Performance of Linked Column System under Seismic forces for Concrete Structures

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ABSTRACT

Structures subjected to seismic forces must have adequate strength and stiffness to control inter storey drift in order to prevent damage to structural and nonstructural elements during excitations. Linked column concept for steel structures was proposed by Peter Dusicka et.al(2009) with the objective of utilizing replaceable components that are strategically placed to protect the gravity load carrying system. The non-braced lateral system relies on the inelastic behavior of bolted shear links. In this paper the concept is extended to concrete structures. The replaceable link beams are also designed as concrete structures connected to the columns through bolted joints. Non-linear pushover analysis was used to investigate the performance of a four-story building. The drift limits and base shear were studied. Results show that this system shows better load dissipation capabilities.

Keywords **–** linked column, push over analysis, Seismic resistance,

1. INTRODUCTION

The challenge faced by structural engineers from the past earthquake is to build structures which are less vulnerable to seismic forces and easier to repair after major earthquake. Researchers have successfully studied and implemented shear walls for reinforced concrete structures. The advantage of Steel braces over shear walls like, lesser member forces, floor displacements, and, consequently reinforcement was presented by V. Kapur and Ashok K. Jain(1983). Jain et.al (1985) presented their research on utilization of steel braces for concrete structures. Further many research work were presented on different types of bracing, material used for bracing, connection for bracing to the frame (3-7).The disadvantage of bracing system is that it occupies movement space and suffers from shortcomings when considering return to occupancy despite their ability to provide stiff and ductile response.

Later the concept of link beam in eccentrically braced frames relying on yielding of a link beam between braces was studied (8). Since the beams are continuous and located at floor levels, they form part of the gravity system. These ductile structural steel systems are well suited to provide the desired of ductility and energy dissipation under seismic loading for life safety without the need to design for elastic behavior. However, the loss of occupancy and the difficulty associated with economically repairing the gravity system following an earthquake can burden the owners and occupants. Peter Dusicka et.al(2009) proposed a lateral load resisting system, referred to as the linked column frame (LCF) system, incorporates aspects of conventional components, but combines them to achieve a system that can be designed for multiple performance objectives. In the LCF building system, selected columns are spaced in close proximity in specific areas and linked independently of the gravity system throughout the height. Under earthquake induced lateral loads, the relative deformations of the closely spaced columns engage the links which are designed to yield in shear to dissipate energy, control drift and limit the forces transferred to the surrounding structural members. The links are bolted to the columns to allow for controlled shop fabrication and more importantly for rapid replacement when severely damaged.

The concept of hybrid steel frame system was presented by Abolmaali. A et.al(2012) in which mixtures of fully-rigid and semi-rigid steel connections are used in the 9 and 20-story steel frames. Different patterns and locations of semi-rigid connection replacements within the frame were examined in order to identify the hybrid frames with most energy dissipation capabilities. Inelastic dynamic analyses are conducted on the proposed selected frames by subjecting them to the Los Angeles earthquake records characterized as those with 10% probabilities of exceedance in 50 years and 2% probabilities of exceedance in 50 years. The maximum story drift for the hybrid frames were determined and compared to the "life safety" and "collapse prevention" limits as recommended by the FEMA 356. The zig- zag model of semi-rigid connections reported a better result in terms of roof-displacement time history, story drift, and member forces.

The objective of this research effort is to develop a lateral load resisting system incorporating the concept of non- bracing system for reinforced concrete framed structure. The feasibility of implementing linked column system with fuse beams is presented. Pushover analyzing using SAP 2000 is used to study the behavior of the proposed structural system.

2. REPLACEABLE LINK BEAM SYSTEM

In the proposed system a secondary frame system is designed as a sacrificial beam column system to yield in the inelastic range whereas the main system is in the elastic range. The link beams are designed as reinforced concrete members to resist shear and are connected to columns through bolted connections to offer a hinge connection and transfer only shear.

3.ANALYTICAL INVESTIGATION

3.1Modelling Of Structure

The structure used for analysis is a reinforced concrete frame structure (S1). The details of the building (Figure 1) are given below:

Number of storey	: G+3
Bay length in x.direction	: 6m
Bay length in y.direction	: 6m
Bay length in z.direction	: 3.5m
Size of the beam	: 0.3 m x 0.4 m
Size of the column	: 0.5 m x 0.5 m
Depth of slab	: 0.15 m

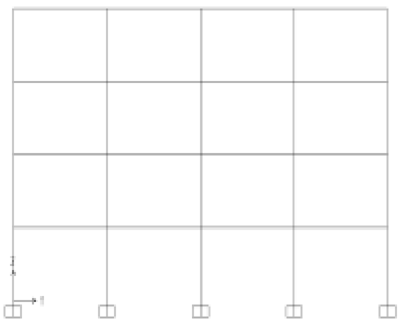

Fig 1: Model of the structure

To study the implementation of linked beam and column system, the links were placed in two different location, i.e., at the end bay (SL1) and the intermediate bay (SL2). The location of the link column was determined based on the point of contra flexure. The details of the link are given below:

Size of linked beam	: 0.2 m x 0.2 m
Size of linked column	: 0.4 m x 0.4 m
Spacing of linked columns in LCF	: 1.1 m

The models of the structure with link column are shown in fig 2 and fig 3.

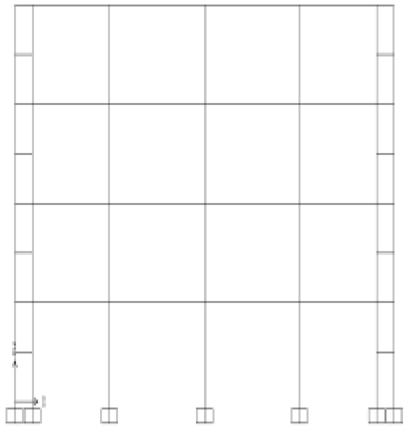

Fig 2: Model with link column at ends

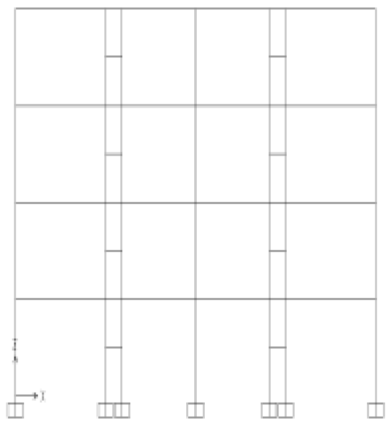

Fig 3 : Model with link column at intermediates

4. MATERIAL PROPERTIES

The basic material properties used are as follows:

Modulus of Elasticity of steel, Es= 21,0000 Mpa
Modulus of Elasticity of concrete, E_C = 22,360.68 MPa
Characteristic strength of concrete, f_{ck}= 25 MPa
Yield stress for steel, f_y = 415 MPa
Poisson's Ratio = 0.2
Co efficient of thermal expansion= 9.9 x 10^{-6}
Concrete cube compressive strength= 27.579 MPa
Bending Yield Stress of Rein.= 413.685 MPa

4.1 The Loading Details

The following loads are applied in the models of the structure.

Self Weight	: SW of the Beam, Column, and Slab
Dead Load	: 2 kN /m^2
Floor Finish	: 0.2 kN/ m^2

Live Load : 2 kN/ m^2
Lateral loads as specified in SAP 2000

5.MODAL ANALYSIS

Modal analysis was carried out on the model without linked columns and with linked columns to determine the mode shape. Mode 1 of the 3 models is shown in Fig 4-6

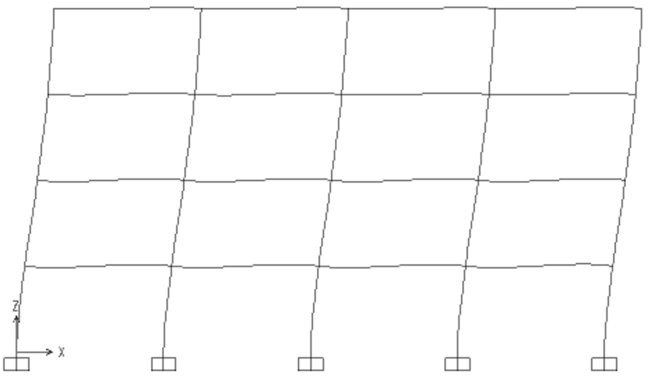

Fig 4 : I Mode shape for model S1

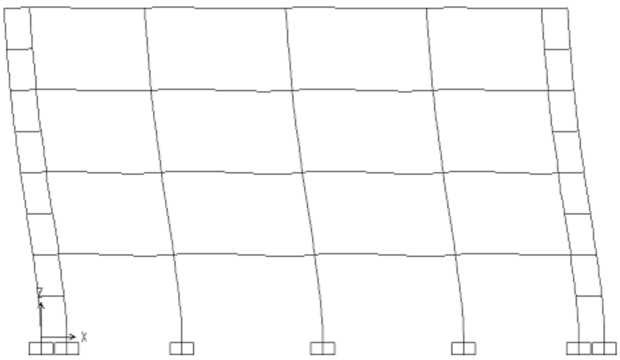

Fig 5 : II Mode shape of the model SL1

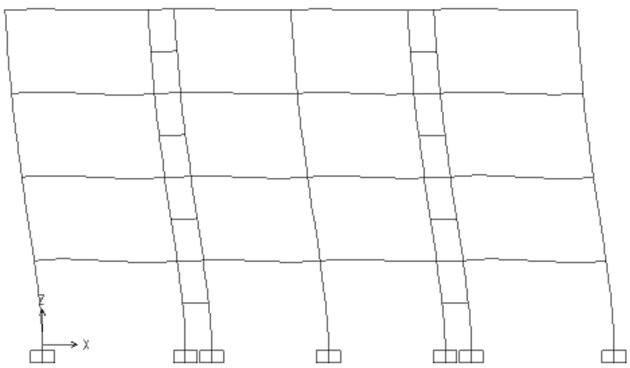

Fig 6 : II Mode shape of the model SL2

The first three frequencies of the three models are given in table1. From the Table 1 it can be observed that,

6. MODAL ANALYSIS

Pushover analysis is an approximate analysis method in which the structure is subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement is reached. Pushover analysis consists.

Table 1 : Frequencies of the models

Modes	S1	SL1	SL2
1	1.560	1.604	1.613
2	1.671	1.722	1.735
3	5.135	5.623	5.290

of a series of sequential elastic analysis, superimposed to approximate a force-displacement curve of the overall structure. A two or three dimensional model which includes bilinear or tri-linear load-deformation diagrams of all lateral force resisting elements is first created and gravity loads are applied initially. A predefined lateral load pattern which is distributed along the building height is then applied. The lateral forces are increased until some members yield. The structural model is modified to account for the reduced stiffness of yielded members and lateral forces are again increased until additional members yield. The process is continued until a control displacement at the top of building reaches a certain level of deformation or structure becomes unstable. The roof displacement is plotted with base shear to get the global capacity curve

All the three models are analyzed using push over method and the formation of hinges pattern are studied. The inter storey drift and the base shear are also accounted for the models. The failure of the building can be found by the hinge formation. The hinge patterns for the models are shown in Figures 7-9. From Figure 7 it can be observed that the hinges start forming in the main beam in the frame without linked columns. When the linked columns were introduced at the end span the hinge started forming in the link beam and in the 4^{th} mode in the main beams (Figure 8). Then the linked column and beam system was introduced in the bay next to the end bay and hinge formation was observed. From figure 9 it can be seen that in the fifth mode after the hinge is formed in all the link beams hinges form in the main beam indicating that the link beams fail first preventing the damage in the main structure.

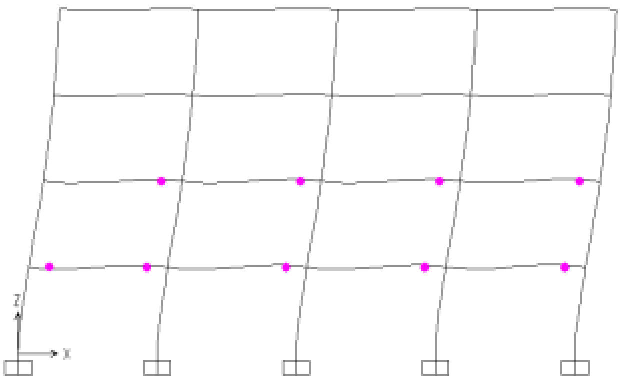

Figure 7 : Hinge formation for model S1 in the 1st Mode

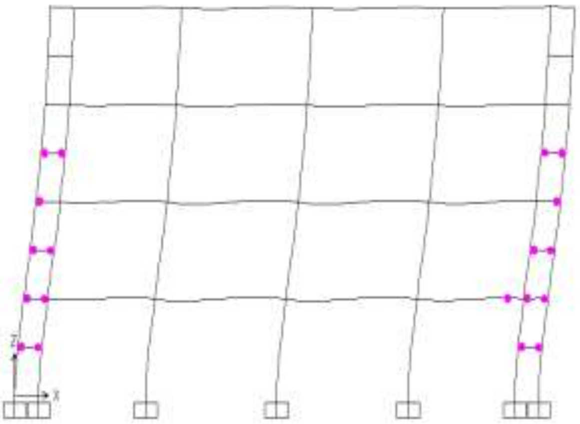

Figure : 8 Hinge formation for model SL1 in the 4th Mode

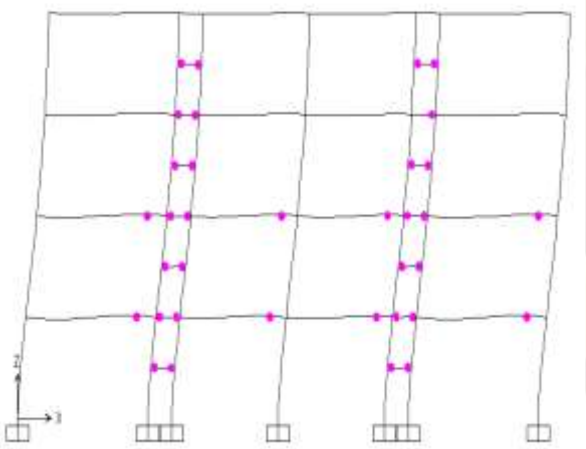

Figure : 9 Hinge formation for model SL2 in the 5th Mode

In SAP2000, a frame element is modeled as a line element having linearly elastic properties and nonlinear force-displacement characteristics of individual frame elements are modeled as hinges represented by a series of straight line segments. A generalized force-displacement characteristic of a non-degrading frame element (or hinge properties) in SAP2000is shown in fig 10.

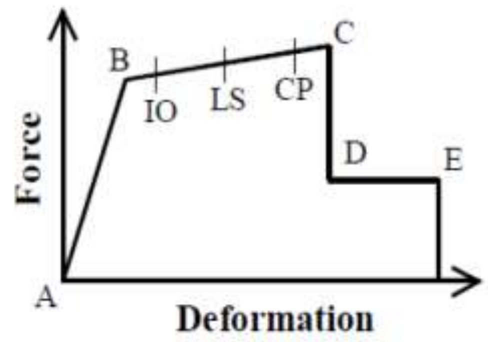

Figure 10 : Force-Deformation for Pushover Hinge

Point A corresponds to unloaded condition and point B represents yielding of the element. The ordinate at C corresponds to nominal strength and abscissa at C corresponds to the deformation at which significant strength degradation begins. The drop from C to D represents the initial failure of the element and resistance to lateral loads beyond point C is usually unreliable. The residual resistance from D to E allows the frame elements to sustain gravity loads. Beyond point E, the maximum deformation capacity, gravity load can no longer be sustained.

Fig 11 shows the base shear vs roof drift curve for all the three models. The improved performance of the frame with linked column can be observed than without liked column.

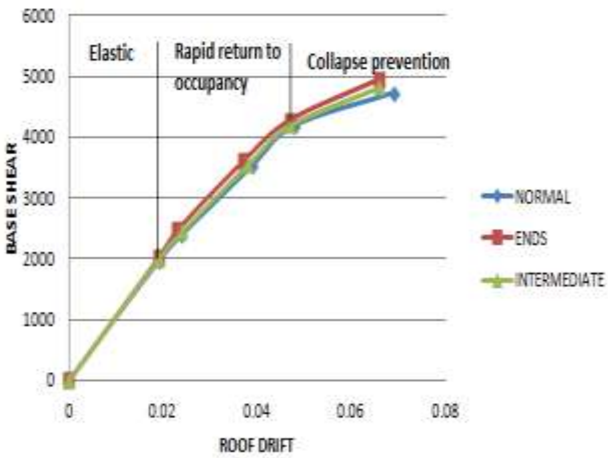

Figure 11: Base shear vs Roof Drift for the Models

7. CONCLUSION

The analytical investigation carried out in SAP 2000 to study the feasibility of implementing sacrificial link beam and column system for seismic resistance of reinforced concrete structures are presented. The following are the conclusions drawn

1. The system incorporates replaceable links placed between closely spaced columns, which under earthquake lateral demands yield the links via a differential movement throughout the height of the structure.
2. From the formation of the hinges and the reduction in drift, it can be said that the linked column frame effectively protects the gravity beams as well as the columns such that the structure could rapidly return to occupancy through link replacement.
3. Since the replaceable links are also modeled as reinforced concrete elements the cost of construction can be greatly reduced.
4. This method can be effectively used as rehabilitation of existing structure not designed to resist seismic forces.

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