

WELD DESIGN CONSIDERATIONS FOR BRIDGE GIRDERS – WELD TYPE, QUALITY AND COST

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ABSTRACT

Ideally, everything required to design a bridge section would be covered by published standards. However, for various reasons, standards do not prescribe the “optimal” design solution for every situation. In some cases designers are left with an option to whether specify a more conservative, but more expensive weld such as full penetration butt weld or consider less costly alternatives such as deep penetration fillet weld.

The paper discusses issues around fabrication costs and fatigue performance of flange to web joints of welded beams. It compares costs and fatigue performance of fillet, deep penetration fillet, compound and butt welds. It considers requirements of commonly used design standards such as NZS 3404.1, AS 5100.6, EN 1993-1-9 BS 5400; and some alternative FEA based assessment techniques available to optimise the joint design..

KEYWORDS:

economics, fatigue performance, fillet welds, compound welds, full penetration butt welds, flange to web joints.

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1. INTRODUCTION

Fatigue is a significant factor in the design of structures such as steel bridges because the live loads regularly approach the maximum permitted fatigue design loading. Bridge girders are usually fabricated using automatic welding techniques such as SAW and FCAW. Welding fabrication costs of the girders are heavily dependant on joint/weld design specified by the designer.

Ideally, everything required to design a bridge would be covered by published standards. However, for various reasons, design standards do not usually prescribe the “optimal” design solution for every situation. This is the case with joint design where designers are often left with an open option to whether specify a more conservative, but more expensive joint design such as full penetration butt weld or consider less costly alternatives such as deep penetration fillet weld.

This article discusses issue around economics and fatigue performance of fillet and deep penetration fillet welds also known as compound welds and full penetration butt welds on flange to web joints junction for application such as main beams for steel and composite bridges. It considers requirements of commonly used design standards and some alternative assessment techniques that can be used in order to optimise the joint design with respect to fatigue performance and fabrication cost. The article gives a general overview over suitable assessment and weld design optimisation methods currently available and is also applicable for other welded beams under fatigue loading.

2. FATIGUE DESIGN BASED ON STANDARD AND ALTERNATIVE METHODS

A fatigue assessment is based on two fundamental components: the analysis of fatigue actions and fatigue resistance of the welded structure. On the load side the fatigue actions can be given in form of forces on the component, nominal stress in the section, structural hot-spot stress at a weld toe, notch stress at an effective weld notch or stress intensity at a crack tip.

The exact knowledge of the actions is one of the greatest unknowns and a source of many uncertainties. The load information is normally provided by the authority responsible and analysed according to the application standard. This article gives no consideration to the loading side.

On the resistance side, the properties are usually given in form of S-N curve, where N is the predicted number of cycles to failure of a stress range S also known as $\Delta\sigma$. Both, the actions and the resistance are compared by an assessment procedure taking into account safety considerations.

Fatigue design standards such as BS EN1993-1-9¹, BS 5400², NZS 3404.1³, AS 5100.6⁴ and AS 4100⁵ are commonly based on the nominal stress range - the average stress range in a welded joint, on the loading side and S-N curves representing resistance side. S-N curves are obtained from fatigue tests of welded samples and components that also have real fabrication tolerances, imperfections and residual stresses.

Resistance of welded joints to the fatigue actions is mainly governed by the joint geometry with other factors like strength of the steel, stress ratio and mean stress being of less significance. Therefore, for practical fatigue design, welded joints are divided into

several classes also called FAT class or detail category, each with a corresponding design S-N curve.

One or few critical weld details that are highly stressed and cannot be moved or improved govern fatigue strength of the whole component. Weld shape and its (macro) features is the major parameter in fatigue design. The stress-rising effect of notches is well known. The most serious notch effect occurs at the weld toe to base metal transition and root of fillet and partial penetration butt welds.

Fatigue cracking from weld toes into the base material is a frequent failure mode as shown in scenario 3.8 of Figure 1. The fatigue crack is initiated at small defects or undercuts at the weld toe where the stress is highest due to the weld notch geometry. Most of the fatigue design recommendations are developed with the purpose of achieving a reliable design with respect to this failure mode.

For fillet welds, even though the joint may be required to carry wholly compressive stresses and the plate surfaces may be machined to fit, the total stress fluctuation should be considered to be transmitted through the welds for fatigue assessment.

In some welded connections the use of fillet and partial penetration butt welds can hardly be avoided and it is also efficient for fabrication. In these welds fatigue cracking can start from weld root with a crack growth through the weld metal (scenario 3.11 of Figure 1).

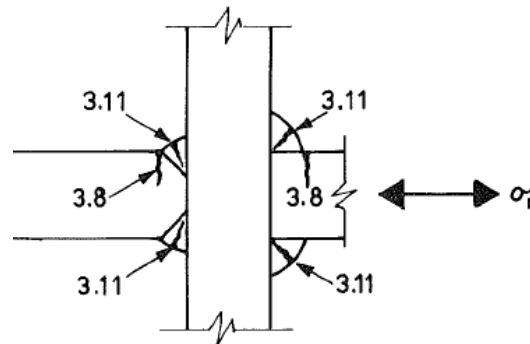


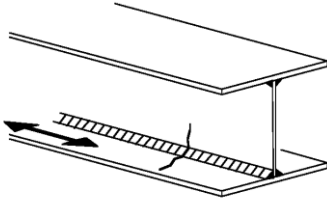
Figure 1: Possible crack locations in the partial penetration butt welds and filler weld (BS 5400 Part 10)

Design should be performed such that fatigue cracking from the root is less likely than from the toe region. The reason for this is that a fatigue crack at the toe can be found by in-service inspection while a fatigue crack starting at the root may not be discovered before the crack has grown through the weld.

In the case of a longitudinal weld in beams, in applications such as main girder for composite bridges where vertical compressive stress range in the top flange to web weld due to wheel loads can be neglected, fatigue crack occur perpendicular to the weld direction located at the tension flange in the mid-span area as shown in the Table 1. This failure mode is independent of the type of the weld used. The key factor here is the presence of weld profile discontinuities such as shrinkage groove, overlap, repair welds and stop-starts that act as stress concentrators. Automatic welds with run-out plates should eliminate this type of discontinuities and ensure the highest fatigue performance

of the joint (FAT 125). As this failure mode is nearly independent of the type of the weld and penetration, it is not considered in this paper in details.

Table 1: Some detail categories for a welded beam at the tension flange with continues longitudinal weld according to EN 1993-1-9

Constructional detail	Detail category	Description
	125	Automatic butt welds carried out from both sides
	112	Automatic fillet or butt weld carried out from both sides but containing stop/start positions
	100	

The likely location of the fatigue crack in a welded joint is largely depended on joint design, weld geometry including penetration profile, fabrication quality and tolerances, and loading mode.

EN 1993-1-8⁶ introduces the definition of an effective full penetration of T-butt welds, as a pair of partial penetration butt welds reinforced by superimposed fillet welds with the total nominal throat thickness not less than the thickness t of the part forming the stem of the tee joint, provided that the unwelded gap is not more than $(t / 5)$ or 3 mm, whichever is less, see Figure 2. EN 1993-1-8 states that welds subject to fatigue shall also satisfy the principles given in EN 1993-1-9.

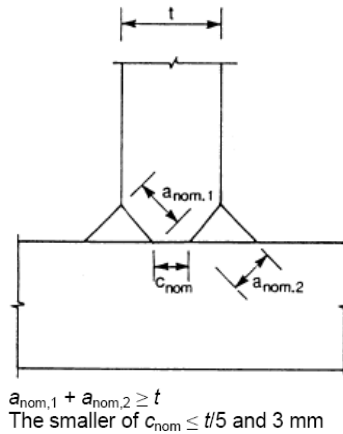


Figure 2: Effective full penetration of T-butt welds according to EN 1993-1-8

EN 1993-1-9 does not recommend any specific weld penetration profiles on T-Joints. However, it specifies detail categories for top flange to web joint of runway beams for applications such as crane runway on whether it is full or partial penetration weld. Using a partial penetration instead of the full penetration weld reduces the fatigue strength from FAT 71 to FAT 36. The standard does not make any provision for the possible improvement of the fatigue life when using deep penetration welds for this application.

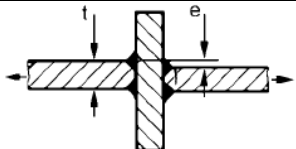
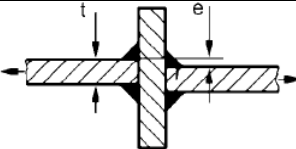
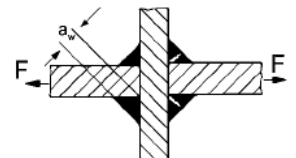
NZS 3404.1, AS 5100.6 and AS 4100 also have the same detail categories for joint configurations above leaving designers with only two choices of either specifying detail category FAT 36 for fillet welds or 71 for full penetration butt weld.

BS 5400-3⁷ states that partial penetration butt welds should not be used to transmit tensile forces or bending moment about the longitudinal axis of the weld in applications such as web-to-flange welds (section 14.6.2.2). However, the standard permits using fillet welds as longitudinal welds for flange to web connections (section 14.6.3.7). Both statements are somewhat contradictory as a partial penetration butt weld is normally treated as a fillet weld. It is therefore understood that the first statement does not apply to T-joints.

BS 5400 Part 10 states that the weld metal failure of type 3.11 of Figure 1 will normally govern in fillet welded joints, unless the total weld leg length is about twice the element thickness. It will also govern in a partial penetration butt welded joints except where reinforced with fillet welds of adequate size. The standard is not specific regarding the size of partial penetration butt. It is understood that the total leg length of a compound weld as defined in the Figure 9 should be twice the element thickness. For example, a deep penetrating fillet weld or compound weld welded from both sides with one-third plate thickness penetration (6.7 mm) between 20 mm thick plates, required a fillet weld of about 13.3 mm leg length in order to avoid root failure.

IIW Recommendations for Fatigue Design¹² classify cruciform joints according to the type of the weld (see Table 2). Similar to BS 5400.10, the IIW Guideline considers the impact of different fillet weld profiles in terms of potential failure modes. In fillet welded joints where root cracking as the potential failure mode is avoided due to specifying adequate weld penetration and geometry the fatigue strength would almost be double at 2 million load cycles (improving fatigue life by one FAT class). Like other standards the IIW guideline does not allow assessment of the possible failure mode depending on the penetration profile.

Table 2: Classification of some cruciform joints and/or T-joints according to IIW Recommendations (partially represented)

FAT Class	Constructional detail	Description
80		Cruciform joint or T-joint, K-butt welds, full penetration, potential failure from weld toe. Nil misalignment.
71		Cruciform joint or T-joint, fillet welds or partial penetration K-butt welds, potential failure from weld toe. Nil misalignment.
36		Cruciform joint or T-joint, fillet welds or partial penetration K-butt welds including toe ground joints, potential failure from weld root. For $a/t \leq 1/3$

Some design guidelines go further in details allowing estimating the possible location of the crack for some joints and loading modes. For example, Det Norske Veritas document⁸ allows evaluation of the possible failure mode depending on the depth of penetration for the welded connection with partial penetration – butt weld with superimposed fillet weld (Figure 3).

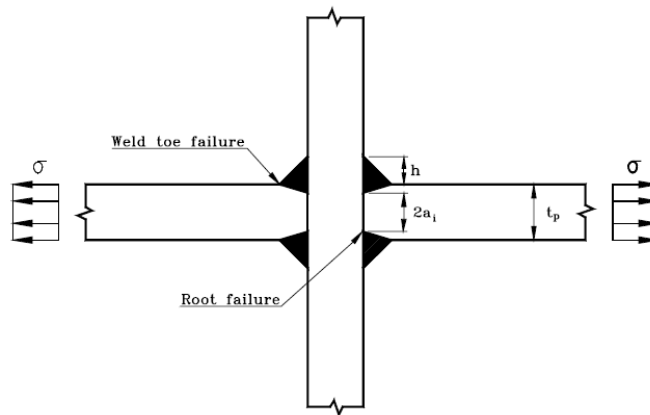


Figure 3: Welded connection with partial penetration weld (Ref. Det Norske Veritas)

Figure 4 can be used for evaluation of required penetration. For example, a deep penetrating fillet weld welded from both sides with one-third plate thickness penetration (6.7 mm) between 20 mm thick plates, required a combined leg length (fillet + penetration) to avoid root failure of about 16.8 mm (throat thickness 11.9 mm).

The assessment procedure above leads to the saving of up to 55% of deposited weld metal through using deep penetrating fillet welds instead of fillet welds of 20 mm leg length as recommended in BS 5400 Part 10.

The procedure may be very useful for designers in order to specify only as much penetration as needed to avoid root cracking, its applicability however is limited to the loading mode and joint design above.

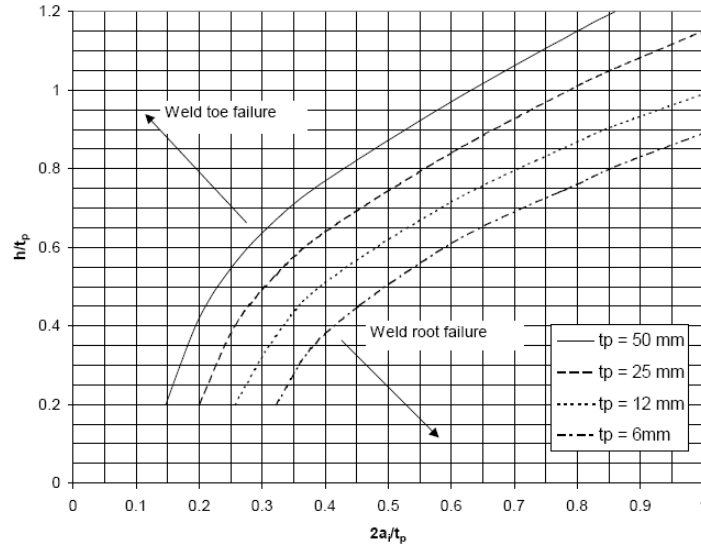


Figure 4: Weld geometry with probability of root failure equal toe failure (Ref. Det Norske veritas)

Further reference is the standard ANSI 360-05⁹ that gives reduction factors for transverse welds on the tension loaded plate element based upon crack initiation side either from the root or toe of the weld.

Maddox¹⁰ discusses the condition of optimal weld geometry for transverse load-carrying (deep penetrating) fillet weld based on test results. Figure 5 shows the optimum weld size: plate thickness relationship for three depth of weld penetration together with the dashed curves derived from on the basis of class W of BS 5400 with stress range calculated on throat area of weld.

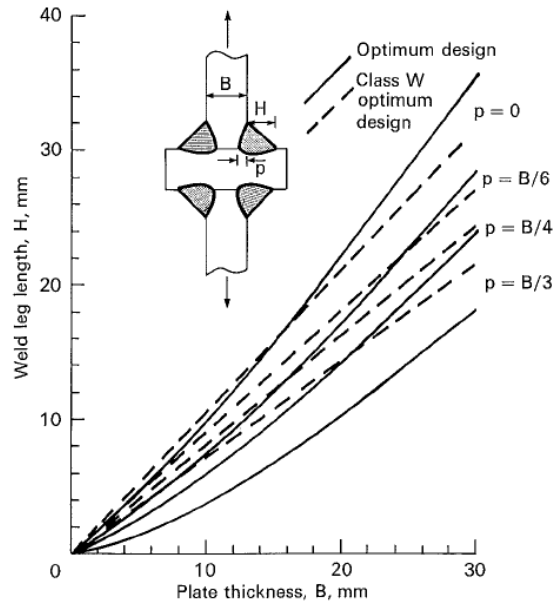


Figure 5: Conditions of optimum geometry of transverse load-carrying fillet weld as compared to weld detail Class W to BS 5400 (Ref. Maddox)

Optimum design of class W means that the weld throat is of adequate size to achieve the same fatigue life as class F2 with the failure mode at the weld toe. Test results show the benefit that can be gained from using deeper penetrating fillet welds. As depth of penetration increases, so the difference between curves increases.

For example, according to the Figure 5, for a weld with one-third plate thickness penetration between 20 mm thick plates, the required leg length (fillet + penetration) to ensure the Class W life is not less than the Class F2 life is about 22.5 mm (throat thickness 15.9 mm). However, according to Maddox's test results, a leg length of 18.5 mm (throat thickness 13.1 mm) would suffice.

The conclusion is that Class W of BS 5400 does not allow advantages to be gained from the use of partial penetration welds potentially leading to over specifying weld size.

Within the multitude of various alternative concepts and assessment methods, some techniques are currently available that can predict a possible failure mode (weld root or weld toe) and assess the fatigue life for virtually any weld joint geometry, penetration profile and loading mode¹¹: Linear Elastic Fracture Mechanics and Effective Notch Stress Approach¹² and Strain-Life Approach.

The Fracture Mechanics is one of the most accurate prediction methods available. However, it is the most complex and time consuming one. It is not expected that Fracture Mechanics is to be used on regular basis by designers. Strain-Life Approach requires exact knowledge of material properties and residual stresses in welds potentially limiting the applicability of this method.

The Effective Notch Stress Approach requires much less time to perform and so is suitable for an initial assessment of the joint design. The method is based on the (FEA) calculation of the notch stress at specific locations of the weld and relating it to the universal S-N curve for the notch stress. Hence, it is linked to the real fatigue test data.

The method allows calculation of the fatigue notch factor K_f at weld root and toe. To exclude the fracture at the weld root, the fatigue notch factor of the weld root should be lower than the relevant factor of the weld toe. It can then be expected that cracking starts at the weld toe first. In this case, the fatigue life of fillet weld equals that of butt weld (on T-joint). Using this method, a number of competing weld geometries can be evaluated.

Supplementing the Notch Stress Analysis by the evaluation of fabrication costs for individual welds, an optimised weld type and profile can be proposed.

Calculated fatigue notch factors $K_{f_{toe}}$ and $K_{f_{root}}$ for the cruciform joint are shown in Figure 6 dependant on the ratio slit length s to plate thickness b , or weld thickness a to plate thickness b . The fracture initiation should shift from toe to root or vice versa in the point of intersection of the $K_{f_{toe}}$ and $K_{f_{root}}$ curves. This point is of particular importance with regard to realisation of minimum weld size in design that would eliminate root cracking.

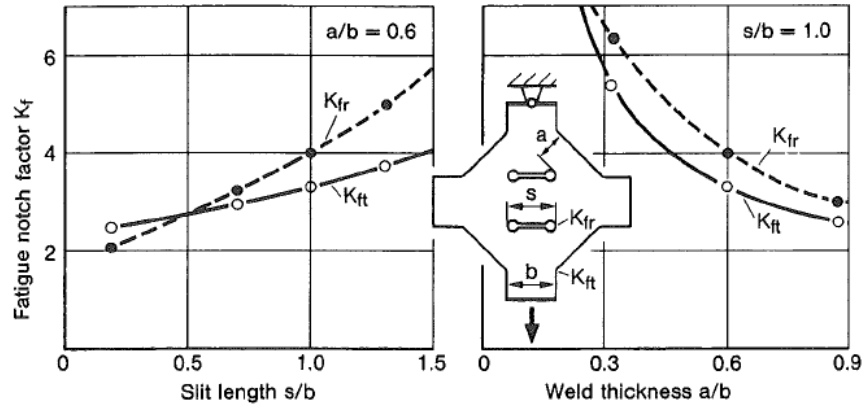


Figure 6: Fatigue notch factors, K_t and K_{fr} dependant on slit length and weld size (Radaj¹³)

For example, a compound weld between 20 mm plates with the throat thickness (a) of the fillet weld of 12 mm (16.92 mm leg length) should have a depth of penetration of about 5 mm to make the probability of root failure equal to that of the weld toe. Hence the total leg length of the weld required (fillet + penetration) is 21.92 mm.

However, in the case of zero penetration ($s/b = 1$) there is no intersection between $K_{f\ toe}$ and $K_{f\ root}$ curves suggesting that it is not possible to avoid root cracking by increasing fillet weld size for weld throat to plate thickness ratio being in the range of 0.3 to 0.9.

There are many examples from overseas where Notch Stress Approach has been effectively used to optimise fatigue design of different welded components¹⁴. Some recent reports^{15, 16, 17}, confirm a good correlation between fatigue predictions using this approach and testing. Effects of weld toe angle, leg lengths and penetration can be assessed as well. Regrettably, this assessment technique has not found its way in design standards yet.

A diagram similar to above that separates weld toe and weld root fracture can also be developed using fracture mechanics. Figure 7 shows two possible location of fracture in the typical cruciform joint depending on penetration for different plate thicknesses.

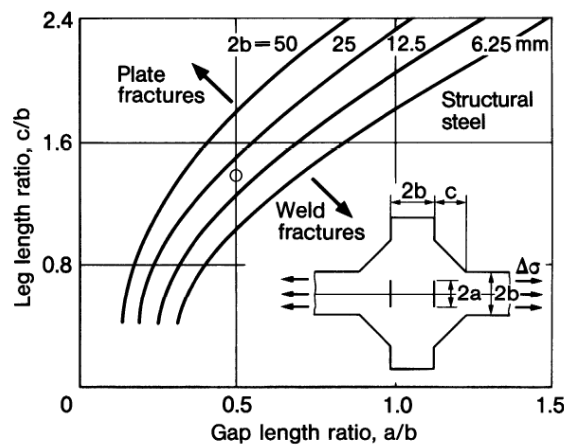


Figure 7: Limit curves separating weld toe (plate) and weld root (weld) fracture in cruciform joints (Maddox, 1974)

For example, to avoid root cracking, a fillet weld with 0 penetration between 20 mm plates should have a minimum leg length of 22 mm (15.6 mm throat thickness); or a compound weld with a fillet leg length of 15 mm should have a minimum penetration of 5mm or 25% of the plate thickness.

Table 3 below summarizes recommended weld size and penetration to avoid root failures based on some example discussed above. It is noticeable that assessment methods used by Det Norske Veritas and Maddox deliver very close results.

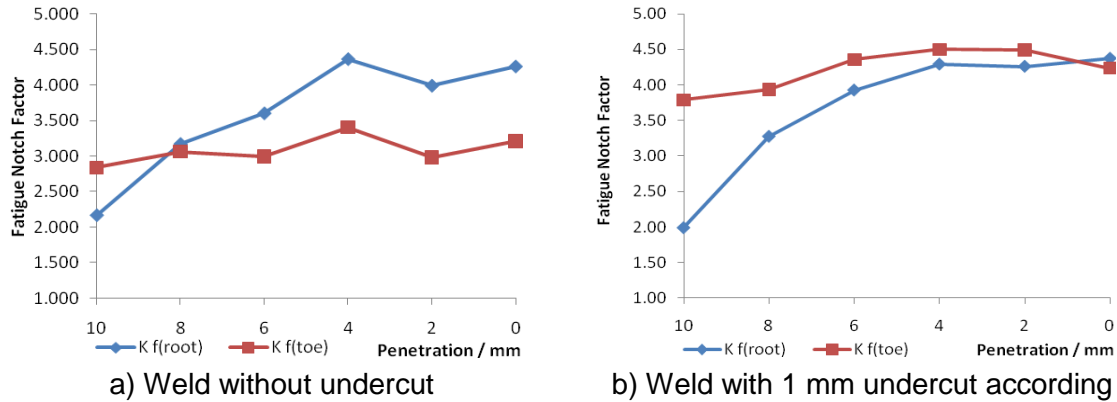
Table 3: Recommended size of the double sided fillet or deep penetration fillet weld between 20 mm plates loaded in cross-sectional direction in order to avoid root cracking calculated according to different sources.

Source	BS 5400.10			Det Norske Veritas	Maddox (Testing)	Radaj (ENSA)	Maddox, 74 (Fracture mechanics)
Fillet leg, mm	20	15	13.3	10.1	11.8	16.92	15
Penetration, mm (see Figure 9)	0	5	6.7	6.7	6.7	5	5

It should be noted that all examples above discussed the fatigue resistance side of welded T-joints with the stress range normal to the weld axis. The corresponding area of a bridge girder subject to this loading mode is at support. Therefore considerations above are not directly (without some adjustments) applicable for other loading modes like bending in the mid-span area. In the case of bending K_f factors will be lower than that in tension.

At mid-span of the girder, the predominant loading mode is tension stress range at the web to bottom flange weld. In the absence of any other details the fatigue performance of the beam in this area will be independent of the type of the weld used for detail category 112 (butt or fillet) according to the Table 1. Therefore, a fillet or deep penetration fillet weld should be considered for this joint as the most cost effective option delivering the same fatigue life.

Weld quality has a significant impact on fatigue life. The effect of undercut in the case of the beam subjected to compression, simulating the situation at support, was analysed for SP weld (according to AS/NZS 1554.1) and weld without undercut using the Effective Notch Stress Approach with the fictitious radius of 1 mm (see Figure 8).



a) Weld without undercut b) Weld with 1 mm undercut according
Figure 8: Fatigue notch factors for weld root and toe depending on weld penetration and undercut; Weld throat thickness kept constant; T-Joint, compressive stress range.

In the case of web to flange welds without undercut, the toe failure will dominate up to the gap length of between weld roots of approx. 4 mm (web thickness 20 mm). The introduction of an undercut with a depth of 1 mm increases probability of toe cracking dramatically. The toe failure will dominate up to the gap length of approx. 18 mm. In the similar way the effect of other imperfections like weld reinforcement, missalimnt and/or their combination may be studied.

Fatigue life of welded joints can be further improved by applying different fatigue improvement techniques such as burr grinding, TIG dressing and hammer peening either straight after welding or in-service. Fatigue improvement is almost exclusively done at the toe region of the weld. It is normally applied for FAT 90 or lower class details. For example, the benefit of burr grinding and TIG dressing corresponds to an increase in allowable stress range by a factor of 1.5, corresponding to a factor of 3.4 on life. This should be taken into account when considering probability of root and toe cracking by increasing fatigue resistance (FAT Class) of the weld toe accordingly^{18,19,20}.

As fatigue design assumes that the weld quality and fabrication tolerances meet requirements of corresponding standard such as AS/NZS 1554 part 1 or 5, careful specification and supervision of fabrication is essential to ensure that the design assumptions are realised in practice.

3. ECONOMIC CONSIDERATIONS FOR FLANGE TO WEB WELDS OF RUNWAY BEAMS

In Australia and New Zealand, welding-fabrication of girders or I sections is covered by the standard AS/NZS 3679.2²¹ and supporting welding standards AS/NZS 1554 Part 1²² and Part 5²³. AS/NZS 3679.2 requires fillet welds in web-to-flange joints to be produced by an automatic welding process. The weld quality shall be category SP throughout.

There are many cost elements associated with welded fabrication some under the control of the Client and some under control of the Fabricator. The Client usually controls design of the item, quality and inspection requirements. The fabricator usually develops the most cost effective welding-fabrication procedure for a given design. Under the control of the fabricator is also the development of shop drawings that may potentially lead to some design changes in order to simplify fabrication.

During the development of the shop fabrication drawings important decisions are made that will ultimately determine the production rate. The appropriate automatic welding process such as SAW or FCAW can be identified for each joint and the optimum joint preparation designed at the shop drawing stage. High productivity welding generally requires welds to be made in the Flat 1G or 1F welding position. It is also necessary to determine a welding sequence to control weld distortion.

However not all fabricators may possess turning equipment that would allow positioning a girder in 1F position for the effective SAW. Applying SAW in the horizontal (2F) position may lead to undesirable weld profile with increased reinforcement. To avoid this, a less productive FCAW may be deployed for the root run and/or the whole weld seam. FCAW has less penetration ability than SAW. As the joint set up is often done without a root gap, arc gouging of the root area is often used in conjunction with FCAW to avoid lack of fusion leading to the increase in fabrication costs.

However, a fabricator's impact on the design is very limited and in most cases they have to accept existing design requirements. In order to optimise fabrication costs, it is essential the design considers ease of fabrication. Details that minimise component weight at the expense of fabrication-friendly design should be avoided. Optimising designs for minimum weight often complicates them unnecessarily.

Examples of this are welded base plates, webs and flanges of different sizes and thicknesses. This can lead to an increase in the amount of stiffeners required and the numbers of feed plates and joint configurations required. Such unnecessary complexity increases the potential for non-conformity in fabrication. Standardised design can simplify fabrication, reduce plate inventory and reduce the number of welding procedures. Plate cost is small compared to the cost of complicated fabrication.

Depending on plate thickness a full penetration butt weld normally requires costly beveling and tight control over the fit-up of the root gap. The costs for producing this type of weld are often much higher than that for the deep penetration fillet weld. If possible, designers should aim to specify a full strength or effective full penetration welds (e.g. as defined in Figure 2) as opposed to complete penetration butt welds.

When comparing the economics of the various types of weld configurations possible for the T joint between the web and flange of a beam, fabrication costs in addition to those of just depositing the weld metal must be considered. These include:

- plate edge preparation
- time for assembly and joint set up
- ease of slag removal between weld runs
- meeting tolerance requirements and control or rectification of welding distortion
- positioning/rotation of assembly for welding
- weld backgouging.

The costs associated with these considerations can vary greatly depending on a fabricator's experience, equipment and workplace organisation.

Submerged arc welding (SAW) has long been established as the "work horse" of beam welding. Root runs are sometimes deposited with another welding process. There are several applicable SAW process variations (including multiple wire) and associated

equipment options (e.g. positioners). High deposition rates and deep penetration welds are achievable with optimised set-ups.

Design approaches are currently available that would allow specifying optimal weld size and geometry for the given application. However, they have not found its way in the standards yet.

Table 4 shows fabrication costs for different weld design options discussed above, that should lead to the same fatigue performance and exclude the occurrence of root cracking. The definition of the weld size is given in the Figure 9.

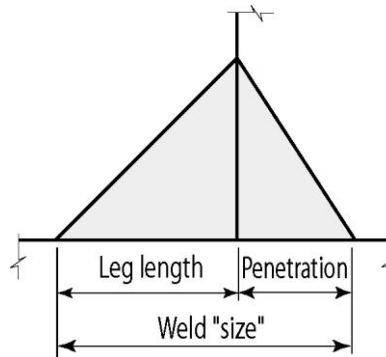

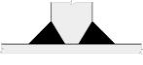






Figure 9: Definition of weld "size"

Among these examples, the most expensive joint is the full penetration butt weld. It offers the same fatigue performance at higher costs. The superior option is to use the compound weld with partial penetration that is about $\frac{1}{3}$ to $\frac{1}{4}$ of the cost of the full penetration option. An increase of the web-plate thickness would lead to even greater deviations in the cost of compound and butt weld.

Table 4: Comparison of fabrication costs for welding-fabrication of weld between 20 mm web plate and flange with different penetration profiles and (hypothetically) similar fatigue performance.

Weld size as defined in Figure 9	20 mm	16.8 mm	18.5 mm	21.9 mm	18 mm	14.6 mm Effective full penetration to EN 1993-1-8 (static loads)
Fillet leg	20	10.1	11.8	16.9	8	6.1
Butt penetration	0	6.7	6.7	5	10	8.5
						
Total Weld area (mm ²) (2 welds)	400	180	217	329	237	162
Cost of depositing weld metal ¹ (\$/m)	95	46	45	57	56	38
Prep, set-up ² (\$/m)		40	40	40	210 - 350	40
Total (\$/m)	95	86	85	97	266 - 406	78

1. Costs are for comparison purposes only based on the same welding parameters using single wire SAW; they are not presented as optimised for this type of joint.
2. This figure is included to show the typical costs where applicable for example of: plate edge preparation, assembly with a root gap, slag removal, backgouging.

The most significant cost factor for full penetration butt welds is the preparation and set up time that, depending on the fabrication technique used, may account for some 75 to 85% of the total welding costs.

4. CONCLUSION AND DISCUSSION

The average cost to produce a full penetration butt weld in flange to web joint is about 4 times higher than that of fillet and compound weld. The most significant cost factor for full penetration butt welds is the preparation and set up time that, depending on the fabrication technique used, may account for some 75 to 85% of the total welding costs. It is therefore essential to specify full penetration butt welds only for application where it is absolute necessarily. In some cases, existing design standards give a good guideline on the use of different weld types. However, there are a number of applications where alternative design methods can be consulted in order to optimise fatigue design.

At mid-span of a girder in applications such as highway bridges, in the absence of any other construction details the fatigue performance is independent of the type of the weld used (butt or fillet). The key factor here is the weld quality. Automatic welds with run-out plates would give the highest fatigue performance of the joint (FAT 125/112). Therefore, a fillet (or deep penetration fillet) weld is the most cost effective option for this joint.

At support, flange to web junctions can be classified as load carrying T-joints. The fatigue performance of these joints is dependant on whether full or partial penetration weld is used. Depending on crack location joints can be classified as FAT 36 for root crack and FAT 80, 71 or 63 of EN 1993-1-9; or Class W for root and F2 for weld toe in BS 5400.

Design procedures such as Det Norske Veritas⁸ are available that would allow estimating optimal weld size and geometry for the given application. However, they have not found its way in the standards yet.

Further optimisation of the weld profile and penetration is possible by applying FEA based Effective Notch Stress Approaches that offers flexibility allowing modeling real weld geometries as achieved in the welding procedure qualification test and weld imperfections such as reinforcement, undercut and misalignment. The method can be used as an optimization tool supplementary to the existing standards. It should normally be followed by testing of representative structural components.

In order not to impair fatigue strength, fabricator's quality management system should be adequate for the type of the product, fatigue service category and failure consequence. It should comply with requirements of AS/NZS ISO 3834 Part 2 or 3.

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