Global Journal of Researches in Engineering: E
Civil And Structural Engineering
Volume 16 Issue 2 Version 1.0 Year 2016
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Experimental Investigation on Dual Column Frame System for Seismic Resistance of Reinforced Concrete Frames

By Joel Shelton J, Venkatesh V & Dr. Hemalatha G
Karunya University, India

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 non-structural elements during excitations. Linked column frame system (LCF) 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. In this paper the concept is extended to Reinforced concrete structures. A design procedure is proposed that ensures that plastic hinges form in the links of the link column at a significantly lower story drift than when plastic hinges develop in the moment frame beams. The experimental investigation consisted of cyclic load test on a single bay frame with and without link column. The test results showed a significant increase in the energy dissipation of the link column frames with a decrease in relative story drifts.

Keywords: non-linear pushover analysis, lateral loading, link column frame, seismic response, energy dissipation.

GJRE-E Classification : FOR Code: 090506

EXPERIMENTALINVESTIGATIONONDUALCOLUMNFRAMESYSTEMFORSEISMICRESISTANCEOFREINFORCEDCONCRETEFRAMES

Strictly as per the compliance and regulations of :

Experimental Investigation on Dual Column Frame System for Seismic Resistance of Reinforced Concrete Frames

Joel Shelton J [α], Venkatesh V [σ] & Dr. Hemalatha G [ρ]

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 non-structural elements during excitations. Linked column frame system (LCF) 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. In this paper the concept is extended to Reinforced concrete structures. A design procedure is proposed that ensures that plastic hinges form in the links of the link column at a significantly lower story drift than when plastic hinges develop in the moment frame beams. The experimental investigation consisted of cyclic load test on a single bay frame with and without link column. The test results showed a significant increase in the energy dissipation of the link column frames with a decrease in relative story drifts.

Keywords: non-linear pushover analysis, lateral loading, link column frame, seismic response, energy dissipation.

I. Introduction

The objective to construct structures that are safe and can withstand natural calamities like earthquake, wind, blast etc., has been essential for all construction activities. Peter Dusicka et.al.,(2009) recommended a lateral load resisting system, referred to as the linked column frame (LCF) system. This system combines features of conventional components to attain a system that can be designed for multiple performance objectives. In the LCF building system, selected columns are spaced in close to each other 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.

In this paper, lateral resisting system i.e. the link column frame (LCF) system, is extended to Reinforced concrete frame as shown in Figure 1. This system consists of easily replaceable link beams between two closely spaced columns and an adjacent flexible moment resisting frame. The links act as sacrificial structural elements that yield to provide nonlinear softening behaviour, ductility, and energy dissipation while limiting the inelastic deformation and related damage to the structural members of the adjacent moment resisting frame. The LCF links behave similarly to links in eccentrically braced frames, that is, they yield in shear and/or flexure depending on their length.

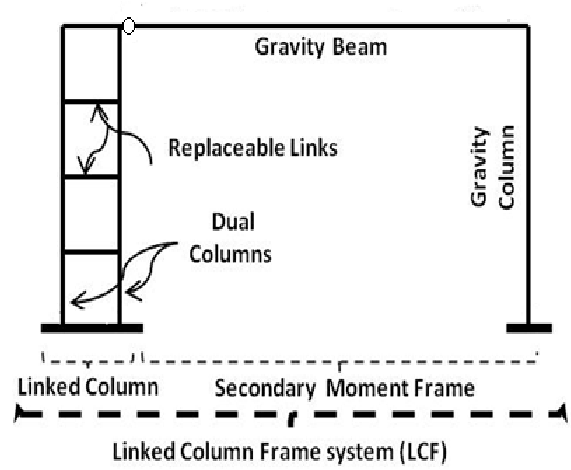

Figure 1 : Typical elevation of the Link Column Frame System

The 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.

II. Specimen for Experimental Investigation

To carry out experimental Investigation three reinforced concrete frames were taken with and without link column system. Model 1 (M1) was cast as bare frame without link column. Model 2 (M2) had link column with rigid connection between the frame and the column, Model (M3) was designed with hinged connection between the beam and the link column. The dimensions of the specimen were scaled down in the ratio 1:3 based on the availability of the facilities in the laboratory. The details of the specimens cast are shown in table 1. Figure 1 shows the schematic view of the specimens.

Author α σ ρ : School of Civil Engineering, Karunya University Coimbatore, India. e-mails: hemalathag@karunya.edu, joelsheltonj@gmail.com, hemalathag@karunya.edu

Table 1 : Details of the Specimen

		M1	M2	M3
Beam	Dimension (m)	0.77 x0.77		
	Reinforcement (nos.)	#4, 8mm		
Column	Dimension (m)	0.77 x0.77		
	Reinforcement (nos.)	#4, 8mm		
Link	Dimension (m)	-	0.2 x 0.2	
Link column	Dimension (m)		0.4 x 0.4 m	
Bay length	in m	1		
Height	in m	1		

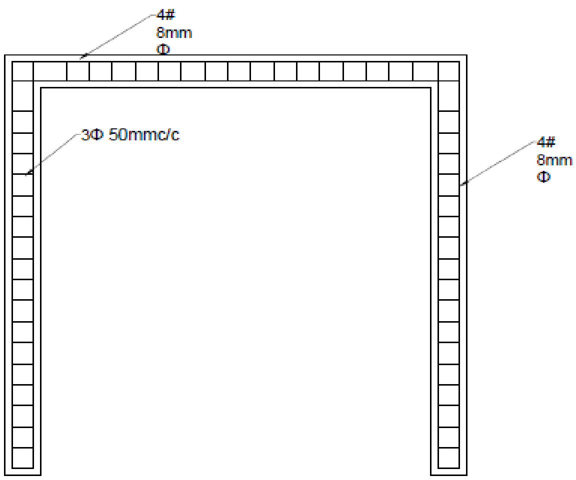

Figure 2a : Bare Frame (M1)

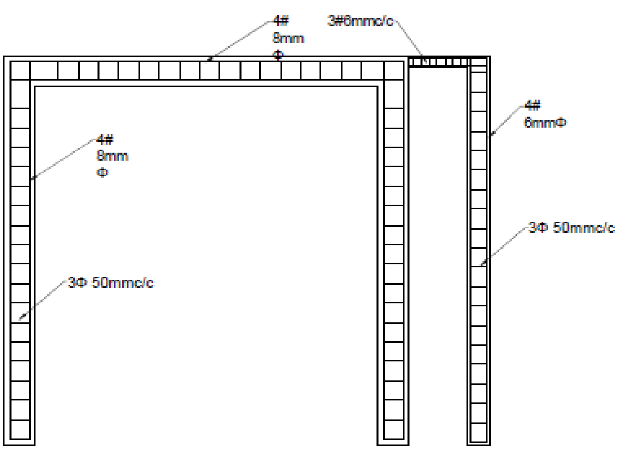

Figure 2b : Frame with rigid beam to column connection (M2)

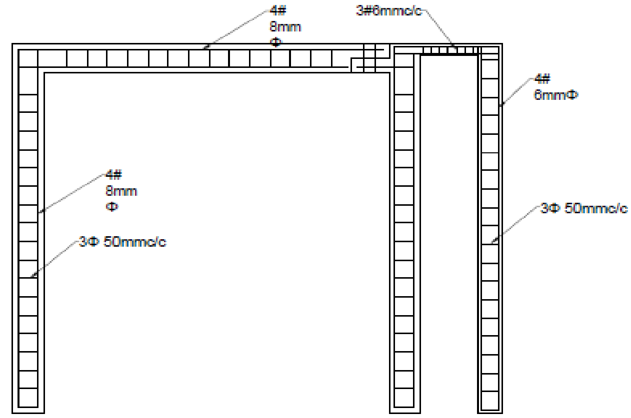

Figure 2c : " Frame with hinged beam to column connection (M3)

III. Design Procedure for Link Beam

The links are designed similarly to links in eccentrically braced frames and their yielding behaviour depends on their length and section properties. AISC Seismic Provisions (AISC) divides links into three categories based on their link length, e, plastic shear capacity, Vp, and plastic moment capacity, Mp. Vp and Mp, respectively, defined as follows [4]:

$$V_p = \tau_y \times A_v \times (1/\gamma_m) \quad (1)$$

$$M_p = Z_p \sigma_y \quad (2)$$

From the above equation, τ_y is the shear stress for the section, A_v is the shear area of the section, γ_m is the partial safety factor of the material, σ_y is the yield stress of the material, and Zp is the plastic modulus Shear links, which yield primarily in shear, have:

$$e \leq 1.6\ (Mp/Vp) \quad (3)$$

flexural links, which yield primarily in flexure, have:

$$e \geq 2.6\ (Mp/Vp) \quad (4)$$

and intermediate links, which may yield in a combination of shear and flexure, have:

$$1.6\ (Mp/Vp) < e < 2.6\ (Mp/Vp) \quad (5)$$

The above equations were used to design the length of the links and the values are given in table 2.

Table II : Length of Links

(Z) mm^3	(A_v) mm^2	Shear link mm	Flexure link mm	Intermediate link mm
6750	196	160	258	200

IV. Analysis of the Links

To choose suitable links for the LCF system, the performance of various types of the links was studied using push over analysis in SAP 2000. The performance point of the frames with various link lengths was observed and is shown in figure 2.

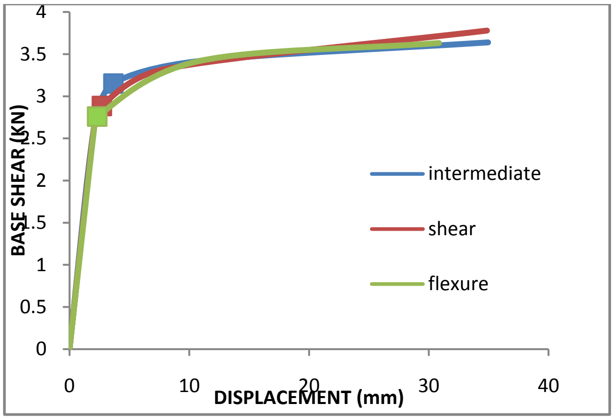

Fig. 3 : Performance levels of various types of links

The performance level of various types of link models were found between IO-LS (Immediate occupancy to life safety). Performance point is higher for the intermediate link model when compared with the shear and the flexural link. The shear links and flexural links started to yield earlier when compared to the intermediate links.

V. Beam to Column Connection with Dowels

For hinged connection in linked column frame (M3), the beam of the moment frame is connected to the linked column using dowel bars. The dowel bars are used to transfer shear loads across construction and movement joints in concrete. With reference to the beam to column connections, the shear force V at the top of the columns was calculated from the resisting moment M_r of the section at the base of the columns with $V = M_r / h$ so that, introducing a Υ_R factor, the force on the connection becomes

$$H = \Upsilon_R V = \Upsilon_R M_r / h \qquad (6)$$

$$\text{and } R_d = 0.9n\,\phi^2\,\text{SQRT}\,(f_y\,f_{ck}\,(1\text{-}\alpha^2)) \qquad (7)$$

Where, n = no of dowels, ϕ = diameter of dowels, f_{ck} = characteristic strength of concrete, f_y = yield strength of steel, σ = normal tensile stress. 2 no's of 20mm ϕ bar as dowel reinforcement was provided for hinge connection. The dowel bar of 20 mm diameter was embedded in the column to a length equal to the development length.

VI. Experimental Investigation

Cyclic load test was conducted on the three frames the behaviour of the specimens were studied. Discussions of the results are as follows

a) Bare frame (M1)

This specimen (M1) was designated as the reference frame to compare its performance against linked column frame specimens. Ten full displacement cycles were applied to the frame. First shear cracks were observed at a displacement of 5.583mm. The corresponding restoring force was measured as 6 kN. At the end of the 5th cycle, at 8.56mm displacement, first yielding of the longitudinal reinforcement was observed. At this drift level, the restoring force was measured as 10 kN and the maximum crack opening was obtained as 1.0 mm. The base shear versus story drift relationship of bare frame and its crack patterns at the final stage of the test are given in Figure 4.

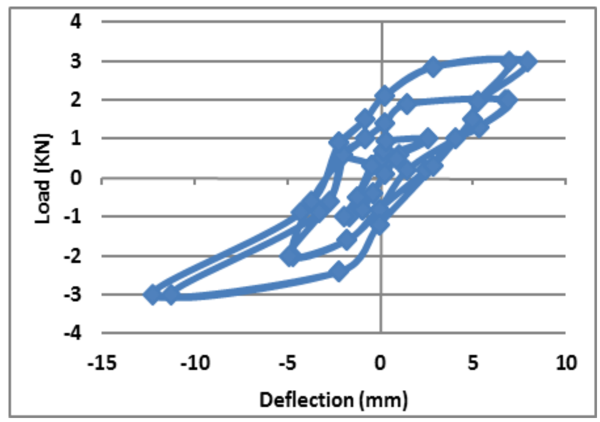

Figure 4a : Base shear vs. story drift (M1)

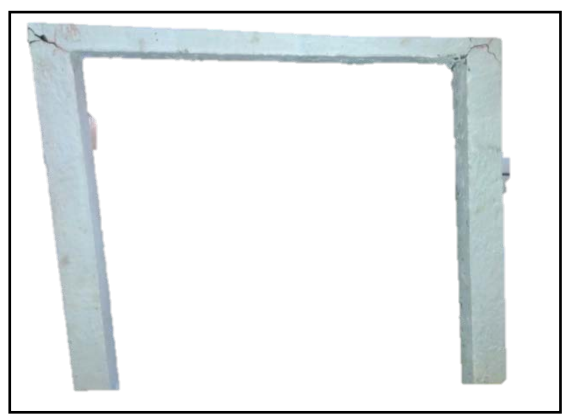

Figure 4b : Damage pattern for bare frame (M1) specimen

b) Rigid link column frame (M2)

This specimen is a linked column frame in which the normal beam is rigidly connected to the linked column. Sixteen full displacement cycles were applied to the frame. First flexural cracks were observed at a displacement of 9.6 mm which is occurred at the link joints. The corresponding restoring force was measured as 18 kN. First shear crack were observed at a displacement of 10.26 mm. The corresponding restoring force was measured as 20 kN. At the end of the 10th cycle, at 15.56mm displacement, first yielding of the longitudinal reinforcement was observed. At this drift level, the restoring force was measured as 30 kN. The base shear versus story drift relationship of bare frame and its crack patterns at the final stage of the test are given in figure 5.

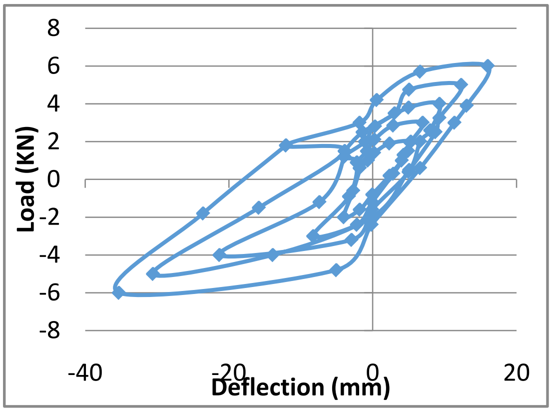

Figure 5a : Base shear vs. story drift

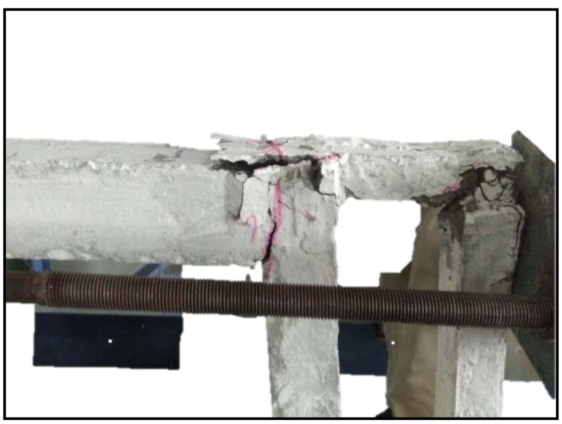

Figure 5b : Damage pattern for M2

c) Hinged link column frame(M3)

This specimen is a linked column frame in which the normal beam is flexibly connected to the linked column. Sixteen full displacement cycles were applied to the frame. First shear cracks were observed at a displacement of 15.6 mm which is occurred at the hinged joint. The corresponding restoring force was measured as 20 kN. At the end of the 10th cycle, at 20.57 mm displacement, first yielding of the longitudinal Reinforcement was observed. At this drift level, the restoring force was measured as 33 kN. The base shear versus story drift relationship of bare frame and its crack patterns at the final stage of the test are given in figure 6.

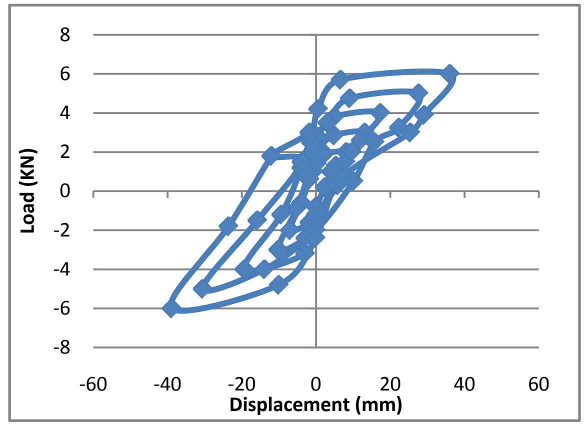

Figure 6a : Base shear vs. story drift (M3)

Figure 6b : Damage pattern for M3

The ability of a structure to dissipate the seismic input energy is an accurate measure of its expected seismic performance. The cumulative dissipated energy is determined as the sum of the area enclosed by each hysteretic loop. The dissipated cumulative energy versus deflection relation for all specimens is given in figure 7. The normal frame is the specimen which has the minimum energy dissipation capacity. The linked column frame which has a flexible connection is the one which dissipates maximum energy when compared with the rigid connection. The hinged linked column frames dissipated 65% more energy than the rigid linked column frame. This enables the plasticization to occur in links in lower drift compared to beams in higher drifts.

d) Lateral stiffness

The lateral stiffness was defined as the slope of the line connecting the positive and negative peaks of a given load–displacement cycle. Variation of the lateral stiffness with respect to story drift for all specimens is given in figure 8. Presence of hinged connection reduces the lateral stiffness of hinged linked column frames. As expected, the lateral stiffness decreases for hinged linked column when compared with the rigid linked column. Initial lateral stiffness is reduced by about 11.7%. The overall stiffness of rigid linked column frame is 1.59 times greater than the normal frame's stiffness, respectively.

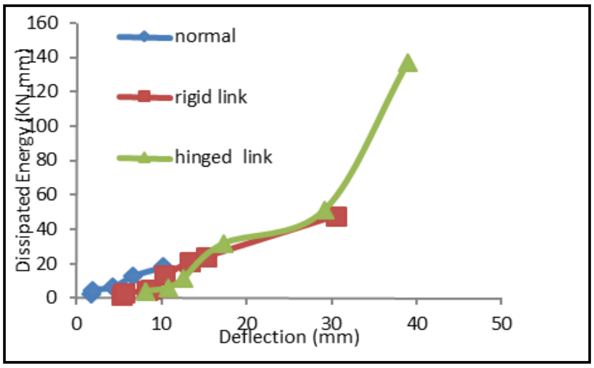

Figure 7 : Energy dissipation vs Deflection

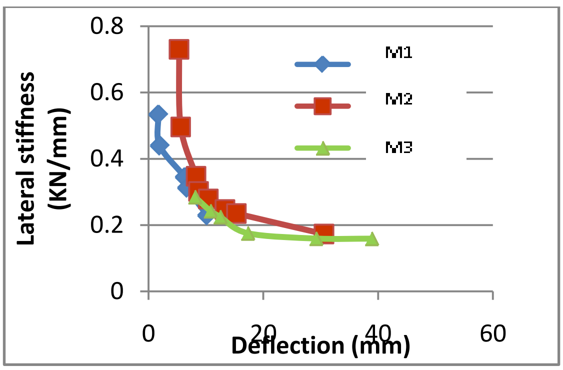

Figure 8 : Lateral stiffness vs Deflection

VII. Conclusion

The Experimental investigation carried out 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

- 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.
- Seismic performance of building can be improved by providing link column, which absorb the input energy during cyclic loading.

Since the replaceable links are also modelled as reinforced concrete elements the cost of construction can be greatly reduced. Effective hinge formation was obtained when dowel bar is inserted and the result shows that the energy dissipation of the linked column frame is better than the normal frame.

VIII. Acknowledgement

The authors are thankful to Ministry of Earth Sciences (MoES), GOI for sponsoring the research work. The authors also extend their sincere thanks to Karunya University for facilitating the research work.

References Références Referencias

1. Abolmaali, Ali, Razavi, Mohammad, Radulova, Dobrinka. "On the Concept of Earthquake Resistant Hybrid Steel Frames" *Journal of Constructional Steel Research 2012, 68(1)*, 39.
2. Arlindo Lopes, Peter Dusicka and Jeffrey Berman, "Lateral Stiffness Approximation of Linked Column Steel Frame System", Structural Congress, 2015, 2408-2420.
3. Debasis Sinha. "Seismic Retrofitting of existing Structure" *IIT Roorkee , M. Tech Thesis*. 2009
4. Malakoutian, M., Berman, J. and Dusicka, P. Seismic Response Evaluation of the Linked Column Frame. Earthquake Engineering and Structural Dynamics; 42:2013, 795-814.
5. Mohd Aarif Khan."Seismic evolution of frame buildings using pushover and dynamic analysis" *IIT Roorkee, M.Tech Thesis*. 2008
6. Nabil Mansour, Yunlu Shen, Constantin Christopoulos and Robert Tremblay. [2008] "Experimental Evaluation of Nonlinear Replaceable Links in Eccentrically Braced Frames and Moment Resisting Frames" *14th World Conference on Earthquake Engineering* October 12-17, Beijing, China.
7. Peter Dusicka. "Steel Frame Lateral System Concept Utilizing Replaceable Links" *NZSEE Conference*.2009.
8. Tena-Colunga A. "Mathematical modeling of the adas energy dissipation device."*Engineering Structures*, 19(10), 1997, 811-820.
9. Thorburn, L. J., Kulak, G. L., and Montgomery, C. J. "Analysis of steel plate shear walls." *Structural Engineering Report* 107, Dept. of Civil Engineering, University of Alberta, Edmonton, Alberta, Canada. 1983
10. Tremblay, R., Lacerte, M., and Christopoulos, C. "Seismic response of multi- story buildings with self-centering energy dissipative steel braces." *Journal of Structural Engineering*, 134(1), 2008, 108-120.
11. Tsai, K. C., Chen, H.W. and Hong, C., and Su, Y. "Design of steel triangular plate energy absorbers for seismic-resistant construction." *Earthquake Spectra*, 9(3), 1993, 505-528.
12. Uang, C. M., B. D., and Lee, C.H. "Cyclic performance of haunch repaired steel moment connections." *Engineering Structures*, 20(4-6)1998, 522-561.
13. Vargas, R. and Bruneau, M. "Experimental response of buildings designed with metallic structural fuses." *Journal of Structural Engineering*, 135(4), 2009, 386-393.
14. Vargas, R. and Bruneau, M."Experimental response of buildings designed with metallic structural fuses. ii." *Journal of Structural Engineering*, 135(4), 2009, 394-403.

This page is intentionally left blank