Evaluation of direct displacement-based designed linked column steel frame (LCF) systems

Javad Tazarv[1], Amin Mohebkhah[2*]

[1]Department of Civil Engineering, Malayer University, Malayer, Iran
[2]Department of Civil Engineering, Malayer University, Malayer, Iran

ABSTRACT

The linked column steel frame system (LCF) is a new load resistant system; that by using replaceable ductile links, it can provide the desired structural behavior. The optimal performance of this system can be achieved by controlling the displacements and the sequence of yielding of fuses in the structure. Direct displacement-based design (DDBD) method is one of the most powerful performance-based design methods that has the ability to control the behavior of a structure. The aim of this study is to investigate the performance of LCF systems designed by DDBD method. For this purpose, 8 sample structures with 3, 6, 9 and 12 stories and with different configurations, were designed with DDBD method; and then their behavior was investigated by nonlinear static analysis. The results showed that in the design base shear calculated with DDBD method, nearly most of the links of the studied structures were yielded; while all the beams of the modified moment frame remained elastic. This result show the ability of the DDBD method to design LCF systems with controlled behavior. The results of the overstrength review of the studied structures also indicated that the overstrength of LCF systems designed with DDBD method depends on the height and configuration. The average value of this coefficient was evaluated as 1.23. Also, the average inherent overstrength coefficient of the structural samples was calculated as 0.48. This result indicates the ability of the LCF systems designed by the DDBD method to achieve their desired failure mechanism.

KEYWORDS

Linked column frame system, Direct displacement-based design, Performance objects, Overstrength, Nonlinear static analysis

[*] Corresponding Author: Email: amoheb2001@yahoo.com

1. Introduction

The linked column frame (LCF) system is a new lateral-gravity load resisting system introduced by Dusicka and Iwai [1]. In this system, damage to the structure during a seismic event is limited to specific members (i.e. replaceable link beams). Limiting damage to these members leads to preventing or reducing damage to the main members of the structure at all seismic hazard levels. Most research and design methods developed for this system are force-based design methods [2, 3 and 4]. Obviously, force-based design methods, while simple, cannot describe the actual (nonlinear) behavior of the structure and guarantee the realization of the structure performance objectives. However, performance-based design methods are the best procedures to the seismic design of structures. Various methods for performance-based design have been proposed in the literature, in which the direct displacement-based design (DDBD) method is one of the best methods [5] proposed by Priestley et al [6]. In 2020, the direct displacement-based design method by Tazarv [7] was developed for the design of LCF structural systems; which allows the design of LCF systems for different performance levels as well as accurate monitoring and control of their behavior. The purpose of this study is to investigate the achievement of the intended design goals in the linked column frame systems designed by the direct displacement-based method. For this purpose, a total number of 8 prototype structures with 3-, 6-, 9- and 12-story and different configurations are designed with this method and evaluated using nonlinear static analysis. Numerical modeling and analysis of the examined frame samples was performed by OpenSees software [8]. In the modeling process, the nonlinear behavior of beams, link beams and connections was carefully modeled and their behavior was calibrated with spme experimental results.

Table 1. DDBD results summary for the case study lcfs

Design parameter		3S-1LC	3S-2LC	6S-1LC	6S-2LC	9S-1LC	9S-2LC	12S-1LC	12S-2LC
Design drift	θ_d (%)	2	2	2	2	1.8	1.8	1.9	1.9
Design displasement	Δ_d (m)	0.16	0.16	0.29	0.29	0.39	0.39	0.57	0.57
Effective height	H_e (m)	7.96	7.96	14.88	15.0	21.86	21.8	28.84	28.84
Effective mass	m_e (kN.S^2/m)	665.32	665.32	1313.66	1317.21	1945.71	1945.71	2574.1	2574.1
MMF ductility	μ	0.54	0.7	0.58	0.68	0.55	0.7	0.61	0.81
LC ductility	μ	3.1	3.3	3.49	2.77	2.1	1.72	2.02	1.66
MMF EVD	%	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
LC EVD	%	15.0	15.2	15.42	14.36	12.66	11.27	13.0	11.0
LCF EVD	%	9.73	11.6	10.25	10.54	8.52	8.56	8.63	8.5
Effective period	T_e (Sec)	1.51	1.56	2.46	2.44	3.11	2.87	3.77	3.74
Design base shear	V_{base}(kN)	1995.7	1887.27	2905.35	2828.14	3848.60	3239.00	4625.60	4691.98

2. Methodology

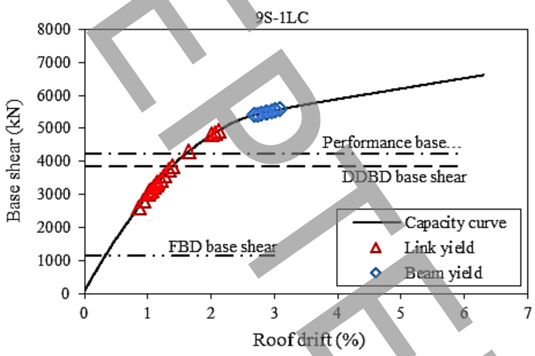
In order to validate the proposed design method, a regular floor plan of a building with dimensions of 25 * 25 meters is used. The considered buildings consist of two groups with equal plan dimensions. The first group is denoted by “nS-1LC” that in each LCF frame, there is only one LC bay, and the second group is denoted by “nS-2LC” in which there are two LC bays. Parameter n stands for the number of stories. The studied structures are of 3-, 6-, 9- and 12-story LCFs with the height of the stories equal to 3.5 m. The acceleration and displacement spectrums of the Iran standard IS-2800 [9] have been used to design the prototype structures; and based on this code, the buildings are assumed to be located in a high seismicity zone on the soil type II.

Using the proposed design method, all 8 samples of the studied structures were designed. Table 1 summarizes the design results.

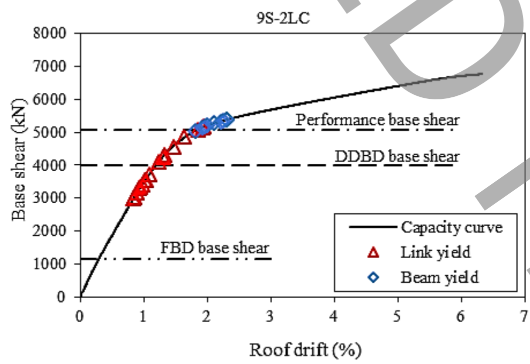
3. Results and Discussion

3.1 General behavior of sample frames

In order to investigate the behavior and overstrength of LCF systems designed by DDBD method, a series of sample frame designed and their behavior were investigated using nonlinear static analysis. For example, Figures 1-a and 1-b show the capacity curve of the 9-story frames. In this research, the design and evaluation of the LCF systems has been done for RR performance level. At this performance level, the optimal behavior of this system is achieved by not yielding of the MMF system fuses (i.e. beams). As expected and shown in Figure 1, in all frame specimens, at the base shear of the DDBD design, most of the link beams are yielded and all the modified moment frame beams are in their elastic region. This indicates the high accuracy of the proposed DDBD of LCF systems in providing the base shear corresponding to the nonlinear behavior (yielding of most link beams) and controlled (no yielding in modified moment frame beams) of the structure.



(a)



(b)

Figure 1. Capacity curve of 9-story structures: (a) Structure sample 9S-1LC; (b) Structure sample 9S-2LC

3.2 Overstrength of sample frames

In this research, the ratio of the performance shear base of the structure (the base shear corresponding to the achievement of the first story to the design drift) to the design base shear calculated by the DDBD method is considered as the overstrength factor of a structure. The calculated values of overstrength factor for the sample structures are shown in Figure 2. As shown in Figure 2, in the LCF structures designed with the DDBD method, there is some overstrength compared to the design base shear; The main reason for this can be attributed to the executive issues, strain hardening of materials and overstrength of the link beams. According to Figure 2, it can be concluded that the overstrength factor of the LCF systems designed by DDBD is a function of height, structure configuration and performance considerations assumed in the design process, and its average value is equal to 1.23.

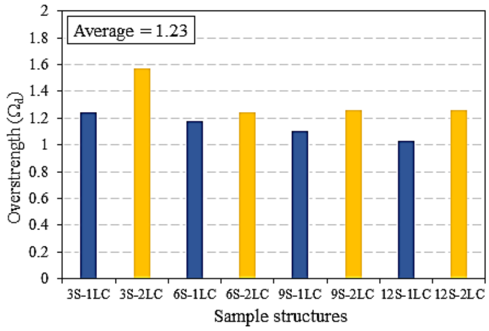


Figure 2. Overstrength of the studied structures

3. Conclusions

In this study, the behavior of LCF systems designed by DDBD method was investigated. The main findings of this study are as follows:

1- The results of the parametric study and the interpretation of the sample capacity curve of the structures showed that in all frame samples, in the design base shear predicted by the DDBD method, most of the link beams are yielded, while all beams of the modified moment frame remain in their elastic range. This behavior, which is completely in line with the concepts of the DDBD method, is a clear proof of the success of this method in providing design forces corresponding to the nonlinear and controlled behavior of the LCF systems.

2- In the sample structures studied in this study, nearly most of the links of the studied structures were yielded. This will increase energy dissipation and provide a uniform distribution of damage along the height of the structure.

3. Based on the studies performed on the overstrength of LCF systems, it was shown that the real overstrength of LCF systems designed by DDBD method depends on the height, structure configuration and executive issues. Its value in this study ranged between 1.03 to 1.57, and an average of 1.23.

References

[1] P. Dusicka, R. Iwai, Development of linked column frame system for seismic lateral loads, In Structural engineering research frontiers, (2007) 1-13.

[2] M. Malakoutian, J. W. Berman, and P. Dusicka, Seismic response evaluation of the linked column frame system, Earthquake Engineering & Structural Dynamics, 42(6) (2013) 795–814.

[3] M. Malakoutian, J. W. Berman, P. Dusicka, and A. Lopes, Quantification of Linked Column Frame Seismic Performance Factors for Use in Seismic Design, Journal of Earthquake Engineering, 20(4) (2016) 535–558.

[4] A. Lopes, P. Dusicka and J. Berman, Linked Column Frame Steel System Performance Validation using Hybrid Simulation, Proc. of 10th US National Conference on Earthquake Engineering, Anc, Alaska, (2014).
[5] T.J. Sullivan, The current limitations of displacement based design, MSc Dissertation, European asachool of Advanced Student in Reduction of Seismic Risk (Rose School), University of Pavia, Italy, (2002).
[6] M.J.N. Priestley, G.M. Calvi, and M.J. Kowalski, Displacement based seismic design of structures, IUSS Press, Pavia, Italy, 2007.
[7] J. Tazarv, Direct displacement-Based Seismic Design of Steel Linked Column Frame Structures, MSc Dissertation, Civil Engineering Dept., University of Malayer, Malayer, Iran, (2020). (in persian).
[8] S. Mazzoni, F. McKenna, M. H. Scott, and G. L. Fenves, Open System for Earthquake Engineering Simulation User Command-Language Manual - OpenSees Version 3.0.3, Pacific Earthquake Engineering Research Center, University of California, Berkeley, Berkeley, CA. Avaliable Online at http://www.opensess.berkeley.edu, (2016).
[9] BHRC-2800, Iranian code of practice for seismic resistant design of buildings: Standard No. 2800, 4th ed., Tehran: Road, Housing and Urban Denelopment Research Center, 2014. (in Persian)