STRENGTHENING OF LOW DUCTILE REINFORCED CONCRETE FRAMES USING STEEL X-BRACINGS WITH DIFFERENT DETAILS

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ABSTRACT:

Many existing reinforced concrete (RC) frame buildings located in seismic zones, designed according to the past seismic codes are often found to have inadequate lateral strength to withstand major earthquakes. In this paper, the use of steel bracings in concrete framed structures is experimentally presented. A series of tests conducted on eight, one bay-one story, with 1:2.5 scale RC model frames. The object of the tests was to determine the effectiveness of cross bracings with various details of bracing connections to the concrete frames, to increase the in-plane shear strength of the concrete frames. The braces connections in model frames were selected to represent most easy, quick and economical techniques to strengthen RC frames by steel cross bracing system. Hence, two frames were not strengthened (un-braced) and were used as control specimens and six others were strengthened by X-bracings, and with five details of connection between frames and bracings. The details were: (i) using bolts and nuts (in two ways for two frames); (ii) using steel jackets around the columns (in two ways for three frames); (iii) using embedded plates (for welding gusset plates) in frame corners before placing the concrete (for studying possible use of steel bracing system in new concrete frames). Model frames were tested under constant vertical and cyclic lateral loadings. The tests results indicate considerable increase in the lateral strength and/or displacement ductility of strengthened frames upon bracing details.

KEYWORDS: Strengthening, Steel bracing, Retrofitting, RC frames

1. INTRODUCTION

One of the simple, cheap and efficient methods for strengthening of reinforced concrete frames against lateral induced earthquake load is using steel cross bracings [1, 2, 3, 4, 5 and 6]. The combination of reinforced concrete frame with steel cross bracing is not a common practice due to unknown behavior and performance that needs to be investigated. Research on the use of this method of retrofitting has begun since 80s in which cross bracings have been used indirectly together with a steel frame confined by a concrete frame [1, 7-10, 11, 12, 4, 13 and 14]. In addition to its great expenses and its possible unsuccessful economic justification, using this system may cause a dynamic interaction between steel bracing and concrete frames. Although in some cases, using additional steel frame to strengthen existing concrete frame, seems to be necessary, but in the stage of system redesigning, the additional loads transferred by cross bracings can be added to the design loads. This may eliminate the need for an expensive and sometimes bothering steel frame [9]. Therefore, establishing a system of steel cross bracing in a way that it has less economic and technical problems seems to be a proper choice. In order to achieve this goal, the use of steel cross bracings which are directly connected to concrete frame Is studied. There are some reports which show the application of this method in practice [3] and experimental [9] models in Iran. In this cross bracing system, the details of cross bracing connection to the frame have significant effect on the behavior of the system and need to be studied and investigated thoroughly. In this investigation, identical reinforced concrete frames with similar cross bracing elements with different details for the connection of cross bracing to the frames, are constructed and tested.

2. CROSS BRACING CONSIDERATIONS FOR REINFORCED CONCRETE FRAMES

Bracing of reinforced concrete frames is usually performed for the purpose of increasing the strength or strength and ductility against earthquake induced forces [15]. This method is appropriate for strengthening those buildings whose connections have enough strength and can be strengthened in some openings by cross bracing (without any disorder in its serviceability). In this method of strengthening, it is necessary to notice the following cases which have a direct effect on the seismic behavior of the structure and to think of an appropriate policy for each of them [16].

- great stiffness caused by using cross bracings in concrete frames
- earthquake induced loads transferring from top stories to the lower stories and foundations
- compressive and buckling strength of cross bracing elements
- extra stresses occurred in the elements
- extra loads which will be imposed on the foundations
- column strength against the shear force caused by cross bracings
- beam and column connections in the locations of the cross bracing connections
- cross bracing connections to the concrete frames

Steel cross bracing system in combination with moment resisting frame may cause an increase in the stiffness and strength of the structure. In general, moment resisting frame and cross bracing system have two different performances which differ from each other in their type of deformation against lateral loads. The predominant deformation mode of the cross bracing system is flexural which is like vertical cantilever, although, moment resisting frames usually deforms in shear mode. The effect of this phenomenon on the performance of braced frames depends on their height as follows:

In low-rise buildings with moment resisting frames which are strengthened by steel cross bracing system, the difference between the deformation modes of frame and cross bracing system is not considerable, and secondary stresses do not have much effect on the stability of cross bracing frame in a severe earthquake [17]. In these buildings, the lateral stiffness of the moment resisting frame can be conservatively neglected, and design the structure assuming that the cross bracing system can carry the lateral loads; or design the cross bracing system for lateral loads excess the moment resisting frame capacity.

In high-rise buildings which have both moment resisting and cross bracing systems, each system amends the other's weak points to be improved so that there will be an increase in the stiffness and lateral strength of the structure. Furthermore, the difference between the performances of the two systems will lead to a non-uniform distribution of the shear forces between them. This is done in a way that during the lateral deformation in the structure's moment resisting frame in the lower stories, the frame leans to the cross bracing system, and in the upper stories the moment resisting frame itself prevents the cross bracing system from deformation. Therefore, in these stories the shear forces carried by the moment resisting frame may be more than the whole applied shear forces on the structure, because of the negative effect of the performance of the system in the upper stories. Here, according to the common simple methods, the distribution of the shear forces proportional with the strength of structural elements, will lead to unrealistic results. It should be noticed that since carrying the whole lateral forces by the cross bracing system is not that much reliable, so it is also necessary to take the interaction of both systems into consideration [18].

Regarding the above mentioned points, it should be noticed that in those buildings which are strengthened by steel cross bracing system, the behavior of the combined structure will be totally different from that of the primary structure. Hence, in the design of cross bracing systems, proper choice of the changes of response modification factor (R) of the building should be taken into consideration thoroughly [18].

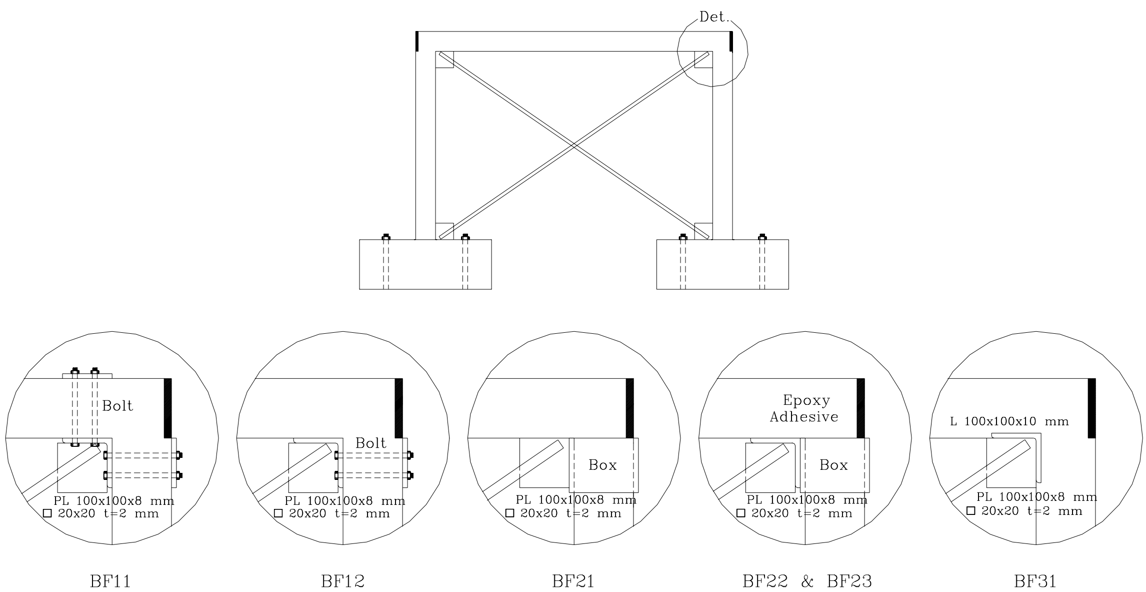
3. EXPERIMENTAL PROGRAM

The experimental research program was carried out at the Structural Engineering Laboratory of Building and Housing Research Center (BHRC). A testing program, consisting of eight 1:2.5-scale concrete frame specimens with the same detailing and construction; were designed to evaluate the seismic behavior of strengthened reinforced concrete frames using steel cross bracings. The specimens were including two not strengthened (i.e. unbraced) frames (UBF11 and UBF12), and were used as control specimens, and six strengthened (i.e. braced) frames, using five details of connection between frames and bracings (BF11, BF12, BF21, BF22, BF23 and BF31). The bracing elements of all braced specimens, constructed as cross bracings; without any connection to the midst of bracing elements (for avoiding the complexity in examination of bracing strain). The specimens are separated from each other by using abbreviator signs. The abbreviations of UB and B are respectively used for unbraced and braced frames. A two-digit number as xy is also used here in which the x digit shows the details of bracing connection to frame, and the y digit is the identification code of the sample. This codification leads to the aforementioned signs. Both of the unbraced frames are completely similar to each other and in the other six braced frames, three details are used (in 5 ways) to connect the bracings to the frames.

3.1. Description of Strengthened Specimens

BF11 and BF12: As shown in Figures 1(a), and 1(b), in these specimens, bolts and nuts was used for the connection of bracings and frame. In BF11, an angle was fixed to the interior face of the frame's edges by bolts and nuts. This was done by making a hole in the body of the beam and column by a drill. In the other side (exterior surface) of the beam and column, steel plate with filler was used. Angles' edges of the columns' bases, which were located on the foundations, are connected to foundations' bolts, which connect the foundations to strong floor, by using steel plates. In BF12, the same method was used for connecting the bracings to frame in which beam connection was eliminated.

BF21, BF22 and BF23: Bracing connections to frame for these specimens were performed by using a jacket box as shown in Figures 1(c) and 1(d). This cover consists of four angles which were welded together and surround the column. This method is simpler than the other methods in which it is not necessary to drill or destroy the beam and floor slab in the column connection. In the first specimen (BF21), no consideration was taken into account to contact the steel box to the concrete surface. In other words, the steel cover could slip over the column surface in the case of large displacements. But in the second (BF22) and third (BF23) specimens, epoxy adhesive has been used to stick the steel jacket to the concrete column surface and a part of the beam.



(a) (b) (c) (d) (e)

Figure 1 Strengthened specimens with cross bracings and their connections' details

BF31: As it is shown in Figure 1(e), in this specimen the connection of bracings to frame was performed by the use of angles which have already located in the corner of beam and column connection before concreting. That was, during reinforcing, there were anchorages that have been welded on the angles which were fixed to the frame's reinforcements and then the formworks installed and the concrete frame was casted. Finally the gusset plates were welded to these embedded angles. This detail is considered to study the possible use of steel bracing system in new concrete frames.

3.2. Test Setup

Loading steel frames (triangle frames) and also concrete frames, which were to be tested, were fixed to the strong floor of laboratory by bolts and nuts, in order to prevent them from possible displacements. This was performed by preparing some holes to fix the frames' foundations to the strong floor of the lab. All measuring devices were placed in appropriate locations and connected to data logger for digital recording.

The specimens' columns were built upon rigid reinforced concrete foundations of 800 mm long by 300 mm width and 300 mm height, which were fixed to strong floor of laboratory. The schematic test setup is shown in Figure 2.

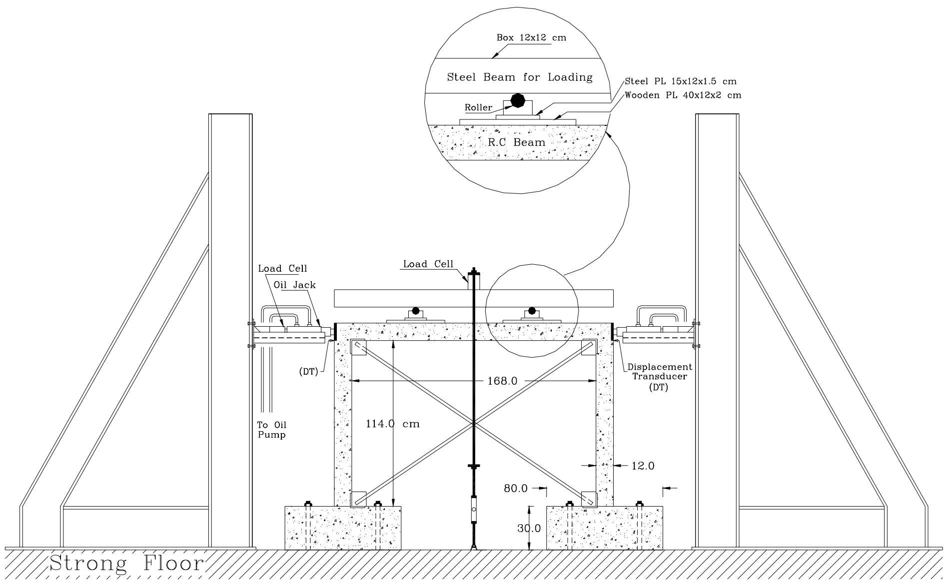


Figure 2 Test setup and loading systems

3.3. Loading Procedure

Two different loading systems were designed in order to apply simultaneous vertical and lateral loads to the frames. Cyclic lateral loads were simulated by imposing lateral forces to the specimens' top corners using two hydraulic jacks on each side (Figure 2). The two jacks were operated in load and displacement control (before and after peak load). In addition each specimen was subjected to an approximately constant vertical load to simulate gravity loading effects. The vertical load was applied on some parts of the beam in the form of two span loads. The vertical loading system was designed in a way that the load was applied on the beam by a pull from the bottom with the help of a turnbuckle. The compressive load cell, which was located over the loading steel beam, used to measure the applied vertical load. Here two roller bearings were used to prevent the process of lateral displacement from being interrupted by the vertical loading system (Figure 2). The vertical loading system was the same in all of the frames.

The loading histories applied to specimens are shown in Figure 3. The frames were instrumented with linear variable differential transducers (LVDTs), in order to measure horizontal displacements at the top of the specimens during vertical and horizontal loadings. Two flat load cells placed between the loading arms and test specimens were used to monitor applied loads. Frames were carefully checked for cracks and crushing, which were noted and marked clearly on the test specimens.

3.4. Description of Test Results

Sample frames were tested under a cyclic lateral load and a vertical load of 18 kN (Figure 3). This figure shows the hysteretic behavior of the frames and also the strain in cross bracing elements against cyclic lateral loads. It can be understood from these curves that in UBF11 and UBF12, unbraced frames, stiffness, strength and energy absorption of them are very little, and so much stiffness degradation is observed in successive cycles. In BF11, braced frame, stiffness and strength of the frame have been significantly increased. In BF12, despite the degradation in the stiffness, here, relative increase in strength together with energy absorption and dissipation is being observed. Hysteretic loops have been pinched because of the slipping of the jacket connection to the columns, and the confined area is made small by a loop which shows the energy dissipation capacity. In BF22 and BF23, stiffness degradation is almost low, and there is significant increase in the strength and proper energy dissipation. In BF31, stiffness is degrading gradually, and both strength and energy dissipation is increasing considerably.

Comparison between different behaviors of the frames shows that BF22, BF23 and BF31 have a better performance than the other frames, because despite the significant increase in the strength of these specimens, the confined area and the extension of the hysteretic loops is more than before.

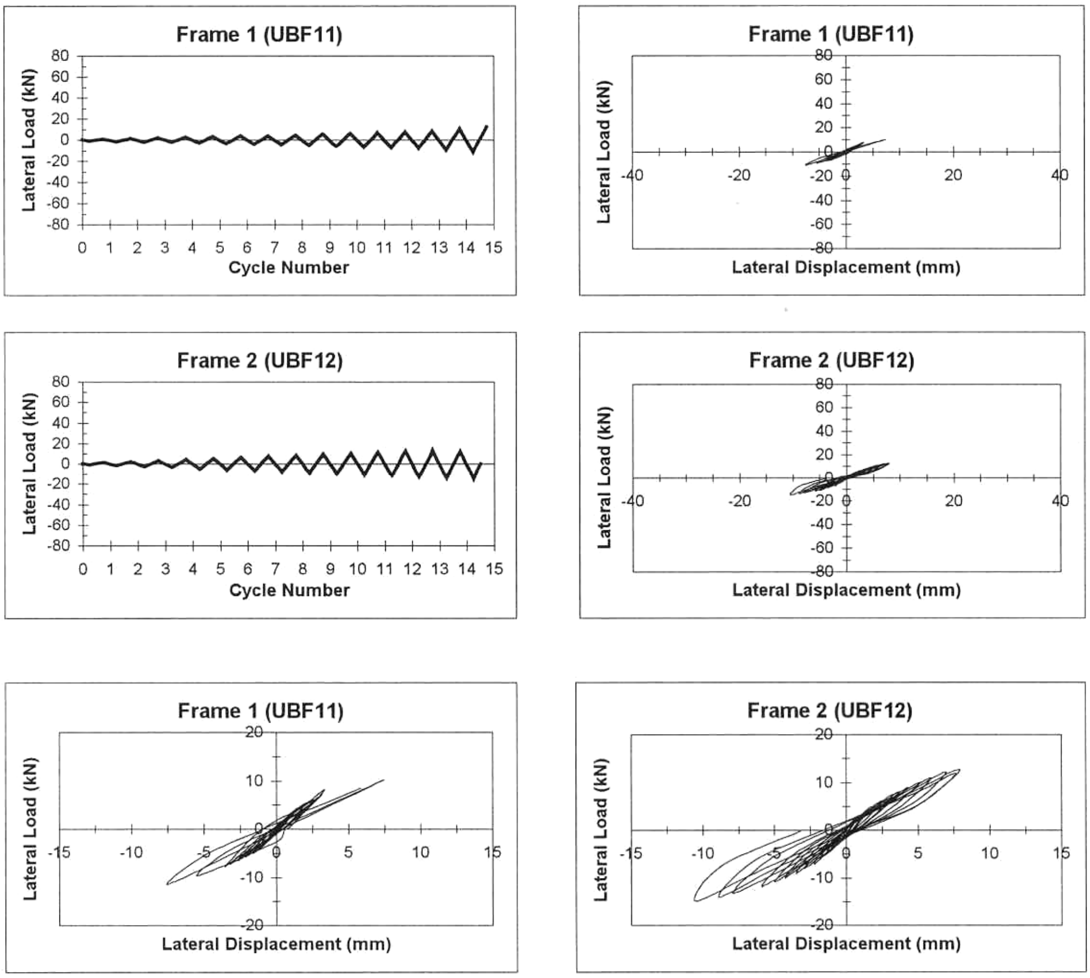


Figure 3 Cyclic lateral loads applied to the frames and their relevant hysteretic behavior

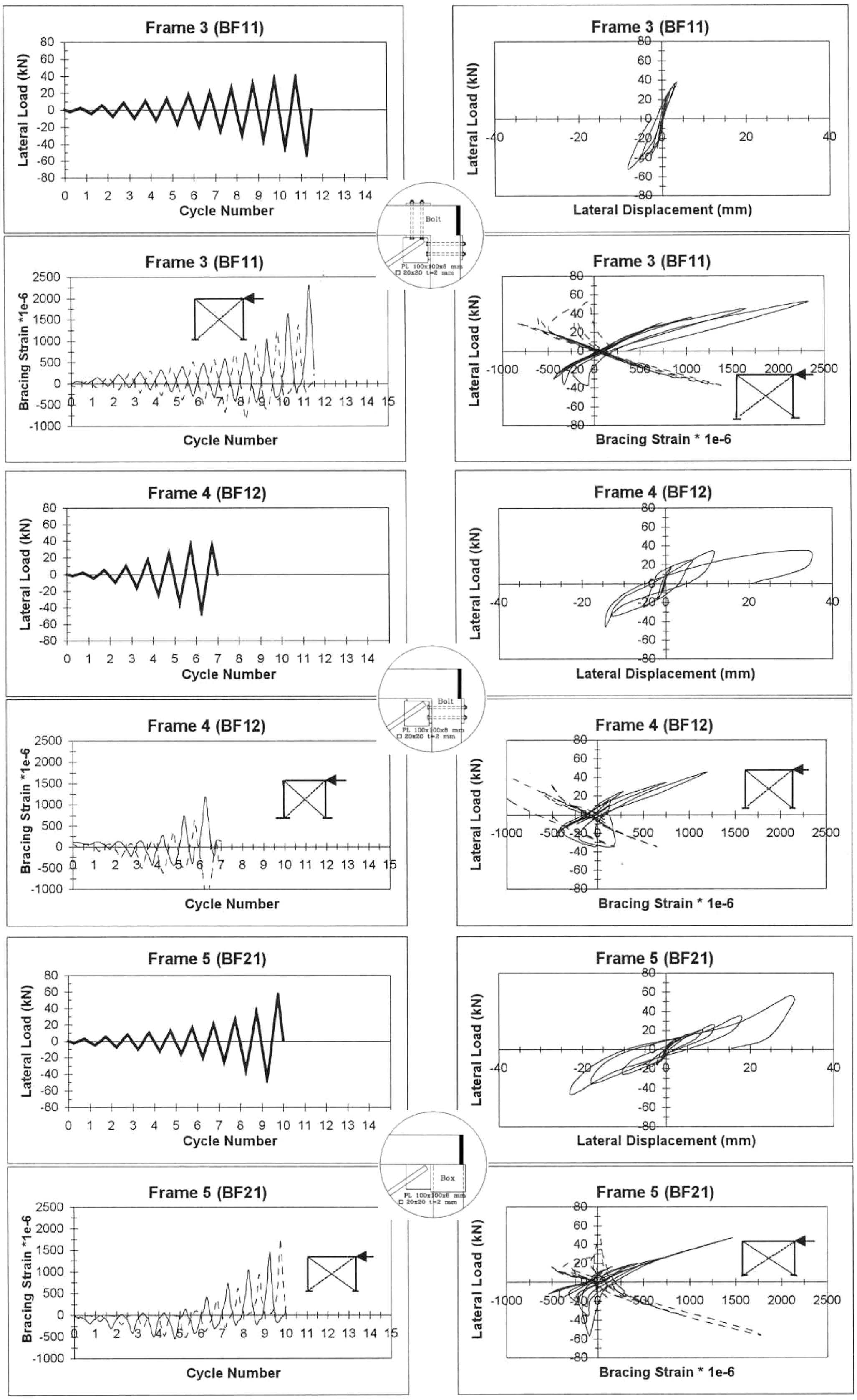


Figure 3 (Continued) Cyclic lateral loads applied to the frames and their relevant hysteretic behavior

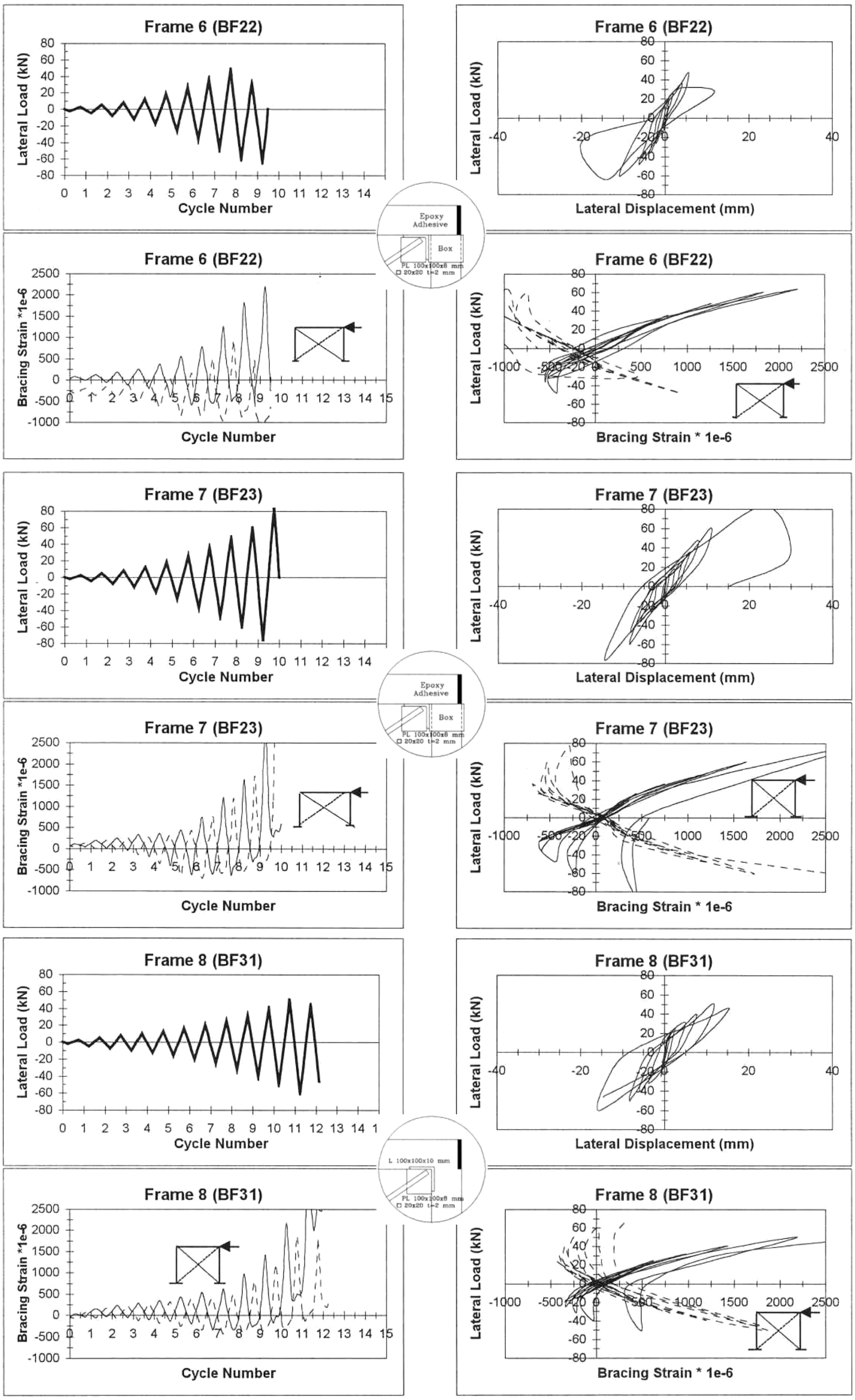


Figure 3 (Continued) Cyclic lateral loads applied to the frames and their relevant hysteretic behavior

4. CONCLUSION

Regarding the results of the analyses of the tests and drawn curves, it can be claimed that adding cross bracings to reinforced concrete frames, depending on the details of the connections, would significantly increase the frame stiffness and change its behavior; but using steel cross bracings, which are not connected to each other in the midst for strengthening the concrete frames, does not change the frames failure mechanism. Among the five types of details of cross bracing connections to frame, the bolts and nuts with connection to beam and column (BF11) increases the frame stiffness in a way so it can be claimed that this model is suitable for low to medium-rise buildings. The bolts and nuts with connection to columns (BF12) don't have that much strength, and strength deterioration is very significant in it; although it is used to increase in the primary steps. Therefore, such details do not seem suitable here. Details of the connections in the form of jacket, without epoxy adhesive (BF21) do not have a suitable performance, because of the slip of steel covering, so it is not recommended to be used. But when the jacket is connected to the frame by epoxy adhesive (BF22 and BF23), and also when the connecting elements of cross bracings and frame, is located in concrete (BF31), the frame has a better performance and therefore much more energy is absorbed.

It is worth mentioning that cyclic loading cause the strength and stiffness to decrease and the displacement to increase in inelastic behavior. As a fact, tensile cross bracing in braced reinforced concrete frame supports a great portion of lateral load, but frame failure caused by the yielding of tensile bracing, occurs after the buckling failure of compressive bracing.

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