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Behavior of Linked-Column System subjected to Seismic Force

J. Joel Shelton* and G. Hemalatha

Civil Department, Karunya University, Coimbatore - 641114, Tamil Nadu, India;
joelsheltonj@gmail.com, hemalathag@karunya.edu

Abstract

Objective: The study investigates the seismic performance of reinforced concrete linked column frame system under earthquake acceleration. The utilization of concrete as link elements to resist shear and optimize its connection to the columns for shear transfer has been presented. **Methods/Analysis:** The seismic responses of the systems was investigated for ground motions using time history analysis for Linked Column Frame for three building models namely, 4, 7 and 10 storey building and the results were compared with the normal frame using SAP 2000. **Findings:** Adding linked column to the normal frame shows that the inter storey drift and base shear are effectively reduced. Results of nonlinear time history analysis show that this system has better load dissipation capabilities. **Conclusion/Application:** Since the replaceable links are also modelled as reinforced concrete elements the cost of construction can be greatly reduced.

Keywords: Base Shear, Inter Storey Drift, Linked Column Frame, Seismic Responses, Time History Analysis

1. Introduction

In the maximum considered earthquake, providing life safety is a major factor while designing a seismic resistant structures; however, with the development of performance-based seismic design, studies and practice have started to focus on reducing the damage to the structure and also reducing repair or replacement costs for moderate seismic events. Researchers have successfully researched and implemented shear walls for concrete structures. But the Shear walls have a disadvantages like, higher floor displacements, member forces and consequently more reinforcement when compared with the steel bracings was presented[1–3]. Researchers presented their research on utilization of steel braces for concrete structures. Further, many researchers has presented on different types of bracing, different materials used for bracing, connection for bracing in the framed structures[4–9]. The bracing system has the disadvantages like occupying the movement space and despite their ability to provide stiffness and ductile response it will suffer from shortcomings when considering return to occupancy.

Later the link beam concept in eccentrically braced frames relying on yielding of a link beam between braces was presented[10]. Since the beams are located at the floor levels and these beams are continuous, they form part of the gravity system. These eccentrically braced frames are well suited to provide the desired energy dissipation and ductility under earthquake loading for life safety. However, the loss of occupancy and the difficulties associated with economically repairing the gravity system following an earthquake will give burden to the owners and occupants[11]. Proposed the Linked Column Frame (LCF) which is a lateral load resisting steel frame system that incorporates easily replaceable link elements and capable of achieving improved seismic performance. The LCF consists of two components (1) A primary lateral system, denoted the linked column, which is built up of closely spaced dual columns interconnected with replaceable link beams. (2) The secondary lateral system denotes a moment resisting frame which acts as part of the gravity load system. The moment resisting frame is designed to be flexible by utilizing the main beams with restrained connections at one end and pinned connections at the

* Author for correspondence

other end[12]. The Linked Column Frame was designed for a multiple performance objectives. Under seismic excitation, the relative deformations of the closely spaced linked columns engage the links which are designed to be yield in shear to control storey drift, dissipate energy and limit the forces transferred to the surrounding members. The links are bolted to the columns for allowing controlled shop fabrication and more importantly for rapid replacement when severely damaged.

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

During October-1979 Imperial Valley earthquake, lot of multi-storey buildings in southern California fell apart and suffered huge damages. After the earthquake, the observations revealed many drawbacks in these structures including lack of seismic resistant features and non-adoption of seismic engineering practices. The seismic performance of a building can be improved by energy dissipating device, which may be passive and active in nature. In this regard nonlinear time history response is most importance for seismic analysis. This motivated to study an effect of link beam column is analysed for the earthquake ground motion for the building frame. Various configurations of this link column profile layout have been considered along with various loading of earthquake acceleration as per IS 1893 (Part 1):2002.

In this research paper the objective is to perform the non-linear time history analysis for structure with two bays of link column used for the 4, 7 and 10 storey building and compare with the normal building considering earthquake acceleration load. Time history analysis using SAP 2000 is used to study the behaviour of the proposed structural system.

2. Methodology

For the study of behaviour of link column system 3 building models, namely 4, 7 and 10 storeys are considered. Time history analysis was done using SAP 2000 with Imperial Valley earthquake data. The procedure adopted is as follows:

Steps	Action
1	Selection of building geometry 3D frame.
2	Material properties should be defined.
3	Section property of beam and column should be defined.
4	Fixed support should be assigned at the joint.
5	Section property of beam and column should be assigned.
6	Load pattern as dead load should be assigned.
7	Ground motion file for earthquake load should be defined.
8	Analysis case should defined with EQ Imperial Valley.
9	Run the analysis program.
10	Analysis results such as absolute displacements, base shear and absolute acceleration should be compared.

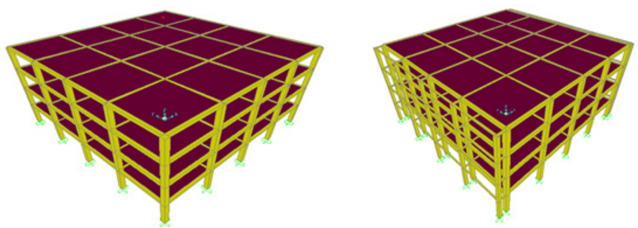
The basic material properties used for the model are as follows:

- Young's Modulus of concrete, EC = 2.236 x 10^5 N/mm^2.
- Young's Modulus of steel, Es = 2.1 x 10^5 N/mm^2.
- Compressive strength of concrete, fck = 25 N/mm^2.
- Yield stress for steel, fy = 415 N/mm^2.
- Poisson's Ratio = 0.3.
- Concrete cube compressive strength = 27.679 N/mm^2.
- Coefficient of thermal expansion = 9.9 x 10^{-6}.
- Bending Yield Stress of Reinforcement = 413.685 N/mm^2.

3. Time History Analysis of Building Frame

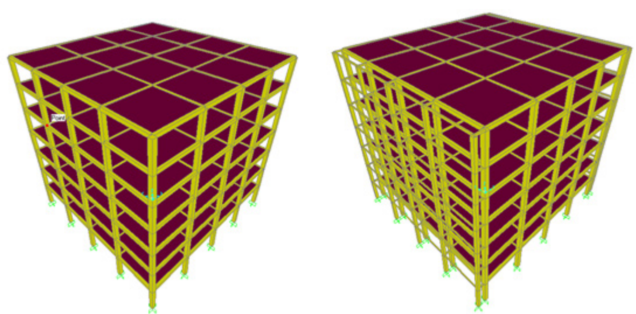
Time history analysis provides for nonlinear or linear evaluation of structural dynamic response under seismic loading which will vary according to the specified time function. A dynamic load is one which changes with time precisely quickly in comparison to the structure's natural frequency. A full time history will give the structures response over time during and after the application of a load. The time history analysis is the advanced level of analysis allows four main loading types. These include base velocity, base displacements, base acceleration factored forcing functions and harmonically varying force input. Time history is a record of the ground acceleration at defined time segments for a specific earthquake in certain direction. The record is usually normalized and therefore needs to be multiplied by the acceleration due to gravity or a factor.

Imperial Valley earthquake data is collected and given as an input to the 3D frame with link column and without link column. With the help of SAP 2000, 3D frame has been analysed for nonlinear time history analysis with link column and without link column. The nonlinear time history analysis is the most important in seismic analysis. The seismic response for the linked beam column during the Imperial Valley earthquake was studied for building frame. As per IS 1893 (Part1):2002 various configurations of this link column profile layout have been considered along with various seismic loading of earthquake acceleration[13]. The modelling of the building models are shown in Figure 1 to Figure 3.



(a) (b)

Figure 1. 3D view of 4th floor. **a**. Normal frame. **b**. Link Column Frame.

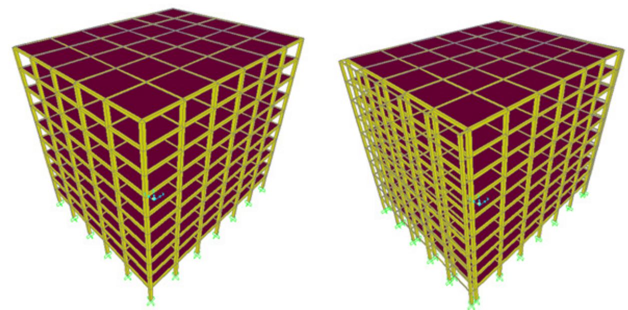


(a) (b)

Figure 2. 3D view of 7th floor. **a**. Normal frame. **b**. Link Column Frame.

The details of the buildings are given below:

- In x. direction, Bay length : 6 m.
- In y. direction, Bay length : 6 m.
- In z. direction, Bay length : 3.5 m.
- 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 : 0.12 m.
- 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.



(a) (b)

Figure 3. 3D view of 10th floor. **a**. Normal frame. **b**. Link Column Frame.

4. Results and Discussion

In the present study, from SAP 2000 the seismic response for the linked column concrete building frame, has been accomplished by 3D nonlinear time history analysis. Nonlinear time history analysis results were tabulated in the form of peak displacement, peak acceleration and base shear at roof top[14]. It has been observed that there is significant variation in results based on the load case as per IS 1893 (Part1):2002.

4.1. Peak Displacement

The maximum values of peak displacement at roof top for 4 storey, 7 storey and 10 storey with and without Link Column Frame for EQ Imperial Valley load are given in Table 1. It can be observed that displacement reduces effectively by 44% for earthquake load case when link columns are provided in 4 storey frame, compared to normal frame (without link column), it reduces 31.2% for earthquake load case when link columns are provided in 7 storey, compared to normal frame and 34.6% for earthquake load case when link columns are provided in 10 storey, compared to normal frame .

Table 1. Peak displacement

Storey	Displacement for Normal frame (mm)	Displacement for Link Frame (mm)
4 storey	4.119	2.306
7 storey	2.893	1.989
10 storey	2.663	1.74

Figures 4- 6 compare Link Column Frame and normal frame with respect to peak displacement for four, seven and ten storey buildings.

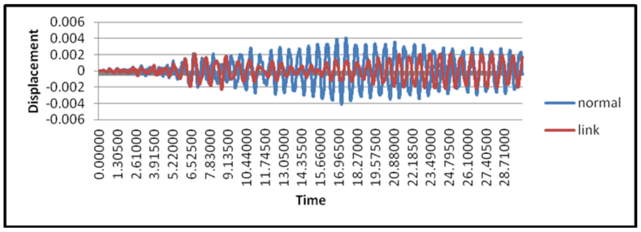


Figure 4. Time vs. displacement curve for 4 storey building.

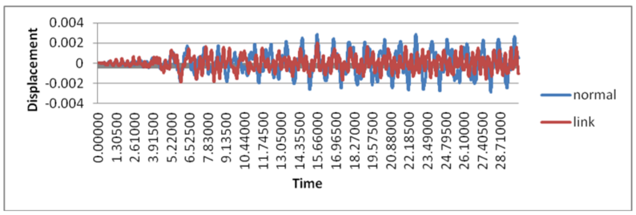


Figure 5. Time vs. displacement curve for 7 storey building.

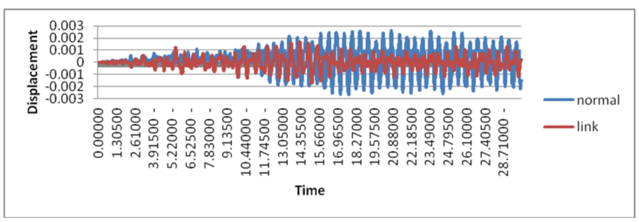


Figure 6. Time vs. displacement curve for 10 storey building.

4.2 Storey Drift

Figures 7 to 9 compare Link Column Frame and normal frame with respect to Storey Drift for four, seven and ten storey buildings. From the figures it is observed that Link Column Frame has lesser storey drift when compared to the normal frame.

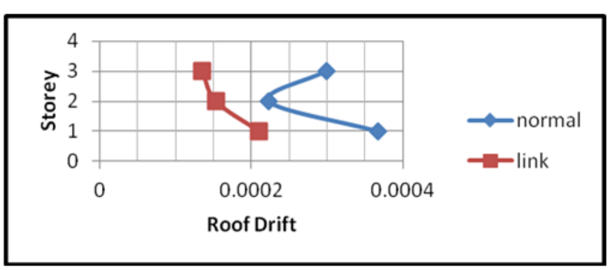


Figure 7. Storey vs. roof drift curve for 4 storey building.

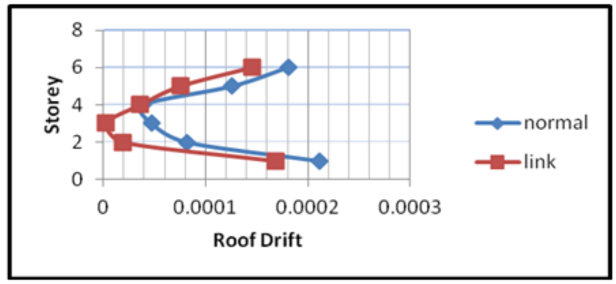


Figure 8. Story vs. roof drift curve for 7 storey building.

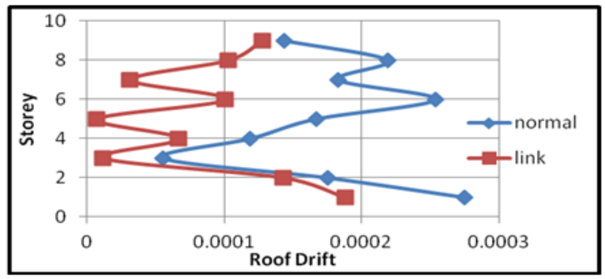


Figure 9. Storey vs. roof drift curve for 10 storey building.

4.3. Peak Acceleration

The maximum values of acceleration at roof top for 4 storey, 7 storey and 10 storey with and without Link Column Frame when from base for EQ Imperial Valley load are given in Table 2. It can be observed that acceleration reduces effectively by 49.4% for earthquake load case when link columns are provided in 4 storey frame, compared to normal frame (without link column), it increases 3% of earthquake load case when link columns are provided in 7 storey, compared to normal frame and 31.8% for earthquake load case when link columns are provided in 10 storey, compared to normal frame given in Table 2..

Table 2. Peak Acceleration

Storey	Acceleration for Normal frame (mm/s^2)	Acceleration for Link Frame (mm/s^2)
4 storey	776.1	392.7
7 storey	830.1	855.2
10 storey	755.3	514.8

Figure 10 shows the comparison graph between Link Column Frame and normal frame with respect to peak acceleration for four, seven and ten storey buildings.

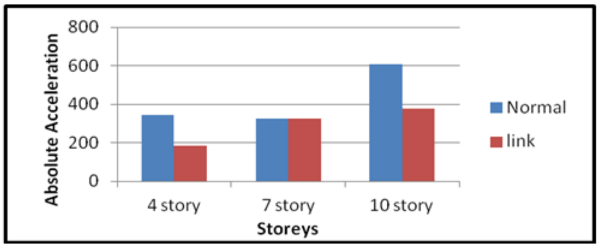


Figure 10. Bar chart for peak acceleration mm/s^2.

4.4 Base Shear

The maximum values of absolute displacement at roof top for 4 storey, 7 storey and 10 storey with and without Link Column Frame are given in Table 3. It can be observed that base shear reduces effectively by 46.4% for earthquake load case when link beam columns are provided in 4 storey frame, compared to normal frame (without link column), it increases 0.24% for earthquake load case when link beam columns are provided in 7 storey, compared to normal frame and 38.3% for earthquake load case when link columns are provided in 10 storey, compared to normal frame given in Table 3.

Table 3. Base Shear

Storey	Base Shear for Normal frame (KN)	Base Shear for link Frame (KN)
4 storey	345.9	185.5
7 storey	324.4	325.2
10 storey	609.8	376.3

Figure 11 shows the comparison graph between Link Column Frame and normal frame with respect to Base Shear for four, seven and ten storey buildings.

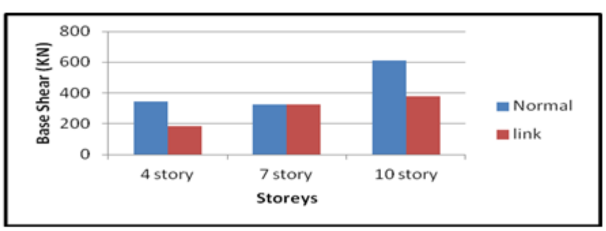


Figure 11. Bar chart for base shear.

5. Conclusions

On the basis of analytical study and reviewed literature the following conclusions can be drawn:

- Seismic performance of building can be improved by providing link column, which absorb the input energy during earthquake.
- By providing link column system in the structure it reduces base shear, acceleration and displacement.
- This method can be effectively used as rehabilitation of existing structures that are not designed to resist seismic forces.

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