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BRACED FRAME USING ASYMMETRICAL FRICTION CONNECTIONS (AFC)

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Abstract: *A single storey moment resisting frame with one bay and equipped with a concentric AFC brace was tested. The asymmetrical friction connection brace (AFC brace) was assembled using one 250PFC channel, two Bisalloy 500 shims, and two M16 Grade 8.8 galvanized bolts. Results show that by introducing the AFC brace, the frame can undergo drifts up to 3.0% without yielding any frame member or component, and more importantly with low degradation on the AFC detail. Results also show that the amount of load that the frame can absorb during a seismic event can be controlled by the AFC brace strength.*

1 INTRODUCTION

The first application of Asymmetrical Friction Connections (AFCs) was based on placing the AFC detail in beam-column joints of moment resisting frames where energy is dissipated when the joint rotates and overcomes the friction force resulting from the clamping force provided by the bolts on the AFC details (Clifton 2005). The concept of braces equipped with an AFC detail at one end of the brace (AFC brace) was proposed by Butterworth 1999, MacRae 2008, and Chanchi et al. 2012. In this type of braces energy is dissipated when the brace experiences axial elongations and the axial force overcomes the friction force on the AFC detail. Testing of AFC braces have been undertaken recently at the University of Canterbury – New Zealand. Results indicated that this type of braces can be considered as fuses for reducing damage associated with a severe seismic event in different structural systems (Chanchi et. al. 2014). However, (i) to date there is not reference of any experimental program supporting this concept, and (ii) the actual behavior of moment resisting frames with AFC braces is unknown. In order to address these issues this paper reports on the quasi-static testing of a single bay frame with an AFC brace and aims to answer following questions:

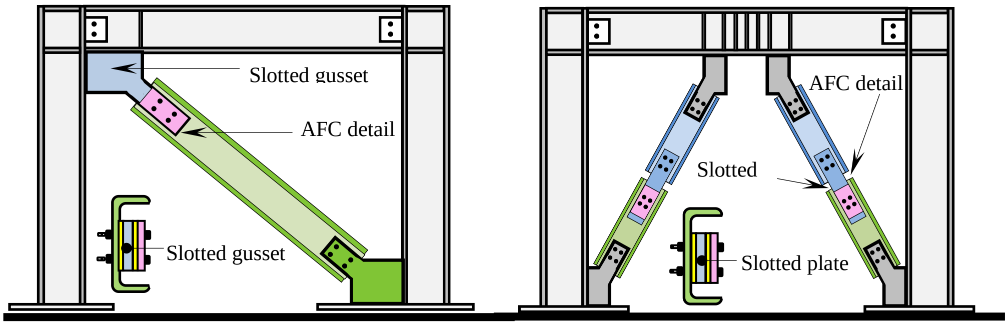
i) What is the hysteretic behaviour of the frame with the AFC brace?

ii) What are the benefits of using AFC braces in moment resisting frames?

iii) Can AFC frames be regarded as low damage structural systems?

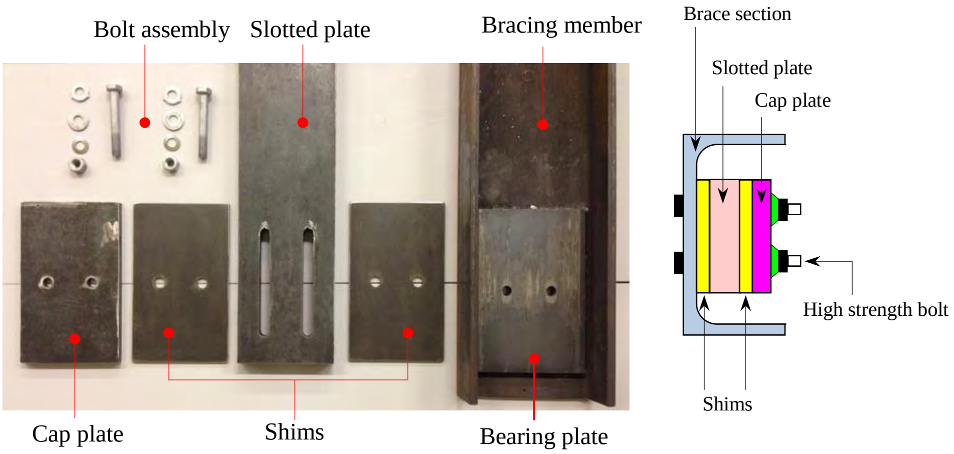
2 CONCEPT

AFC braces are braces that can be assembled using a bracing member and an AFC detail that can be placed at one end or within the bracing member (Figure 1a, b). The AFC detail is assembled by clamping onto the bracing member a slotted plate and a cap plate by means of high strength bolts (i.e. bolts with ultimate strength around 800 MPa.). Thin plates termed shims can be inserted at the interfaces between the slotted plate and the bracing member, and at the interface between the slotted plate and the cap plate in order to improve the hysteretic behavior of the AFC detail. The use of a bearing plate welded on the bracing member is also recommended in order to prevent any bearing issue resulting from the force transmission from the bolts to the bracing member (Figure 1c).



a. AFC brace with AFC detail at one end on singly braced frame

b. AFC brace with AFC detail within the brace on eccentrically braced frame



c. AFC brace components and AFC detail cross section

Figure 1. AFC brace

The AFC brace can be installed in a moment resisting frame by attaching each end of the AFC brace on to a gusset by means of a bolted or welded connection. In both cases the brace can absorb moment from the frame joint, to minimize this issue a pinned connection can be used so that the brace is subjected to axial load only. AFC braces are considered as a fuses that dissipate energy through friction, and they can be used to protect the frame members from yielding at large drifts (i.e. drifts greater than 1%). Energy

A-A

Brace section

dissipation in the AFC brace is developed when the slotted plate is pushed or pulled to a force that is greater than or equal to the clamping force induced by the bolts on the AFC detail so that the sliding mechanism of the slotted plate is activated. The force that fully activates the sliding mechanism of the slotted plate is termed sliding force, and the magnitude of this force depends on the number of bolts, on the number of sliding interfaces (i.e. 2), on the assembling force on the bolts (i.e. bolt proof load), and on the effective friction coefficient directly related to the type of sliding surfaces. The use of Mild Steel slotted plates and high hardness shims such as Bisalloy 400 or Bisalloy 500 shim is recommended in the AFC detail in order to achieve a stable hysteretic behavior (Chanchi et al.2011).

3 APPLICATIONS

AFC braces are designed to dissipate seismic energy. Dissipation of seismic energy is achieved when the frame is laterally loaded and deformed by the seismic forces that induce axial loads on the AFC braces. Depending on the magnitude of the axial force on the AFC brace two stages can be identified on the behavior of the frame: (i) an initial stage where the seismic forces can increase and the axial load on the brace is less than the force that triggers the sliding of the slotted plate. This stage can be considered as the relatively stiff elastic phase of the frame as shown in Figure 2, and (ii) a second stage where the seismic forces induce an axial force on the brace that is greater than or equal to the force that triggers the sliding of the slotted plate. As the slotted plate slides the stiffness of the frame reduces significantly and the frame deforms laterally with only minor increments on the lateral load as shown in Figure 8. This second stage can be considered as the inelastic phase of the frame where sliding on the AFC detail limits the seismic energy being transferred to other critical members of the frame such as the beams, the columns and the beam-column joints, thus protecting those critical members from limit states such as yielding or buckling (Butterworth 1999, MacRae 2009, Chanchi et. al. 2012).

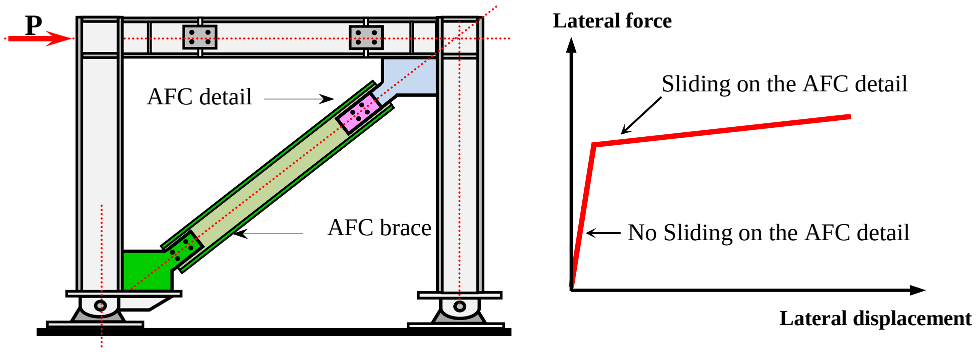
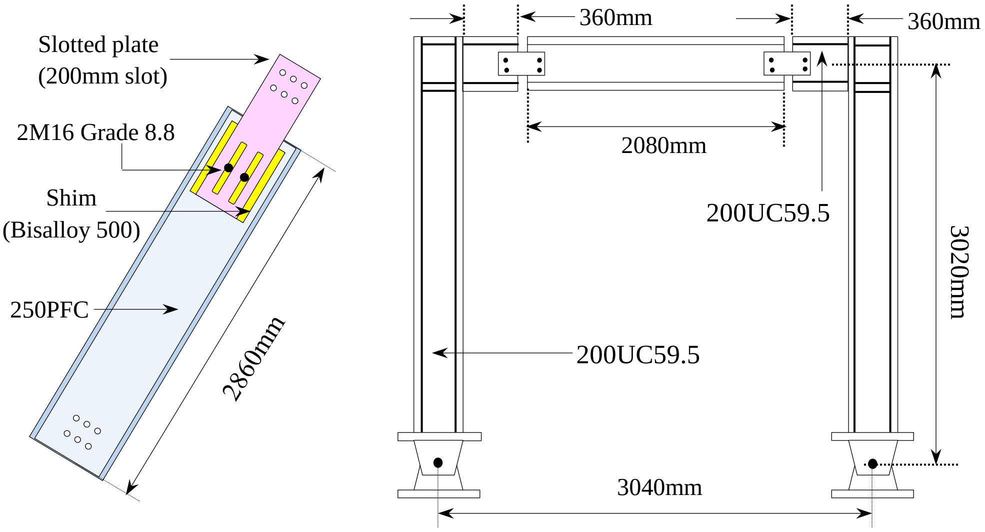


Figure 2. Theoretical behaviour of moment resisting frames equipped with AFC braces.

4 MATERIALS

A Grade 300 steel hot rolled 250PFC (i.e. parallel flange channel cross section) with 2860mm length was used as bracing member. The web of the bracing member was reinforced at the location of the AFC detail by welding a Grade 300 plate with 16mm thickness aiming to avoid any bearing issue related to the transference of load from the bolts to the web of the bracing member. The AFC detail was assembled with a Grade 300 steel cap plate, two Bisalloy 500 shims, a Grade 300 steel slotted plate with two 200mm elongated holes, and two M16 Grade 8.8 bolts of 130mm in length with single Belleville washers. The threaded length of the bolts was 60mm. Thickness of 16mm, 6mm, and 32mm were used for the cap plate, shims, and slotted plate respectively (Figure 3a).



a. AFC brace dimensions b. Bare Moment Resisting Frame dimensions

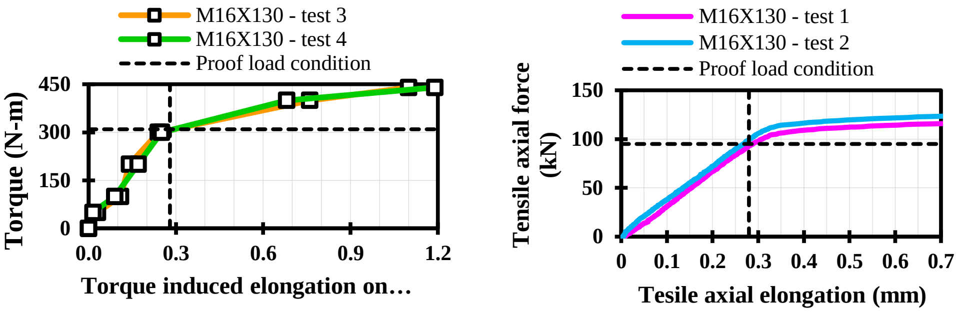
Figure 3. Dimensions of the AFC brace and the bare Moment Resisting Frame

Grade 300 200UC59.5 steel hot rolled I-section was used for assembling the columns and beams of the moment resisting frame. The beam of 2830mm length was assembled with two short beams of 360mm length and one long beam of 2080mm length. Each end of the long beam was connected to one of the short beams using two 20mm thick Grade 300 steel plates and four M24 Grade 8.8 bolts of 90mm in length. The gap between each short beam and the long beam was 15mm. The columns of the frame were designed to be continuous and their bases were welded to pin connections bolted onto the reaction floor. Beam-column joints were rigidly assembled by welding the beam all around onto the column. Two gussets Grade 300 with 40mm thickness with six standard holes of 24mm were used to bolt the AFC brace onto the frame. The top gusset was eccentrically bolted onto the short beam and onto the column with an eccentricity of 48mm in order to line up the AFC detail with the bracing member, and the bottom gusset was concentrically bolted onto the column and onto the pin connection. Global dimensions center to center of the frame member were 3040mm wide, 3020mm tall, and with a brace length of 2860mm (Figure 3b).

5 EXPERIMENT METHODS

5.1 Assembling Methods of AFC details

The AFC detail in the brace was assembled with the torque control method by using a calibrated torque wrench. The amount of torque required to tension the bolts up to the proof load (proof load torque) was extrapolated from a relationship between the applied torque and induced bolt elongations found from two bolts with same length as the ones used in the AFC detail (Figure 4a). The bolt elongation used to extrapolate the proof load torque was defined as the elongation exhibited by two bolts when reaching the proof load from tensile testing (Fig. 4b). Using this methodology, the proof load torque was defined to be 310N-m from the hand tight condition. This value of proof load torque correspond to nut rotations of 1/4 – 1/2 of turn when considering the nut rotation method.



a. Torque-bolt elongation relationship

b. Tensile testing relationship

Figure 4. Relationships used for assembling the AFC details.

5.2 Testing Procedures

Testing of the frame was carried out on a setup where the pinned bases of the columns were attached to a reaction floor, and the top side of the left column was pinned onto an actuator pinned onto a reaction tower. This setup was instrumented with a load cell in series with the actuator, a rotatory pot placed on the top of the right column, and an extensometer placed across the AFC detail (Figure 5).

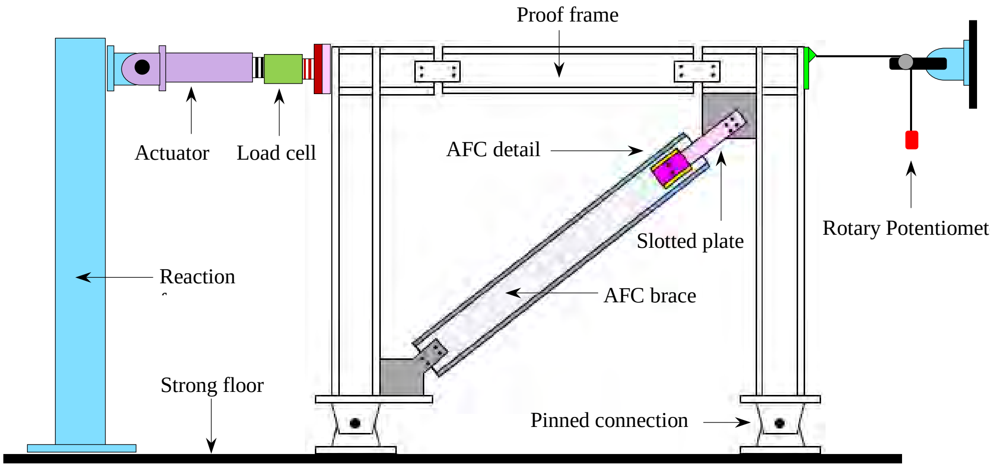


Figure 5. Testing setup of AFC frame.

Testing was based on subjecting the frame to a cyclic displacement regime with a constant velocity of 3mm/s, the displacement regime comprises 20 sawtooth cycles with amplitudes ranging between 3mm and 90mm that correspond to lateral drifts on the frame of 0.1% - 3%. (Figure 6). Testing of the frame comprised two stages: (i) an initial stage where the frame without the AFC brace (bare frame) was subjected to the displacement regime, and (ii) a final stage where the frame with AFC brace (AFC frame) was subjected to the displacement regime. In the final stage the AFC brace was bolted onto the top and bottom gussets by using slip critical connections of 6 M24 high strength bolts (i.e. Grade 8.8 with an ultimate strength of 880 MPa).

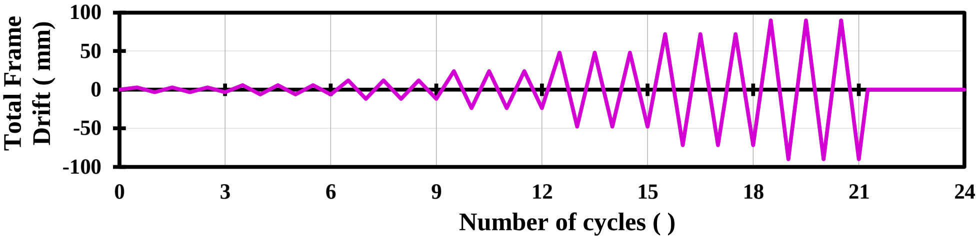


Figure 6. Displacement regime.

6 RESULTS

6.1 Hysteretic behaviour of the AFC brace itself

Testing of the AFC brace itself was carried out by Chanchi et al. 2014 when quasi-statically testing an AFC brace with same dimensions and configuration to the AFC brace used in this research work. Hysteresis loop recorded by Chanchi et al. 2014 are used here as benchmark to quantify any benefit on using the AFC brace as dissipater of the bare moment resting frame (Figure 7).

Figure 7. Hysteretic behavior of an AFC brace using Bisalloy 500 shims and two galvanized grade 8.8 M16 bolts.

In Figure 6 it can be seen that the hysteresis loop is almost rectangular, and two well defined stages termed pre-sliding and sliding can be observed. In the pre-sliding stage the hysteresis loop adopts a very steep stiffness tendency interrupted by a zone with very low stiffness where the bolts are laterally loaded by the shims after the slotted plate and the shims slide due to the bolt hole tolerance. This stage represents the case before the sliding mechanism of the slotted plate is fully activated. In the sliding stage where the sliding mechanism of the slotted plate is fully activated and the slotted plate slides for a given distance the hysteresis loop adopts a very low stiffness. Increments in force presented as the slotted plate slides are attributed to the development of prying forces resulting from the eccentricity between the slotted plate and the brace section. It can be also seen that the sliding forces in tension on the top side of the hysteresis loop are 10% greater than those in compression on the bottom side of the hysteresis loop.

6.2 Hysteretic behaviour of the bare frame

The hysteretic behaviour of the frame in Figure 8 shows that frame performed to the horizontal load in a bilinear fashion, with no post-elastic stiffness. That means that the hysteresis loop is defined by an initial stage with a linear tendency and a final stage with a flat tendency.

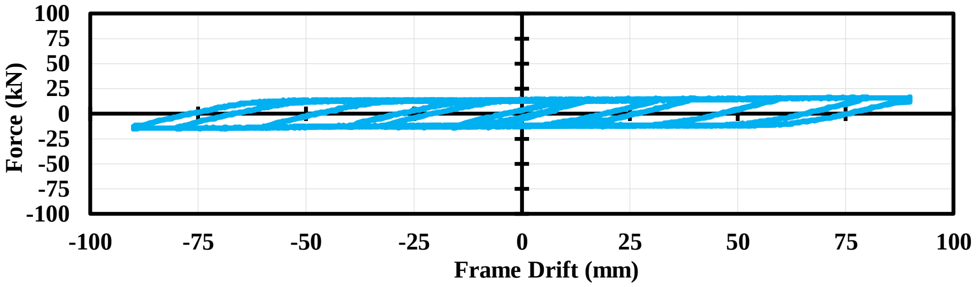


Figure 8. Hysteretic behavior of the bare frame.

The initial stage is termed elastic and it is defined by the lateral stiffness of the frame where increments on lateral load produce increments on the lateral drift. The final stage is characterized by the increments on the drift of the frame for a constant lateral load. This behaviour occurred not because of the yielding of any of the frame members, but it was caused by the generation of a two hinge mechanism at the connections of the long beam with the two short beams. Hinges were developed when the axial force on the beam overcame the frictional clamping force at the beam connections allowing the long beam to rotate so that the frame behaved with two frictional hinges at the beam and two pins at the base of columns.

6.3 Hysteretic behaviour of the AFC frame

Figure 9 shows the hysteretic behaviour of the AFC frame. The hysteretic behaviour of the AFC frame can be described as stable and similar to the hysteretic behaviour of the AFC brace shown in section 6.1. For that reason, it can be said that the behaviour of AFC frame is significantly influenced by the behaviour of the AFC brace, and that the behaviour of the AFC frame can be idealized from two stages that adopt the same tendency to the pre-sliding and sliding stages observed in the hysteretic behaviour of the AFC brace.

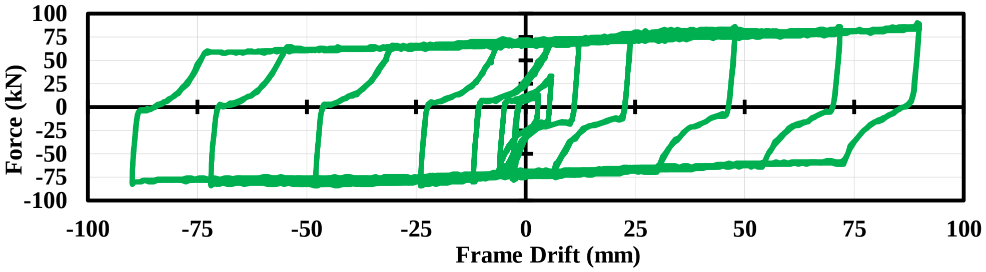


Figure 9. Hysteretic behavior of the singly braced frame.

When comparing the hysteresis loop of the AFC brace with the hysteresis loop of the AFC frame it can be seen that the latter is more symmetrical. That means that the presence of the frame benefits positively the behaviour of the AFC brace reducing the occurrence of the prying effect due to the high stiffness of the connections at the ends of the brace. It can be also seen that the force that triggers the sliding mechanism of the slotted plate on the AFC brace (i.e. ranging between 60kN and 80kN) is similar to the variation of the force at the inelastic stage of the AFC frame showing that the lateral load capacity of the frame can be controlled by the strength of the AFC brace. In addition, when comparing the hysteresis loop of the bare frame with the hysteresis loop of the AFC frame, it can be seen that the force at the initiation of nonlinear behaviour in the AFC frame is much greater than the similar force in the bare frame showing that by adding the AFC brace to the bare frame the strength can be increased with no damage on the frame. For that reason that AFC braces can significantly enhance the lateral performance of the moment resisting frames allowing this type of structural systems to undergo high drifts with minor to no structural damage. This happened even though there was rubbing of the bolts on the sides of the slots during the lateral displacements.

7 CONCLUSIONS

This paper describes the hysteretic behavior of a singly braced frame equipped with an AFC brace (AFC frame). It was shown that:

i) The hysteretic behaviour of AFC frames is stable and almost rectangular. This hysteretic behaviour can be described by an initial stage termed pre-sliding where the frame absorbs lateral load until the sliding mechanism of the brace is activated, and a second stage termed sliding where the frame can undergo high drifts with very low increments on the lateral load.

ii) By adding AFC braces to moment resisting frames the lateral capacity of the frame can be controlled and assumed equal to the force that fully activates the sliding mechanism of the slotted plate on the AFC brace. AFC braces also increase the ductility of moment resisting frames allowing them to undergo high drifts without yielding any frame member and with low damage on the brace.

iii) AFC frames can be considered as low damage structural systems given that the hysteretic behaviour is stable over an amount of cycles comparable to those typical in a severe earthquake, and also because AFC frames can dissipate the seismic energy via friction and exhibiting large drifts rather than yielding or degrading severely any member or component of the structural system.

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