Introduction to Structural Steel Design for Fabrication

August 2021

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FOREWORD

This series of Technical Notes addresses specific issues in steel construction with the aim of promoting the efficient and economic use of steel. To be competitive, steel construction must be cost effective. Cost effective solutions, however, are continuously changing with changing fabrication technology, steel price, labour cost, regulations and other market forces. There is a need for the building professionals to be informed on the changing scene.

While the Australian Standard for Steel Design AS 4100 has remained substantially unchanged for the last 30 years, the technologies that support the design and fabrication activities have undergone considerable changes with the increasing use of computers in many fields of activities. There have been also changes in the regulatory environment including building regulation and work safety. Each technical note will address a specific issue in steel construction when it is felt that a review of current practice may lead to better outcomes for the industry. It is not aimed to be a comprehensive treatment of the subject. Subjects under consideration include fabrication, robustness, performance-based design, conformity assessment etc. depending on the perceived needs of the industry and the availability of information.

This is an industry initiative from Swinburne University of Technology and Association of Consulting Structural Engineers Victoria, designed to provide independent, non-proprietary information about steel design to professionals involved in building design and construction.

ACKNOWLEDGEMENT

This Technical Note is authored mainly by Anthony Galgano of Apex Welding and Steel Fabrication Pty Ltd.

Other contributors include Maria Mavrikos, Managing Director, Structural Challenge, Andrew Matthews Chief Executive Officer, Skrobar Engineering, Kirk Matthews, Managing Director, Skrobar Engineering, Matt Meinhardt, Director, Aus Iron Industries, Lam Pham, Emad Gad, Tilak Pokharel and Mike Simmons of Swinburne University of Technology.

The Technical Note has been reviewed by Russell Keays of Keays Engineering and Emil Zyhajlo, Structural Consultant, Russell Brown, R.I.Brown Pty Ltd, Peter Golding, Galvanizers Association of Australia and edited by Anita Amirsardari of Swinburne University of Technology.

Disclaimer

1 INTRODUCTION

This document was developed in response to discussions with fabricators and designers to improve steel construction efficiency and economy. The comments in these *notes* are specifically relevant to multi-storey steel framed building structures. Recent changes in erection procedures for steel frames requires updating design to also including erection requirements and to achieve cost effective designs. Early discussions should occur between the designer and fabricator on specific project details.

This technical note is written from a fabricator's perspective with the aim of producing more economic designs. It reviews the advances in elements for steel fabrication that have implications on the cost effectiveness, reduction in occupational health and safety (OH&S) risks and minimisation of environmental impacts. The following items are discussed:

1. Fabrication Equipment & Technology
2. Materials & Procurement
3. Architectural Considerations
4. Steel Detailing
5. Connections
6. Cambering
7. Surface Treatments
8. Welding
9. Fasteners

These production activities are mostly relevant to suppliers and fabricators, however to achieve cost effectiveness of the structural design will require designer awareness and input. Standard connections are typically detailed by designers, however they are not always appropriate. Therefore, project specific, steel frame specific, erection specific requirements should dictate.

General issues to be considered in design from the fabrication's perspective, include:

- A minimum weight steel structure based on rigid connections and/or continuity and sizeable cambering of beams may not constitute an economical design. The handling costs during processing, involving loading and unloading during fabrication, sorting and lifting/erecting and connecting components may far outweigh the increase in material costs.
- Designs based on flexible/simple connections reduce fabrication and erection costs and time, and where material costs are less influential may produce a better outcome.
- The cost to improve a structure's appearance has no merit if the structure is going to be clad or covered up.
- Steel fabrication costs are dependent on factors that include: labour rates, the construction cycle, workplace health and safety, the processing technology available. Preferred solutions for particular design will vary with fabricator depending on the type of processing methods and equipment available to them at certain points in time. A collaborative design combining

input from designer and fabricator will facilitate efficient solutions, and connections design by the fabricator's engineer if available may be preferred.

- Revisions to design drawings and specifications necessitated for fabrication or erection reasons, must be clearly documented and communicated. It is important to have an accurate as-built documentation for future reference. This is a major deficiency of the Australian construction practice as revealed by recent enquiries (e.g. Shergold and Weir (2018) report).
- Steel structures do have a direct impact on OH&S and the environment. The fabrication activities including prepping, welding, turning/rotating, lifting, painting etc. carry risk from an OH&S and environmental perspective. A steel structural frame that has reduced laborious activities during fabrication and erection results in less risk and cost.

2 FABRICATION EQUIPMENT AND TECHNOLOGY

Technology advances in structural steel detailing and fabrication have reduced one of the main structural steel cost centres - labour. Automation has also improved speed and quality. The duration between completing fabrication drawings/details and the fabrication process has narrowed since the introduction of software share between the drafting desk and the saw, drill and set out of plates.

3D modelling in steel detailing enables designers to zoom in, out and rotate whole structures showing connection details via a standard 3D pdf viewer, showcasing a scaled version of the structure before it is built. This provides further opportunity for detailed design improvements prior to fabrication.

The following automated equipment is typically accessible to fabricators through various means, including in-house, through a distributor, or a specialist supplier:

- **Beamlines:** Used for cutting, drilling, coping, scribing of main steel members

  Examples:
  - Peddinghaus Beamline: Drill/Saw/Scribe/Notch/Cope
    https://www.peddinghaus.com/news_fullarticle.asp?&seo=news-1&vID=657
  - Python X: Plasma cutting
    https://www.pythonx.com/product-video/

- **Plate Processing/Plasma:** Used for plate processing

  Examples:
  - Peddinghaus Plate Processing:
    Drill/Tap/Countersink/Milling/Scribing/Plasma & Oxy Cuting
    https://www.youtube.com/watch?v=4yrz8mPdfbc

Key points

- To maximise benefits from using such equipment, it is essential to minimise the handling. The design where possible should standardise on sizes (size changing requires extra setting up procedure).
- A reasonable balance has to be chosen between standardising steel member sizes/weight compared to including also lighter weight members sizes. Including minimum weight members will not necessarily reduce overall cost.
- In most situations, labour cost and rework or repair costs outweigh the materials and equipment cost. Hence, mass of steel or costs of fasteners and accessories may not be the critical factor for competitive design.
- Encouragement of sharing models between consultants and detailers

3 Materials and Procurement

3.1 Overview

- Local and imported manufactured steel sections are currently supplied across the construction industry. Depending on supply & demand, these steel sections are also sourced from overseas manufacturers.
- Standard structural materials which are generally "off the shelf" are as follows:
  - Structural Products: https://www.libertygfg.com/media/165356/seventh-edition-hot-rolled-and-structural-steel-productsseventh-edition-hot-rolled-and-structural-steel-products.pdf
  - Pipe & RHS Products: https://www.libertygfg.com/metalcentre/products-services/structural-tube/
- Large steel circular hollow sections (CHS), square hollow sections (SHS), and rectangular hollow sections (RHS) are imported as they are not manufactured locally
- Welded Sections:
  - Welded beams (WBs) and welded columns (WCs) are usually made to order, however limited stock may be available "off the shelf" from time to time.
  - Local fabricators can manufacture WBs and WCs, but this is not usually economical for large quantities.
- Ensure steel is 3rd party accredited when requesting materials.

Imported steel disadvantages:

- Procurement/lead times are typically 6-10 weeks
- Minimum order quantities may be required for uncommon section sizes.
- Longer sections may affect shipping/lead time.
- Quality assurance and compliance verification may be problematical.

3.2 Steel Grades

- Steel is available in several grades depending on the section type/size. Typical grades are as follows in Table 1.

Table 1: Typical grades of steel members for various section types

Section type	Grade (MPa)	Availability	Comments
Hot Rolled: (Universal sections, Flats, Round & Square Bar etc.)	300	Standard	
Plate:	250	Standard	
Plate:	350	Limited	
Plate:	Z Grade	Limited	Requires testing & has lead time implications
Hollow Sections: (SHS, RHS, CHS & Line pipe)	350	Standard	Limited 450MPa also available
Cold Rolled: (Purlin Sections)	450	Standard	
Welded Sections: (WB's & WC's)	300 or 400	Limited	Varies between 6-10 weeks

Key points

- Grade 350 plate should not be specified for the whole job – just the specific parts that benefit from the higher strength material.
- Z-Grade is useful in badly designed joints. AS 1554.1, Appendix H gives guidance on how to assess joints.
- Flat bars are typically produced to a yield strength of 300MPa, but the fabricator will often prefer to cut small cleats from plate. Thus, the designer should use Grade 250 for calculations and note this in the General Notes.

3.3 Steel Standard Lengths

Steel is available in several stock lengths depending on the section type/size. Typical lengths are as follows in Table 2.

Table 2: Typical length of steel members for various section types

Section type	Min. Length (mm)	Increments	Typ. longest length (mm)	Comments
Hot Rolled - UBs & UCs:	9000	1500	18000	Larger sections can be sourced at 20000mm
Hot Rolled Flats	6000	NA	6000	
Hot Rolled – Small Angles	6000	1500	9000	
Hot Rolled – Large Angles	9000	NA	12000	200x200 Angles only avail in 12000
Hollow Sections - Small	8000	NA	12000	
Hollow Sections – Large	12000	NA	12000	
Welded Sections: (WBs & WCs)	9000	1500	18000	

NA: Not applicable

Key points

- General Notes and Specifications should reflect Grade 250 plate as the standard plate grade. Flats have a stress grade of 300 plus compared to plate which has a grade of 250. For design, assume that flats and plates are grade 250 as flats are often substituted for grade 250 plate.
- Availability of selected steel types and sizes should be taken into account in design. If a long waiting period is expected, other options should be explored.
- The use of Z plate should be carefully considered.
- Refer to Onesteel and/or Bluescope websites for standard steel sections.

4 Architecturally Exposed Structural Steel

Buildings constructed of steel structure framing and exposed as an architectural feature are now common. These exposed frames may demand tighter dimensional tolerances and smoother and special surface finishes that will add to the cost. Often much of that exposed surface treatment work is not in view and hence not appreciated. For instance, do welds need to be contoured and blended if they are more than six metres away?

If the architect has a requirement for a specific level of "beauty", then it is his/her duty to include the requirement in his/her documentation, and not the responsibility of the structural engineer. But the engineer must satisfy himself/herself that the required dressing of welds does not compromise the strength of connections shown on the engineering drawings. In particular, grinding flush might compromise the strength of a weld nominated as "Full Strength" – using the term "Full Penetration" might be more appropriate.

Designers do include "standard notes" on their drawings for surface treatments that may not be necessary, but will add to cost if carried out. The Canadians have implemented a system of Categories for architecturally exposed structural steel (AESS), where a simple chart (see Table 3 below) stipulates the necessary treatment standard for a variety of cases. This will help ensure that only necessary cosmetic work is carried out.

Based on the Canadian Guide, the Australian Steel Institute (ASI) has issued a Guide titled "Australia/New Zealand guide for specifying architecturally exposed structural steel" which is available for purchase. This guide serves as a companion to two other documents, produced by ASI, which can be downloaded free as PDF's from the following links:

AEES E Sample Specification (for Engineers) (PDF)
AEES F ASI Code of Practice (for Fabricators) (PDF)

Much of the information from these documents is shown in Appendix A.

Table 3: AESS Category Matrix in ASI/SCNZ AESS Document E

	Category	AESS C	AESS 4	AESS 3	AESS 2	AESS 1	SSS
	Characteristics	*Custom Elements*	*Showcase Elements*	*Feature Elements* *Viewed at a distance of < 6m*	*Feature Elements* *Viewed at a distance of > 6m*	*Basic Elements*	*Standard Structural Steel* *AS4100/ NZS3404.1*
1.1	Surface preparation to AS1627 Sa2/Class2		*x*	*x*	*x*	*x*	
1.2	Sharp edges ground smooth		*x*	*x*	*x*	*x*	
1.3	Continuous weld appearance		*x*	*x*	*x*	*x*	
1.4	Standard structural bolts		*x*	*x*	*x*	*x*	
1.5	Weld spatters removed		*x*	*x*	*x*	*x*	
2.1	Visual Samples		*Optional*	*Optional*	*Optional*		
2.2	One half standard fabrication tolerances		*x*	*x*	*x*		
2.3	Fabrication marks not apparent		*x*	*x*	*x*		
2.4	Welds uniform and smooth		*x*	*x*	*x*		
3.1	Mill marks removed		*x*	*x*			
3.2	Butt and plug welds ground smooth and filled		*x*	*x*			
3.3	RHS/CHS weld seam oriented for reduced visibility		*x*	*x*			
3.4	Cross sectional abutting surface aligned		*x*	*x*			
3.5	Joint gap tolerances minimized		*x*	*x*			
3.6	All welded connections		*Optional*	*Optional*			
			x				
4.1	RHS/CHS seam not apparent		*x*				
4.2	Welds contoured and blended		*x*				
4.3	Surfaces filled and sanded		*x*				
4.4	Weld show-through minimised		*x*				
C1							
C2							
C3							
C4							
C5							

Note: C1 to C5. Additional characteristics may be added for custom elements.

5 STEEL DETAILING

Improvements in the Steel Detailing process can be made as described in the following subsections.

5.1 Design

- Drawings should be complete and certified by an independent expert and project dependent prior to commencement of shop drawings. The designer must check that the typical details illustrated cover the complete range of geometries existing in the structure shown on the Arrangement Drawings.
- Typical connection details are acceptable; however, specific connections should be clearly detailed and referenced on drawings where required. This practice will also contribute to streamline the request for information (RFI) process.
- Use this document to improve efficiencies for fabrication and erection processes.

5.2 Communication

- Designers should be open to direct lines of communications with the steel fabricator during the shop drawing process. The combination of drawings, specifications and RFI's should enable shop drawings to be issued for approval with minimal reviews/comments (unless information has been missed from the steel detailer). Changes at this point have major cost implications.
- Shop drawings should be issued to the design team as searchable pdfs (and with 3D model if available). Providing the model enables the engineer to expedite the checking process and take snapshots to better describe issues.
- General notes on drawings should be reviewed, updated and include project specific/relevant information. Furthermore, the following should be included:
  - Standard material grade requirements
  - Specific bolting requirements
  - Surface treatment requirements (allowing for approved equivalents)
  - Weld category and testing requirements
- Engineering Drawings should clearly show:
  - Member plans
  - Elevations and sections
  - Connection details
  - Project specific member schedule and proper use of special remarks/comments
  - Maintain a high degree of coordination with architectural drawings
- Specifications should be reviewed, updated and be project specific/relevant.

Key points

- ➢ Whenever possible, the structural designer should be available to communicate with the fabricators during the shop drawing process.
- ➢ General notes should be kept relevant and project specific (adding notes taken off other projects drawings should be reviewed for relevancy).

6 CONNECTIONS

There should be a preamble drawing attention to AS 4100 Clause 9.1.4 – connections need to have a minimum strength relative to the capacity of the section used:

1. Joints carrying bending moments – 50% of the section capacity in bending.
2. Joints carry shear – 15% of the shear capacity.
3. Joints in tension/compression – 30% of the tension/compression capacity.
4. Rod bracing – 100% of the tension capacity.

These rules are there to ensure residual stresses from construction do not cause a joint to fail at working loads.

6.1 Connection Repetition

Connection repetition can significantly reduce fabrication costs. Connection designs that minimise the number of types of plates and types of connections enables using mass fabrication techniques.

6.2 Plate Profiles

Plate processing using automation has led to reduced costs for irregular plate profiles and fastener holes layouts. Important plate design considerations should include:

- Standardisation of plate thicknesses
- Appropriate bolt quantities

6.3 Bolting vs Welded Connections

Fabrications that consist of bolted connections are generally faster and therefore more cost effective than the welded connection alternative. The addition of automation to steel sections and plate processing has further reduced the cost of bolted connections. Bolted connections in steel frames also dramatically reduce steel erection durations and costs. Site welded connections should be avoided wherever possible.

Bolted connections can be applied to provide rigid fixity connections by bolt tensioning or bolting arrangement, or to provide for flexible simple (shear) actions, and the type must be specified on drawings. Welded connections are typical rigid and to provide flexibility to the connection thinner (more flexible) connection plates can be used.

6.4 Through Plates

Through plates are an expensive connection detail (example provided in Figure 1). Slotting of hollow sections to fit plates and then welding is a laborious exercise compared to welding an end plate with cleat (example provided in Figure 2). The through plate connection is typically used on secondary steel members within a design, so it is advantageous if these can be avoided wherever possible.

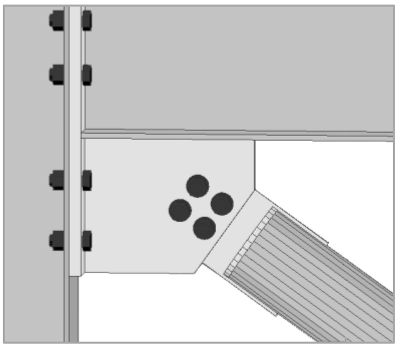


Figure 1: Through plate connection

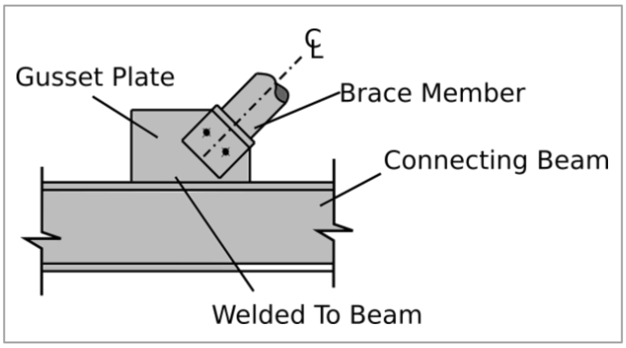


Figure 2: Welded end plate with cleat

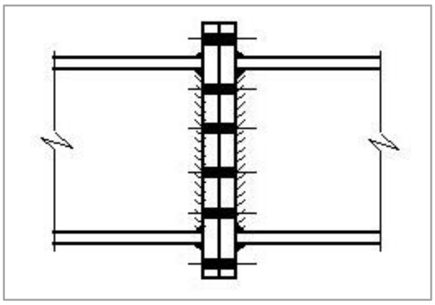
Figure 1 shows a lap joint for the fin plate on cleat – sometimes there is a stability issue which can be conveniently resolved by the use of double cover plates. This is a most efficient and simple connection. With double cover plates at the bolt holes, the plate simply needs to be as strong as the tube. Make the slot length 150% diameter and size the fillet weld to be as strong as the tube. This should not be used as a typical connection. Use double cover plates only when required.

There are new structural blind bolting techniques which may substantially reduce the overall cost of construction.

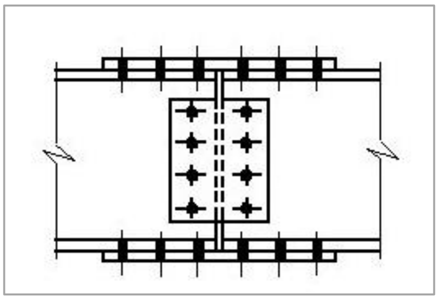
6.5 End Plate vs Splice and Welded Connections

Bolted connections are always the preferred splice connection for universal beam (UB), universal column (UC) and parallel flange channel (PFC) sections. Bolting through beam endplates is usually the most cost effective, however flange and web splice plates are always more efficient than full strength butt weld (FSBW) sections together. End plates are usually not required in temporary structures or in low moisture environments. Examples of the different types of connections is shown in Figure 3.

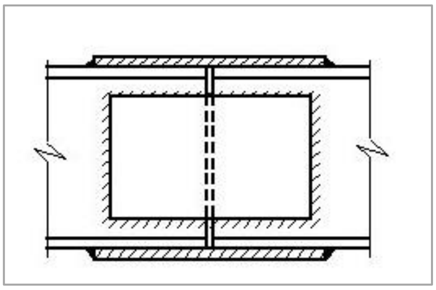
Shop joints to make a long member out of two stock lengths of UB/UC should be a full-penetration butt weld. Field joints should be bolted flange and web plates – single-sided if no more than 8 bolts are required.



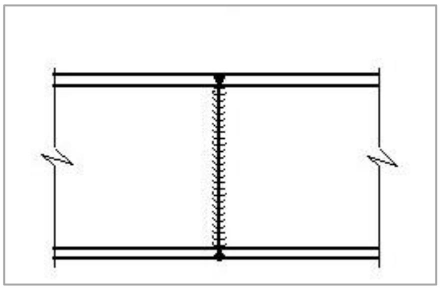
(a) End plated



(b) Bolted cover plates



(c) Fully welded one sided cover plates



(d) fully butt welded

Figure 3: *Different types of connections*

6.6 Holes in Steel

Bolt holes are often drilled through steel beams and plates, however most steel fabrication automation these days employs the use of laser/plasma or waterjet profile cutting. Hole sizing are within the Australian Standards (AS) tolerances, and design consideration should be given to the fact that holes in beams and connection plates are usually carried out using steel fabrication automation. AS 4100 allows holes to be machine (flame) cut, but the hole shape should not be marred by a pierce-point. General Notes and Specifications should be updated accordingly, otherwise, Fabricator should ask Standard Notes to be changed as required.

6.7 Cutting Steel

Steel beams are often cold cut using a saw, however the introduction of plasma beam lines for automation employs the use of plasma profile cutting. Cutting is carried out within AS tolerances, therefore design consideration should be given to the fact that cutting of beams is often carried out using a plasma cutter. General Notes and Specifications should be updated accordingly, otherwise, Fabricator should ask Standard Notes to be changed as required.

6.8 Notching and Coping

Notching and coping of steel is usually manually carried out. Even if it is carried out through automation, extra time required will add to the cost to the steel fabrication process. Extending and upsizing the thickness of the cleat is an option for cases of continuity by the secondary member, for discontinuous beams simple shear connections may require notching/copping. Examples shown in Figure 4 and Figure 5. Not shown is the use of flexible end plates connected to the secondary beam for bolted connection to the web of the supporting beam (to eliminate eccentric load onto supporting beam).

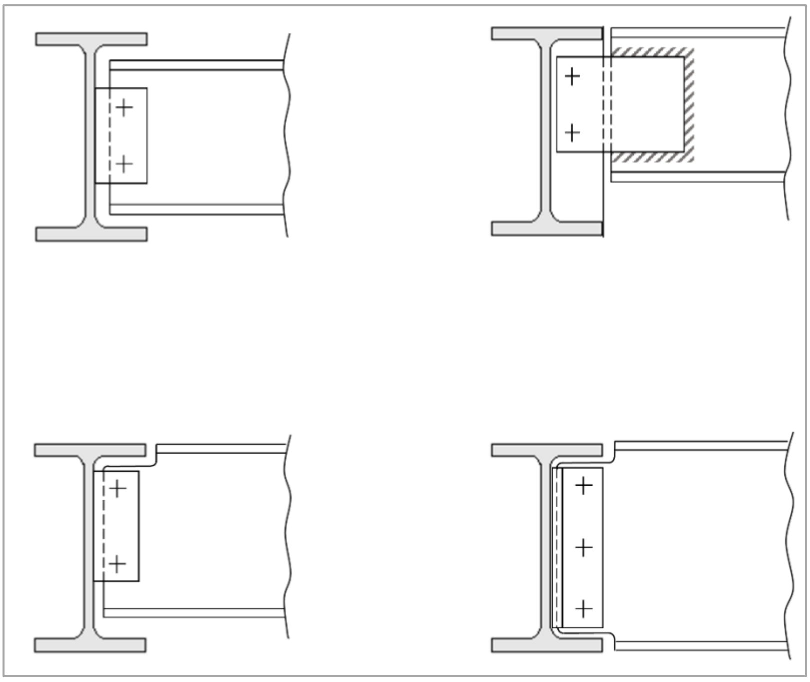


Figure 4: Coping and notching examples

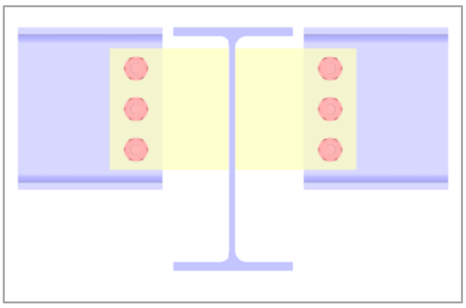


Figure 5: Coping and notching example

Figure 5 may not be strong enough unless there is a composite floor above. This should be checked.

6.9 Gussets, Stiffeners and Double Plates

The inclusion of gussets, stiffeners & doubler plates increase the time and labour costs in steel fabrication process (see Photo 1). Designers should keep in mind compression and buckling and only nominate these plates when required to prevent buckling, prevent web bearing failure, or facilitate stress distribution, reinforce end plates against tensile actions. It is less cost to thicken the end or base plate to avoid needing gussets, as shown in Photo 2. An estimated cost difference for the thicker connection plates is 50% less cost, than using gussets. For more information, see pages 62 and 63 of the CIDECT DG1 publication, Design Guide for Circular Hollow Section Joints Under Predominantly Static Loading (Wardenier et al., 2008), or Field Joints for Tubulars - some practical Considerations by Russell Keays (Keays, 2006).

***Photo 1:** Stiffened base plates*

***Photo 2:** Thickened base plates*

6.10 Beam and Column

The connection type, rigid or simple, axial or eccentric will be governed by force actions and beam and column stiffness. Designers should aim to minimise the number of plates and types of welds in connections. Beam to column connections often consist of a cap plate at the top of the post, the knife cleat connecting to web of beam. Fabrication efficiencies can be achieved by using an oversized cap plate that can bolt through the bottom flange of the beam. This detail not only reduces the materials used, but also the set out required for the knife cleat. (Refer to Figure 6)

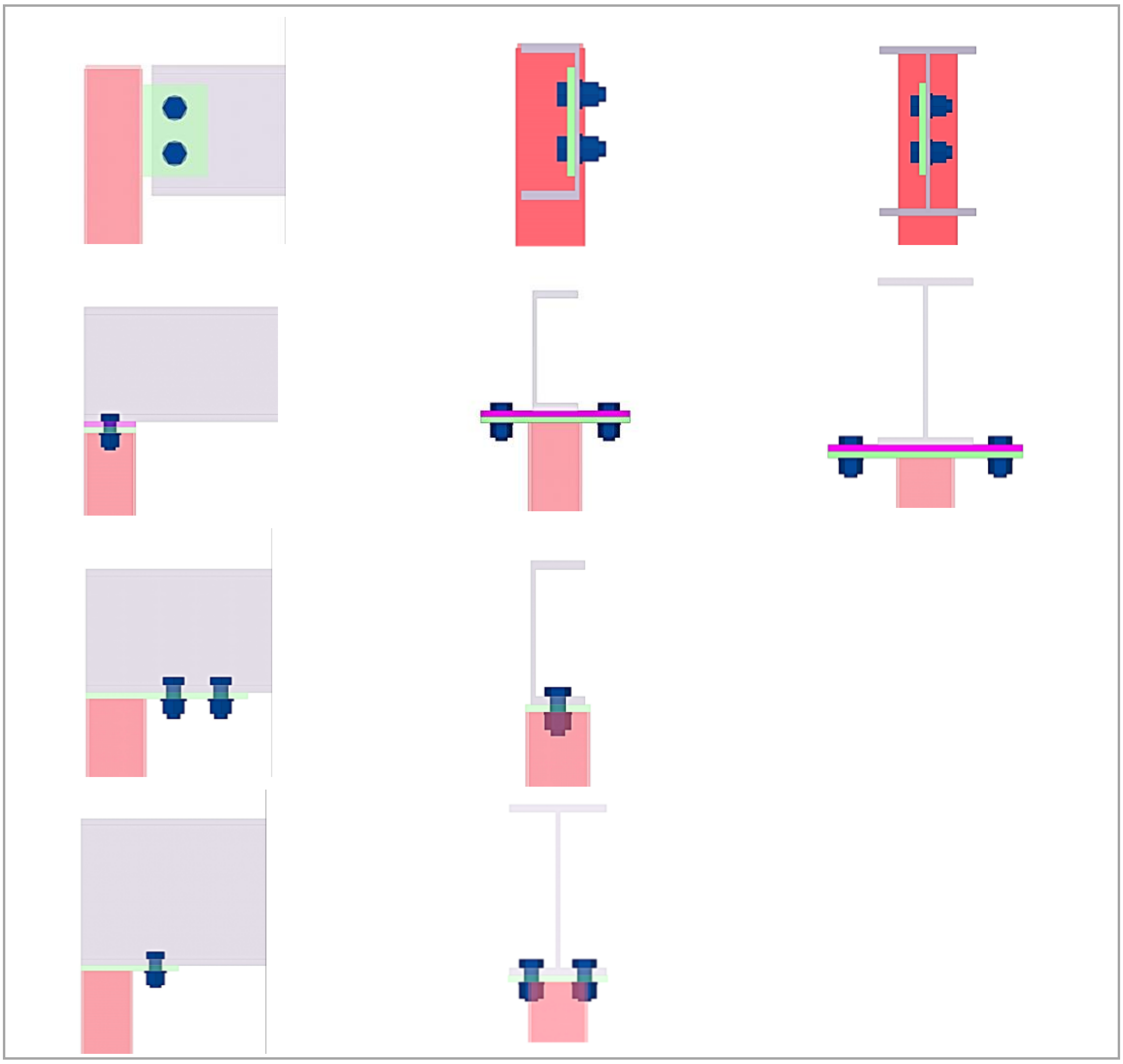


Figure 6: Examples of standard SHS/RHS post to PFC/UB/UC connections

6.11 Fascia Trusses Fabrication

Designers should aim to minimise the number of cuts and notches required to fabricate trusses. Internal verticals and diagonals should be smaller sections than the top and bottom chords, and all diagonals should have single mitre cuts at each end, to create central axis intersection point at junctions (compound or double cuts avoided). Simply bolted connections at end verticals will improve fabrication and installation efficiencies.

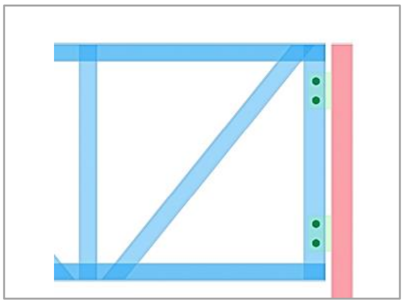


Figure 7: Typical standard SHS/RHS post connection to truss EA end vertical

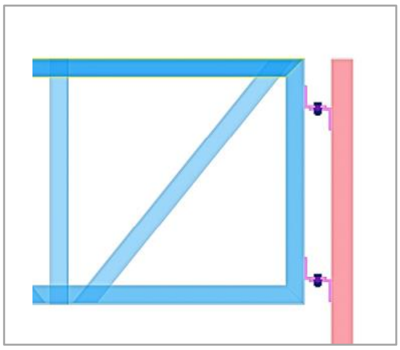


Figure 8: Typical standard SHS/RHS post connection to truss PFC/SHS/RHS end vertical

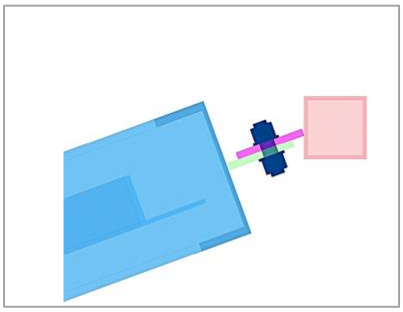


Figure 9: Typical standard SHS/RHS post connection to truss PFC end vertical (with direction change)

6.12 Bolted Connections

Standard bolted connections may be, simple snug tight bolting, or high strength tensioned friction-bearing bolting for frame action requiring rigid-nonslip connection. Friction & bearing connections can increase the time and labour costs in steel fabrication and erection process. TF connections are usually confined to road and rail bridges, while TF connections might be useful on process structures where vibration issues may cause bolts to loosen. Structure designers should only specify tensioned bolting connections when rigid connections are required.

6.13 Hollow Section Connections

Hollow bolts work well for fixing steel to a hollow steel section. They should only be used in accordance to the manufacturer instruction. They are extremely expensive to purchase (more than 10 times the cost of a regular 8.8 grade bolt). Blind bolts are generally quick to install, but all connection alternatives (t-plate connections using standard bolts) or captive nuts or through bolts should be explored before using blind bolts. (Refer to Photo 3 and Figure 10)

Photo 3: *Hollow Bolts used to connect 400x200x12.0 RHS to in lieu of site FSBW (site welding, grinding and surface treatment avoided)*

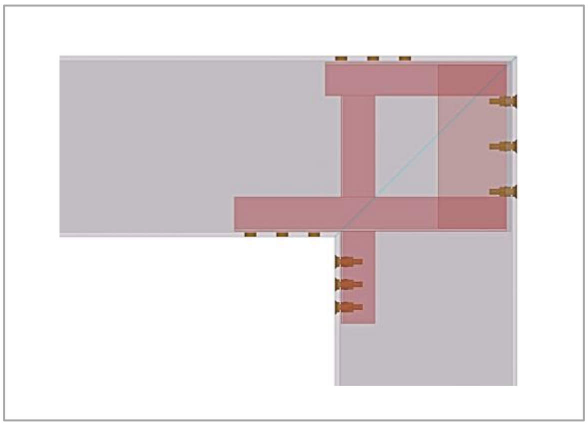
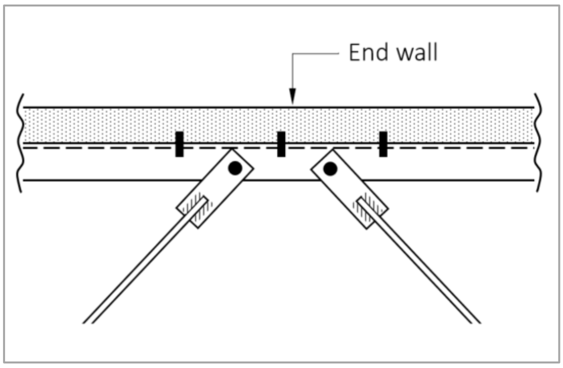


Figure 10: *Hollow bolting arrangement with internal stiffeners*

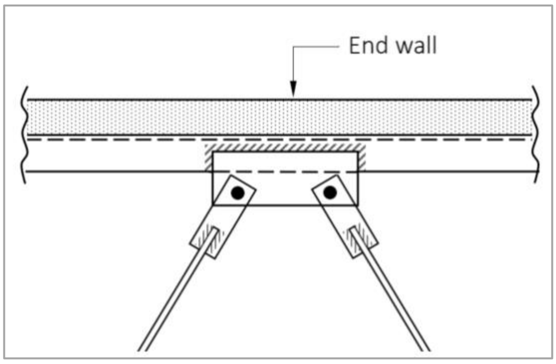
6.14 Bracing Connections

D Brackets used for bracing connections to beams and rafters are the most economical form of bracing when considering fabrication and installation time and cost. Turnbuckles should be avoided where possible as they are expensive and require purchasing and fabrication coordination.

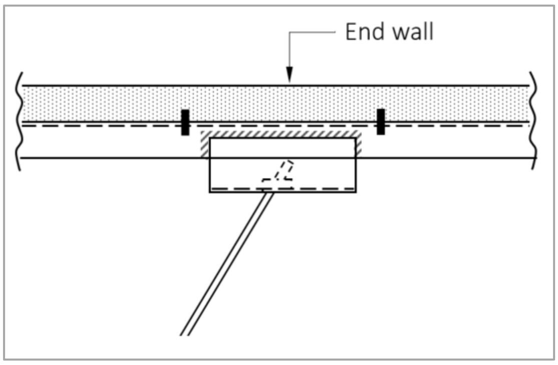
When designing bracing to raker connections, consideration should be given to the type of bolt and material connection. Preferences for bracing connections are provided in Figure 11.



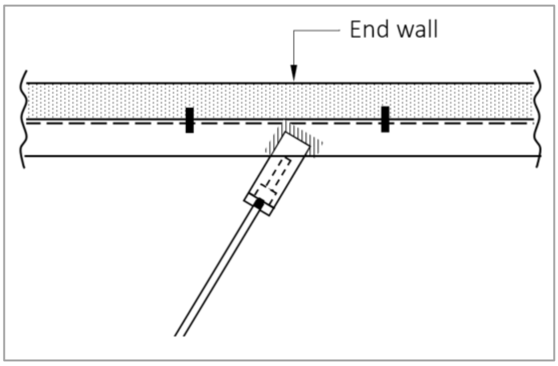
(a) Option 1 (preferred)



(b) Option 2 (preferred)



(c) Option 3 (avoid)



(d) Option 4 (avoid)

Figure 11: *Bracing connections (threaded end or turnbuckle is required for bracing in above Option 1 and 2)*

6.15 Purlin/Girt Cleat Connections

Purlin & girt cleats are usually high in quantity. The welding requirement should be specified economically. 6 continuous fillet weld (CFW) are used for cleats to Z and C profile purlins and girts, however the cleats used for C profile purlins and girts are of longer length, the weld length can be reduced to as shown in Figure 12. The cleats welded connection strength is superior to that of a purlin web or girt web which would tear through the bolted connection before the cleat weld would fail.

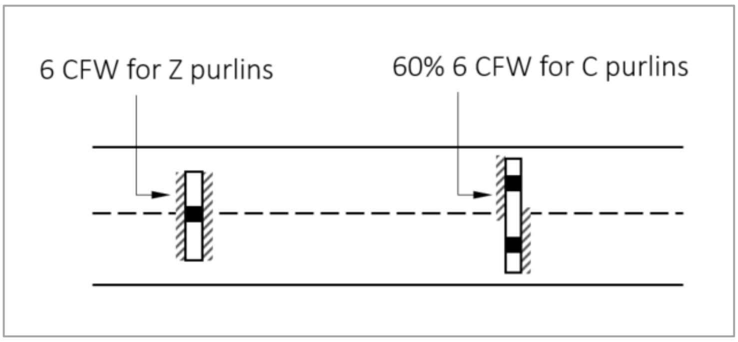
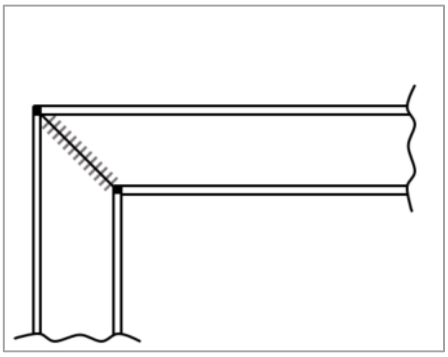


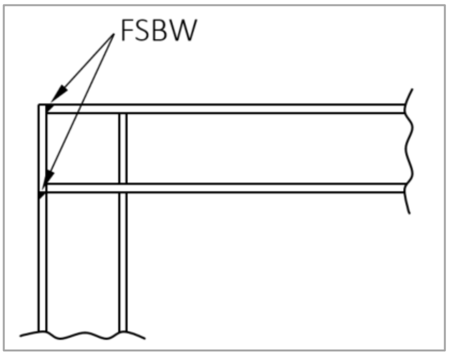
Figure 12: *Purlin and girt cleat connections*

6.16 90° Welded Connections

There are several options available for welded 90° rigid fixed joint connection. The options presented in Figure 13 are generally preferred due to minimal labour and material costs.



(a) When no stiffness is required - FSBW flanges, CFW web



(b) When stiffness is required - FSBW as noted, C6 CFW balance

Figure 13: *Preferable options for welded 90° moment joints*

Key points

- The best designs for fabrication have a minimum number of types of plates and connections.
- Reduce the variety of sizes of components.
- In general, connections should involve shop welding and site bolting. Site welded connections should be avoided as it may cause problems with work safe.
- Some connections are easier to be assembled and should be considered in design.
- Avoid unnecessary complex details such as stiffeners, gussets, etc., if possible.

7 CAMBERING

- Avoid standard camber notes as a general note on drawings such as “any members over 2.0m…”
- Pre-set connections can be used in lieu of cambering if structurally acceptable.
- Preference for cambering should be to cold form roll or push rather than heat application
- When camber is required, the magnitudes, direction and location of camber, and the beams that require camber should be clearly nominated on a beam schedule.

Cambering options:

- Cold push
- Cold roll
- Heat treatment

Cambering tolerances:

- Cold push/roll: Nominally +/- 5.0mm
- Heat treatment: Nominally +/- 10mm

Key points

Camber to beams should not be as a general note. For cantilevers the specified camber may be up or down, depending upon the framing and loading.

8 SURFACE TREATMENTS

Surface treatment requirements must be clearly shown on drawings & specifications. The 5 main treatment options and their uses are as follows:

- Raw:
  - Steel is completely untreated:
    - Used when the steel member is to be fire sprayed on site
    - Used when the steel member is fully concealed in its final condition and not subject to moisture
    - Used at bolted friction grip connections area
  - Steel treated with diluted special acids and agents to get the uniform rusted finish:
    - Used when rusty finish is desired (already corroded and protected due to the insoluble oxide layer)
    - There may be already proprietary coated treatments

- Shop Prime (AS 1627.4 Sa1):
  - Steel surface is cleaned via whip blast (class 1), mechanical wire brush or hand wire brush, then coated with 1 coat of primer (usually zinc phosphate primer):
    - Used when steel is not in direct contact with weather (wind, rain or sun)
    - Can be internal exposed steel work (such as factories & warehouses)
    - It is not considered an architectural finish
    - Does not provide warranty period

- Paint System (AS 2312.1 Table 6.1 (then system designation as required)):
  - Steel surface preparation usually Class 2.5 blast. Then treated with primer and top coat(s):
    - Use for architectural steel
    - Can be used for internal/external conditions
    - Usually applied by an accredited painting organisation
    - Will provide a warranty period (product dependant)

- Hot Dip Galvanizing (AS/NZS 4680 (batch dipping) or AS/NZS 1214 (fasteners))
  - Surface preparation integral to the process, with all parts of the article protected including pre-drilled bolt holes and shop welds. Will need detailing for venting and draining surfaces (refer https://gaa.com.au/basic-design-guidelines/).
    - Used for all conditions, but typically industrial, construction and infrastructure
    - Can be used for internal/external conditions
    - Applied in the factory
    - Durability is defined in AS/NZS 2312.2 and is dependent on steel thickness
    - See GAA Website https://gaa.com.au/ for more on durability.
  - Hot dipped galvanizing is used on steelwork exposed to weather. It usually has smoothness and colour surface imperfections, however is the most economical form of surface treatment for exposed steel.

  - Galvanized steel sections or frame sizes are usually limited to the size of zinc baths.
  - Specialist contractors prep, dip and clean steel.
  - Warping of steel can occur depending on:
    - How steel is supported during dipping process
    - Steel section sizes/composite fabricated members

- Fire Protection:
  - Vermiculite (site applied) on raw steel
  - Intumescent Paint – Upsize mass of steel to minimise expensive coating thickness

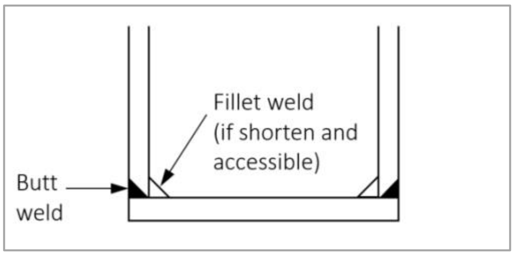
Key points

Different types of surface treatments are available, and the treatment type required should be specified as needed, not a general note.

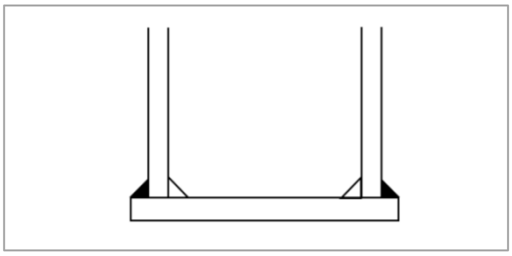
9 WELDING

Steel welding is predominantly a manual process and that increases costs relating to speed and time for fabrication. Welding efficiencies can be improved by design and specifying fillet welds in lieu of butt welds, by increasing stitch welding instead of “all welds to be continuous” and by reducing the requirement of grinding/cleaning welds. Manual weld preparation work also significantly increases OH&S risk, therefore use welded connections only when necessary. Fillet welds should be used instead of butt welds when:

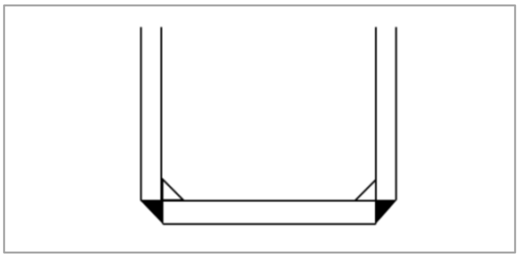
1. Connecting beam flanges to webs to form box sections and I beams
2. Attaching stiffeners
3. Where plates can be repositioned or resized to enable a fillet weld
4. At full contact splices in connections



(a) Typical FSBW connection



(b) Extended plate to allow CFW all sides



(c) Alternative FSBW using weld preparation by shortening plate and CFW all sides

Figure 14: *Types of welded connections for end plate*

9.1 Weld Category

Designers should specify, General Purpose (GP) weld category when satisfactory, in lieu of Special Purpose (SP).

There are 2 main differences between GP and SP weld categories:

1. Weld inspection requirements
2. Weld cleaning/spatter/grinding

For structural steel that is concealed, and SP category weld is used, the strict requirements for weld cleaning/spatter and grinding should be removed and reduce costs. There is no structural or architectural benefit if welds are cleaned and never seen again!

Designers should specify GP category welding and specify the weld inspection requirements to ensure structural integrity is maintained.

9.2 Fillet vs Full Penetration/Butt Welds

Fillet welding is an efficient method of welding steel components together. Full penetration welding requires extensive preparation and welding to apply, adding to the labour and time costs in fabrication. 6 CFW welding should be used as a standard size on base plate and end plate connections, stiffeners, gussets, and in all locations providing the designed structural integrity is maintained.

Fillet welds of 6 CFW should apply in most to welding gussets and stiffeners up to 10mm or 12mm in thickness, unless load transferring through connection plates require larger fillet sizes and/or lengths.

Fillet welds should also be considered for mitre connections where grinding is not required.

9.3 Partial Penetration Welds

For structural elements designers will nominate full penetration or equivalent fillet welds. Partial (incomplete) penetration. When applicable, the use of partial penetration welding can reduce welding costs by up to 65% compared to using FSBW when full strength is not required. Partial penetration welds should be used more frequently in lieu of FSBW in the following types of connections:

1. Mitre joints
2. End caps to hollow sections
3. Architectural steel framing

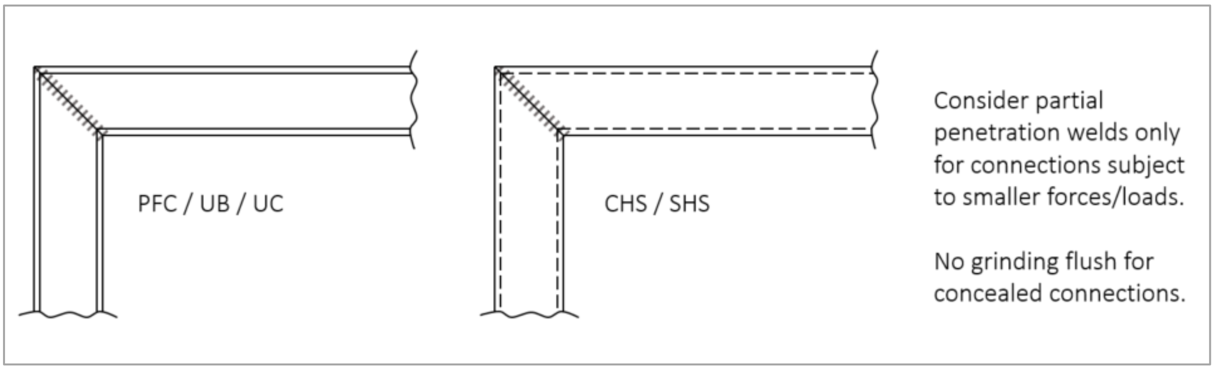


Figure 15: Partial penetration weld connections

Deep-penetration fillet welds for web/flange connections should be considered in 3-plate girders. This is also used to advantage on WB and WC sections.

9.4 Stitch Welding vs Continuous

Stitch welding should be specified when welding long steel sections together (refer to Figure 16). Some examples include stiffeners, T-bars, composite section lintels, secondary steel framing and architectural framing.

The main reasons to nominate stitch (intermittent) welding over continuous welding are:

1. Stitch welding requires less time, therefore reduces fabrication costs.
2. Steel is subject to distortion under the heat produced during the welding process. Continuous welding engages much more heat, and the time costs associated with restoring distorted members is costly. Fabricators are usually unable to manipulate the sections to restore to perfectly straight.

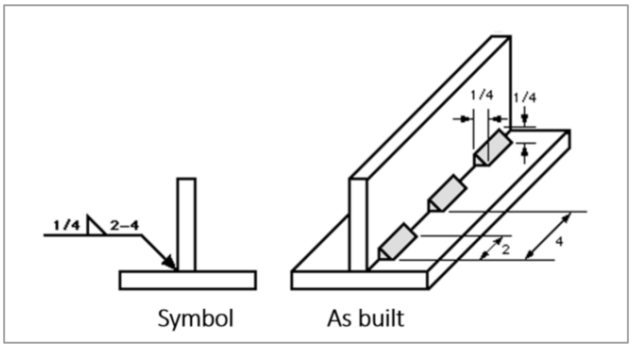


Figure 16: Stitch weld connection

General notes on drawings should not have the phrase “all welds to be continuous”. The Designer should nominate where intermittent welding can be used and dimension the hit/miss lengths.

9.5 Weld Specifications and General Notes

All welding should be in accordance with AS/NZS 1554.1

General Notes on drawings should include the following key requirements:

1. Weld specifications
2. Weld types
3. Weld inspections

General Notes should not specify E48XX welding consumables, a note such as "an equivalent should be used" should be added.

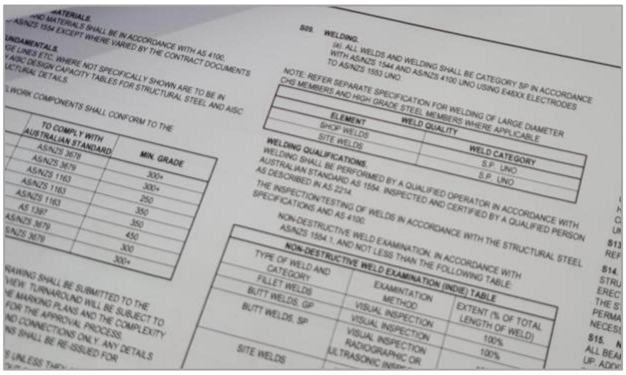


Figure 17: *Extract of typical General Notes*

9.6 Welding Doubler Plates

Doubler plates can for most situations be tack welded or at the very most, small stitches welded to steel. (Refer Figure 18)

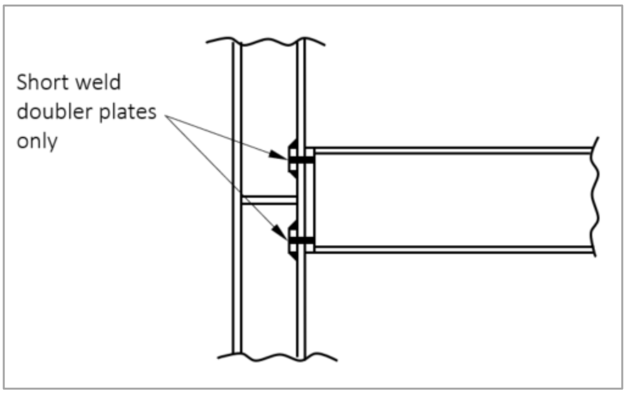


Figure 18: *Short weld double plates*

Key points

- SP welds should only be specified when needed and not as a general rule.
- Fillet welds are less cost than butt welds and should be used when structurally acceptable.

10 FASTENERS

10.1 Steel to Concrete/Masonry Connections

The anchor types available include requirements for installation sequence horizontally into concrete/masonry walls, vertically into underside of concrete slab, screw-type, chemical bonding, expansion type, and for a range of load capacities. The appropriate anchor is selected in consideration of load capacity, installation procedure, and tolerances required, and total cost if a choice can be made. It is reasonable for engineers to ask that all anchors be proof-loaded by torque to the supplier's recommendation. This provides a simple check that the anchor has engaged with the concrete. When considering these types of connections, preferences for fixings are provided in the following subsections.

10.1.1 Concrete

1. Stud anchors: Stud anchors (also known as through bolts) are torque controlled expansion anchors with a nut in one end and these are preferred when fixing in walls and floors. Fixing to slab soffits for sizes greater than M16 is not recommended due to installation difficulties. Drilling the correct size hole is critical for stud anchors. (Refer Figure 19)

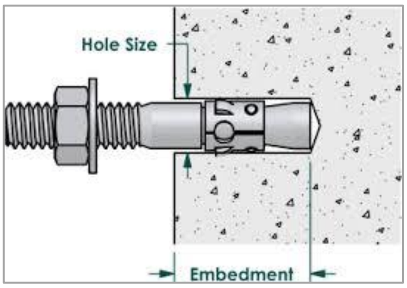


Figure 19: Stud anchor / Through bolt

2. Drop-ins: These anchors are displacement-controlled expansion anchors and are suitable for smaller loads only. Correctly drilled size hole and compatible installation tool (setting hammer) is required for the proper installation of drop-ins.

3. Chemical anchors: Chemical anchors (also known as bonded anchors) allow more tolerance for positioning the drilled holes. The curing time after installation varies with temperature and type of chemicals used. The total installation time for chemical anchors is longer than for expansion anchors.

   The performance of the chemical anchors depends on the cleanliness of the drilled hole and requires experienced installation according to Manufacturer's Installation Instructions (MII). Obviously chemically installed anchors must not be loaded until fully cured. These anchors should not be loaded until fully cured. Drilling into rebar, requires drilling through the rebar or repositioning the anchor!

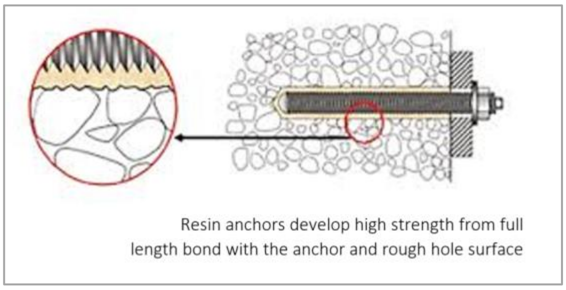


Figure 20: Chemical/Bonded anchor

4. **Concrete Screws:** Screw anchors may be economical for low load capacities, and also requires fixtures (steel elements) to be in position before installing the screws. The correct size hole and correct installation torque are very important for the screws. (Refer Figure 21)

Figure 21: Concrete Screw

5. **Heavy duty expansion anchors**: These anchors are torque controlled expansion anchors and may be expensive compared to chemical anchors but are fast to install in the right conditions. Similar to other anchors and to expansion anchors (torque controlled and displacement-controlled anchors) heavy duty expansion anchors, they must be embedded fully. These anchors cannot be installed on an angle to avoid steel reinforcement. The expansion anchors require larger edge distance (compared to chemical anchors) from the edge of concrete member. Correct size hole and installation torque are very important for the desired performance of these anchors. (Refer to Figure 22)

Figure 22: Torque controlled expansion anchor

6. Cast in ferrules/inserts: In principle, cast in ferrules/inserts have superior structural integrity and are the fastest to fit steel to concrete, if they are installed correctly. There is a possibility of these anchors cast out of position as they move during the concrete placement. As a result, compensating washers and site welding may be needed therefore higher installation time and costs.

   The fixtures with structurally rated fixture plate with washer systems can be used to accommodate small alignment issues. (Refer Figure 23)

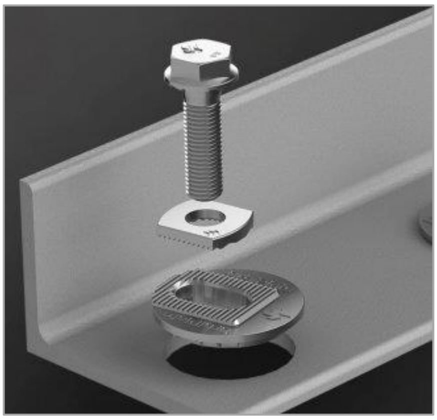


Figure 23: *Orbi Plate*

7. Holding Down Bolts: In principle, as per cast in ferrules, cast in holding down (HD) bolts have superior structural integrity and are the fastest to fit steel to if they are installed correctly. There is a possibility of HD Bolts to be cast out of position because of movement during concrete placement. Slotting plates, compensating washers and site welding may be needed, however this method is proven (extra costs accepted).

10.1.2 Connection to Masonry

1. Sleeve Anchors: Thin or Thick sleeve anchors could be the most cost efficient in terms of purchase price and installation, thin sleeve anchors have a lower load capacity.

Figure 24: *Sleeve anchor*

2. Drop-ins: Are suitable for smaller loads. However, similar to other expansion anchors, these anchors need to be placed with stipulate clearance form edges or openings.

3. Stud Anchors: Stud anchors/through bolt are economical to purchase and install, however they must be installed into brick (not mortar joints) and not close to edges.

4. Screw anchors: Screw anchors are economical to purchase and install, however they slow down installation while pinning steel as they cannot be screwed in unless the steel member is in its final position. These screws do not work in mortar or close to brick edges.

5. Chemical Anchors: Chemical anchors can be used for general fixing to masonry. Threaded rods (all threaded) can be used for fixing to multiple layers of brick if required. For use in hollow masonry (or masonry with cavities) appropriate mesh sleeves should be used. Chemical anchors take longer time to install than expansion anchors and screws. These anchors should not be loaded until fully cured.

Figure 25: Mesh sleeves

10.2 Steel to Steel Connections

10.2.1 General

- Bolting should be designed in accordance with AS 4100/AS 4600
- Designer specify the bolting type (S, TB, TF – progressively more expensive) based on as designed connection forces in structure, use S-type if satisfactory, rather than TB of TF for convenience.
- TF/TB connections require specified tensioning in accordance with the relevant codes, as does the verification method.
- For TF connections, friction factor between connecting members should be maintained and assured at the assumed design value. This will probably require specific treatment of the interface surfaces (e.g. sand blasting, special friction enhancing paints, or no priming allowed).

10.2.2 Cold Rolled Connections

- To minimise costs designers should avoid nominating high tensile (Gr 8.8) bolts for purlin connections. These are non-standard bolts with limited availability. The wall strength may NOT even exceed Gr 4.6 capacity.
- Additional oversize washers would significantly improve the load transfer and stiffness of the joint.
- Large number of small diameter bolts is far better than small number of large diameter bolts.
- Self-Drilling Screws (SDS) or certified rivets may provide adequate connections.

10.2.3 Cast in Place Connections

Welding connection plates to site cleats is usually more expensive than bolted connections.

Designers should especially avoid nominating cast in place connections (CIPs) where members are to be welded directly between CIPs. CIPs cast in concrete out of position or level result in expensive rectifications, and increasing erection costs.

Key points

- Many special fasteners have been developed to connect steel to concrete/masonry for specific applications and they should be used in accordance with manufacturer's instructions.
- Bolting type (S, TB, TF) should be selected based on design requirement rather than convenience.

References

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Appendix A

General Requirements: When structural steel members are specifically designated as "Architecturally Exposed Structural Steel" or "AESS" in the Contract Documents, the requirements in Sections 3 and 4 shall apply as modified by this section. AESS members or components shall be fabricated and erected with the care and dimensional tolerances that are stipulated in Sections 1.2 through 1.5.

Categories are listed in the Architecturally Exposed Structural Steelwork (AESS) Matrix shown in Table 1 where each Category is represented by a set of Characteristics. The following Categories shall be used when referring to AESS:

- AESS 1: Basic Elements
  Suitable for "basic" elements which require enhanced workmanship.

- AESS 2: Feature Elements viewed at a Distance > 6 m
  Suitable for "feature" elements viewed at a distance greater than six metres. The process involves basically good fabrication practices with enhanced treatment of weld, connection and fabrication detail, tolerances for gaps, and copes.

- AESS 3: Feature Elements viewed at a Distance < 6 m
  Suitable for "feature" elements - where the designer is comfortable allowing the viewer to see the art of metalworking - welds are generally smooth but visible, some grind marks are acceptable. Tolerances are tighter than normal standards. The structure is normally viewed closer than six metres and is frequently subject to touch by the public.

- AESS 4: Showcase Elements
  Suitable for "showcase or dominant" elements - used where the designer intends that the form is the only feature showing in an element. All welds are ground and filled edges are ground square and true. All surfaces are sanded/filled. Tolerances of fabricated forms are more stringent - generally 14 of standard tolerance. All surfaces to be "glove" smooth.

- AESS C: Custom Elements
  Suitable for elements which require a different set of characteristics as specified in Category 1, 2, 3 or 4.

Notes

1.1 Prior to blast cleaning, any deposits of grease or oil are to be removed by solvent cleaning, AS1627 Part 1.

1.2 Rough surfaces are to be deburred and ground smooth. Sharp edges resulting from flame cutting, grinding and especially shearing are to be softened.

1.3 Intermittent welds are made continuous, either with additional welding, caulking or body filler. For corrosive environments, all joints should be seal welded. Seams of hollow structural sections shall be acceptable as produced.

1.4 All bolt heads in connections shall be on the same side, as specified, and consistent from one connection to another.

1.5 Weld spatter, slivers, surface discontinuities are to be removed. Weld projection up to 2 mm is acceptable for butt and plug welded joints.

2.1 Visual samples are either a 3-D rendering, a physical sample, a first off inspection, a scaled mock-up or a full-scale mock-up, as specified in Contract Documents.

2.2 These tolerances are required to be one-half of those of standard structural steel as specified in CSA S16.

2.3 Members marked with specific numbers during the fabrication and erection processes are not to be visible.

3.1 All mill marks are not to be visible in the finished product.

3.2 Caulking or body filler is acceptable.

3.3 Seams shall be oriented away from view or as indicated in the Contract Documents.

3.4 The matching of abutting cross-sections shall be required.

3.5 This characteristic is similar to 2.2 above. A clear distance between abutting members of 3 mm is required.

3.6 Hidden bolts may be considered.

4.1 RHS/CHS seams shall be treated so they are not apparent.

4.2 In addition to a contoured and blended appearance, welded transitions between members are also required to be contoured and blended.

4.3 The steel surface imperfections should be filled and sanded.

4.4 The weld show through on back-face of the welded element caused by the welding process can be minimized by hand grinding the backside of the weld. The degree of weld show-through is a function of weld size and material.

C. Additional characteristics may be added for custom elements.

The above definitions, chart and notes are from ASI AESS Series Document E Code of Practice (for fabricators)- Architecturally Exposed Structural Steel.

Key points

Specific surface finishes could be expensive and should only be specified when needed, not as a general note.