ENHANCEMENT OF SEISMIC PERFORMANCE FOR REINFORCED CONCRETE STRUCTURES

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ABSTRACT

In many places around the world, Reinforced Concrete (RC) structures are designed using codes that are now not providing adequate safety under seismic action. Such gravity load-designed RC buildings generally fail to provide the required seismic demand and suffer extensive damage leading to a partial or complete collapse of the buildings as observed in several past earthquakes around the world. Providing life safety is the first priority in the earthquake resistant design. Due to the rise of performance-based design, the researchers have started to focus on decreasing the damage in the building and minimizing the costs for repairing and replacement in the mild seismic events. The structural and non- structural components of a building is subjected to seismic forces that must have adequate strength and stiffness to minimize the inter-storey drift during structural excitations. In the present study, lateral resisting system, i.e. the Link Column Frame (LCF) system, for the reinforced concrete structures was investigated. This system consists of link beams which are intended to yield in shear placed between closely spaced dual columns and an adjacent flexible moment resisting frame in which the beam is restrained at one end and hinged at another end. A seismic strengthening technique using a concrete link beam as an energy-dissipating device is proposed to enhance the lateral strength, the lateral stiffness, and the energy-dissipation potential of a deficient RC frame. The links act as a structural fuse which sacrifices itself by yielding to provide ductility, energy dissipation, and nonlinear softening behaviour while limiting the relative damage and inelastic behaviour of the structural members of the nearby moment frame.

Keyword:*Earthquake,Link coloumn Frame,Concrete beam*

1. INTRODUCTION

Earthquakes in populated regions throughout the world create extensive damage to the built environment that results in catastrophic loss of human life and enormous economic losses. The largest earthquake recorded in the world had a Richter scale of 9 in Japan in the year of 2011. The destructiveness of an earthquake, however, not only depends on its intensity but a number of factors such as focal depth, epicenter distance, duration, local geology, soil structure interaction and the structural characteristics of the building including the energy absorption capacity of the structures. Based on the concept of saving human lives, in conventional seismic design, acceptable performance of a structure during earthquake ground shaking is linked to the lateral force resisting system being able to absorb and dissipate vibrational energy due to ground motions in a stable manner for a large number of cycles of motions. In specially detailed plastic hinge regions of columns and beams the energy dissipation generally occurs, which also form part of the gravity load carrying system. Regardless, because of economic considerations provided this design approach is acceptable and also it provides life safety and structural collapse is prevented during the low prospect design earthquake event.

1.1 PERFORMANCE OF RC BUILDINGS

Several past earthquakes around India demonstrated very poor performance of RC buildings. In most cases, these buildings have suffered severe damage in the columns of ground-storey. For example, earthquake measured Ms 8.1 occurred near the Nepal Pokhara (Gorkha earthquake 2015). RC frame structure is one of the housing structures which are widely recognized and built by all sectors of the Nepalese people. the ideas of aseismic design has not been considered and the normative construction methods have not been used in self-built reinforced concrete frame structure. Reinforced concrete frame structure suffered destruction in different degrees in the earthquake and strong aftershock (Varum et al., 2018). In the 2001 Bhuj earthquake, most of 150 buildings that collapsed or suffered severe damage were RC buildings without seismic resistant configurations (Jain et al., 2002). Virtually all the earthquake induced are concentrated in the columns of the building displace like a rigid body. In addition, majority of past earthquakes, such as, the 2006 Sikkim earthquake (Kaushik et al., 2007), showed rather poor performance of such building frames. Figure 1.2 shows the typical failure of the RC building in past Indian earthquakes.

Figure 1.1 Typical failure of RC buildings in past earthquakes

1.2 OVERVIEW OF THE PROPOSED SYSTEM

Dusicka introduced a new lateral load resisting system called Link Column Frame system (LCF) for steel structures. The LCF system incorporates aspects of conventional systems such as Moment Resisting Frames (MRFs) and EBFs, which has the advantages of brace-free steel frame construction which address the rapid return to occupancy design performance. In the LCF system, the non-moment transferring connections were introduced at all columns to foundation locations and in strategic beam to column locations (Dusicka and Iwai, 2007) during the initial development of the system. These idealized pin connections at the base of each column will minimize damage to the columns by yielding at the foundation that is typical in ductile moment frame designs. The lateral stiffness was also reduced because of the pinned connections in the gravity moment frame. In the LCF system link beam will act similarly to links in eccentrically braced frames, i.e. they can yield in flexure or shear depending on their link length. Under lateral loading caused by an earthquake, the displacement of the dual columns engages the links which are designed to yield in shear to control drift, dissipate energy and limit the forces which are transferred to the nearby structural members.This LCF system make use of replaceable link beams that act as yielding energy dissipaters and then provide initial stiffness to prevent damage to the structural members of the adjacent moment resisting frame and to provide nonlinear ductility, energy dissipation, and softening behavior while limiting the inelastic deformation..

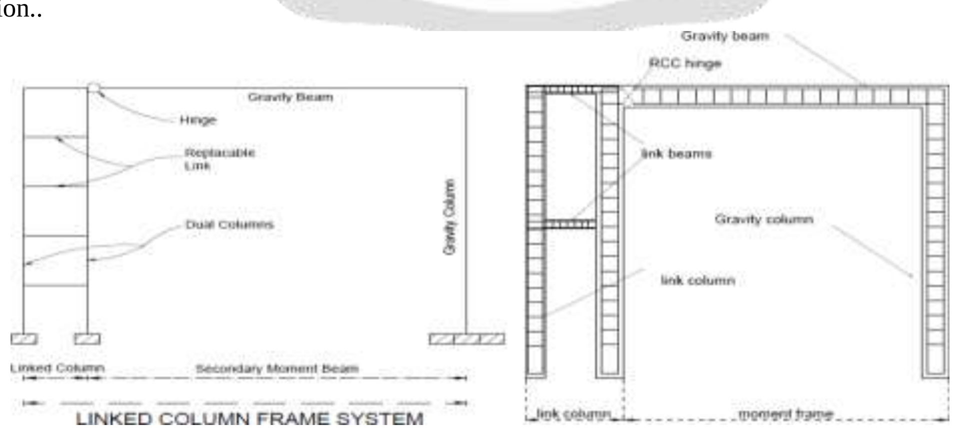

Figure 1.2 RC buildings

2. LITERATURE REVIEW

Youssefa et al. (2018) have shown that by using the appropriate forms of direct internal bracing, it is possible to increase the lateral resistance of the concrete frame to the desired level while maintaining or enhancing the ductility of the brace/frame system. However, the seismic performance of steel bracing system depends on successful design of the connections between steel brace and RC frame elements.

Nader et al. (2014) designed the new San Francisco Oakland Bay Bridge (SFOBB) and one of their approaches to have a clearly defined plastic mechanism for response to lateral loads was to provide replaceable shear links between the tower shafts which would yield in the event of a major earthquake with a clear failure sequence.

Lewis (2010) studied replaceable link connections with the intent of limiting plastic strain at the link-to-end plate connection and thereby minimizing 15 undesirable failure modes. Recently, designers started to utilize built-up sections in large span bridges to be used as shear links. Built-up sections have advantages over rolled shapes because they offer the flexibility of being proportioned to any desired geometrical dimensions. Thus, the designer can most of the design equations were limited to relatively shallow beams with compact webs. Usually, built-up sections have relatively thin webs and deep sections. Therefore, there is a need to investigate the behaviour of built-up shear links under large deformations.

Okazaki et al. (2014) performed an experimental and analytical investigation of the seismic performance of various types of link-to-column connections for eccentrically braced frames. The main objectives of this research were the following; to evaluate the performance of link- to-column connections used prior to the Northridge earthquake, to test moment resisting frame connections developed after the Northridge earthquake as link-to-column connections, to investigate the stress and strain environment at link-to-column connections, to check whether it is possible to predict the performance of these connections with finite element simulations and to provide recommended design guidelines for EBF link-to-column connections.

(Chopra, 2007). Over the past two decades, considerable effort has been directed toward the development of passive energy dissipation systems in order to enhance the seismic performance of civil engineering structures. These systems may consist of energy dissipating braces or a combination of ordinary braces and energy dissipation devices. A building structure equipped with energy dissipation devices and bracing. Such a building composed of two independent structural system: the ‘main frame’ and the ‘lateral load resisting system’ (consisting of bracing and dissipater assembly).

(Cardone et al., 2004). This results in a heavy, large size, and expensive brace system, which must be accommodated with in the original structure. Proportioned after fulfilling the stiffness requirements, steel-based braces are very effective in limiting the inter-storey drift, and thus the structural damage, even under earthquakes much stronger than the design earthquake.

Banarjee (2005) suggested that the inelastic shear buckling of web plates of aluminium shear panels could be delayed to some extent by using rubber pad son both sides of it. This problem of inelastic buckling canal so be avoided by reducing the spacing between the transverse stiffeners. As web depth-to-thickness ratio is decreased, the tendency of buckling of the panel is significantly delayed to larger strain level seven until the tearing of web plate.

Jain et al. (2018) proposed a criterion to predict the post-yield cyclic shear buckling strength of aluminium shear panels. Moreover, rolled or extruded shape with a fillet between the web and flange are more resistant to the tearing of web, thus enabling the panels to undergo larger strain levels developed an analytical model to design of aluminium shear panels as energy dissipation devices for structural system and verified the proposed model for an example steel building under a set of selected recorded ground motions. Recently, verified the effectiveness of aluminium shear panels on a reduced scale two-storey braced frame under shake table testing.

3. DESIGN OF FRAME SYSTEM

The choice of a suitable technique depends on many factors, such as, building configuration, effectiveness of technique in enhancing the desired properties, total cost required for strengthening, accessibility of the building during strengthening process, reduction in usable floor area, etc. Therefore, these structures are expected to achieve lateral ductility when subjected to earthquake loading through yielding beams or columns, and the connections must be capable of remaining intact through several cycles of inelastic rotation. The LCF system is a new lateral load resisting system being developed with the goals of rapid return to occupancy via yielding of sacrificial components..

3.1 CANTILEVER COLUMN

The knowledge of the ultimate structural behavior of the structure is essential in order to achieve more predictable structural performance under lateral seismic forces. Therefore, design factors such as drift for given hazard levels should become part of the design process from the beginning. The important factors affecting the behavior of LCF buildings using the cantilever column are allowable storey drift, modulus of elasticity, the lateral seismic force given by the equivalent lateral force procedure and storey height

3.2 EVALUATION OF FRAME SYSTEM

Overall seismic performance evaluation of a deficient structure must be conducted based on its as-built information, such as structural type, details and orientation, material strength etc., prior to its strengthening. Generally, four different procedures, such as the linear static, the linear dynamic, the nonlinear static (pushover analysis), and the nonlinear dynamic procedure are available for seismic evaluation of the existing structures (FEMA 356,2000). The results of these analyses provide critical information for selection of proper strengthening techniques (Bai and Hueste, 2003). Moreover, seismic performance of the structures strengthened using selected techniques should be evaluated to verify the effectiveness of the selected strengthening strategies. This chapter presents the seismic evaluation of a typical four-storey and seven-storey RC building by nonlinear static and time-history analyses using a computer package SAP 2000. The design of reinforcement in beam and column sections was carried out as per IS 456:2000 design provisions. As per IS 1893:2002 (part 1) seismic design has been carried out. A strengthening scheme i.e. LCF is adopted to enhance the performance of the normal frame considered in this study. The design of link and link column of the link column

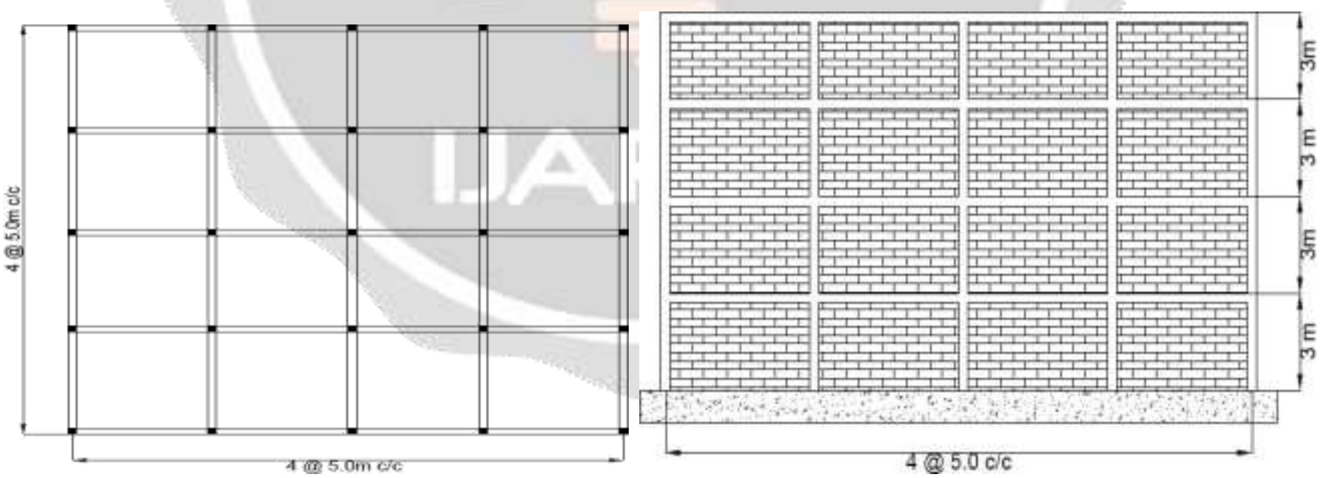

Figure 3.1 RC buildings

3. FINITE ELEMENT MODELING

The finite element software package ANSYS 15.0 WORKBENCH is used to create the models of the tested specimens of normal and the link column frame. Using these models, the load-deformation behavior and lateral stiffness of link column frame under cyclic loading are compared with the experimental results.

The specimen's dimensions and the reinforcement detailing of the proposed analytical model was described in Chapter 6, the same cyclic loading history applied in the experimental program for the specimens was applied in the analytical investigation. In this chapter, a detailed description of the proposed models is provided, and the accuracy of these proposed models are verified by comparing to the results of the experimental programs.

3.1 FINITE ELEMENT MODELING

In the link column frame, three different connections were made to optimize the connection. The different types of connections are (i) rigid link column frame (i.e. the main beam is rigidly connected to the link column) (ii) Hinged link column (i.e. there is hinge connection between the main beam and link column by using dowel bars. (iii) Hinged link column (i.e. there is hinge connection between the main beam and link column by using Mesnager hinges as per IS 12303:1987. An analytical investigation is also carried out for the link column frame with additional link beam i.e. links were provided in both beam level and at the middle of the column height. The models of the specimens are detailed as per IS 456:2000.In order to validate the experimental test performance, the specimens were modeled and analyzed using ANSYS. The specimen's dimensions and the reinforcement detailing of the proposed

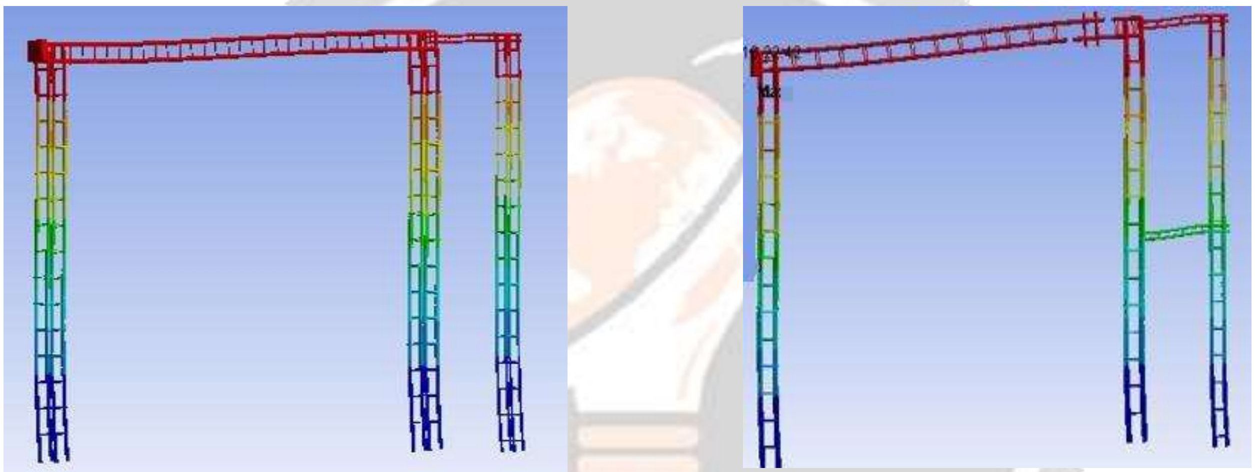

Figure 3.2 Reinforcement modelling

4. Stress Distribution

From the finite element analysis, for the hinged link column frame with an additional link (as per IS 12303:1987), the stress is found to be uniform throughout the main frame and the stress is more at the link region. After 11th cycle only, a rapid increase in stress in the main frame was observed i.e. after the yielding of link beam only the cracks begin to form in the main beam. Whereas, in the normal frame the stress is concentrated in the beam-column joints. During the 6th cycle itself, the maximum stress was observed in the normal frame.

The stress distribution pattern predicted by the finite element analysis shows maximum stress occurring at the link region in the link column frame and it is shown in red colour. From the comparison of stress distribution in all the specimens, the link column frame with hinge connection between the main beam and link column which was designed as per IS 12303:1987 shows better connection in terms of transferring stresses to the main RC frame. From the analysis of the frame under cyclic loads, it was found that by increasing the load, stress intensity is increased, and the maximum stress

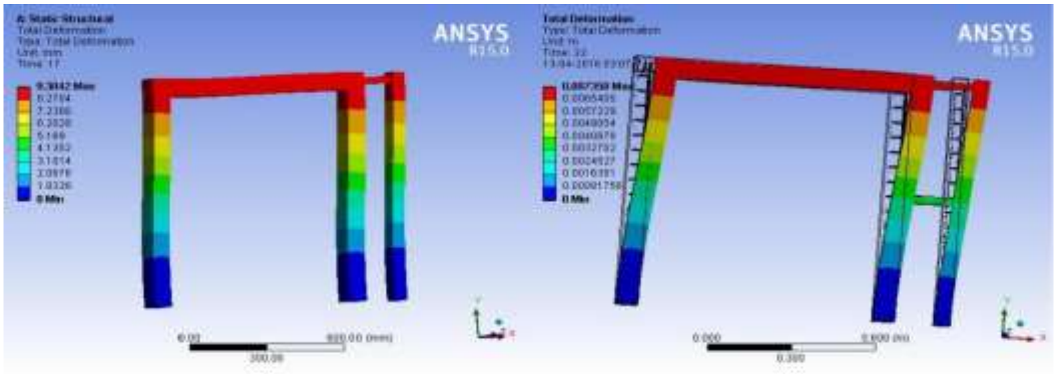

Figure 4.1 Stress Distribution

5. CONCLUSIONS

The link column frame remained elastic until rapid return to occupancy performance level was achieved, while links yielded and deformed plastically. Shear links are shown to be effective in protecting gravity system and participating well past 4% drift. From the formation of the hinges and the reduction in drift, it can be said that the link column frame effectively protects the gravity beams as well as the columns such that the structure could rapidly return to occupancy through link replacement.

Based on analysis results for the ground motions Imperial valley and Northridge seismic hazards, the design procedure was found to be broadly adequate. For the selected ground motions, the average contribution of shear links is effective for the link column frame. Providing link column system in the structure reduces base shear and top displacement. It was shown that under lateral earthquake loading, the links yield before the beams of the secondary moment frame. From the analytical investigations, the link column which is provided at the end shows the optimum position in the RC building. Apparently, additional link in the link column gives some additional stiffness to the entire system.

5. FUTURE SCOPE

In present work, concrete link beams were used in the linked column frames. Alternative materials like steel links may be used as link beams, which may be investigated for their effectiveness as energy dissipation.

The work is carried out on a reduced scale single-storey RC frame. A full-scale RC link column frame needs to be investigated experimentally under gradually increased cyclic lateral loads to further verify the effectiveness of proposed link column frame.

Further analysis of the simulated dynamic results is required for future work to evaluate the accelerations at floor levels for a link column frame building and compare these floor accelerations with the normal RC frames.

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