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Link Column Frame System for Multi-Storey Building: A Comparative Study of RC Link-RC Column and RC Link-CFST Column Structure

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Abstract - *Linked Column Frame (LCF) system is a new brace free lateral load resisting system which has main objective to achieve the rapid return to occupancy criteria. The LCF system comprises of main Moment Resisting Frame (MRF) and dual columns which are interconnected by link beams. Purpose of MRF system is to resist gravity load while LCF system will act as lateral load resisting system. The LCF system overall exhibits three performance criteria, linear elastic, rapid return to occupancy and collapse prevention. Link beams are designed as sacrificial beams and yield prior to gravity beams and avoid the failure of MRF system. Once the link beams are yielded, they can be replaced and structure can be occupied rapidly. In this paper normal RC building (RCNB) is compared with Link RC-Column Frame system (RC_LCF) and Link CFST-Column Frame system (RC_CFLCF). Six structures are modeled in ETABS 17.0.1 of 4-storey and 7-storey. Pushover Analysis and Time History Analysis is used to compare the performance of all structures by comparing Time Period, Frequency, Base shear, Storey Displacement and Storey Drift.*

Key Words: **Linked Column Frame, Moment Resisting Frame, CFST, Time Period, Base Shear, Rapid Return to Occupancy**

1. INTRODUCTION

The main challenge in front of structural engineers is to develop a lateral load resisting system which is effective in resisting the seismic loads and will get repaired easily as well as economically after an event of earthquake. Further, to maintain aesthetics of a structure many times architectures demand for a brace free solution. There are some well-known lateral load resisting systems which are listed in Table 1 along with their shortcomings.

Table -1: Different Lateral Load Resisting Systems with their deficiencies

Lateral Load Resisting System	Brace Free Solution	Immediate Occupancy
Special Moment Resisting Frame	✔	✘
Concentrically Braced Frame	✘	✘
Eccentrically Braced Frame	✘	✔
Special Truss Moment Frame	✘	✘
Special Steel Plate Shear Walls	✔	✘

From table 1, it is clear that the mentioned lateral load resisting systems are not satisfying both the objectives. Therefore it is a need to develop a system which will be a brace free and will achieve the criteria of immediate occupancy. The LCF system consists of moment resisting frame (MRF) and linked columns with replaceable links. The MRF carries gravity load and under earthquake excitation the structure remains elastic. The link column consists of closely spaced dual-columns interconnected with links, which are designed to yield, deform plastically and be replaceable. The LCF system's ability to achieve rapid return to occupancy relies on the behavior of the replaceable links. The LCF system also offers architectural advantages of open perimeter bays and occupation versatility in the interior floor layout.

By superimposing the lateral response contributions of the LC and MF as shown in Figure 1, the resulting lateral response of the LCF system provides for three performance levels as follows,

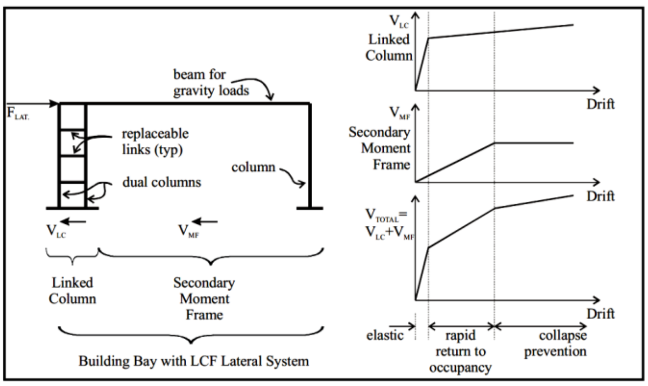

Fig-1: Linked Column Frame Elevation and Base Shear Distribution [2]

a) Elastic behaviour: Under service loads, the entire structure remains elastic and the primary stiffness is provided by the LC assembly. [3]

b) Rapid return to occupancy: Under extreme lateral loads, the links plastically deform while the rest of the structure remains elastic. [3]

c) Collapse prevention: Moment Resisting Frame beams are also get damaged. [3]

2. LITERATURE REVIEW

[1] Dr. Marwan Nader et.al. 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 to provide replaceable shear links between the tower shafts which would yield in the event of a major earthquake with a clear failure sequence. The idea behind the LCF system was based on developments in long span bridge design and applied to building construction. [2] Dr. Peter Dusicka and A. Lopes investigated the inelastic model of built-up shear links for seismic protection of bridges through the use of large-scale experiments, material investigation and numerical analyses. Built-up shear links were shown to be effective as hysteretic energy dissipaters. [3] Dr. Peter Dusicka and Robert Iwai presented the study of the building layout used by the SAC research project for moment frame buildings. [4] Dr. Peter Dusicka and G. Lewis studied replaceable link connections with the intent of limiting plastic strain at the link-to-end plate connection and thereby minimizing undesirable failure modes. [5] M. Malakoutian et.al. studied the seismic performance of the LCF system which was investigated through numerical simulation. [6] Allistair Fussell et.al. modeled four storey office building designed to the New Zealand Loadings and Steel Structures Standards and compared this to a conventional ductile moment frame alternative. They found that the LCF system was effective over conventional ductile moment resisting frame.[7] Joel Shelton J. et. al. presented experimental and analytical results carried out on single bay RC frames with and without link column. [8] D. Darling Helen Lydia and Dr. G. Hemalatha studied the implementation of linked beam and column system, the links were placed in two different location, i.e., at the end bay and at the intermediate bay. They found that the link beams used at end bay were more effective in protecting the gravity beams. [9] J. Joel Shelton and G. Hemalatha investigated the seismic performance of reinforced concrete linked column frame system under earthquake acceleration. [10] Chinju C. Mathew and Anoop P. P. investigated the performance of LCF system with and without infill. [12] Mohammad Ali Kafi et. al. used performance-based plastic design method, a highly accurate and simple design procedure was proposed for this system. 9 prototype structures with 3, 6 and 9 stories and with 3, 4 and 5 bays were selected for parametric design and assessment. [13] Shahrokh Shoeibi et. al. presented a simplified force-based seismic design method for linked column frame system based on parametric studies on different structures, which were designed with displacement-based method.

3. METHODOLOGY

In this study each model is analyzed for Pushover Analysis and Time History Analysis.

3.1 Pushover Analysis

The Pushover Analysis is a Nonlinear Static Method which is used in a performance based analysis. The main objective of Pushover Analysis in this study is to check prior yielding of link beams than gravity beams so that the gravity beams can be saved from damage.

3.2 Time History Analysis

Nonlinear Time-History Analysis is by far the most comprehensive method for seismic analysis. The earthquake record in the form of acceleration time history is input at the base of the structure. The response of the structure is computed at each second for the entire duration of an earthquake. In this paper Time History Analysis is carried out to check and compare the performance of different models. Eleven Time Histories are taken from PEER Ground Motion Data Base and used, which are mentioned as follow in Table 2,

TABLE - 2: Time History Data

Sr. No.	Name	Magnitude
1	Helena, Montana-02	6.65
2	Imperial Valley-02	6.35
3	San Fernando	6.61
4	Northwest Calif-02	6.6
5	Northern Calif-03	6.50
6	Superstition Hills-01	6.22
7	Chi-Chi, Taiwan-05	6.2
8	Parkfield	6.19
9	Chalfant Valley-02	6.19
10	Southern Calif	6.1
11	Caldiran, Turkey	7.21

Each model is undergone by following procedure as shown in Fig. 2,

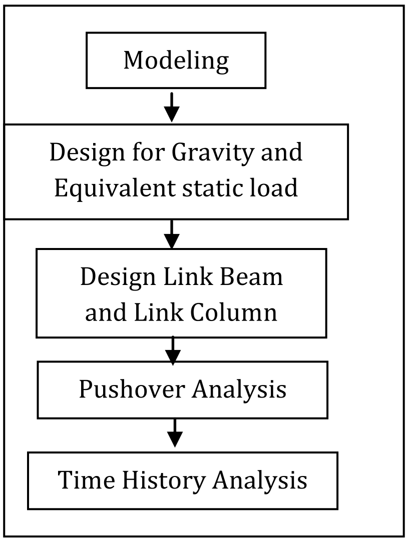

Fig-2: Flowchart of Analysis

3.3 Design of Link Beam Length

There are three criteria by which length of link beam can be designed and those are Shear link, Flexural link and Intermediate link. The study made by D. Darling Joel Shelton and Dr. G. Hemalatha shown that shear links are effective over other two links, therefore in this study the shear links are designed as per following criteria, [7]
Shear links, which yield primarily in shear, should have length (e),

$$e \leq 1.6*\left(\frac{MP}{VP}\right) \quad (1)$$

The moment capacity MP and plastic shear VP of the link are determined from the following equations,

$$VP = \tau y \; AV \left(\frac{1}{\gamma m}\right) \quad (2)$$

$$MP = ZP \; \sigma y \quad (3)$$

Where, τy is the shear stress for the section, AV is the shear area of the section, γm is the partial safety factor of the material, σy is the yield stress of the material, and ZP is the plastic modulus.

3.4 Design of Link Column

The link column is designed as cantilever column to take the entire lateral load on a particular floor.

$$ILC = \frac{x^{4.6} \, P \, h^3}{8E\Delta} \quad (4)$$

$$\Delta = \frac{PL^3}{3EI} \quad (5)$$

Where, Δ is the displacement, P is the lateral load, ILC is the moment of inertia of link column, E is the Modulus of elasticity and I is the Moment of Inertia of the section, x is the number of stories, L is the storey height for a single linked column and h is the storey height of the linked column frame.

3.5 Design of Link Beam

$$IL = \frac{0.6 \; ILC \; H}{h} \quad (6)$$

Where, H is the link length.

4. STRUCTURAL MODELING

The six structural systems are considered for this study are 4 and 7-storeyed buildings with 4-bay symmetrical about both horizontal axes are reinforced concrete frame slab buildings. Out of six structures three are of 4-storeyed and three are of 7-storeyed. Further, out of three models, first is of normal RC building without linked column Frame system, second is of RC building with Link RC-column frame and third is of RC building with Link CFST-column frame. The details of model are shown in Table. 3-6 and models are shown in Fig. 3-9,

TABLE -3: Material Properties

Grade of Concrete	Grade of Steel Rebar	Grade of Steel
M25	Fe415/Fe500	Fe250

TABLE -4: Building Description (mm)

Elements	4-Storey	7-Storey
Column	500 x 500	500 x 500
Beam	300 x 350	450 x 500
Link Column	450 x 450	450 x 450
Link Beam	200 x 200	200 x 200
Slab Thickness	125	125
Storey Height	3000	3000
Bay width	4000	
Link Length	1100	

Table -5: Load Details

Live Load (KN/m^2)	Floor Finish (KN/m^2)	Wall Load (KN/m)
3	1.5	External Wall=11.5 Internal Wall =5..75 Parapet Wall= 4.6

TABLE -6: Seismic Properties (IS 1893:2016)

Seismic Zone	V
Response Reduction Factor	5
Importance Factor	1.2
Zone Factor	0.36

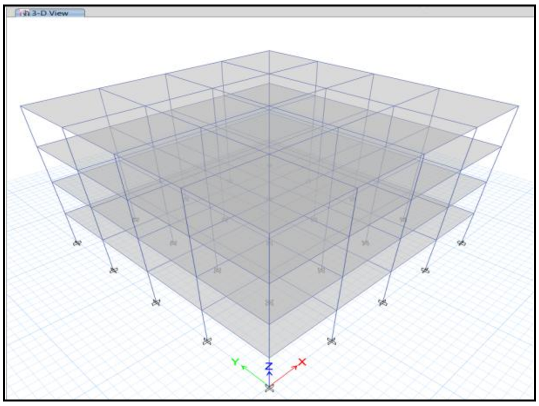

Fig- 3: 4 Storey RC Normal Building (4RCNB)

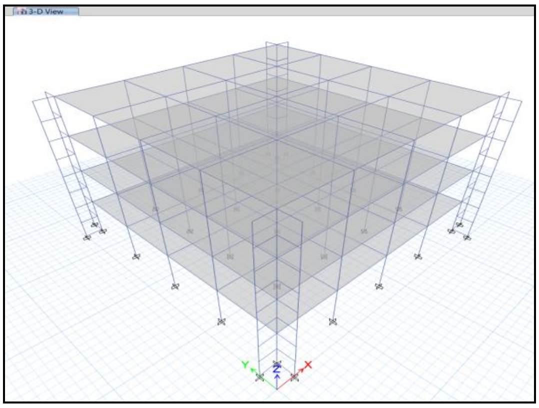

Fig -4: 4 Storey RC Building with RC LCF (4RC_LCF)

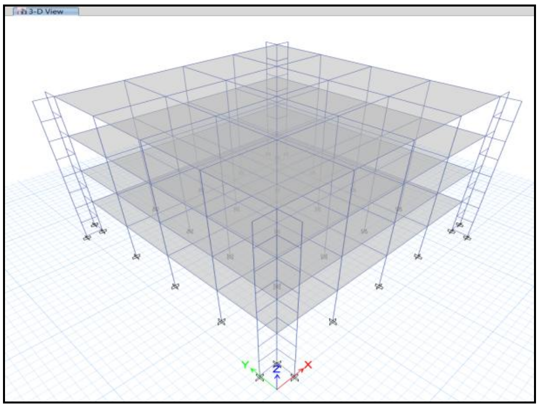

Fig -5: 4 Storey RC Building with RC LCF (4RC_LCF)

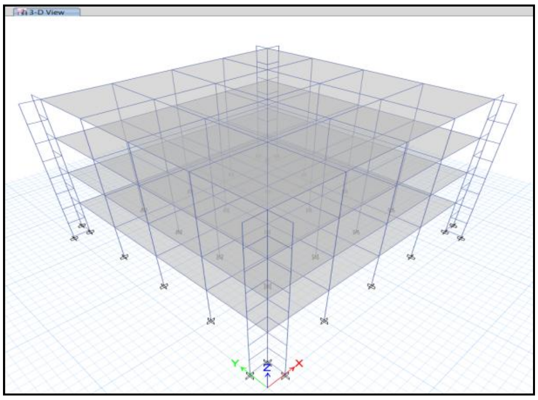

Fig -6: 4 Storey RC Building with CFST LCF (4RC_CFLCF)

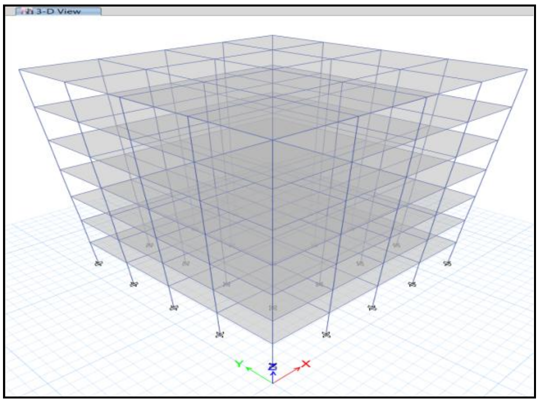

Fig -7: 7 Storey RC Normal Building (7RCNB)

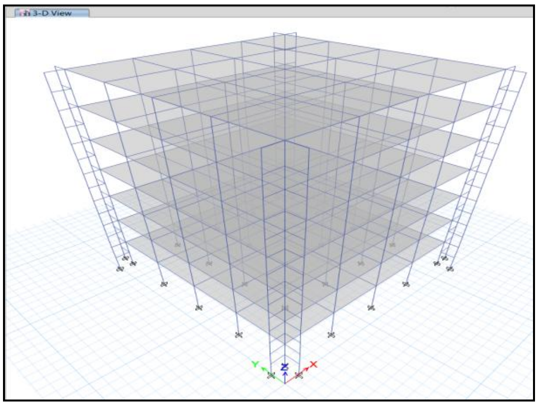

Fig -8: 7 Storey RC Building with RC LCF (7RC_LCF)

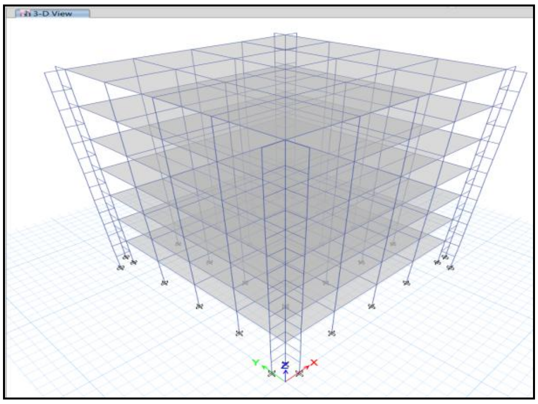

Fig -9: 7 Storey RC Building with CFST LCF (7RC_CFLCF)

5. RESULTS AND DISCUSSION

5.1 Pushover Analysis Results

Pushover Analysis is performed to check the yielding behavior of the link beams. The Pushover analysis is carried in ETABS 17.0.1. The comparison of Time period and Frequency is shown in Table 7 and hinge formation for all models are shown in Fig. 10-15

TABLE -7: Time Period and Frequency

No. of storey	RCNB		RC_RCLCF		RC_CFLCF	
	T (sec)	ω (c/sec)	T (sec)	ω (c/sec)	T (sec)	ω (c/sec)
4	0.925	1.081	0.869	1.151	0.829	1.207
7	1.056	0.946	1.006	0.994	0.987	1.013

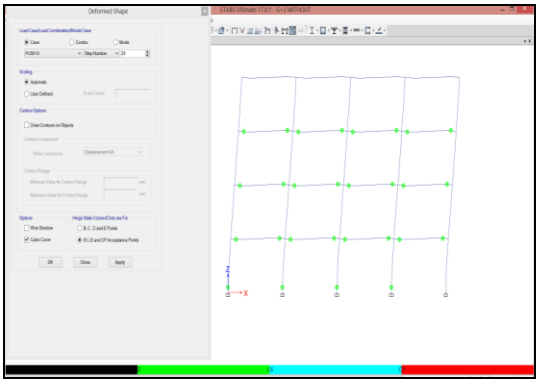

Fig -10: Hinge Formation in 4 Storey RC Normal Building (4RCNB)

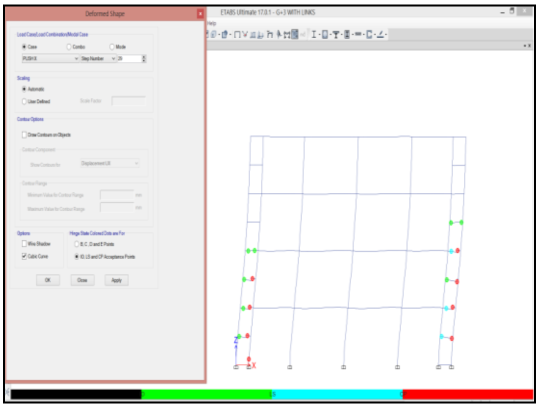

Fig -11: Hinge Formation in 4 Storey RC Building with RC LCF (4RC_LCF)

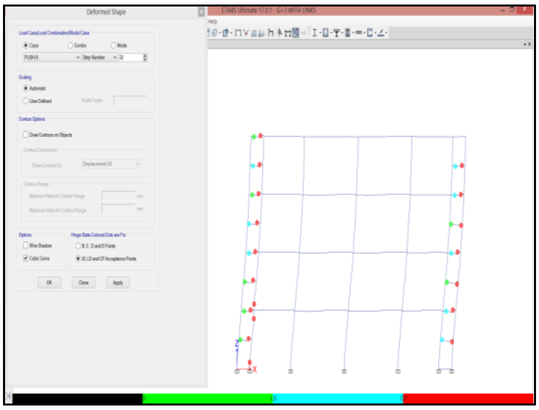

Fig -12: Hinge Formation in 4 Storey RC Building with CFST LCF (4RC_CFLCF)

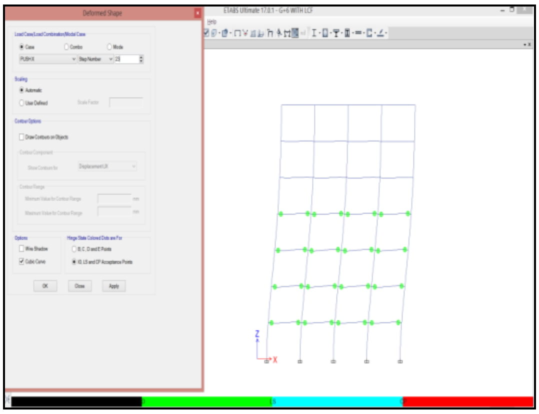

Fig -13: Hinge Formation in 7 Storey RC Normal Building

(7RCNB)

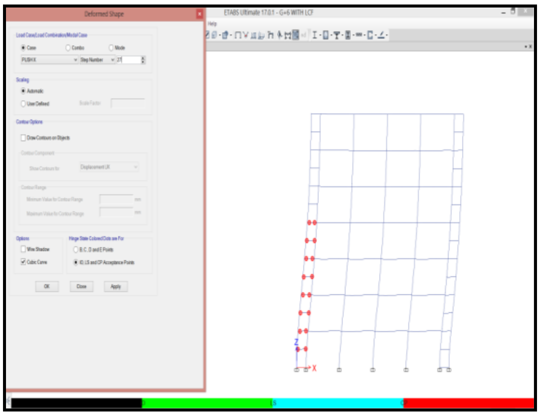

Fig -14: Hinge Formation in 7 Storey RC Building with RC LCF (7RC_LCF)

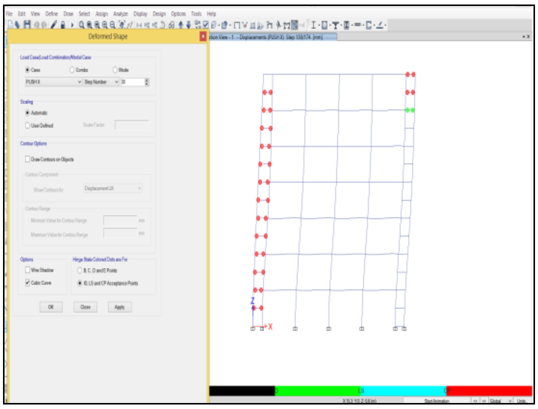

Fig -15: Hinge Formation in 7 Storey RC Building with CFST LCF (7RC_CFLCF)

5.2 Time History Analysis Results:

The performance of all models is checked by the Time History Analysis, and out of eleven time history analysis results the critical results are tabulated below in Table 8-10,

TABLE -8: Base Shear (KN)

No. of storey	RCNB	RC_RCLCF	RC_CFLCF
4	791.6898	947.1527	954.1815
7	1451.5714	1671.512	1705.351

TABLE -9: Storey Displacement (mm)

No. of storey	RCNB	RC_RCLCF	RC_CFLCF
4	51.034	39.439	33.621
7	96.033	60.501	50.596

TABLE -10: Storey Drift

No. of storey	RCNB	RC_RCLCF	RC_CFLCF
4	0.005411	0.004232	0.003531
7	0.006942	0.004373	0.003684

From the above results following comparison is done in Table 11-13 in terms of percentage for Base Shear, Storey Displacement and Storey Drift.

TABLE -11: Percentage Increase in Base Shear

No. of storey	RC_RCLCF	RC_CFLCF
4	19.63	20.52
7	15.15	16.79

TABLE -12: Percentage Decrease in Storey Displacement

No. of storey	RC_RCLCF	RC_CFLCF
4	22.72	34.12
7	36.99	46.92

TABLE -13: Percentage Decrease in Storey Drift

No. of storey	RC_RCLCF	RC_CFLCF
4	21.78	34.74
7	36.99	46.91

6. CONCLUSIONS

From the results obtained from Pushover Analysis and Time History Analysis, the following conclusions can be drawn,

1) The prior yielding of link beams save the gravity beams from damage.

2) The Base shear of the structure is increased in case of RC_LCF structures and further increased in case of RC_CFLCF structures.

3) The storey displacement and storey drift of the structure is decreased in case of RC_LCF structures and further decreased in case of RC_CFLCF structures.

Therefore the LCF system is an effective brace free lateral load resisting system, whereas using CFST column as Link columns the performance of LCF system can be increased.

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