Update Meeting (Public)

Use of AWS D1.1-2000 Criteria for Structural Welds

(Vogtle LAR 15-009, V.C. Summer LAR 15-09, WEC LAR-110)

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Agenda

- LAR Background & Meeting Purpose
- Application of Load Directionality
  - Directionality Provisions Included in AWS D1.1-2000
  - Use of Directionality Provisions for Out-of-Plane Loads
  - Use of Directionality Provisions for Circular Weld Groups
    - Including a discussion of Finite Element Analysis
- Applicable UFSAR Changes

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LAR Background & Meeting Purpose

LAR-110 Background

- LAR-110 has been submitted for NRC approval
  - The LAR proposes changes to Tier 2* information to clarify the relationship between AISC N690-1994 requirements (including AWS D1.1-1992) and AWS D1.1-2000.

- Code reconciliation b/w AWS D1.1-1992 and AWS D1.1-2000 was performed
  - Primary difference is that AWS D1.1-2000 allows for load directionality in linear fillet welds and includes an increase factor on structural fillet weld strength.

- NRC provided feedback on 6/11/2015 that additional justification is needed for the use of directionality on circular weld groups

Meeting Purpose:

- Provide an update on how load directionality provided in AWS D1.1-2000 is proposed to be extended to linear and circular welds experiencing out-of-plane loads

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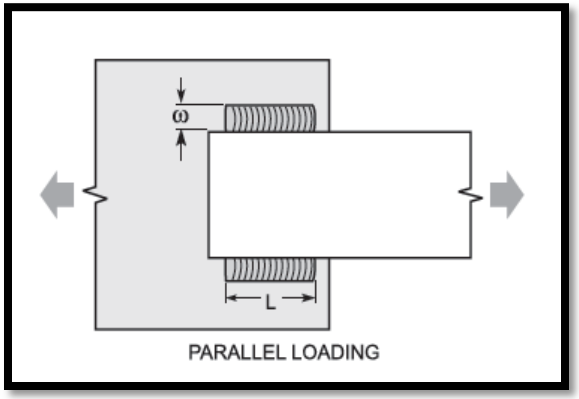
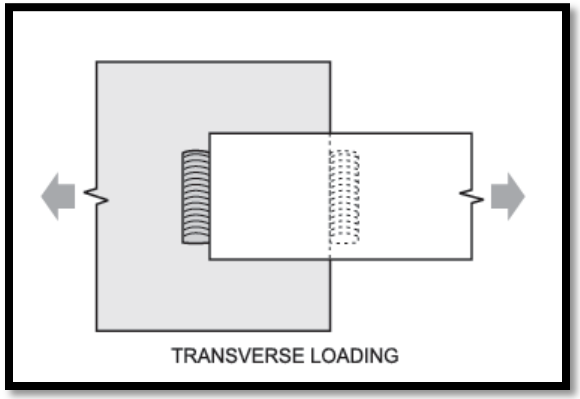
Directionality Provisions Included in AWS D1.1-2000

- AISC N690 defines the allowable stress for the weld design
- The allowable fillet weld stress is the same in AWS D1.1-2000 compared to AISC N690-1994 except for the directionality consideration of a fillet weld loaded under an angle to the longitudinal axis of the weld.





- An increase factor is utilized per AWS D1.1-2000
  - For a fillet weld loaded parallel to its longitudinal axis the increase factor is 1.0 and would gradually increase to 1.5 for a fillet weld loaded transverse to its longitudinal axis.

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Directionality Provisions Included in AWS D1.1-2000

- AWS D1.1-2000 directionality provisions for the increased strength of a fillet weld group loaded transverse to the axis of the weld is also recognized in:
  - AISC N690-1994 Commentary Section CQ1.5.3
  - AWS D1.1-1992 Commentary C8.2 Part B

- AWS D1.1-2000 directionality provisions for the increased strength of a fillet weld group loaded transverse to the axis of the weld is also supported by industry testing:
  - "*Proposed Working Stresses for Fillet Welds in Building Construction,*" by T. R. Higgins and F.R. Preece.

Based on testing, the margin of safety is not significantly reduced from that previously considered in AWS D1.1-1992

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Supplemental Requirements for Directionality Provisions in AWS D1.1-2000

- For fillet weld groups concentrically loaded in the plane of the weld and consisting of elements oriented both longitudinally and transversely to the direction of applied load, additional requirements are provided to supplement the provisions for directionality included in AWS D1.1-2000.
  - Supplemental requirements address the deformation capability of the elements when combined in a weld group and loaded in plane.

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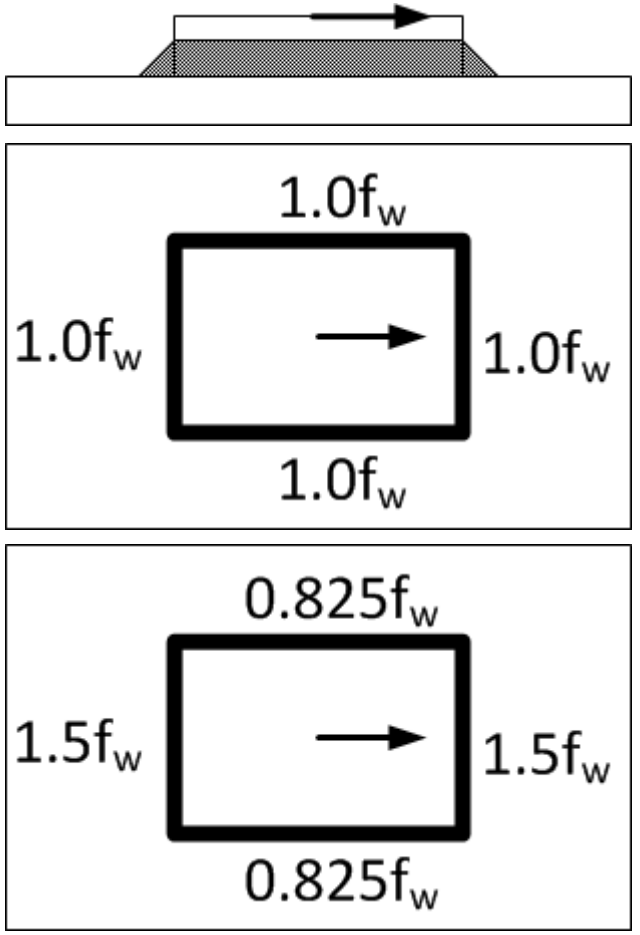
Supplemental Requirements for Directionality Provisions in AWS D1.1-2000

- The strength of the weld group is limited to the larger of:
  1. Combined strength of the individual weld elements using 1.0 times the strength of the longitudinally oriented element and 1.0 times the strength of the transversely oriented element and

  2. Combined strength of the individual weld elements using 0.825 times the strength of the longitudinally oriented element and 1.5 times the strength of the transversely oriented element.



These supplemental requirements are consistent with provisions in recent AISC N690 and AWS D1.1 codes.

Use of Directionality Provisions for Out-of-Plane Loads

- Testing for weld groups loaded out-of-plane with respect to the axis of the weld group has been performed and described in industry literature
  - Testing performed by Gomez et al. ("*Strength and Ductility of Welded Joints Subjected to Out-of-Plane Bending*," Final Report to AISC)
    - Confirms that the strength increase defined in AWS D1.1-2000 Section 2.14.4 does not have to be restricted to loads in-plane with the axis of the weld group.
    - Results indicated that the strength of fillet welds is not affected significantly by the presence of the root notch

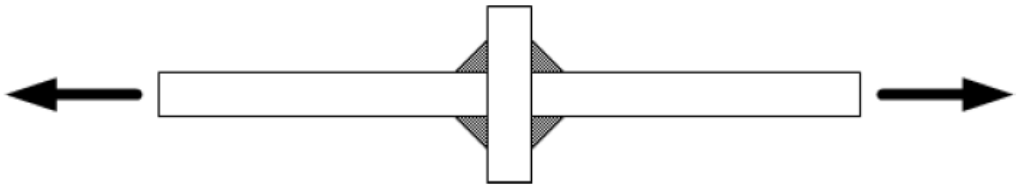


Figure 2. Cruciform Configuration Out-of-Plane Fillet Weld Loading

Test results indicate no significant change in strength

Use of Directionality Provisions for Out-of-Plane Loads

- Recent AWS and AISC codes allow for the same increase described in AWS D1.1-2000 with similar language for both in-plane and out-of-plane loading conditions.
  - Commentary to AWS D1.1-2010 Section C-2.6.4.2 describes that the increase in strength is due to the angle that the applied force makes with the axis of the weld
- A literature review and review of test results for fillet welds loaded out-of-plane is also described in the paper by Anthony et al., ("*Behavior of Transverse Fillet Welds: Experimental Program, Engineering Journal, Second Quarter, 2004*").
  - The review of test results supports application of increased fillet weld capacity when loaded out-of-plane and transverse to the weld axis.
- Review of specific fillet weld test data demonstrates the shift in failure angle through the weld. The shift in failure angle results in an increase in the strength of the weld because the area measured on the fracture surface is significantly larger than that of the theoretical throat oriented at 45°.
- The configuration of the weld group, whether in a straight line or rectangle, does not affect the shift in the failure angle through the weld.
  - Additional weld lines that create a rectangular weld group result in an equivalent loading condition and equivalent stress distribution in the weld if the overall length of weld is the same

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Directionality provisions in AWS D1.1-2000, Section 2.14.4 can be extended provide acceptable requirements for welds loaded out-of-plane

Use of Directionality Provisions for Out-of-Plane Loads

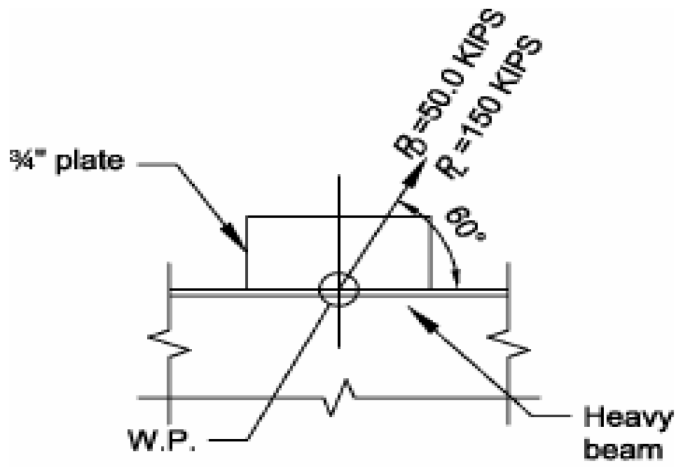
- An example of the application of directionality for out-of-plane loading can also be found in AISC 360-05 (Design Examples Version 13.0, Example J.2)
  - The example shows the use of directionality for a fillet weld at the edge of a gusset plate
  - The example applies fillet weld strength increase to an out-of-plane configuration

Because the angle of the force relative to the axis of the weld is 60 degrees, the strength of the weld can be increased as follows:

$$k_w = 0.60F_{EXX}\left(1.0 + 0.50\sin^{1.5}\theta\right)$$

$$= 0.60(70)\left(1.0 + 0.50\,(0.866)^{1.5}\right)$$

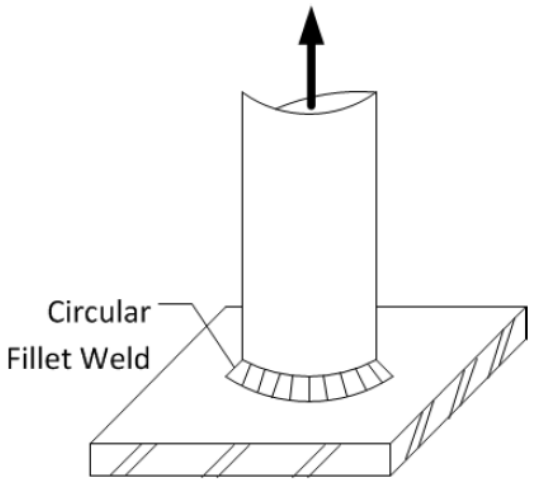
$$= 1.40$$



Equation applied is equivalent to the equation specified in AWS D1.1-2000 Section 2.14.4

Use of Directionality Provisions for Circular Weld Groups

- A circular-shaped weld group loaded out-of-plane to the axis of the weld has a loading condition and behavior equivalent to a rectangular weld group
  - Shift in the fillet failure angle resulting in the increase in the strength of the weld occurs in the same way whether the axis of the weld is straight or circular.
  - The parameter of interest is the angle that the applied force makes with the axis of the weld.



Circular Weld Loaded Out-of-Plane to Axis of Weld

Use of Directionality Provisions for Circular Weld Groups

- A finite element analysis (FEA) for out-of-plane loading on the fillet weld was performed
  - compared the differences between linear welds, concentrically loaded rectangular weld groups, and concentrically loaded circular weld groups
  - The magnitude and location of the stress path with the largest average shear stress was compared in order to confirm that the fillet weld behavior is not influenced significantly by the “shape” of the weld group.
  - Confirms that concentrically loaded circular-shaped weld groups loaded out-of-plane behave in the same way as straight-line weld groups loaded out-of-plane.

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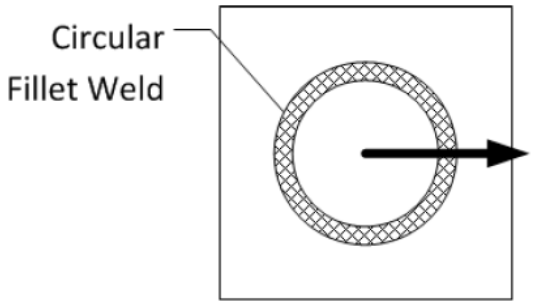
Use of Directionality Provisions for Circular Weld Groups

- The use of directionality for circular welds is limited to loading out-of-plane to the axis of the weld.
  - Due to this complexity, application of AWS D1.1-2000 Section 2.14.4 is excluded for circular welds loaded in-plane to the axis of the weld.
- The provisions for directionality are not applied to fillet welds of HSS-to-HSS T, Y, and K connections described in Table 2.5 of AWS D1.1-2000.
  - The provisions for directionality are applied to out-of-plane circular welds, not other curved welds



Circular Weld Loaded In-Plane to Axis of Weld

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UFSAR Changes (Section 3.8.3.2)

[• *American Welding Society (AWS), Structural Welding Code - Steel, AWS D 1.1:2000*

AWS D1.1-2000 may be used in lieu of AWS D1.1-1992 for the design, qualification, fabrication, and inspection for AISC N690 applications;

AWS D1.1-2000 may be used to replace and supplement provisions in AISC N690-1994 as noted below:

– *Provisions in Sections 2.14.4 and 2.14.5 of AWS D1.1-2000 may be used for the application of directionality to increase allowable weld stress for fillet welds identified in AISC N690, Section Q1.5.3 and Table Q1.5.3.*

For fillet weld groups concentrically loaded in the plane of the weld and consisting of elements oriented both longitudinally and transversely to the direction of applied load, the deformation capability of the elements shall be considered. As a supplement to the provisions in AWS D1.1-2000, the strength of the weld group is limited to the larger of the two following evaluations:

1. *The combined strength of the individual weld elements using 1.0 times the strength of the longitudinally oriented element and 1.0 times the strength of the transversely oriented element*

2. *The combined strength of the individual weld elements using 0.825 times the strength of the longitudinally oriented element and 1.5 times the strength of the transversely oriented element*

UFSAR Changes (Section 3.8.3.2 continued)

– *Provisions in Section 2.3.4.1 of AWS D1.1-2000 may be used to size complete joint penetration groove welds for tubular members. The provisions for directionality are not applied to fillet welds of HSS-to-HSS T, Y, and K connections described in Table 2.5 of AWS D1.1-2000.*

– *Provisions for matching weld metal identified in AWS D1.1-2000, Section 3.3 and Table 3.1, may be used for ASTM A992 steel and supplement the information in AISC N690 Section Q1.4.4.*

The provisions in AWS D1.1-2000 for the application of directionality to fillet welds for linear welds are supplemented by extending the provisions to weld configurations not specified in AWS D1.1-2000 as noted below.

– *The application of directionality provisions in AWS D1.1-2000 may be used for out-of-plane loading for linear fillet weld groups, including lines and rectangular configurations.*

*The application of directionality provisions in AWS D1.1-2000 may be used for out-of-plane loading for circular shaped configurations. The use of directionality provisions in AWS D1.1-2000 for circular fillet weld groups is limited to out-of-plane loading.]**

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