1. Welded Connection Detailing

The load-bearing aspect of structural design is a subject beyond the scope of this publication. Engineers responsible for this are expected to have a fundamental appreciation of selection of member materials and sizes to withstand applied loads, and make efficient use of the materials employed. It is assumed the designer is using the limit state design method as covered by AS 4100 [Reference 1] or the working stress method detailed in AS 3990 [Reference 2] to design members and joints. The designer has many factors to consider and strength is only one of them. Rigidity, corrosion performance, and several other factors affect the integrity of the structure. After structural integrity, cost is the major factor, and this is made of design, material, fabrication and erection costs. Usually the fabrication and erection costs represent a significant portion of overall cost. Cosmetic appearance is sometimes a factor.

This book looks at design from a more practical viewpoint, showing where savings in fabrication costs are possible. It is necessary to ensure connections are structurally sound, but poor details cost the fabricator and the overall project heavily. This part will consider where detailing can be optimised for producibility.

Designers must always consider the main intents are to:

- Provide a structure that is as safe as possible during its lifetime, that it can withstand all foreseeable service conditions
- Provide a structure that is cost effective, and can be completed as quickly as possible.

In the second requirement, the total cost is of most importance. Saving material costs by using lighter members with large numbers of braces and stiffeners increases fabrication and erection cost. It extends the fabrication and erection time and possibly causes delays.

Poor design can increase the risk of structural failure in a number of ways. It can create unwanted residual stress concentrations at edges and corners. More subtly it makes welding more difficult, increasing the risk of defects, and sometimes makes detection of flaws difficult or impossible.

Poor design also increases fabrication, welding and assembly cost. Poor access for welding leads to low productivity as well as poor quality welds. Welders need to break more often if working in cramped locations. They tend to spend a lot of time cleaning and grinding welds to achieve a neat surface round edges and corners, often when a simple design amendment could have saved this work.

1.1. Major Design Factors

Welded design usually depends on application of established principles learned from existing structures. The designer and detailer of a welded structure should consider the following factors.

- Consider fabrication at the design stage. Check with the fabricator for cost-saving ideas and producibility.
- Consider the assembly and welding sequence, so that distortion, accessibility and productivity are optimised.
- Consider modular design. Many subassemblies can be built concurrently, even at different locations. Schedule times, labour costs and handling costs are reduced. Distortion may be easier to control.
- Erection of large modules is more efficient than erecting small ones, despite increased cranage and transport costs. Check that the constructor has the crane capacity.
- Where possible standardise subassembly design. This allows easier fabrication, warehousing and erection. Robotic mechanisation may become feasible.
- Minimise the number of pieces. Use larger members, rather than lighter members with multiple stiffeners. A couple of lines on a drawing representing stiffeners may have negligible design effort, but they will have considerable fabrication or erection cost impact.
- Avoid complicated designs of multiple tiers of sub-assemblies. This requires excessive material handling.
- Design components that fit together easily. Design so the component is erected by sitting it on top of existing structure, rather than having to be manoeuvred into it.
- Avoid details that have to be trimmed to fit. Example: avoid full width stiffeners to transfer loads between flanges and webs in an 'I' section where triangular gussets will do.
- Avoid components that require to be made to high tolerances in order to fit together.
- Consider the jigging or fixturing necessary to assemble and hold components for erection or welding. Can permanent members be used to help avoid building special jigs?
- Keep an open mind and think laterally. Use weldments rather than forgings or castings where this saves costs. Use a casting rather than a complicated weldment for a complex connection if this is cheaper.
- Bend components from plate rather than having separate flat components welded together.
- Design so that as much welding as possible is undertaken in the flat position.
- Avoid turning heavy fabrications to weld the other side. Use one-sided welds, with temporary or permanent backing.
- Make welds simple to mechanise or automate where this can lead to cost savings.

1.1.1. Categories of Structural Welds

Australian Standard AS/NZS 1554.1 [Reference 3] specifies two quality levels, and this approach is repeated in other parts of AS/NZS 1554. Welds that are not subject to fatigue loading and do not exceed 50% of the permissible design stress can be designated General-Purpose (GP) category. Welds which are more highly stressed are classified

Special-Purpose (SP). Technical Note 11 [Reference 4] gives examples of where each weld category is appropriate for standard structural connections, and suggests an appropriate level of NDE. It is inferred that GP welds are cheaper to make than SP welds, but this is not always the case. AISC standard costs as used in the 'STEELestimator' cost estimation program [Reference 5] and Costing of Steelwork [Reference 6] do not distinguish between the two categories. It is worth discussing the potential savings of GP welds with the fabricator.

One difference between SP and GP welds is the level of testing required to qualify a welding procedure. Provided they meet certain criteria, Category GP welds are prequalified and can be established without producing a test weld. There is now no such thing as a prequalified SP welding procedure. At least a macro test is required to qualify it. The differences in test cost are largely irrelevant for major fabricators. These companies only have category SP procedures, and have a comprehensive suite of them built up over years. Production of Category GP procedures is only undertaken by smaller fabricators who only ever undertake minor work.

While there may be little difference in the cost of making a weld, there could be considerable differences in the costs of inspection and repair. GP welds should not be subjected to radiography or ultrasonic inspection or to any more than 25% visual inspection. Category SP butt welds are subjected to between 10 and 50% visual inspection and up to 10% ultrasonic inspection or radiography.

There are differences in the acceptance criteria for surface flaws between the two weld categories, but these are only significant to the fabricator if the structure is all Category GP. Where there is a mixture of SP and GP welds, the fabricator generally works to the higher standard. Having two standards is confusing to welders. They have to be qualified to meet the highest standard required for the work. Welders generally try to work to the highest standard, and do not deliberately try only to just achieve the minimum standard.

The differences in acceptance standard between SP and GP welds are minor and of little practical significance. Distinguishing between undercut depths of 1 and 1.5mm is difficult practically and seems of little significance from a structural viewpoint. Certainly, it is of no significance when making the weld. Only one difference has practical significance to the welder and that is the amount of excess weld metal (reinforcement). This is unrestricted for GP welds and has easily achieved limits for category SP welds. Only poorly skilled welders cannot achieve the standard. From an engineering viewpoint, excess weld metal is undesirable only if it causes distortion, or alternatively if the weld bead height is such that it causes acute notches at the bead toes. Why there is such a difference between the two categories of welds is questionable.

Full-penetration butt welds have to be backgouged or ground to ensure freedom from root defects. Because GP welds are not subject to internal inspection techniques, procedures do not need to assure freedom from internal defects. In particular full-penetration butt welds can be made without backgouging or back grinding, and this should allow considerable savings. However many fabricators do not follow this concept and will back grind the root run of both SP and GP welds. This avoids the risk of a SP weld being made to GP category. There is no difference in the procedure for making fillet and partial penetration welds.

Remember also that welds subject to high fatigue loading should be made to the higher standard detailed in AS/NZS 1554.5. These welds are surface dressed and have higher defect acceptance standards to achieve a long fatigue life. They are therefore much more expensive.

1.1.2. Weld Accessibility

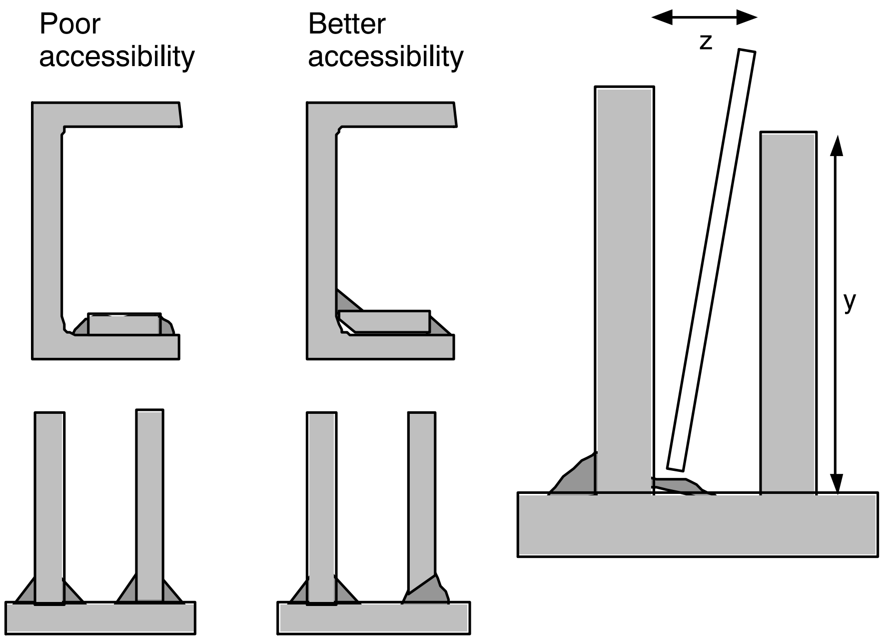

Figure 1 Weld Access

In designing a complex structure, the designer must ensure the welder has adequate access to make the weld. A sound weld cannot be made if the welder cannot see the fusion faces and have room to manipulate the heavy gun or electrode holder. The welder needs to get his eyes to within reading distance (about 250mm) of the weld being made.

Figure 1 shows the effects of having components too close together and how this will adversely affect weld quality. Suggested methods of overcome the problem are also shown. To ensure access is sufficient for fillet welds, the spacing between adjacent components (z) should be more than half the height of the adjacent component (y). If sufficient clearance is not provided the fillet will have an unequal leg length, the penetration into the root will be inadequate, and fusion to the sidewall will be poor.

Designers should avoid creating spaces that are awkward, cramped or dangerous to work in. If welders have to work where access is restricted, the risk to health is high. There is a difficulty avoiding breathing fume. Repetitive strain injury and other muscular skeletal problems can occur. The efficiency of welding in these conditions is very much reduced and fabrication costs dramatically increased. The more productive welding processes, such as submerged arc welding require far better access than for manual metal arc welding. Careful design can overcome many of these problems.

Avoid putting critical welds where access for inspection is limited. Radiographed welds need to have a constant thickness and there needs to be access to both sides, to place the film, radiation source and image quality indicators. Ultrasonic testing can only be undertaken if the technician has clean, flat base material on both sides of the weld. There should be a minimum distance of at least five-times the plate thickness of unobstructed plate material next to the toes of the weld being scanned.

1.1.3. Engineering and Detail Drawings

The design engineer usually produces engineering drawings, which seldom are suitable for use at the fabrication workshop or construction site. Engineering drawings should show sufficient information for detailed drawings to be produced. Often the fabricator has the task of producing detailed shop and erection drawings. AISC has produced a manual describing the minimum requirements for engineering drawings [Reference 6], and a manual for steel detailers [Reference 7]. While Reference 6 is written for structural steelwork, its principles can be used much more widely.

The aim of engineering drawings is to provide sufficient information to:

- Clearly communicate the designer's intent,
- To provide contractually enforceable design requirements,
- Enable the fabricator and erector to accurately tender for the scope of work,
- Enable the production of detailed shop and erection drawings.

Engineering drawings should provide only sufficient information to meet these needs. For example, dimensions are given only once on a set of drawings to avoid the possibility of ambiguity. Engineering drawings may need to be used in conjunction with architectural drawings to show the full picture. Engineering drawings should describe the designer's intent completely. Lack of detail will necessitate the fabricator and detailer assuming what is required, or will generate technical queries.

Engineering drawings may contain sufficient detail to manufacture each item, but this is not normal, and detailed drawings are required. Detailed shop drawings will show enough information for the fabricator to cut and assemble each sub-assembly without reference to too many drawings. They contain more dimensions and detail than engineering drawings, and show weld bevel angles. Erection drawings show the location of each component and the method of joining (field welding or bolting). Information such as piece weight, crane positions and sling locations may also need to be thought out. The erection sequence should be shown.

The detailer should be familiar with the workshop and construction site conditions and equipment. The detail drawings should show how the structure is made using the available equipment.

Shortcutting of the design process is likely to lead to catastrophe. It is common for minor items such as temporary platforms or jigs to be built directly from designer's sketches. Checking is sometimes omitted for expediency. This can lead to problems if these sketches do not fully describe the required structure, and there may be serious consequences if the structures fail.

1.2. Weld Preparation Details

The selection of weld preparations for fusion welds is described in this section. Details of typical welded connections follow. Examples of their usage are found in the chapters on specific types of structure.

1.2.1. Joint Configurations

It is useful to distinguish between joint types and weld types. A joint forms the union between two or more members. The joint type describes the configuration of the members being joined and usually is one of the five types shown in Figure 2, as described in Reference 8. The designer usually has a choice as to whether to use butt welds (groove welds), or fillet welds (or indeed some other joining process) to make the joint.

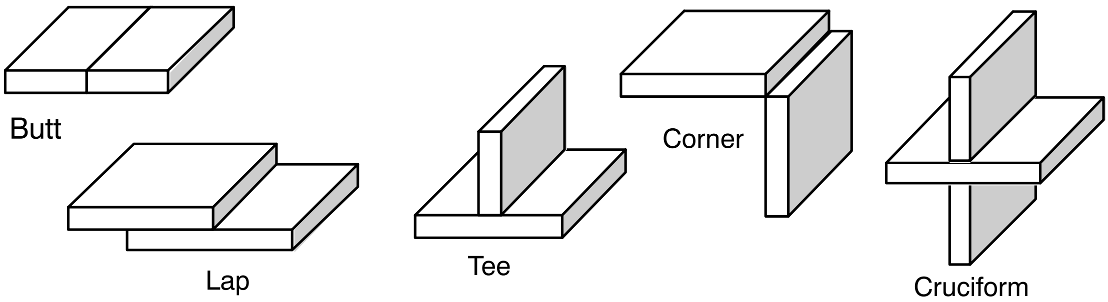

Figure 2 Five Main Joint Types

1.2.2. Types of weld

From a design viewpoint, there are only two types of weld used for making joints: butt welds and fillet welds. Butt welds are preferred for joints where maximum strength is required. Fillet welded joints are more economical, unless large welds are required. The joint types described above can be made with one or more of these weld types. There is a third weld type, which is surfacing. This is the build-up of a surface to correct dimensions (buttering) or to apply a wear- or corrosion-resisting overlay.

American terminology for a 'butt weld' is 'groove weld'. The Americans restrict the term 'butt' to a particular joint type. In Australia and Europe, the distinction between a 'butt joint' and a 'butt weld' often causes confusion.

Welders also classify welds as one of two types in terms of easiness to make: backed welds and unbacked welds. Backed welds are those where the root run is well supported or is accessible on the opposite side to be cleaned and seal welded. Unbacked welds are full penetration welds that have to be made from one side with the back inaccessible and unsupported. In this case, the root run has to be perfect. This requires much more skill as the welder cannot easily see what is happening to the other side of the joint, and yet must penetrate and fuse to the other surface properly (see Section 1.2.10.).

1.2.3. Selection of Weld Joint and Type

The common weld joints and types are discussed in this section, together with their attributes. In selecting a particular weld detail, the following factors should be considered. Some of these factors conflict and compromises are necessary.

- Select a weld that adequately carries static and dynamic stresses, but avoid over welding.
- Select a weld with sufficient access for welding and inspection, and where possible allow for mechanised or automatic welding.
- As far as is possible, avoid details with members intersecting at less than 60 degrees. Access for welding and inspection is much reduced.
- Choose the weld with the least amount of weld metal to minimise residual stress, distortion and cost.
- Where possible, choose a weld detail with the minimum preparation cost: fillets rather than butts, square edges rather than bevelled edges, bevelled edges rather than 'U' or 'J' preparations.
- Chose a weld with the highest tolerance for fit up. Choose a fillet rather than a butt, a double-welded butt rather than a single-welded butt and a butt on

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