were compared. It has been concluded that the results obtained by IS 1893-2016 codal provision was found to be more when compared to IS 1893-2002 because of new revision on IS code.

3. CONCLUSIONS

The studies collectively emphasize the critical importance of designing steel frame buildings that can withstand seismic loads to ensure structural integrity and safety. Key conclusions include the necessity for effective lateral load-resisting systems to enhance seismic performance and reduce vulnerability to collapse. The impact of vertical and horizontal irregularities on building stability highlights the need for specific design considerations. Nonlinear dynamic analysis is identified as the most accurate method for predicting the dynamic response of irregular structures under severe loads. Furthermore, advanced seismic design approaches, incorporating both static and dynamic finite element methods, are essential for addressing geometrical and material nonlinearities and ensuring compliance with modern standards such as Eurocode 8. Overall, a multi-faceted approach involving architectural design, material selection, and comprehensive analysis techniques is crucial for the development of earthquake-resistant structures.

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