DESIGN OF ECCENTRICALLY LOADED BRACING CLEATS

Introduction

A recommended design model for light bracing cleats was published by the Australian Institute of Steel Construction in 1994 (Sections 4.11 and 5.11 of Reference [1]—known commonly as the 'Green Book'). The recommended design model in Reference 1 ignored the effect of eccentricity on the design of the cleat and contained what subsequent research showed to be an unconservative assumption for the buckling strength of a cleat subject to compression.

The Australian Institute of Steel Construction also published in 1996 a publication dealing with light bracing cleats with hollow section bracing members connected to them (Sections 6 to 9 of Reference [2]—known commonly as the 'Blue Book'). The bracing members considered were as follows:

— flattened end circular hollow section bolted to the bracing cleat;

— cleat welded to cap plate to form a tee, cap plate welded in turn to a hollow section brace member;

— cleat fitted into a slot in a hollow section member and welded along the slot.

The basis of the design model for all member types in Reference [2] was the Kitipornchai, Al-Bermani and Murray paper (Reference [3]) which had recommended taking account of the eccentricity in connections involving brace members bolted to cleats through a specifically formulated yield line approach based on test results. An effective length factor of 0.5 was used in the design.

Subsequently, as more information became available, the Australian Steel Institute drew attention to the fact that the design method based on Reference [3] may be unconservative (Ref. [4] of March 2004) and then issued an Advisory Note (Ref. [5] of December 2005) regarding the bracing cleat connection. Engineering Systems also issued similar cautionary advice (Ref. [6]).

The connection types to which the above advice applied were the slotted tube, welded tee end, and flattened end connections. Unless restrained against sidesway, each of these connections deflects laterally as it is loaded in compression, developing a plastic hinge in each plate at a fraction of the section compression capacity. The real capacity of the connection is very much less than would be computed assuming the presence of lateral restraint or the absence of eccentricity. The problem is exacerbated for connections in short compression members and for compression members that are not exclusively wind bracing members.

The following recommendations were contained in References [4] and [5] and since they remain applicable are repeated here.

Recommendations in References [4] and [5]

- Do not use an eccentric hollow section bracing connection for a short compression member unless it is stiffened against sidesway. *A concentric connection should be used if there is no sidesway stiffening.*
- Design eccentric hollow section bracing connections taking eccentricity into account by rigorous application of design code rules for combined bending and compression—do not use the method in *Design of Structural Steel Hollow Section Connections*' (Reference [2]).

New Design Guidance

The Australian Steel Institute has now published Steel Construction Vol 43 No 2 (Ref. [7]) in order to address the design of bracing cleats for light bracing members.

Reference [7] is intended to provide a revised recommended design model for the bracing cleat connection that addresses the issue of eccentricity in cleats subject to both tension and compression and also addresses the issue of the buckling capacity of the cleat when subject to compression. The recommendations in this publication are formulated in terms of the provisions of AS 4100 (Reference [8]).

Design for Tension in Reference [7]

The recommended design model for a bracing cleat subject to a design tension force is primarily based on the provisions contained in AS 4100 since suitable provisions are available.

The design checks for bolts in shear, bolts bearing on the bracing cleat and plate tearout in the bracing cleat are based on Clause 9.3.2.1 of AS 4100 and Section 3 of Handbook 1 (Ref. [9]). The design of the bracing cleat subject to axial tension is based on Clause 7.2 of AS 4100 and Section 5.4 of Handbook 1. The bracing cleat is not designed for any eccentricity when subject to tension force, and neither is the weld connecting the bracing cleat to the support.

The design check for block shear failure of the bracing cleat is based on the recommendations in Section 5.4 of Handbook 1, while the design check for the weld group is based on Section 11 of Handbook 1.

Design for Compression in Reference [7]

The recommended design model for a bracing cleat subject to a design compression force is also primarily based on the provisions contained in AS 4100 where suitable provisions are available.

The method adopted in the recommended design model in Refe4rence [7] has the following features:

(a) a sway mode of failure is assumed;

(b) an effective length of 1.20x the distance between the supporting member and the end of the bracing member is used based on one end being rotation fixed, translation fixed (supporting member) and one end being rotation fixed, translation free (from Figure 4.6.3.2 of AS 4100);

(c) eccentricity is accounted for;

(d) no amplification of the design moment is assumed;

(e) an α_b of 0.5 is used to select the column curve for design for axial compression;

(f) Clause 8.4.4.1 of AS 4100 is used to determine the out-of-plane design capacity for the bracing cleat subject to combined bending and compression.

Eccentricity

For eccentricity about the minor axis of the bracing cleat, the following applies:

Concentric loading — double angles as bracing members, one each side of bracing cleat;

Eccentric loading
- — single angle as a bracing member connected one side of bracing cleat;
- — rod with fin plate connected to one side of bracing cleat;
- — flat bar as bracing member connected to one side of bracing cleat;
- — flattened end CHS bracing connected to one side of bracing cleat;
- — fitted fin plate to hollow section bracing member connected to one side;
- — tee plate end connection to hollow section bracing member with projecting plate connected to one side of bracing cleat.

The notional eccentricity involved for the eccentrically loaded connections is taken to be the distance from the centre of the bracing cleat to the centre of any connection plate to the bracing member, except for the single angle bracing member where the eccentricity is taken as the distance from the centroidal axis of the angle to the centre of the bracing cleat.

The approach taken in Reference [7] is as follows:

(i) for bracing cleats subject to tension, no eccentricity is allowed for in design based primarily on similar design models and past practice in Australia (Refs [1] and [2]) and since any eccentricity present does not cause a stability issue such as occurs in compression;

(ii) for bracing cleats subject to compression, the eccentricity noted above is designed for as per item (iii);

(iii) the resulting design moment due to the eccentricity is divided between the bracing cleat and the attaching cleat on the brace member or the brace member itself (if there is no cleat) on the basis of the relative stiffness of each. If the bracing cleat and the attaching cleat on the brace member are of similar length and thickness, this will result in a 50% assignment to each cleat. In the case of angle brace members and flattened hollow section brace members, the stiffness of the brace member is much greater than the stiffness of the bracing cleat and a minimum of 10% of the design moment due to the eccentricity is recommended to be used, based on advice given in Reference [6] (which is in turn based on modelling done using Microstran).

(iv) the weld is designed for the same value of eccentricity as the bracing cleat.

Prying force on bolts

Bracing cleats are usually 8 mm to 12 mm in thickness and may deflect under both tension and compression loads. This flexing may give rise to prying forces at the interface of the two cleats which may result in some applied tension on the fasteners, which are usually bolt(s) but may be a pin. The bolts are typically only designed for shear forces.

Properly installed nuts should be installed in bolts and the use of lock nuts considered, particularly if any vibration is likely. Tensioned bolts may be used but tensioning can be difficult due to access and because the tensioning procedure may result in deforming the relatively thin bracing cleat which essentially cantilevers from the supporting member. This may mean that the bolts may not be fully tensioned as the bolt tensioning procedure bends the plate rather than tensions the bolt.

Pins require retention plates in this type of connection.

REFERENCES

[1] AUSTRALIAN INSTITUTE OF STEEL CONSTRUCTION, ‘Design of structural connections’, 4th edition, Authors Hogan, T.J. and Thomas, I.R., Editor Syam, A.A., 1994.

[2] AUSTRALIAN INSTITUTE OF STEEL CONSTRUCTION, ‘Design of structural steel hollow section connections’, 1st edition, Authors Syam, A.A. and Chapman, B.G., 1996.

[3] Kitipornchai, S., Al-Bermani, F.G.A. and Murray, N.W., ‘Eccentrically connected cleat plates in compression’, Journal of Structural Engineering, ASCE, Vol. 119 No 3 1993, pp767–781.

[4] Anon, ‘ASI recommended design method may be unconservative—Eccentrically loaded cleats’, AUSTRALIAN STEEL INSTITUTE, Steel Construction, Vol. 38 No 1, March 2004, p.10.

[5] AUSTRALIAN STEEL INSTITUTE, Advisory Note, ‘Design method for eccentrically loaded cleats not to be used’, Author Munter, S., Steel Construction Vol. 39 No 2 Dec 2005, p.16 (ASI Web Site Release March 2006).

[6] LIMCON V3, ‘Limit states design of steel connections’, ENGINEERING SYSTEMS web site, <www.steel-connections.com>.

[7] Hogan, T.J. and Collins, R.T., ‘Design model for light bracing cleat connections’, AUSTRALIAN STEEL INSTITUTE, Steel Construction, Vol. 43 No 2, March 2010.

[8] STANDARDS AUSTRALIA, AS 4100—1998, ‘Steel structures’.

[9] AUSTRALIAN STEEL INSTITUTE, ‘Handbook 1: Design of structural steel connections’, Author Hogan, T.J., Contribution Author and Editor Munter, S.A., 2007.