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CONCENTRIC BRACED FRAMES WITH AFC CONNECTIONS – A DESIGNERS VIEW

B. J. Leslie[1], S. Gledhill[2], M. Moghaddassi[3]

ABSTRACT

This paper provides a designer's view on Asymmetric Friction Connections (AFC), its advantages and disadvantages, and how to consider its application in Concentrically Braced Frames (CBF).

AFCs are a type of sliding friction connection specifically developed by the University of Canterbury and The University of Auckland to enable engineers to select a joint connection type and determine a pre-set yield point through a defined displacement for a known ductility. Friction connections can dissipate significant amounts of energy, assisting the remainder of the building to remain within the elastic limits. The dissipation of energy in these connections is achieved through a stable sliding mechanism and additional frictional damping along hardened low alloy abrasion resistant shims. In this context, friction connections can provide an efficient means of seismic energy dissipation as they offer a predictable response which is also simple to design and construct.

Based on recent research conducted at the University of Canterbury on AFCs, and the application of this technology on three projects by Aurecon - New Zealand, it has found that CBFs using AFCs are more cost effective compared to the conventional systems. More specifically, the connection provides a better protection to the braces, collector beams, and columns resulting in more economic section sizes. In addition, significantly less damage is expected for the frames with AFC systems, particularly, at maximum credible earthquake (MCE) level, while similar lateral resistance to the conventional CBFs is still provided. The AFC type connection when employed within a CBF system also offers advantages over buckling restrained brace systems (BRB) as it provides similar performance at lower cost.

Introduction

Steel framed buildings are the perfect material for the Christchurch rebuild for many reasons, mainly as they are fast to construct, robust, and easily fire protected; but most of all they are generally more resilient than reinforced concrete buildings. Certain types of bracing systems are stiffer and offer wall like performance and generally have lower drifts than steel frames.

Diagonally braced steel frame systems such as eccentrically and concentrically braced frames offer wall like emulation, without comparable levels of damage experienced by wall structures. Whilst the EBF has undoubtedly performed well in the Christchurch earthquakes, the 'Achilles heel' of CBF's has always been the wide variance in buckling modes of the diagonal brace which has always demonstrated a limited ductile response. To provide greater levels of certainty in this valuable system the addition of a resilient and ductile end fuse connection between the frame and the diagonal brace provides the designer the exciting opportunity of:

- Reviewing Building Geometry
- Choosing an appropriate joint ductility
- Designing an AFC connection family for a project
- Sizing a brace using appropriate member category, slenderness limits then using a capacity design approach to size collector beams, columns and hold down bolts.

[1]Structural Engineer, Aurecon, Level 1, 102 Customhouse Quay, Wellington 6022.
[2] Technical Director, Aurecon, Level 1, 102 Customhouse Quay, Wellington 6022.
[3] Structural Engineer, Aurecon, Level 1, 102 Customhouse Quay, Wellington 6022.

Low Damage Design Philosophy

Prior to the Christchurch earthquakes in September 2010 and February 2011, the public's perception may have been that structural engineer's designs were robust and conservative, and would be recoverable from a disaster. They did not foresee the reality that if a building suffers an Ultimate Limit State (ULS) earthquake, i.e. design earthquake, it would likely become an economic right off requiring demolition. That scale and nature of the damage could not have been expected, nor is wished to be seen again.

Traditionally, modern structures are designed and detailed for an appropriate level of ductility. A well detailed ductile structure will undoubtedly perform well in terms of its ability to survive a big event and dissipate seismic energy via predetermined hinge zones. However, it might be significantly damaged requiring major repair or demolition. Clearly, compliance with strength and displacement requirements of our standards does not necessarily address or limit control of 'damage'.

However, society now expects engineers to provide resilience to their buildings – and they are right. The engineers should consider low damage or resilient structures, and should work hard to provide them as the natural evolution of capacity design. In addition, it is important to note this expectation unnecessarily limits consideration of low damage design due to the cost perception of the available technology.

It has been a well-documented recent trend from research institutions to consider incorporating a 'low damage design' philosophy in the structural design process. Numerous academics have been leading the charge utilising both concrete and steel structures. While numerous presentations of concepts and test buildings have been presented to consulting engineers, a common market perception is still that some of these solutions are neither elegant nor cost effective to implement. To date only a handful of steel structures have been designed and detailed with true damage avoidance features.

For steel structures, suitable low damage systems of consideration include: 1) Concentrically Braced Frames (CBF) with Asymmetric Friction Connections (AFC); 2) rocking systems; 3) Buckling Restrained Braced systems (BRB); and 4) braced systems with viscous dampers. Herein, Aurecon – New Zealand's findings on one of the low damage solutions proposed for traditional CBFs is discussed.

Concentrically Braced Frames (CBF)

Traditional CBF Systems

The Christchurch earthquake of February 22, 2011 caused significant damage to unreinforced masonry buildings, and some limited, but notable, failures of a significant number of reinforced concrete buildings. On the other hand, steel structures performed better, considering the severity of the earthquake. Considering the different types of steel structures that survived this earthquake, Eccentrically Braced Frames (EBF) and Concentrically Braced Frames (CBF) performed notably well (Bruneau et al 2011).

In traditional CBF systems, the bracing elements are subjected primarily to axial forces responding to the seismic loading. In this context, to force the system beyond the elastic response, the inelastic demands are concentrated into the braces. Therefore, the inelastic behaviour of the CBF systems is very dependent on the effect of inelastic demand on the braces. More specifically, the CBF behaviour mainly depends on: 1) the slenderness ratio of the braces; and 2) the structural form of the bracing elements (HERA Report 1995).

The slenderness ratio has a significant influence on the inelastic behaviour of the bracing elements since they respond less satisfactorily in compression. Figure 1 illustrates hysteresis response of the bracing elements in tension and compression with slenderness ratio of 40, 80, and 120.

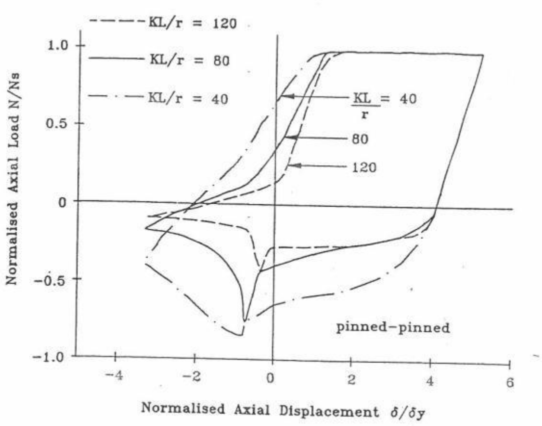


Figure 1. CBF’s hysteretic behaviour (HERA Report R4-76 1995)

Clearly, when the system is in tension, a more stable and energy dissipative hysteresis response is expected. However, when the system experiences the compression cycles, the inelastic mechanism achieved is not favourable, especially for slender braces.

Due to this less favourable response of CBF systems in compression, i.e. buckling potential of the braces, NZS 3404, requires CBF systems to have: 1) braces in pairs; 2) a maximum height limitation; and 3) an increased seismic load coefficient.

Considering the above mentioned unsatisfactory response of the CBF systems in compression, and the subsequent limitations imposed on the design procedure, a great need is recognised to evolve the system and use all its advantages. In this context, a modification should be think of to prevent the bracing elements from buckling, while still providing some energy dissipation mechanism. Some research has been carried out at the University of Canterbury in this regard (Chanchi et al 2012). The outcome of these works is a connection solution called the AFC connection.

Low Damage Evolution of CBF Systems

Buckling Restrained Braces (BRB)

In the late 1990’s, in recognition of the damage potential of CBF systems, researchers developed proprietary systems such as Buckling Restrained Braces (BRB) to be used conjunction with CBF frames. BRB’s involve a steel insert within a grout filled steel tube sleeve. The systems have been tested in laboratory conditions involving thousands of cyclic tests conducted on different arrangements with varying levels of performance observed.

BRB’s provide a measure of resilience through dependable tension and compression yielding, and demonstrate good hysteric behaviour with limited slip and loss of strength, although are prone to some levels of post event residual displacements.

Using a strength hierarchy approach, proprietary BRB systems of known strength and ductility enable the designer to de-tune the frame member categories, whilst still complying with the code. These evolved systems are more economic and dependable, capable of surviving the main earthquake event and thousands of subsequent aftershock scenarios. It’s this reliable nature of the brace, and the protected approach to the design of its connections, supporting beams and columns that have evolved from traditional CBF frames.

Recently, research and development on CBFs has focused on exploring the system performance of areas such as collector beam interaction with composite floor systems, considered the elastic column concept, axial column shortening and impact of base plates and hold down bolts.

Asymmetric Friction Connection (AFC)

Until recently, the challenge in the New Zealand context has always been the weak relative strength of our currency, making the cost of importing proprietary braces prohibitive. This has brought about the need for local innovation.

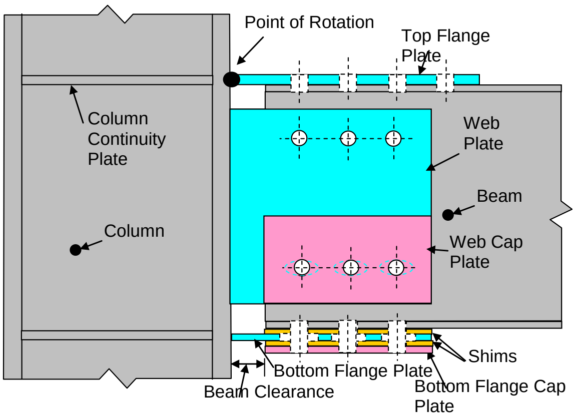
Following the 2011 Christchurch Earthquake sequence, engineers and researchers have widely recognised the need for stiff, low displacement/drift structures that remain resilient with only minor levels of damage. Following a design level seismic event, building bracing systems needed have a resilient backbone or skeleton and have easily replaceable parts and components.

In response to the growing societal and engineering fraternities drive towards low damage design or recoverable buildings, recent research has looked to further evolve seismic structural systems. Significant volumes of work has been conducted at the University of Canterbury and The University of Auckland centring around the Asymmetric Friction Connection (AFC), primarily following the work of Dr Charles Clifton and his invention of the semi rigid flexure AFC connection known as the Sliding Hinge Joint (Clifton, 2005).

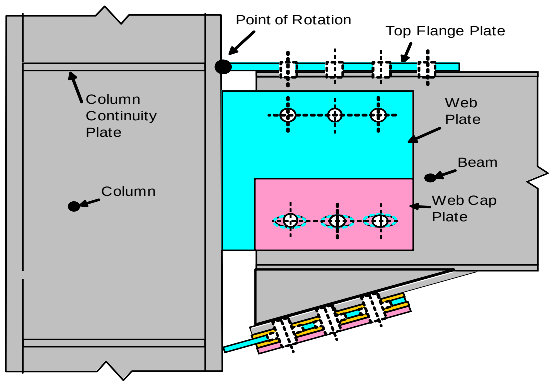
Researchers and structural engineers such as Aurecon have proposed the evolution of the CBF system, using simple components and bolted connections, by replacing the “buckling brace” with AFC connections. The evolution 4 of this structural system creates a formidable, resilient and highly cost effective system, made all from local parts.

The system is simple to design and construct, and offers reliable performance (in the right conditions) to ensure the CBF frame is recoverable post event.

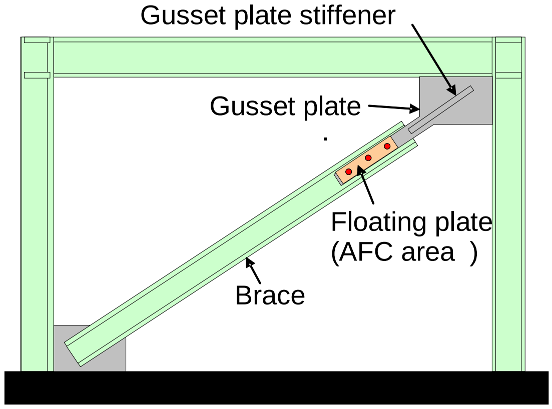
A number of other AFC connections and arrangement have also been proposed and assessed during this research, as shown in Figure 2.



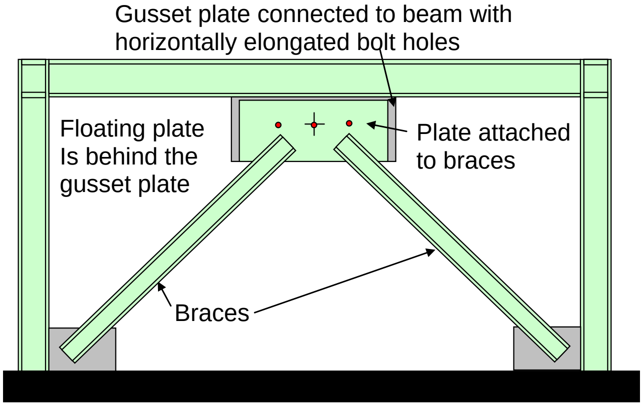
(a) AFC Connection in Sliding Hinge Joint (C.Clifton, UOA)



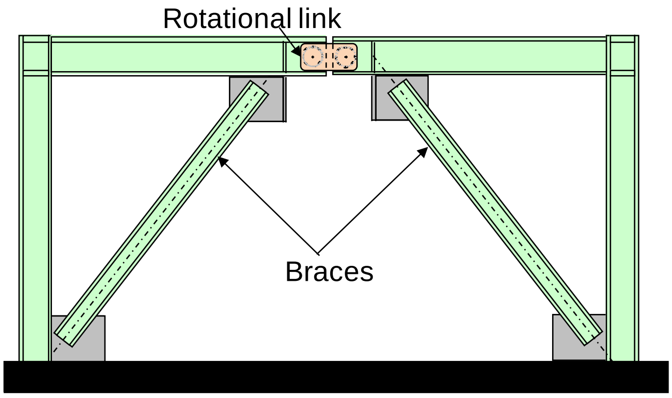
(b) AFC Connection in Sliding Hinge Joint (J.Chanci, UOC)



(c) CBF with AFC at brace end (G.MacRae, UOC)



(d) CBF with AFC at top of braces (G.MacRae, UOC)



(e) AFC Rotational link
(C.Clifton, UOA)

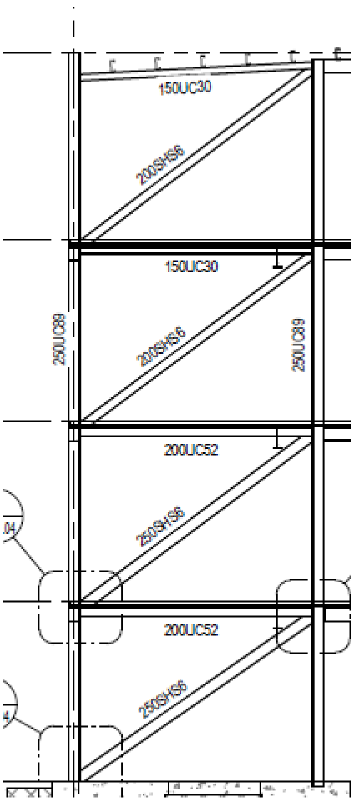
Figure 2. Examples of asymmetric friction connection technology (courtesy of the University of Auckland and the University of Canterbury)

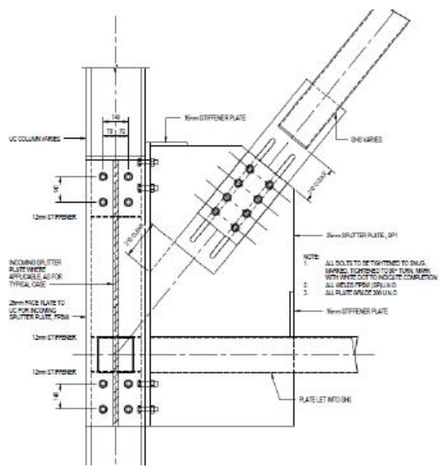
Introduction to Asymmetric Friction Connection Systems (AFC)

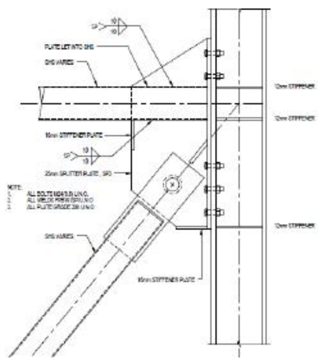
Friction connections offer efficient seismic energy dissipation because they are cheap and easy to fabricate and install. In addition, the connections present a high level of resilience as they enable rapid damage assessment and relative ease of repair, reducing the economic cost to restore building function after severe seismic events.

The use of asymmetric friction connections in CBF frames has several advantages over traditional frames. The slotted holes in the connection enhance the deformation capacity of the frame. Because the strength of the connection can be reliably predicted and tuned, the maximum forces in the structure can be reliably predicted and elements designed to suit. As a result, no damage is expected in the CBF frame elements and low levels of damage are expected in the AFC connection. In addition, the cost of construction of the connection is similar to conventional steel connections.

The AFC connection is formed using 3 parallel plates with abrasion resistant hardened steel shims placed between the two plate interfaces. The central plate is fabricated with slotted bolt holes, which allows the connection to slide and deform. The connection is clamped together with high strength bolts. The mechanism of sliding of the central plate across the surface of the alloy shims dissipates large amounts of energy through friction. The arrangement of a CBF incorporating AFC connections is shown in Figure 3 and Figure 4.







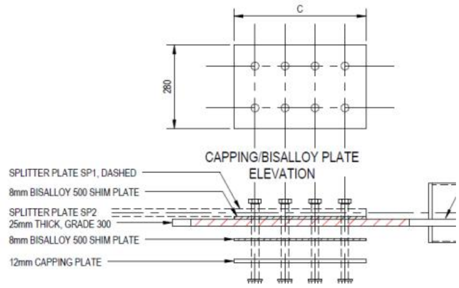
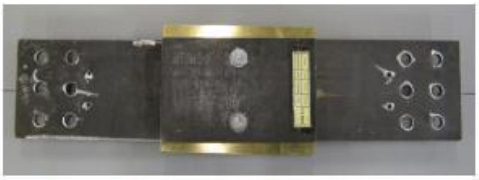


Figure 3. AFC connection configuration from a case study building



a. Plan view of Asymmetrical Friction Connection

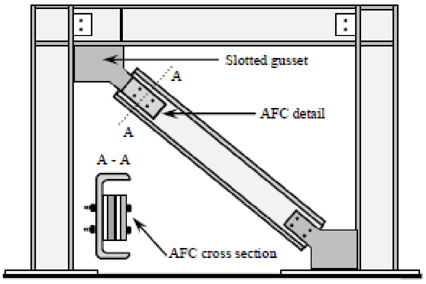
b. Frontal view of Asymmetrical Friction Connection

c. Top, bottom, cap plate and brass shims

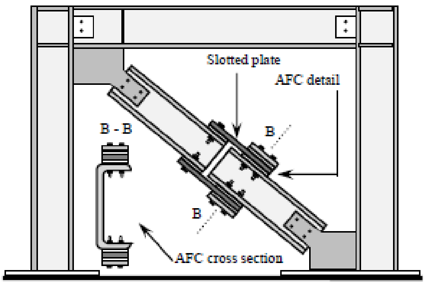
Figure 4. AFC connection configuration (Chanchi, 2012)

Recent Experimental Results and Developments

A number of studies investigating the application of friction connections as energy dissipaters in structural systems have been carried out. Although much of the original research was conducted by C.Clifton whilst creating Sliding Hinge Joints (SHS's) the most relevant research for CBF applications was and recently carried out by Chanchi and MacRae at the University of Canterbury. The experimental and analytical research investigated the performance of the AFC system under seismic loading and developed analysis and design criteria to allow application of the connection and its adoption into industry. Figure 5 shows a variety of CBF configurations adopting AFC connections, as proposed by Chanchi and MacRae (2012).

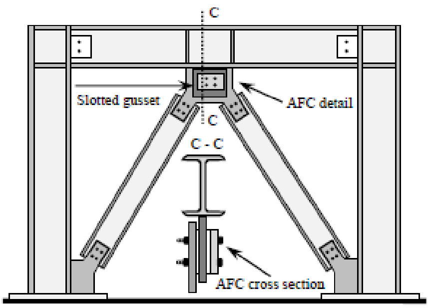


a. AFC detail placed at the end of the brace

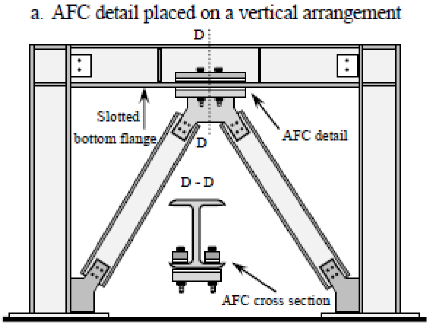


b. AFC detail placed within brace

(a) AFC's in single braced CBF Frame



a. AFC detail placed on a vertical arrangement



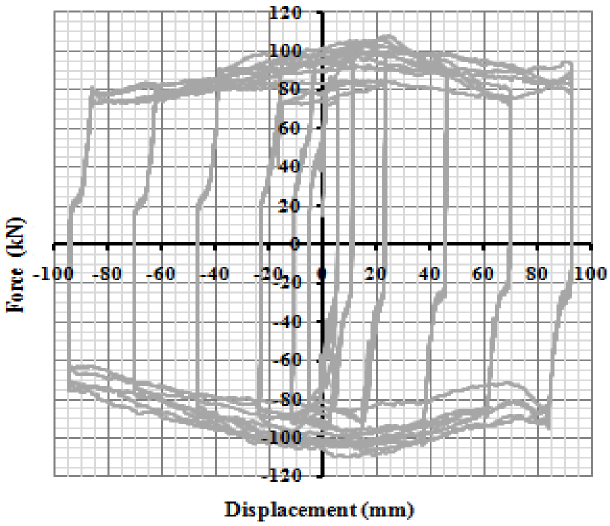
b. AFC detail placed on a horizontal arrangement

(b) AFC's in chevron braced CBF Frame

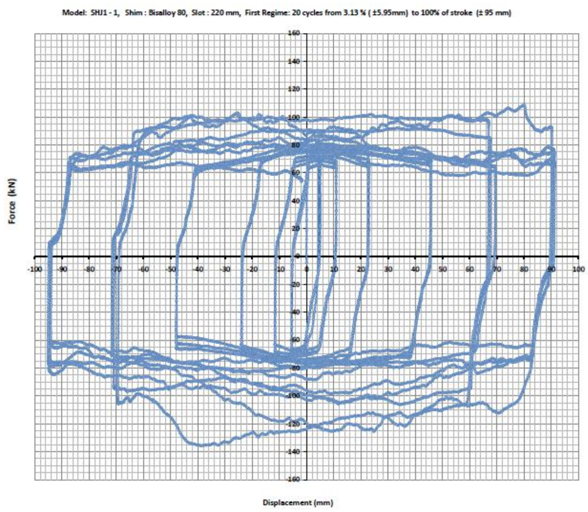
Figure 5. Proposed AFC configurations for CBF frames (Chanchi et. al, 2012)

Figure 6 shows the experimental hysteretic behaviour and performance of the connection with different shim materials. The hysteresis loops displays high dissipation characteristics resembling elasto-plastic behaviour.

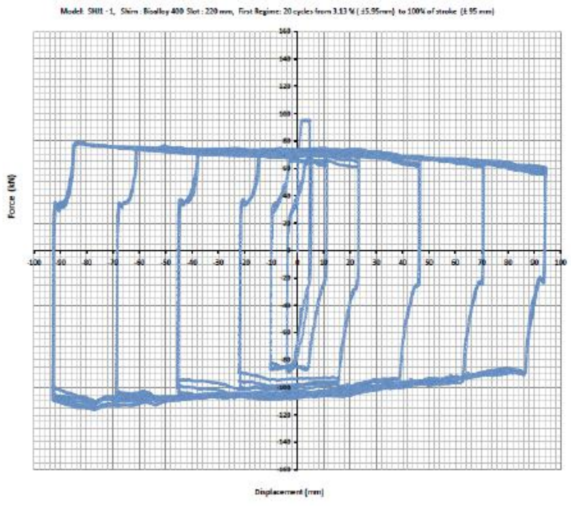
A variety of shim materials have been investigated, with results showing significant differences in the stability and dissipation characteristics of the connection. Shim materials tested included brass, steel and different grades of hardened abrasion resistant steel. The research compares the hysteresis loops for the different shim materials, and highlights that the highest hardness bisalloy 400 and 500 abrasion resistant steel shims produced the most stable sliding behaviour and reliable energy dissipation. The researchers recommended that bisalloy 400 or 500 shims be adopted for AFCs. This shim material ensures high resilience, enabling the connection to survive the initial design level event and subsequent aftershocks, albeit some softening of the joint will likely require levels of re-tightening of fasteners.

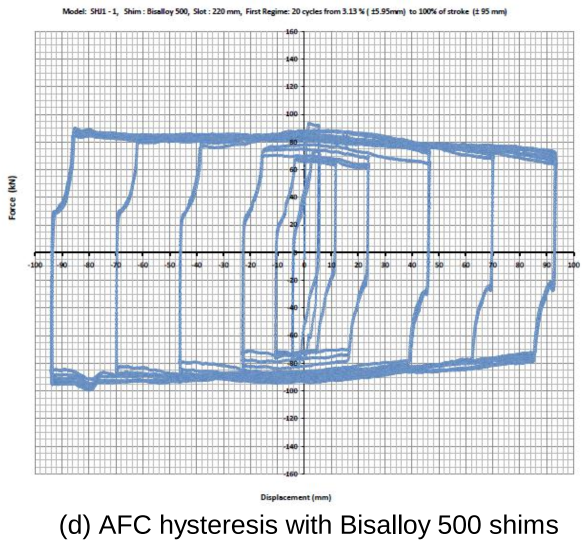


(a) AFC hysteresis with Brass shims



(b) AFC hysteresis with Bisalloy 80 shims





(c) AFC hysteresis with Bisalloy 400 shims

(d) AFC hysteresis with Bisalloy 500 shims

Figure 6. Comparison of AFC hysteresis loops for different shim materials (Chanchi et al, 2012)

Discussion on Aspects of Design and Application of AFC's from a Designer's Perspective

Collaboration between Aurecon's engineers and researchers was essential in developing the AFC design and detailing considerations, for implementation into industry. This section introduces the key developments on AFCs which have evolved over the last 12 months.

The AFC connection evolution stems from several key joint components which have been tested. These include; The bolt group model, belleville springs and washers, bisalloy shim testing, AFC joint behaviour, slot length testing, over-strength assessments and AFC durability testing, and to resolve these issues the team have really benefited from the researchers assistance.

Slot Length

A key parameter for AFCs is the slot length. Once the yield force of the connection is reached, the bolts slide along a slot in the central plate. The slot length, L, can be calculated using Equation 1, where *db* is the maximum elongation or shortening of the brace, *d* is the standard hole diameter for the bolt size used in the connection, and ϕs is an oversize factor (>1.0) to avoid any localized yielding at the ends of the slot caused by bolt bearing. The elongation or shortening of the brace, *db*, is calculated using Equation 2, with Figure 7, where *H* is the storey height of the frame, *S* is the spacing of the frame columns, and *B* is the un-deformed brace length.

$$L = \phi s \times (2db + d) \tag{1}$$

$$db = \sqrt{H^2 + (S + \Delta)^2} - B \tag{2}$$

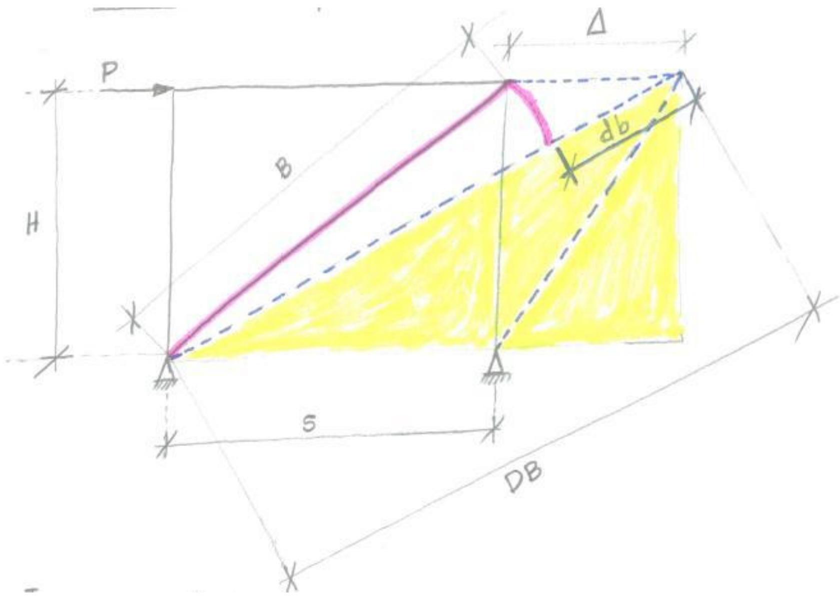


Figure 7. Frame deformation parameters for determining AFC slot length (Chanchi, 2012)

Joint yield strength

The joint sliding force, F_s, can be expressed in terms of the number of shear planes, *n*, the proof load per bolt, N_{tf}, and the friction coefficient between steel and the shim material, as derived in Equation 3. In this equation two shear planes are considered, values of the proof load for bolts Grade 8.8 are recommended by New Zealand Standards, and values for the effective friction coefficient have been reported by MacRae et al (2010) to be in the range 0.21 to 0.22 for steel and abrasion resistant steel shims.

A strength reduction factor of Φ=0.8 is applied to AFCs, in accordance with NZS3404 bolted connection requirements.

$$F_s = \mu \times n \times N_{tf} \tag{3}$$

Table 1. Bolt strengths are derived directly from NZS3404 table 15.2.5.1

Nominal diameter of bolt	**Minimum bolt tension N_{tf} (kN)**
M16	95 kN
M20	145 kN
M22	180 kN
M24	210 kN

Efficiencies in Frame Component Design

The performance and behaviour of AFC systems imparts a number of design efficiencies for the frame member components compared to traditional CBF systems. The non-linear response of AFC frames can be more reliably predicted than traditional CBFs. As a result, lower design forces can be justified compared to traditional CBFs enabling relaxation such as C_s=1.0 for the design of AFC frames.

The brace loads in AFC frames are expected to be similar in tension and compression, once the sliding mechanism is engaged, resulting in a better seismic behaviour and response. Because ductility and inelastic action is concentrated in the connection, a high degree of protection is provided to the column, beam and brace elements. The braces in AFC frames can therefore be designed as elastic elements with less stringent requirements for slenderness compared to traditional CBFs. Similarly, the collector beam is designed as an elastic element and has significantly less severe forces induced during an earthquake. A traditional CBF frame has large bending moments and shears induced in the collector beams as brace buckling occurs, a behaviour which is avoided in AFC frames.

Bolt Model

Recently, a refined bolt model for AFCs and sliding hinge joints has been developed at The University of Auckland. The model considers moment-shear-axial force (MVP) interaction as sliding in the connection occurs and the bolts deform in double curvature. It has been highlighted that bolt behaviour and sliding strength varies with different bolt diameters. A key factor in determining the response is the contact point between the bolt shank and the connecting plates. The researchers recommend the use of M24 bolt diameters (and smaller) and no less than four bolts per connection. The normalized sliding force resulting from the refined bolt model is similar to 0.21 recommended by MacRae for preliminary design.

AFC - Connection Arrangements

AFC connections can be tuned to meet a range of seismic demands. The designers found that the mixing of bolt sizes in the connection arrangements improved the range of connection strengths that could be achieved, which improved the efficiency of the frame system by minimising the overstrength demands on the brace, collector and column elements. Table 2 presents a range of connection sliding strengths for a variety of different bolt arrangements.

Table 2. AFC connection strengths for different bolt arrangements

Bolt Arrangement	Dependable Sliding Force ΦFs
4/M16	128 kN
2/M16 and 2/M20	162 kN
4/M20	195 kN
2/M20 and 2/M24	238 kN
4/M24	282 kN
4/M20 and 2/M24	336 kN
4/M24 and 2/M20	380 kN
6/M24	423 kN
4/M24 and 4/M20	477 kN
6/M24 and 2/M20	521 kN
8/M24	565 kN

Overstrength Factor

A number of factors affect the overstrength factor for AFC's. By working with researchers, an overstrength factor of Φ_{os}=1.4 was proposed, to be applied to the nominal sliding force, F_s . The overstrength factor was derived from a number of influencing factors, including site and environmental effects and variability in bolt tightening and strength, as well as uncertainty in the friction coefficient between the sliding surfaces.

Use of Belleville Springs

These springs have a conical shape that deflects and flattens linearly at a given rate. Hence when demands on the bolts reduce and bolt tension relaxes (as the joint movements slow) the spring pushes outwards to maintain the levels of installed tension. The AFC connection has been tested both with, and without Belleville springs and was found to perform more reliably "with" these springs.

The researchers have suggested that Belleville springs and washers be provided between the bolt heads and the outside plates of the connection. Researchers have indicated that there is some variability between the bolt sliding forces with the current connection configuration, and it is suggested that the use of Belleville springs will minimize bolt sliding variability, increasing the bolt sliding force and reducing elastic strain losses. Further research into the performance of Belleville washers in AFC's is proposed to refine the number of washers and installed bolt tensions.

Use of Hardened Abrasion Resistant Steel Shims

Recent research at The University of Auckland has confirmed that bisalloy 400 shims produce a more stable hysteresis than steel or brass shims, and are therefore the researchers preferred shims, particularly with bolt size M24 or less. The limitation of the bisalloy material is that it can only be used for interior applications as there are issues with corrosion of the material in exposed conditions.

Ductility Discussion

The ductility for AFCs is generally governed by the Serviceability Limit State (SLS) requirements. At SLS the building should be designed so that no sliding or yielding occurs in the connections, and the structure responds elastically. In addition, no yielding or sliding should occur under the Ultimate Limit State (ULS) wind event. The maximum ductility which may be applied to the design of AFCs at ULS can then be determined, ensuring that the seismic coefficient at ULS (for the targeted ductility) exceeds the seismic coefficient at SLS and the ULS wind demands.

MCE Earthquake Event

To ensure reliable performance of AFCs and the structure during an extreme earthquake, the connection must be designed to ensure that all bolts have sufficient slot length to accommodate seismic drifts under both the Ultimate limit State (ULS) and the Maximum Considered Event (MCE).

Chanchi's original design procedure suggested providing a slot oversize factor to ensure that localized yielding of the end of the slot, caused by bolt bearing, is avoided. Aurecon's design approach was to size the slot length based on MCE drifts, with an allowance of ±25mm for construction tolerance.

Brace Moment Design

Due to the load eccentricity present in AFC's, the induced bending and second order effects on the brace must be considered in combination with the axial load in the brace. Stiffening of the end cleats may be necessary to transfer the bending moment through the connection and into the brace member.
The brace is designed to have one end pinned with the active end with the AFC connection sliding. Oversizing of the slotted holes in the AFC cleat is required in order to ensure that a pinned end condition at the sliding end of the brace is achieved. This is discussed in a later section of this paper. The pin end connection can be reliably formed with a shear pin arrangement, similar to that shown in Figure 3.

Connection Stability

Because AFCs are asymmetric connections, careful consideration is required when designing the connection cleats. It is proposed that the end cleats be designed using the Eccentric Cleats in Compression design method in HERA Report R4-142:2009. For braces with high axial load demand and high seismic drifts, the AFC connection cleats will likely require stiffening in order to ensure lateral stability under compression loading.

Oversized Slots

In order to achieve a pin-ended brace condition, researchers recommend that the slots be oversized or belled out at the ends in order to accommodate seismic rotations and avoid second order effects being induced in the brace and connection. The proposed slot oversizing is shown in Figure 8.

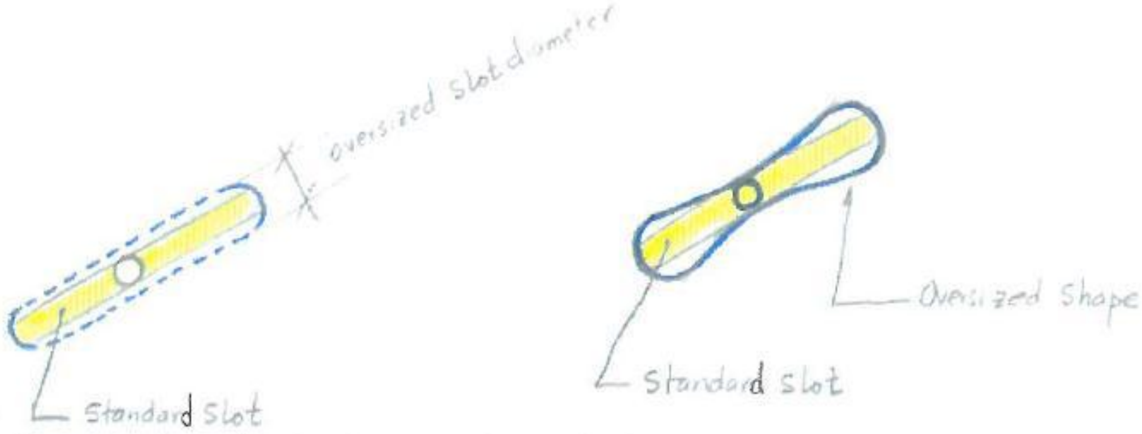


Figure 8. Slot oversizing to allow connection rotation during seismic drift (Chanchi, 2012).

Bolt Tightening Procedure

The following procedure is followed when tightening the bolts in AFC connections. Once the frame is aligned, the bolts should all be snug tightened. Bolt tensioning to the bolt proof load is conducted considering that the Belleville washers also need to be flattened. For normal bolts, this is generally done according to NZS 3404 Clause 15.2.5.2 (Part turn method), through a 120 degree rotation, with a tolerance of + 10deg maximum, - 0 degrees minimum.

Once each bolt has been snug tightened a clear mark should be placed adjacent to the head of each numbered bolt and one on the cap plate. A second mark is required on each bolt head to enable structural engineers to verify the required rotation has been achieved.

An additional issue with the bolts was to ensure that there is sufficient thread length within the bolt grip so the proof-loaded bolt does not fracture during tightening or when sliding initiates (Chanchi et al. 2012). It is desirable if NZS3404 minimum recommendations are significantly exceeded to ensure good behaviour.

Post Disaster - Building Recovery

Pre earthquake – planning for damage locations

During the building planning stage the discussions around resilience need to address the following ideas;

- Future access to resilient connections – good discussions with clients and owners and architects should centre around the potential need to access resilient connections and what this may do the fit-out and function of the building
- The structural engineer should highlight expected levels of drift and shaking the contents may experience, such that movement and resilience of services can be achieved so that the building achieves an overall toughness. The engineer should highlight that incoming road services may not survive, but at least the buildings recovery can be facilitated with standby services.
- Level of earthquake activation needs data - our recommendation would also be that all buildings ideally need a network of accelerometers and displacement transducers installed at each floor level. This would enable the designer to assess the local accelerations and joint demands/travel to ascertain if bolts may need replacement

Post Earthquake – Recovering a low damage building

Should a building experience a design level earthquake (ULS) and subsequent large aftershocks, we would consider the structural engineer should conduct a thorough inspection, prior to the building it re-commencing service. The following are general items that will require review

- AFC Connections – Bolt performance and condition, levels of permanent displacement
- AFC Connections – Shim plate performance, condition and deformation
- Hold-down bolts - performance and condition
- A sample of the joint weld conditions.

Once these basic items are reviewed, a status report should be considered and issued to an independent expert for consideration. A more detailed study will be required of all items to identify areas needing rectification and further study.

Responsible innovation

Any key innovation requires collaboration and communication of ideas. To resolve issues in innovation requires a continual feedback loop only possible through the trials of continual exploration, failure, correction and re-attempt. It's important to point out (from the consultant's perspective) that although research and test data may seem reliable, something as simple as installed bolt tension, can skew data, lead to false economy and non-conservative joint strengths. Our findings were that whilst the research conducted as very rigorous, subtle idiosyncrasies still surround the cutting edge, distinguishing it from readily available and more easily understood technology. A key lesson learnt in the application of AFC technology by Aurecon is that of 'rigorous challenge' and the benefit of having multiple organizations involved in review, peer review and development. We highlight that without the valued support of The University of Auckland, University of Canterbury and particularly SCNZ, Aurecon would not have been able to move forward with cutting edge technology such as the AFCs in CBF's.

Aurecon considers significant future testing of CBFs with AFCs will benefit the New Zealand Construction industry and would encourage SCNZ to consider the development of a "Design Guideline for Asymmetric Friction Connections".

Conclusion

In general the Asymmetric Friction Connection (AFC) poses an exciting opportunity for designers, as it provides a true tension/compression yielding connection that offers excellent energy dissipation through friction developed between sliding surfaces.

Why AFCs:

1- Reliable inelastic behaviour- as opposed to buckling of the diagonal brace
2- Reliable source of energy dissipation – post event may only need to retighten or replace bolts
3- Easy tuning of ductility level – the system is tuned to the strength of the connection, not any member
4- More efficient design in terms of collector beam, brace, and columns
5- No more brace buckling – resilience improved without needing to import a Buckling restrained brace (BRB).

Resilient buildings constructed from CBFs with AFCs will provide vastly superior response to large earthquakes and help reduce resulting damage that may occur. The connection is suitable for inside use behind weathering or sealed envelopes. The sliding movement enables protection of primary structural members, reduces damage, and lowers the cost of structural recovery.

Post-earthquake recovery of the primary structural system will require inspections of the connections, possible bolt replacement, re-tensioning of bolts, but should not result in demolition.

With a recoverable primary frame, simple replacement of any affected ceilings and walls will enhance the efficiency in bringing the building back into operation.

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