Design

Static Strength of Welded Joints

Lecture Scope

- Static strength of welded joints
  - need for strength design
  - types of loads carried by welds
  - effective weld area
  - stresses acting on weld area
  - allowable stresses on welds
  - design of weld groups

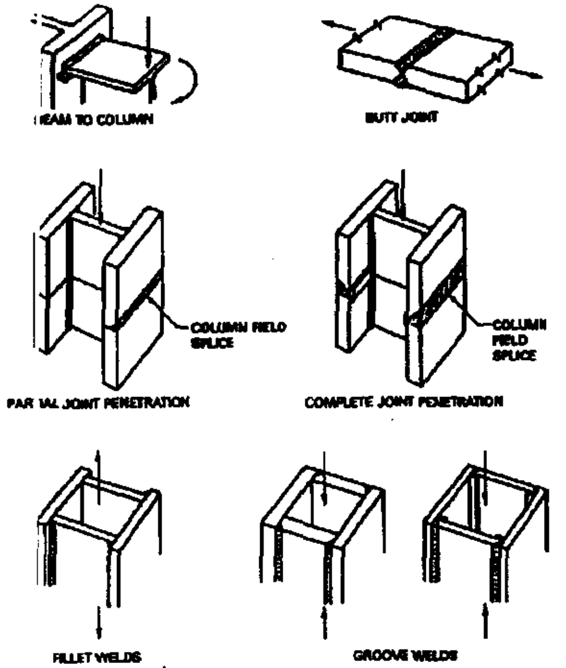
Need for Strength Design

- Strength and rigidity are not critical in some welded parts
  - e.g. machine guards, furniture
  - In such cases only casual attention is paid to weld strength
- Many other welded structures must meet requirements for strength and/or rigidity
  - Bridges, ships, pressure vessels
  - Methods are required for ensuring that welded joints between members possess adequate strength

Weld Joint Strength

- Strength design implies knowledge of
  - loads
  - load carrying area
  - material properties
  - failure criteria

Types of Loads Carried by Welds

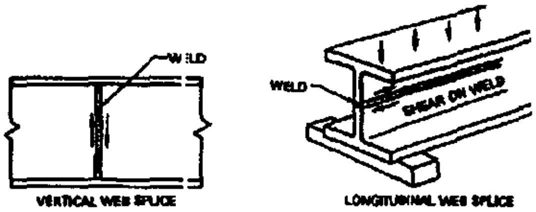


Full penetration groove welds in tension

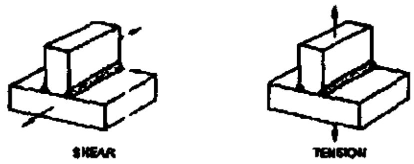
Compression normal to axis of weld

Tension or compression parallel to weld axis

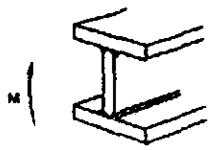
Types of Loads Carried by Welds



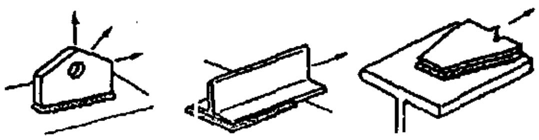
Full penetration groove welds in shear



Partial penetration welds in shear



Shear parallel to weld axis



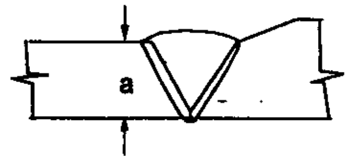
Fillet welds loaded in shear

Weld Design

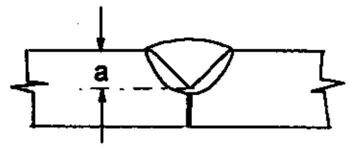
- Full Penetration Groove Welds
  - Usually treated as a continuous part of the structure and not specifically analyzed
  - Welds assumed to match parent strength
  - Some codes reduce the allowable stress in welds not subject to NDE by applying a "Joint Efficiency Factor"
- Partial Penetration Groove, and Fillet Welds
  - Since the effective area differs from the area of the base metal, methods are needed to ensure the welds have adequate strength to carry the imposed loads

Effective Weld Area

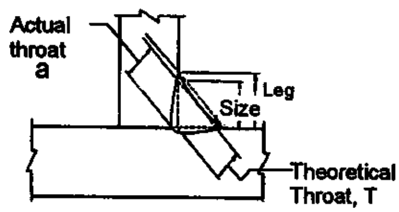
- Full Penetration Groove Welds
  - the effective area is the thickness of the thinner part joined



- Partial Penetration Groove Welds
  - the effective area is normally the depth of the chamfer multiplied by the weld length (may be reduced for narrow weld preparations)



- Fillet Welds
  - The effective area is normally taken as the theoretical throat multiplied by the weld length
  - for equal leg fillets T = 0.707*fillet size



Stresses on Weld Area

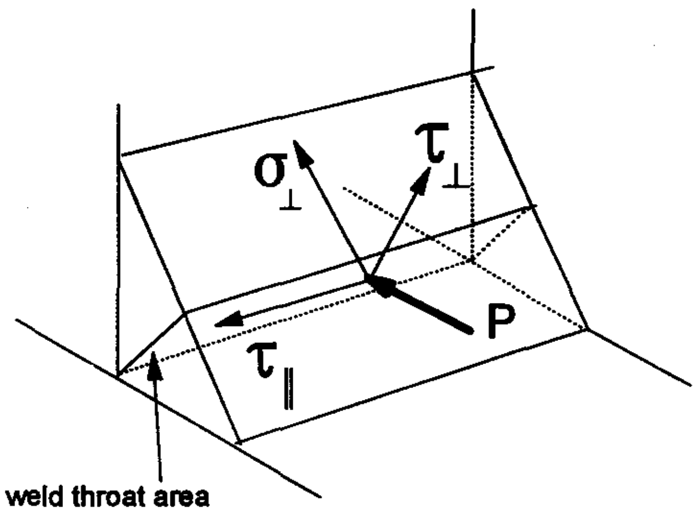
The force transmitted by a unit area of weld may be decomposed into shear and normal stress components (fillet weld shown)

P = Force vector

$\sigma_\perp$ = Stress normal to weld throat

$\tau_\perp$ = shear stress acting perpendicular to weld axis

$\tau_\parallel$ = shear stress parallel to weld axis



Design Stresses on welds

- IIW/ISO criterion for fillet weld stresses
  - The International Institute of Welding has published the following criterion (see IIW doc XV-358-74 & Welding in the World article Vol 2 No 2 1964.)
  - adopted by ISO as recommendation R617

$$\sigma_a \geq \beta\sqrt{\sigma_\perp^2 + 3(\tau_\perp^2 + \tau_l^2)}$$

$$\sigma_a \geq \sigma_\perp$$

σ_a = allowable stress in the base material

β = 0.7 for structural steels up to 500 MPa UTS and 0.85 for high-strength steels with UTS <= 600 MPa

Design Stresses on Welds

- Prerequisites for IIW approach:
  - Structural steels UTS <= 600 MPa and minimum elongation 12%
  - Proper design
  - Adequate weld quality

Design Stresses on Welds

- AWS D1.1 standard approach for fillet/partial penetration welds in steel structures
  - Defines allowable values for each stress component based (primarily) on weld metal tensile strength
  - CSA W59 uses a similar approach but differs in detail
  - Always consult the applicable standard

Design Stresses on Welds

AWS D1.1

- Full Penetration Welds

Stress in Weld	Allowable Stress
Tension or compression normal and parallel to effective area	Same as base metal
Tension or compression parallel to axis of weld	Same as base metal
Shear on the effective area	0.3 of nominal UTS of weld metal, but not more than 0.4* yield strength of base metal

Design Stresses on Welds

AWS D1.1

- Partial Penetration Groove Welds

Stress in Weld	Allowable Stress
Compression normal to effective area (joints not designed to bear)	0.5 times nominal tensile strength of weld metal but not more than 0.6 times yield strength of base metal
Tension or compression parallel to weld axis	Same as base metal. Need not be considered in design of welds joining components of built-up members
Shear parallel to axis of weld	0.3 nominal tensile strength of weld metal but not more than 0.4 yield strength of base metal
Tension normal to effective area	0.3 nominal tensile strength of weld metal but not more than 0.4 yield strength of base metal

Design Stresses on Welds

AWS D1.1

- Fillet Welds

Stress in Weld	Allowable Stress
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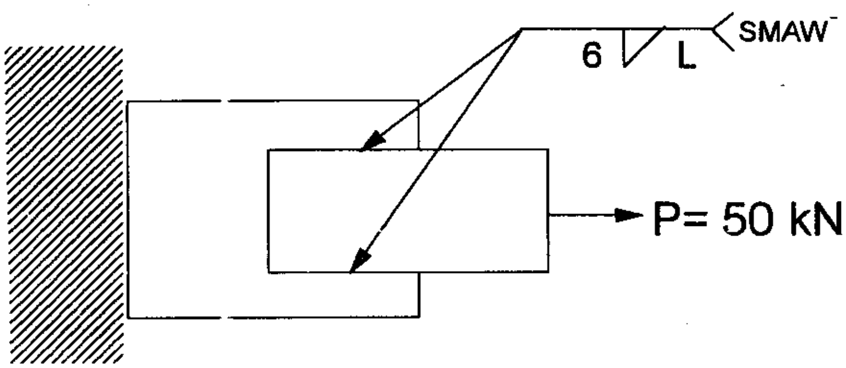
Shear parallel to axis of weld	0.3 nominal tensile strength of weld metal but not more than 0.4 yield strength of base metal
Tension normal to effective area	0.3 nominal tensile strength of weld metal but not more than 0.4 yield strength of base metal

Example

Determine the required length L of the fillet welds



Base meta ASTM A36 carbon steel
YS = 250 MPa (30 ksi) UTS = 410 MPa (60 ksi)
6018 SMAW electrodes

Example

AWS Approach:

Weld effective area = 2*6*0.707*L = 8.5L
From statics, the applied stress = P/A = 50000/8.5L MPa
Stress is shear parallel to weld axis

AWS D1.1 allowable stress is minimum of:
   0.3*weld metal UTS = 0.3 * 410 = 123 MPa
   0.4* base metal yield strength = 0.4* 250 = 100 MPa

Therefore P/A <= 100 MPa
i.e. 50000/8.5L <= 100 MPa
L >= 58.8 mm

Specify 60mm long fillets.

Example

IIW Approach:

$$\sigma_a \geq \beta\sqrt{\sigma_{\perp}^2 + 3(\tau_{\perp}^2 + \tau_{\parallel}^2)}$$

Weld effective area = 2*6*0.707*L = 8.5L
Applied stress P/A = 50000/8.5L MPa = $\tau_{\parallel}$

Assume the allowable stress in the base material σ_a is the lesser of

0.33 * ultimate strength = 0.3*410 = <u>123 MPa</u>
0.67* yield strength = 0.67*250 = 167 MPa

Then,

$$123 >= 0.7*\sqrt{3*(50000/8.5L)^2}$$

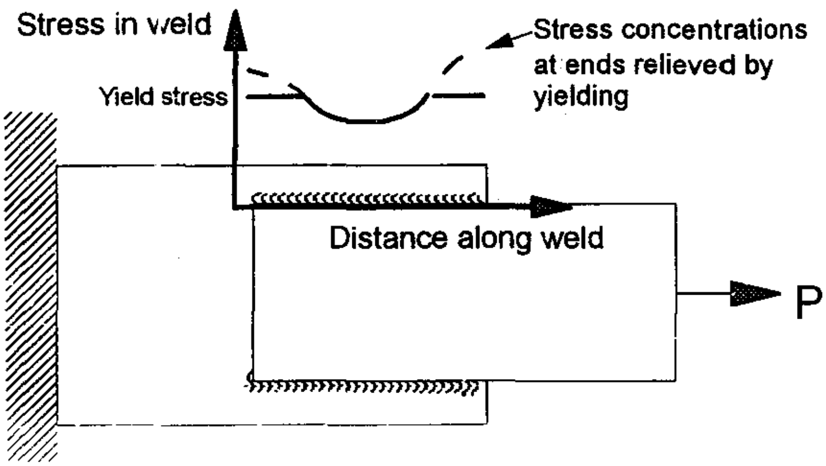
L >= 57.98 mm (agrees with AWS)

Strength design of weld groups

- In the previous example, the force carried by the welds were determined by applying the principles of static equilibrium
- The forces carried by welds in more complicated connections cannot be so easily determined
- Various methods have been proposed to determine the capacity of the weld group
  - Mostly empirical rules
  - Either elastic or plastic analyses

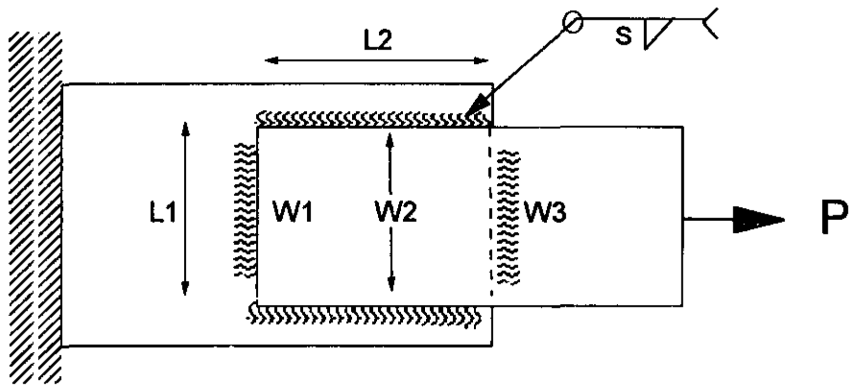
Fillet Weld Stress Distribution

- Design methods usually assume uniform stress in welds and ignore stress concentrations at ends and residual stress
- OK if welds have sufficient deformation capacity



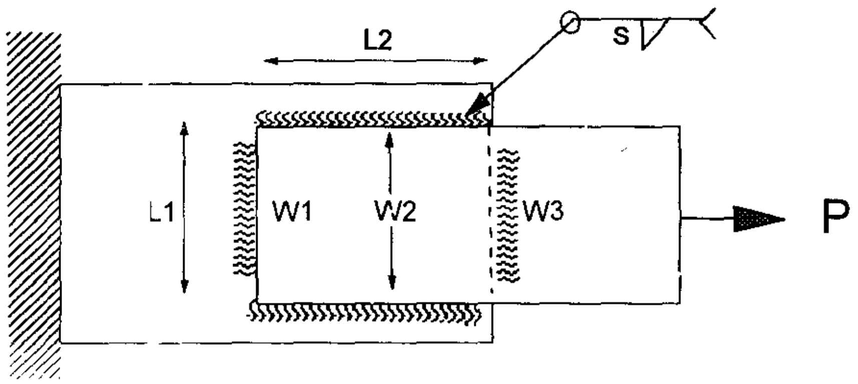
Fillet Weld Stress Distribution

- When welds W1 or W3 exist, the load carried by each weld is not readily calculated
  - depends on loading and stiffness of parts joined



Weld Stress Distribution

- Qualitative behaviour
  - L2 >> L1, W3 not present: the load is carried by W2
  - L2<L1, W3 not present, the load is carried mostly by W1
  - When W3 is present it takes most of the load
  - The case of L2<1.5*L1 with W3 present is considered useless



Weld Groups

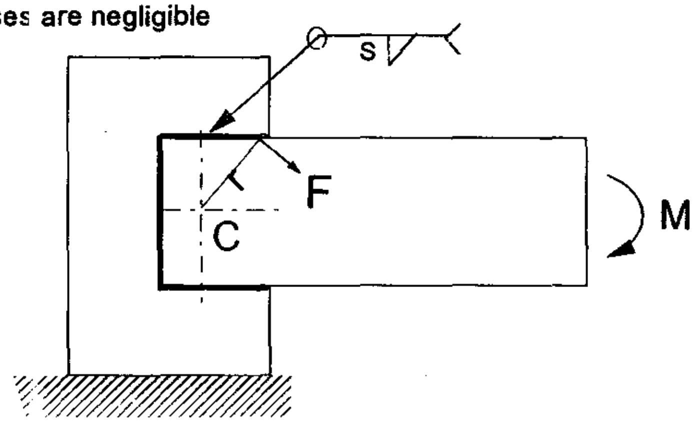
- A simple method for design of planar connections subject to shear forces and bending moments is to consider the welds as a pattern of lines
- Known as the "polar moment method"
  - Welding in World article, p 180, Welding Handbook

Weld Groups

Derivation

Assuming:

- The welds are of equal size S
- The force per unit length F at any point in the weld group is proportional to the distance from the centroid C, i.e. F = kr.
- F acts normal to the line joining the centroid
- residual stresses are negligible



Weld Groups

If dL is any elemental length of weld,

$$M = \int F r \, dL$$

Since $F = kr$, $M = \int kr^2 \, dL = kJ_w$

Where J_w is the linear polar moment of inertia of the weld group about the axis through C and normal to the plane.

Hence:

$$F = \frac{Mr}{J_w}$$

The weld throat T required to satisfy allowable stress limits can be found using:

$$F = \tau T$$

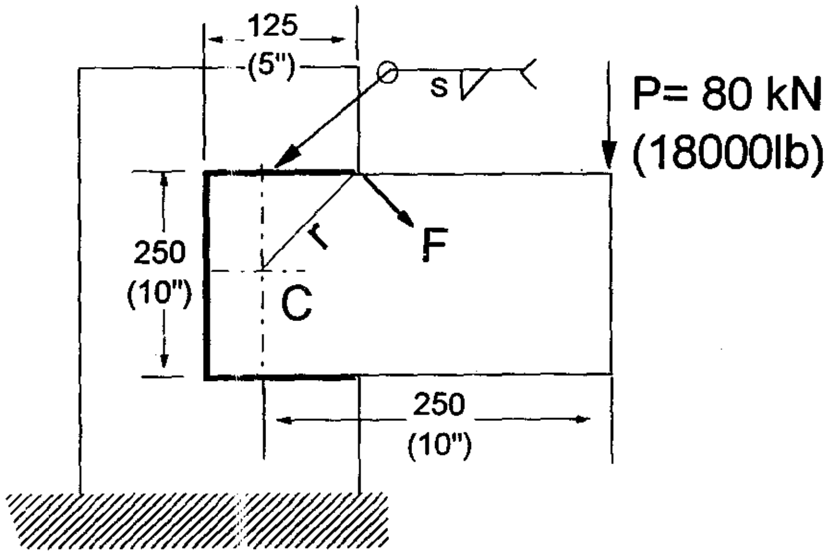
Weld Groups

- Similar results apply for bending moments parallel to the plane of the weld group.
- Shear forces are assumed uniformly distributed

Weld Groups

- Procedure for polar moment method using tabulated formulas
  1. Find the position on the welded connection where the combined forces are maximum
     - usually the position furthest from the centroid of the connection
     - more than one load combination or position may need to be considered
     - shear forces are assumed uniformly distributed
  2. Find the force per unit length resulting from each loading at this position using the tabulated formulas
  3. Add the forces vectorially
  4. Determine the required throat size by dividing the total unit force by the allowable weld stress

Example 2



Example 2

- Step 1: Identify the most highly stressed location
  - The point of maximum combined unit force is at the top right hand corner
- Step 2: Determine unit forces at this point
  - The distance from the centroid to the point of combined stress, and the polar moment of inertia are given by the table (handout) as:

$$c_{yr} = \frac{b\ (b+d)}{2b+d} = 95\ mm$$

$$J_w = \frac{b^3}{3} + \frac{(b+2d)}{2b+d} + \frac{d^2}{12}(6b+d) = 6.3\times 10^6\ mm^3$$

Example 2

- Step 2 (cont'd)
  - The horizontal and vertical components of the twisting moment are given by:

$$f_h = \frac{Td/2}{J_w} = 410 \quad N/mm$$

$$f_v = \frac{Tc_{yr}}{J_w} = 306 \quad N/mm$$

  - The vertical shear force is
    $fs = P/Lw = 158\ N/mm$

Example 2

- Step 3: Determine the resultant force

$$f_r = \sqrt{f_h^{\,2} + (f_v + f_s)^2} = 620\ N/m$$

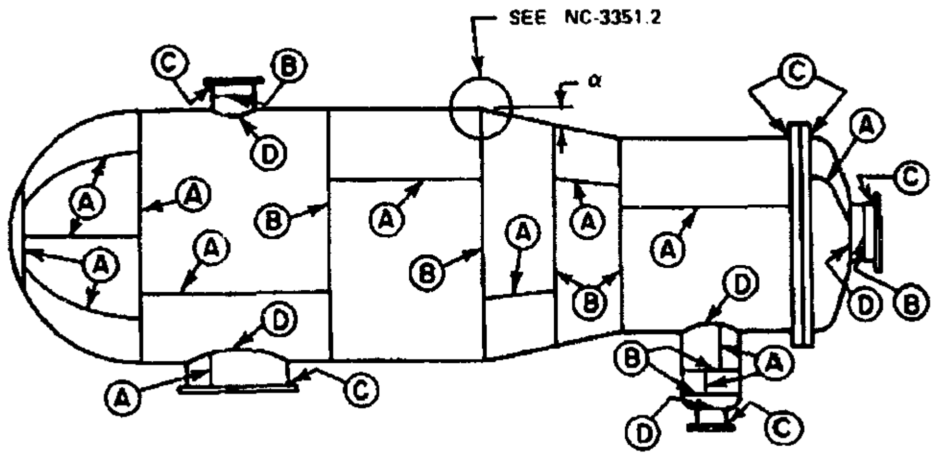
- Step 4: Determine the required weld size

Allowable weld stress for 6018 electrodes = 0.3*410 = 124 MPa
Required throat T = 620/124 mm = 5 mm
Assuming equal leg fillets, weld size = T/0.707 = 7mm

An 8 mm fillet weld should be specified on the weld symbol

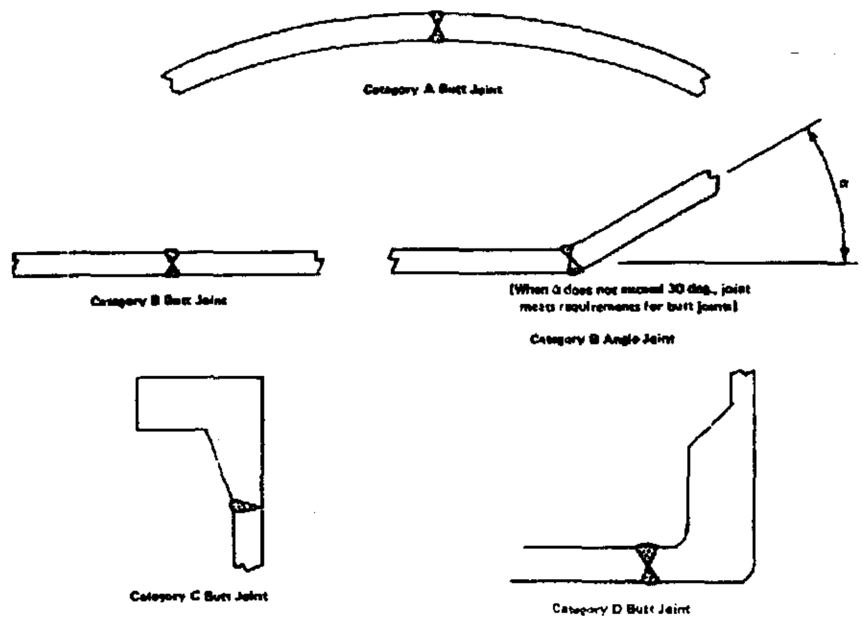
ASME Boiler & Pressure Vessel Code

Categories of weld joint in Class 3 nuclear vessels



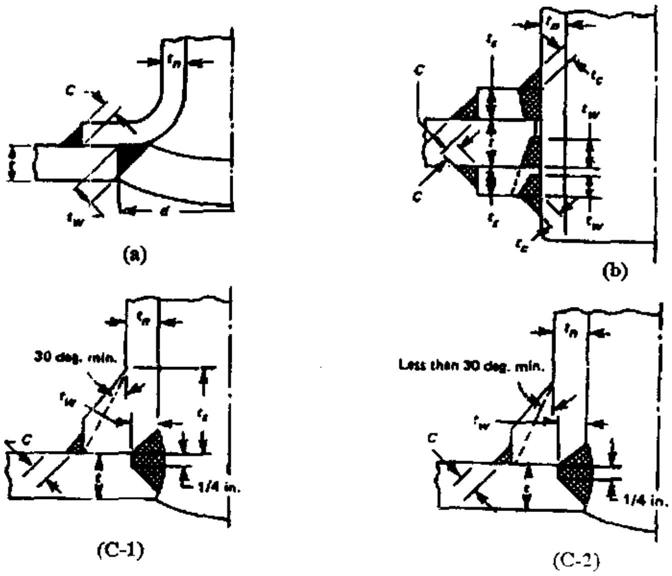
ASME B&PV Code

Categories of Butt Joints

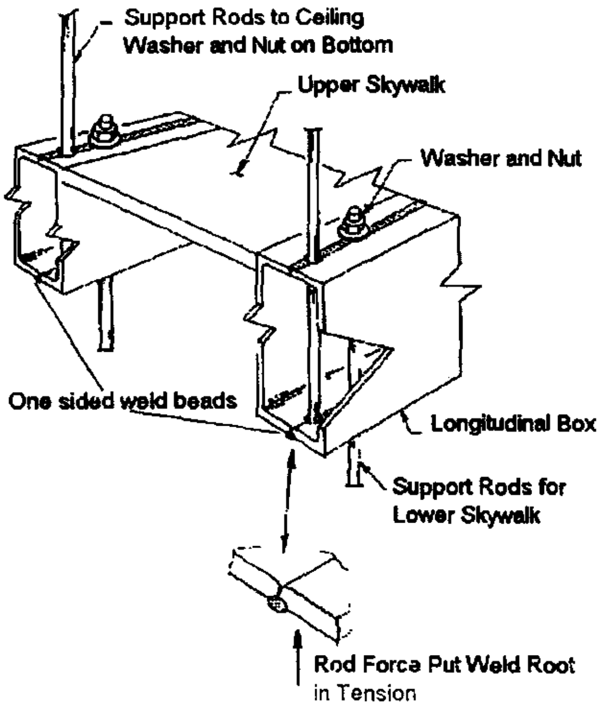


ASME B&PV Code

Examples of permissible nozzle connections for Class 3 nuclear vessels



Hyatt Regency Skywalk Failure



Weld Structural Failures

- Failures of welded structures result in financial loss, damage to the environment, and injury or loss of life
  - Hyatt Regency hotel walkway collapse
  - Ramsgate ferry ramp collapse
- Codes and standards define rules for welded joint design for various types of critical structure, e.g. buildings, bridges, pressure vessels based on tests, analysis and experience
- Use of the applicable codes is advisable and may be legally required.