ARTICLE IN PRESS
HBRC Journal (2015) xxx, xxx–xxx

Housing and Building National Research Center
HBRC Journal
http://ees.elsevier.com/hbrcj

Cyclic behavior of braced concrete frames: Experimental investigation and numerical simulation

Hadad S. Hadad, Ibrahim M. Metwally *, Sameh El-Betar

Concrete Structures Research Inst., Housing & Building Research Centre, P.O. Box 1770, Cairo, Egypt

Received 28 May 2014; revised 2 November 2014; accepted 9 November 2014

KEYWORDS
Bracing;
Infilled frame;
Cyclic loading;
IDARC

Abstract RC shear walls have been widely used as the main lateral-load resisting system in medium and high-rise buildings because of their inherent large lateral stiffness and load resistance. But, in general, the energy dissipating capacity of RC shear walls is not very good and it is found that using the bracing system gives good results. The main purpose of this paper is to study the effect of the different types of bracing on the lateral load capacity of the frame. Also, the research contains a comparison between the braced and infilled frames to decide the best system. The research scheme consists of four frames; the bare frame, two frames one was braced with concrete, the second was braced with steel bracing and the fourth frame was infilled with solid cement bricks. All the specimens were tested under cyclic loading. The results gave some important conclusions as; braced and infilled the bare frames increased the lateral strength of the bare frame depending on the type of bracing and infill. Also, the different types of bracing and the infill increased the initial stiffness of the bare frame by a reasonable value. The energy dissipation for the braced and infilled frames is always higher than that for the bare frame up to failure. Also, numerical modeling was carried out with the nonlinear software platform (IDARC). The numerical results obtained with the calibrated nonlinear model are presented and compared with the experimental results. Good agreement was achieved between the numerical simulation and the test results.
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Introduction

In order to make multi-storey structures stronger and stiffer, which are more susceptible to earthquake and wind forces, the cross sections of the member increases from top to bottom and this makes the structure uneconomical owing to the safety of the structure. Therefore, it is necessary to provide a special mechanism and/or mechanisms that improve lateral stability of the structure. Braced frames develop their confrontation

* Corresponding author.
E-mail address: dr_ibrahimmetwally@yahoo.com (I.M. Metwally).
Peer review under responsibility of Housing and Building National Research Center.

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http://dx.doi.org/10.1016/j.hbrcj.2014.11.007
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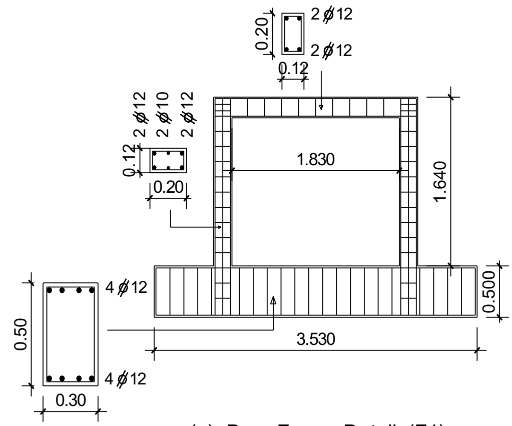
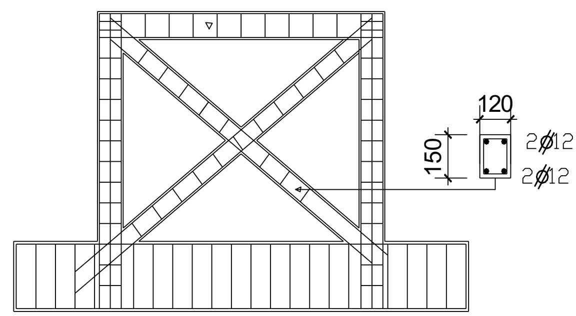
to lateral forces by the bracing action of diagonal members. Fully braced frames are more rigid. From the saving view point arbitrarily braced ones have least forces induced in the structure and at the same time produce maximum displacement within the prescribed limits [1]. In areas of high (sometimes moderate) seismic zones, RC shear walls have been widely used as the main lateral-load resisting system in medium and high-rise buildings because of their inherent large lateral stiffness and load resistance. But, in general, the energy dissipating capacity of RC shear walls is not very good [2]. Until recently, seismic codes are used to assign lower behavior for buildings with shear walls than for buildings with frame systems. For instance, in the CEB Seismic Code [3], q-factors for frame structures vary from 2.0 to 5.0, for coupled shear walls from 2.0 to 4.0, and for isolated walls from 1.4 to 2.8; it is seen that the values for structures with walls are up to 44% lower than for frames. In the uniform building code [4] and Egyptian Code for Loads [5], the behavior factor (or structural response modification factor) is 50% lower for buildings with shear walls, compared with ductile frame systems. At the same time shear wall capacity is more than frames capacity by more than four to five times so it is found that one of the most effective and practical methods for enhancing the seismic resistance and increase the energy absorption capacity of structures is combining two braced elements in the frame. Xu and Niu [2] found that, using concrete K bracing increases the single frame lateral load capacity by about 250% and decreases the yield displacement capacity by about 55%. The value of increase in lateral load capacity was 155% when using steel bracing. Youssef et al. [6] tested three types of steel bracing, and the increases over the not braced were 215%, 150% and 125%, respectively. A 12-story reinforced-concrete building was retrofitted in 1980 after a small earthquake identified seismic deficiencies. Retrofitting included bracing the perimeter frames in the weak (short) direction of the building. The exterior steel truss features heavy steel columns that carry high overturning forces. Truss geometry preserves accessibility to the building and an underground parking garage. The slabs were reinforced to transfer shear to new stiff perimeter frames [7]. The aim of this paper is to present the behavior of the steel and concrete cross bracing and its effect on the lateral load capacity and the dissipated energy of the concrete frame. Also to compare the braced frame with the infilled frame. Hence, it gives an insight about the strengthening of the concrete frames using crossed steel and concrete frames to increase their lateral load capacity.

Experimental program

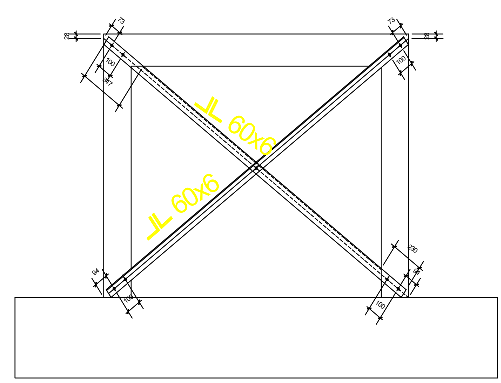
The experimental program consists of four RC frames; specimens F1, F2, F3 and F4. F1 is the bare frame, F2 has a crossed concrete bracing frame, F3 has a crossed steel bracing and F4 has an infill with cement brick. The dimensions and the details of the four specimens are shown in Fig. 1. The concrete bracing was casted with the frame and it could be cast after the frame casting and connected to it by sufficient dowels. The steel bracing (two L-shaped steel angles with equal legs, its size is $60 \times 60 \times 6$ mm) was connected to the frame using hilti bolts 12 mm after the concrete reached its strength (after 28 days). All frames have the same concrete dimensions and steel reinforcements.



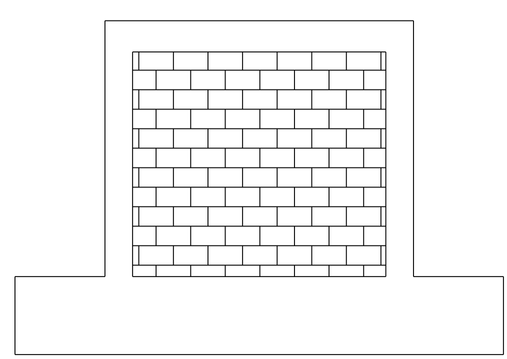
(a): Bare Frame Details(F1)



(b): Concrete Braced Frame Detail(F2)



(c): Steel Braced Frame Detail(F3)



(d):Infilled Frame detail(F4)

Fig. 1 The specimen reinforcement and details (F1, F2, F3, and F4).

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