Bolting & Welding

Part 1: Welded Connection Design

Duane K. Miller, Sc.D., P.E.
The Lincoln Electric Company
Cleveland, OH

Part 2: Fundamentals of High-Strength Bolting

Geoffrey L. Kulak, Ph.D.
University of Alberta
Edmonton, AB
Canada

July 28, 2006
Chicago, IL

Bolting & Welding

Part 1: Welded Connection Design

Duane K. Miller, Sc.D., P.E.
The Lincoln Electric Company
Cleveland, OH

This document contains material used courtesy of
The Lincoln Electric Company
and
The James F. Lincoln Arc Welding Foundation

AISC 2006
Educational Series

WELDING
AND
BOLTING

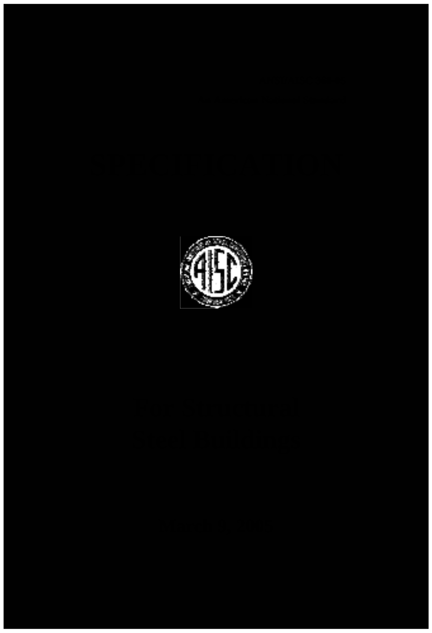
Welding Short Course

- Welding Processes Overview
- Introduction to Welded Connections
- Determining Weld Size
- Principles of Design
- Distortion
- Cost Reduction Ideas

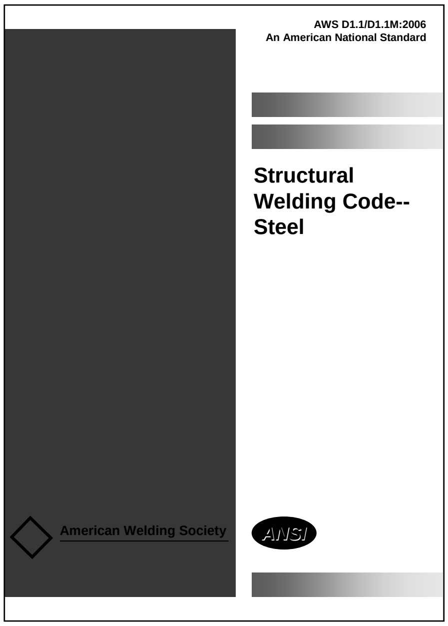
AISC

Specification

2005



AWS D1.1 Structural Welding Code--Steel



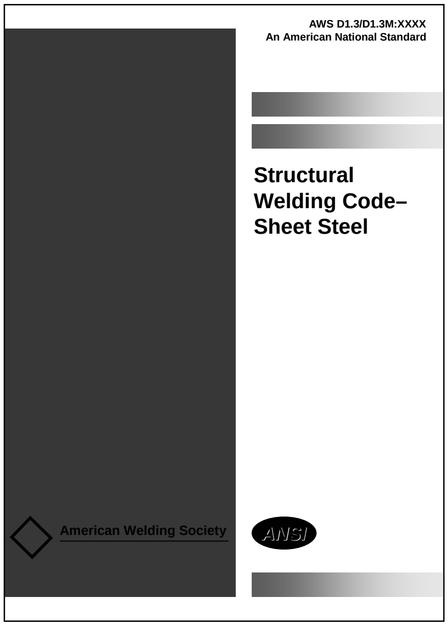
AWS D1.1/D1.1M:2006
An American National Standard

Structural Welding Code--Steel

American Welding Society

ANSI

AWS D1.3 Structural Welding Code—Sheet Steel



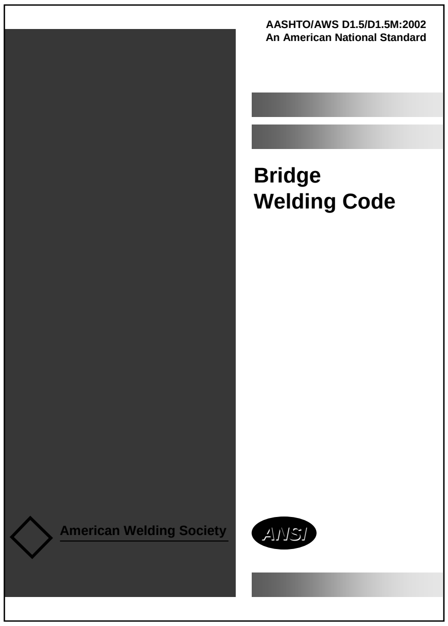
AWS D1.3/D1.3M:XXXX
An American National Standard

Structural Welding Code–Sheet Steel

American Welding Society

ANSI

AASHTO/AWS D1.5 Bridge Welding Code



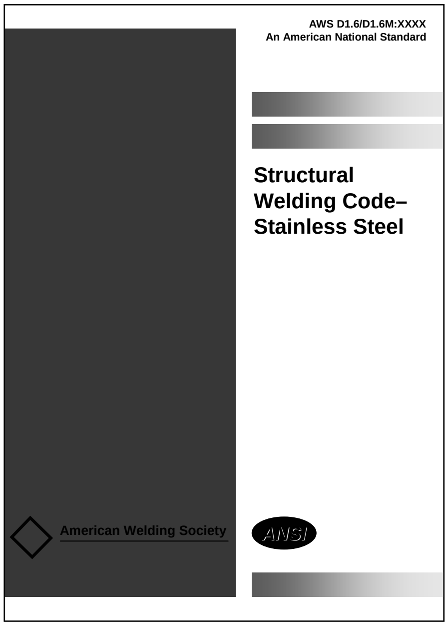
AASHTO/AWS D1.5/D1.5M:2002
An American National Standard

Bridge Welding Code

American Welding Society

ANSI

AWS D1.6 Structural Welding Code— Stainless Steel



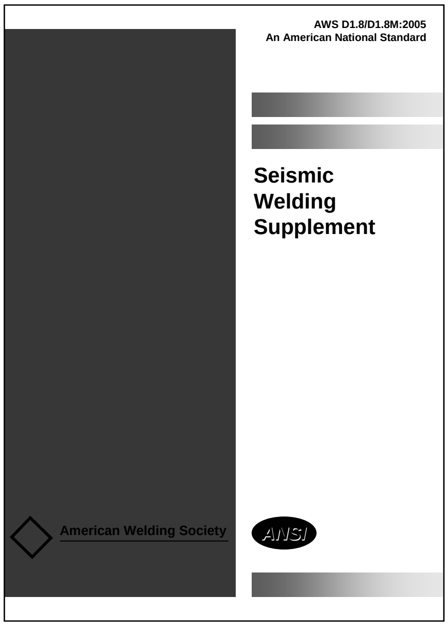
AWS D1.6/D1.6M:XXXX
An American National Standard

Structural Welding Code– Stainless Steel

American Welding Society

ANSI

AWS D1.8 Seismic Welding Supplement



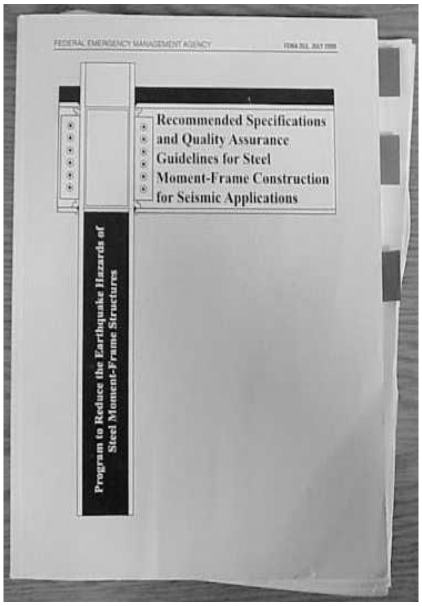
AWS D1.8/D1.8M:2005
An American National Standard

Seismic
Welding
Supplement

American Welding Society

ANSI

FEMA 353

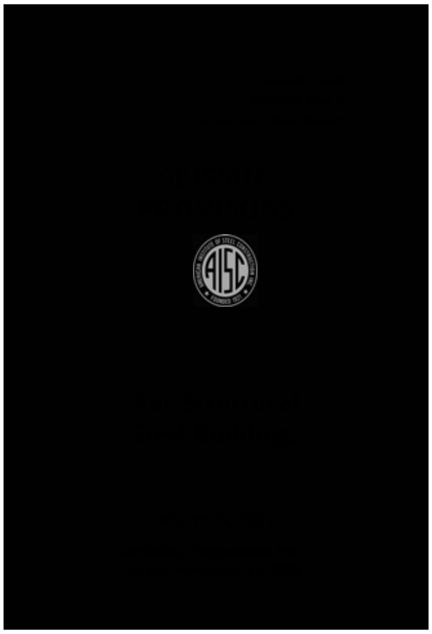


FEDERAL EMERGENCY MANAGEMENT AGENCY

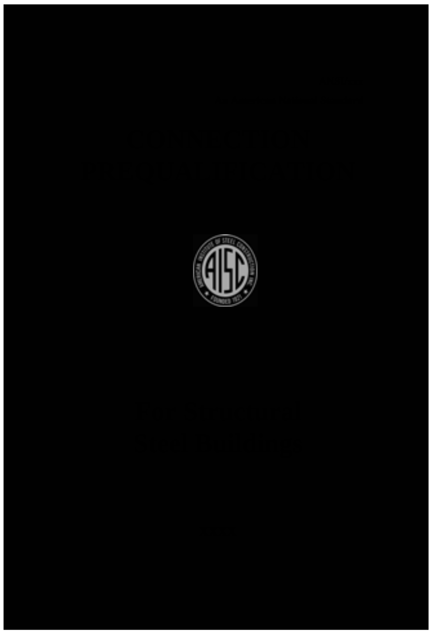
Recommended Specifications
and Quality Assurance
Guidelines for Steel
Moment-Frame Construction
for Seismic Applications

Program to Reduce the Earthquake Hazards of
Steel Moment-Frame Structures

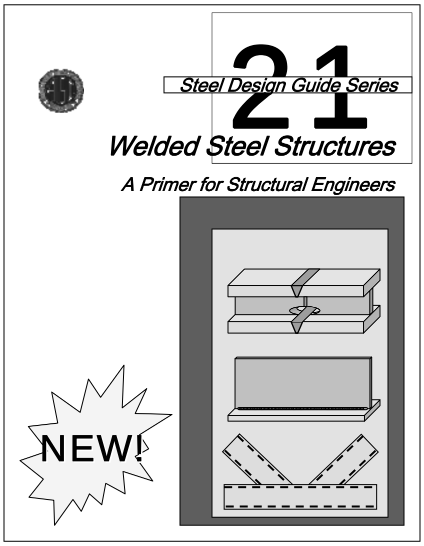
Seismic Provisions



AISC Connection Prequalification



AISC DESIGN GUIDES



21

Steel Design Guide Series

Welded Steel Structures

A Primer for Structural Engineers

NEW!

Arc
Welding Processes

Fusion vs. Penetration

REQUIREMENTS FOR FUSION:

1. Atomic Closeness
2. Atomic Cleanliness

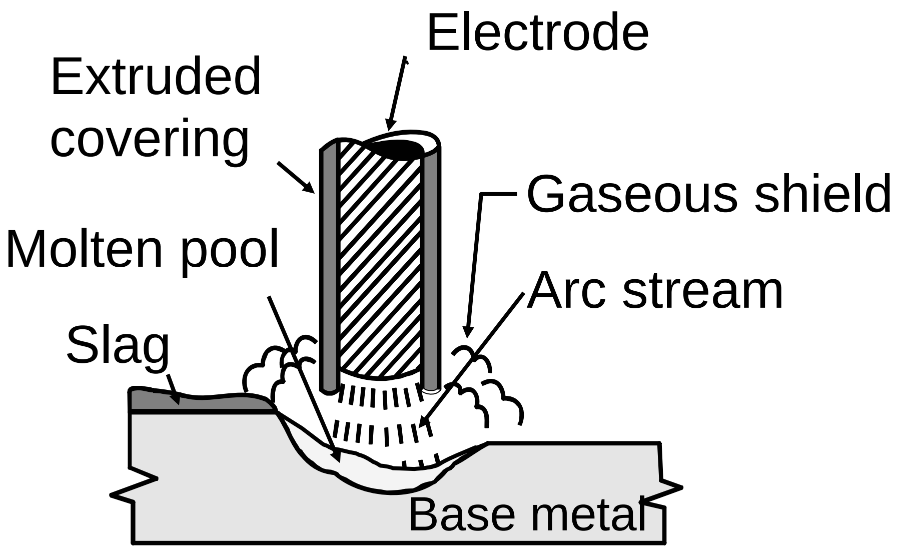
SHIELDING OF MOLTEN PUDDLE

- Shield from nitrogen, oxygen
- Shield with slags
- Displace atmosphere with gasses

Arc Welding Processes

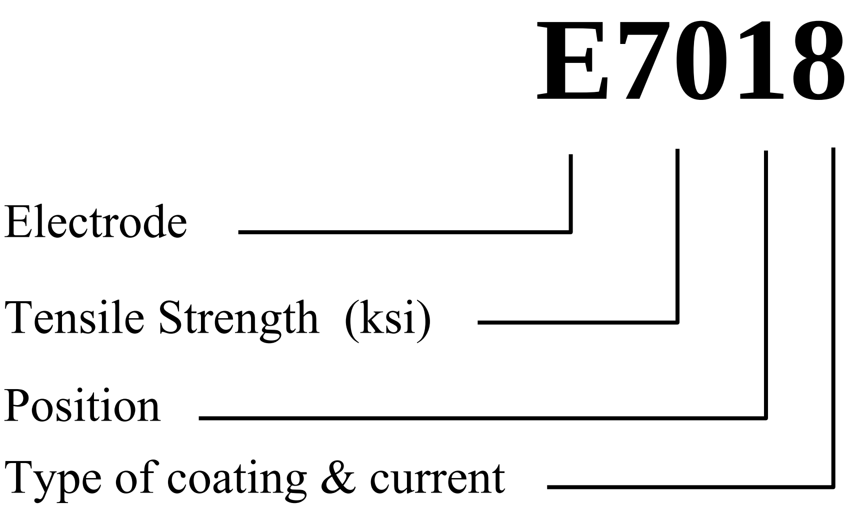
Shielded Metal Arc (SMAW)
Flux Cored Arc (FCAW)
Gas Metal Arc (GMAW)
Submerged Arc (SAW)
Gas Tungsten Arc (GTAW)

Shielded Metal Arc (SMAW)



SMAW

AWS Numbering System



E7018

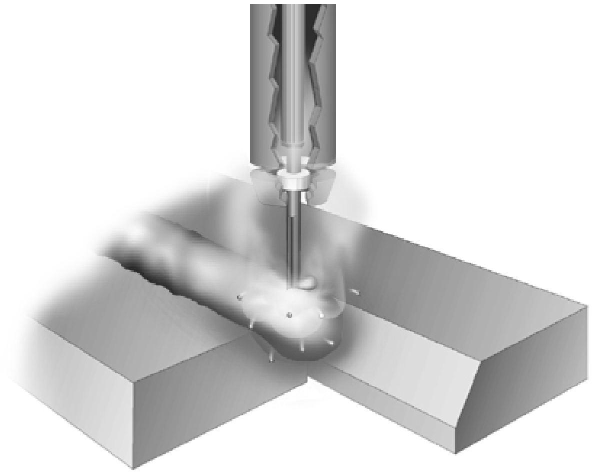
Electrode

Tensile Strength (ksi)

Position

Type of coating & current

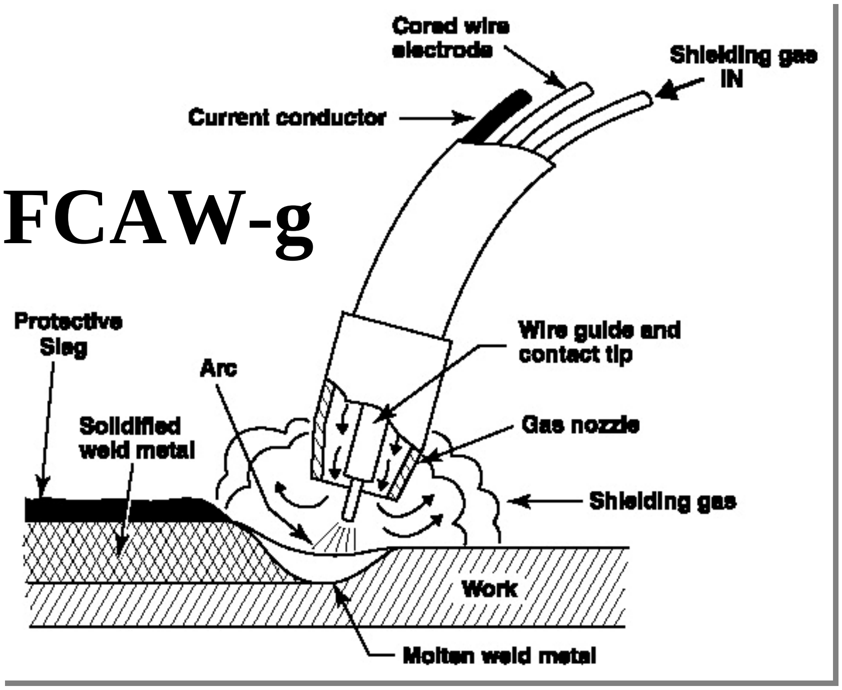
Flux Cored Arc Welding (FCAW)



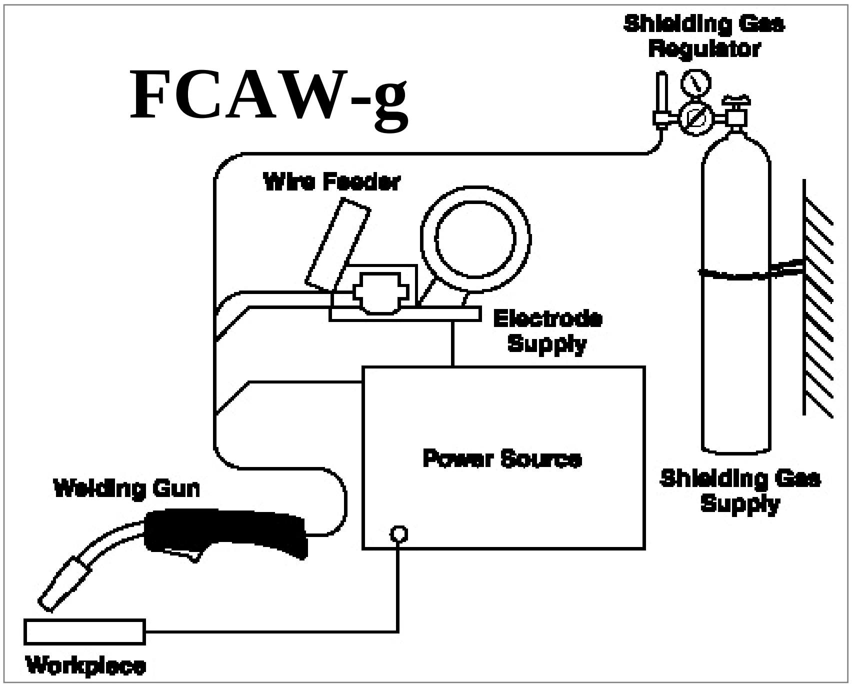
FCAW: two types

Gas Shielded
Self Shielded

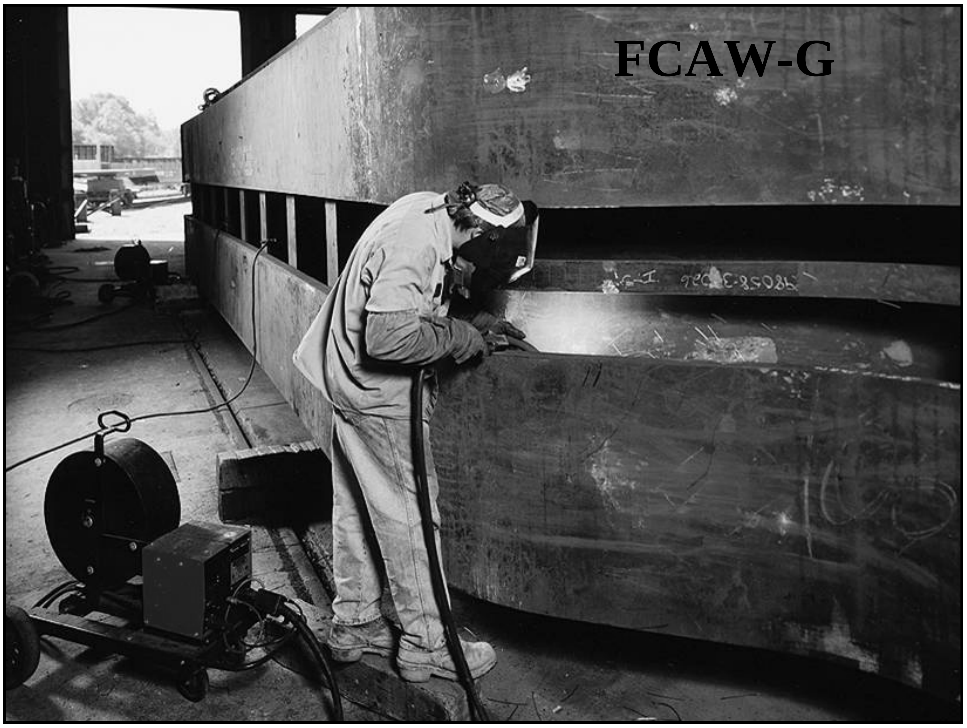
FCAW-g


Cored wire electrode
Shielding gas IN
Current conductor
Protective Slag
Arc
Wire guide and contact tip
Solidified weld metal
Gas nozzle
Shielding gas
Work
Molten weld metal

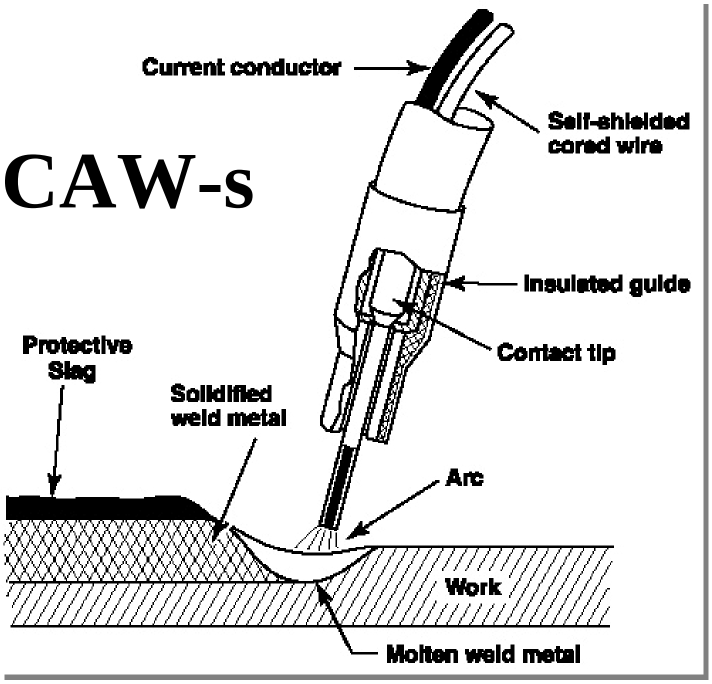
FCAW-g


Shielding Gas Regulator
Wire Feeder
Electrode Supply
Power Source
Shielding Gas Supply
Welding Gun
Workpiece

FCAW-G

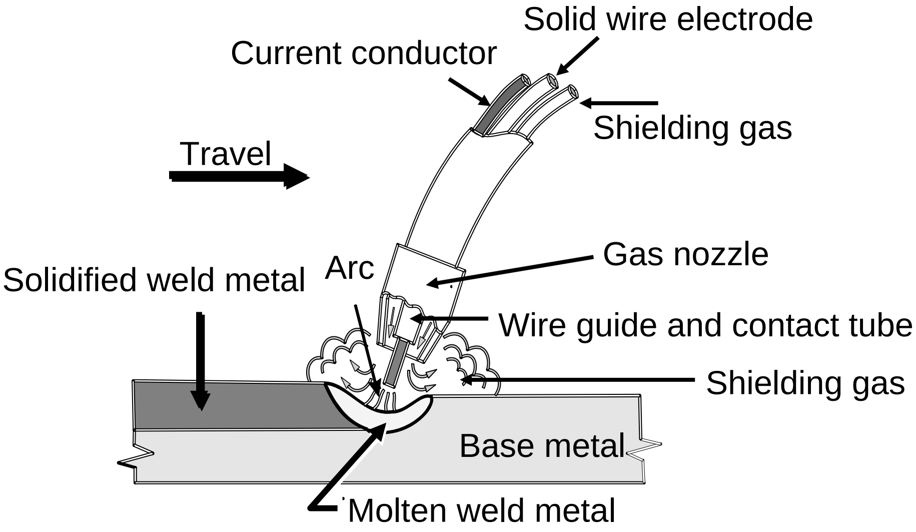


FCAW-s


Current conductor
Self-shielded cored wire
Insulated guide
Contact tip
Protective Slag
Solidified weld metal
Arc
Work
Molten weld metal

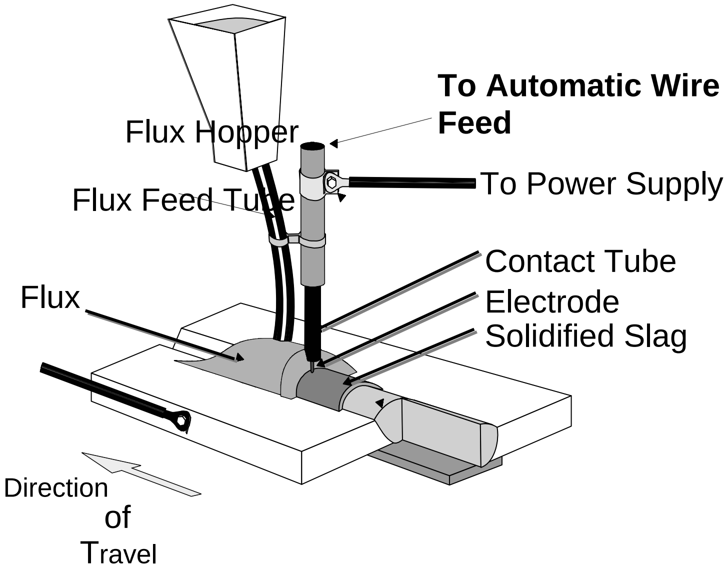
FCAW-S

Gas Metal Arc Welding (GMAW)

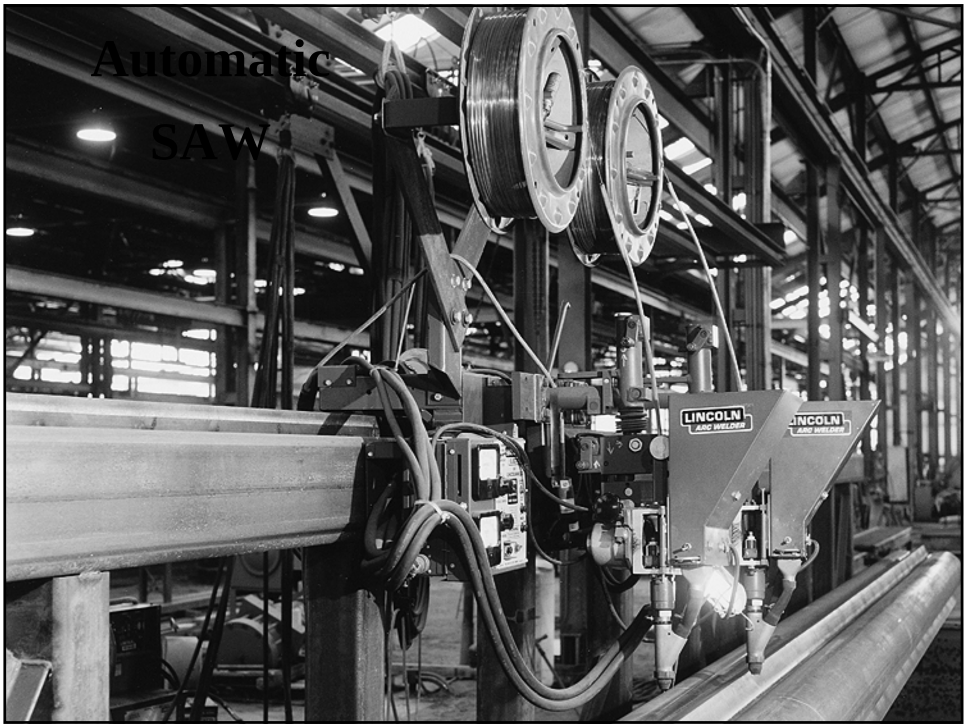


GMAW

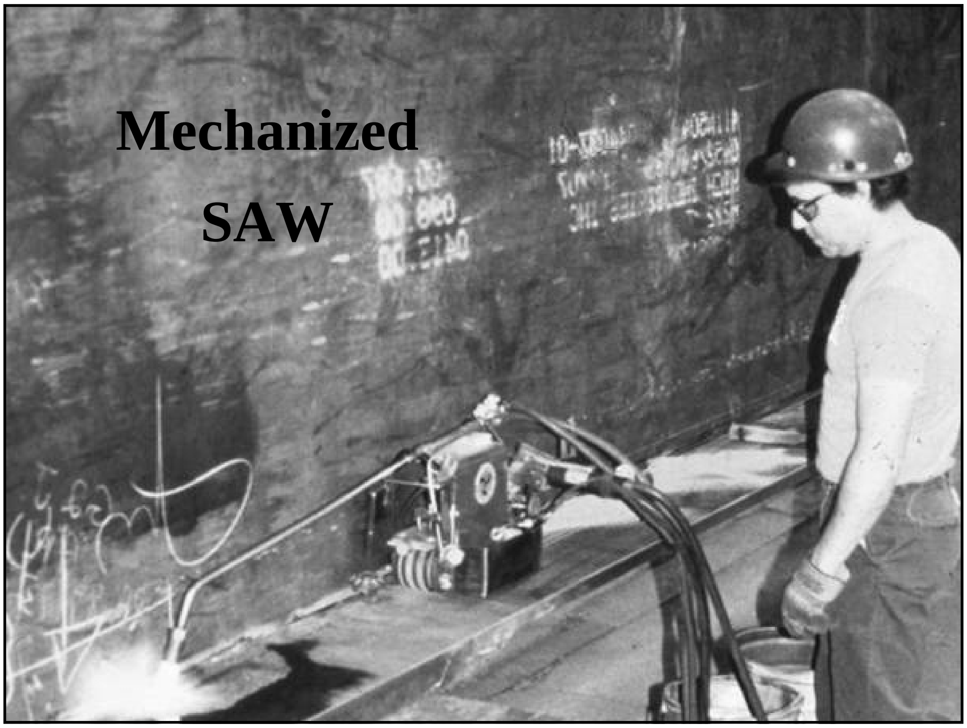
Submerged Arc Welding (SAW)



Mechanized SAW



Automatic SAW



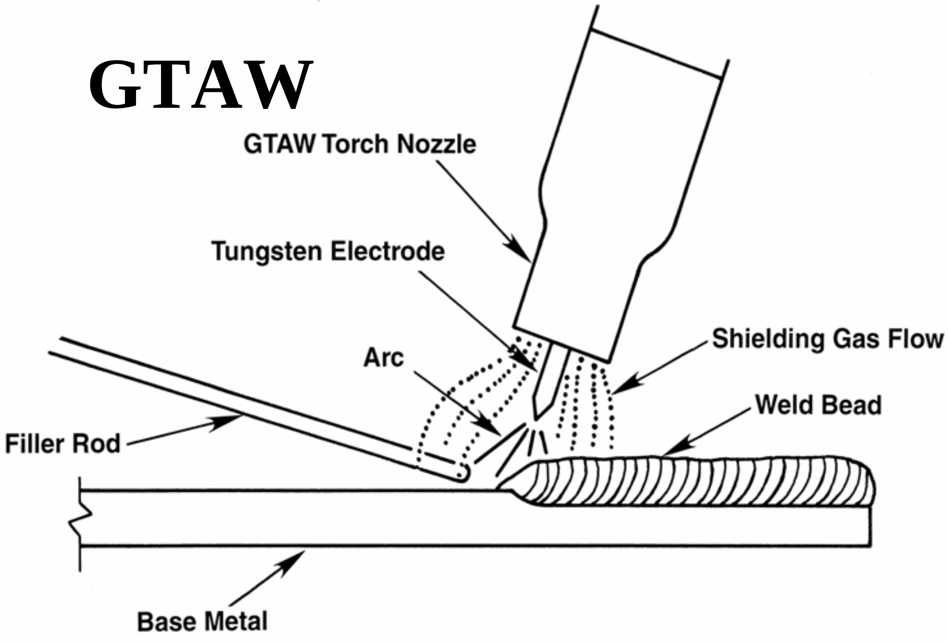
Mechanized

SAW

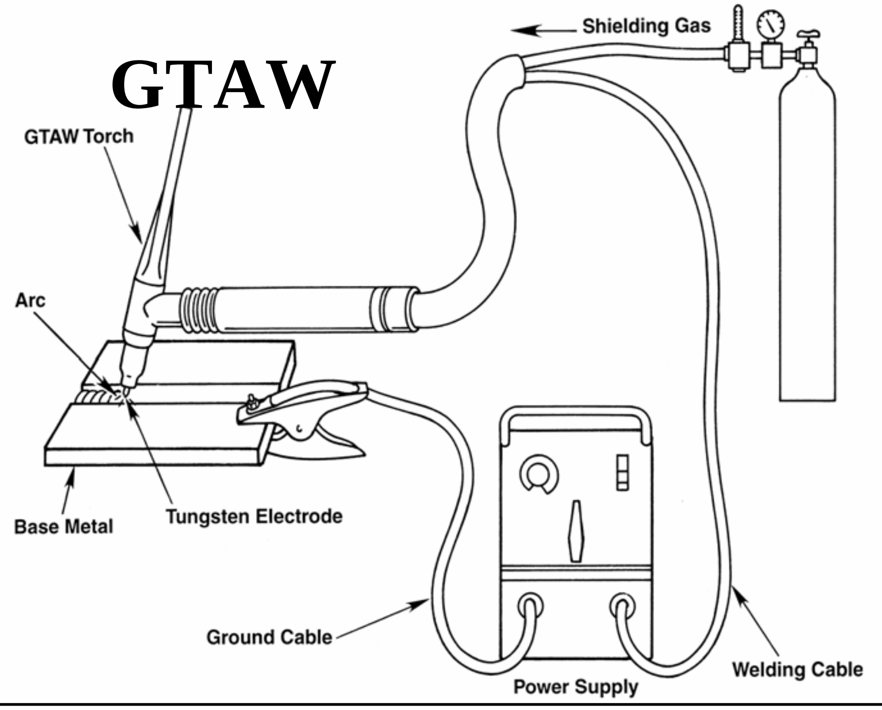
Semiautomatic

SAW

GTAW


GTAW Torch Nozzle
Tungsten Electrode
Arc
Shielding Gas Flow
Weld Bead
Filler Rod
Base Metal

GTAW

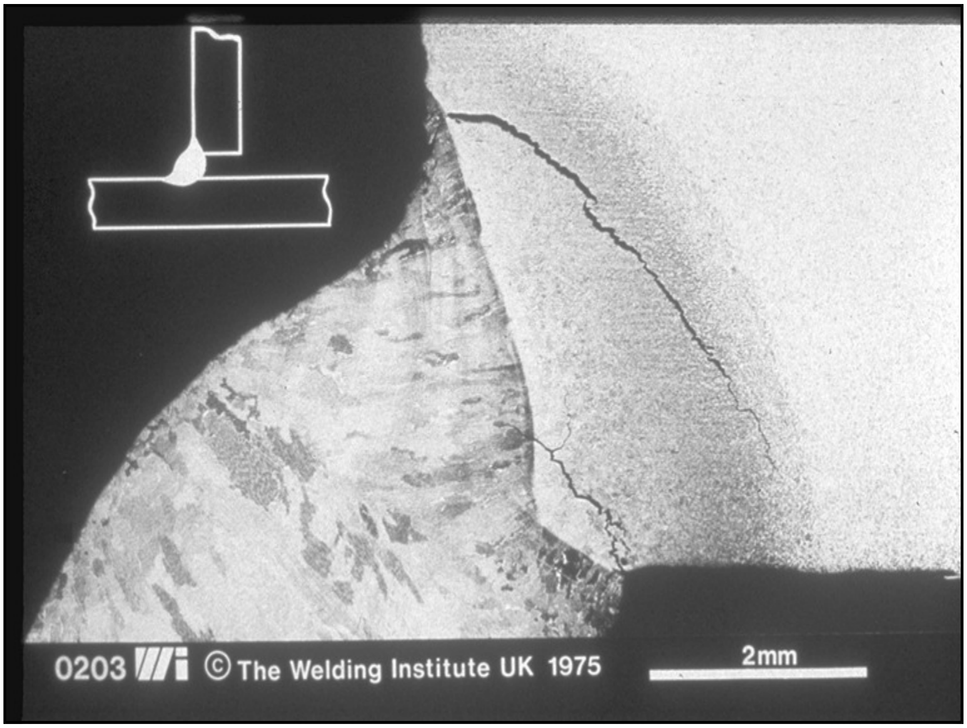

Shielding Gas
GTAW Torch
Arc
Base Metal
Tungsten Electrode
Ground Cable
Power Supply
Welding Cable

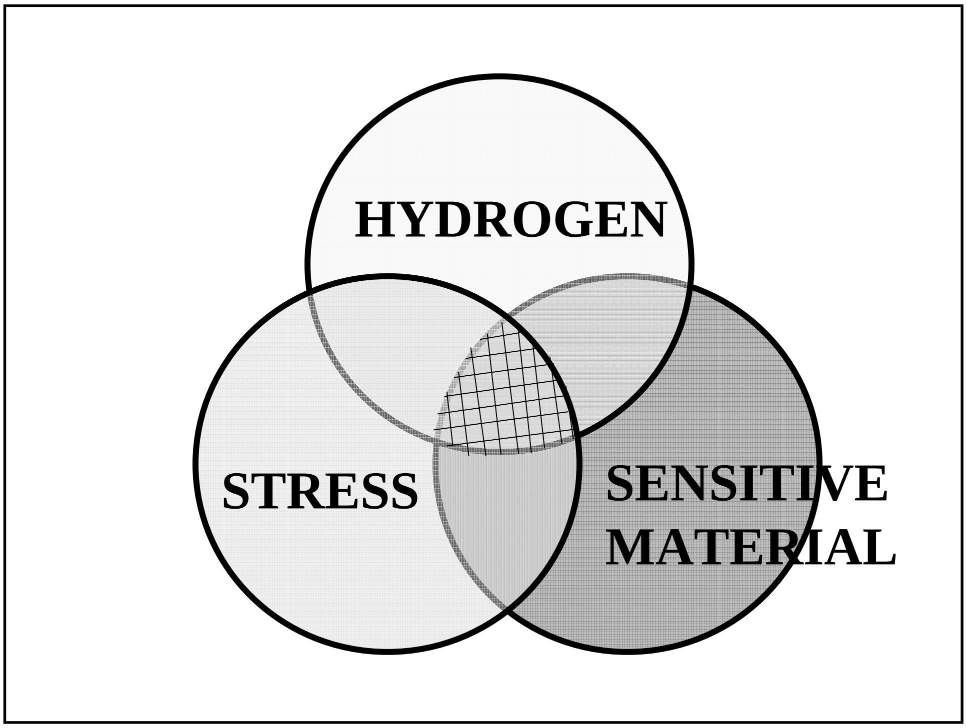
GTAW

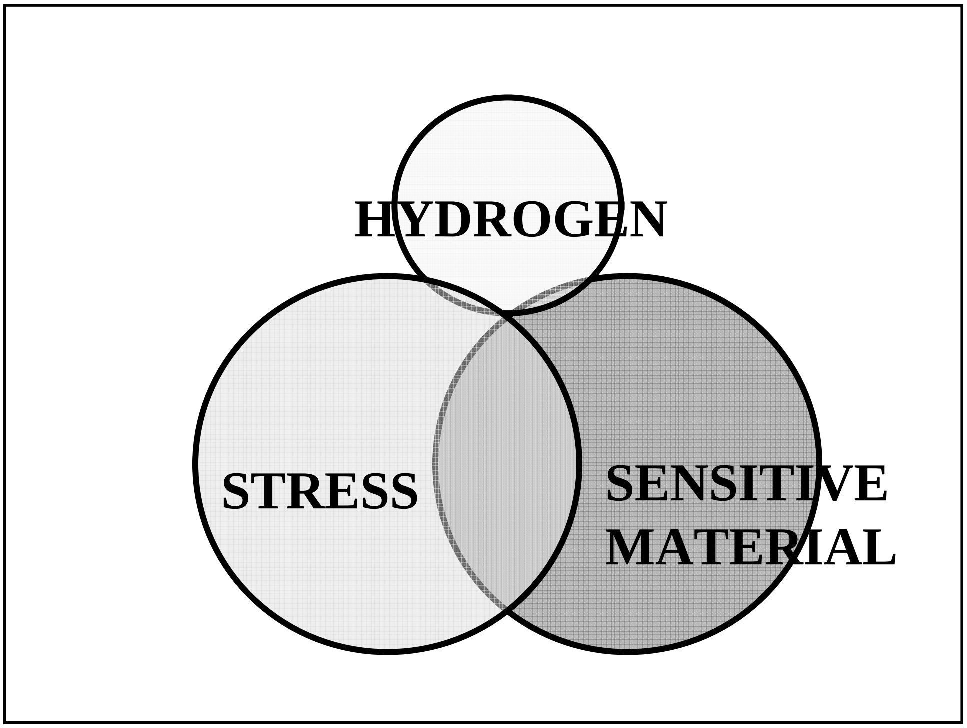
GTAW

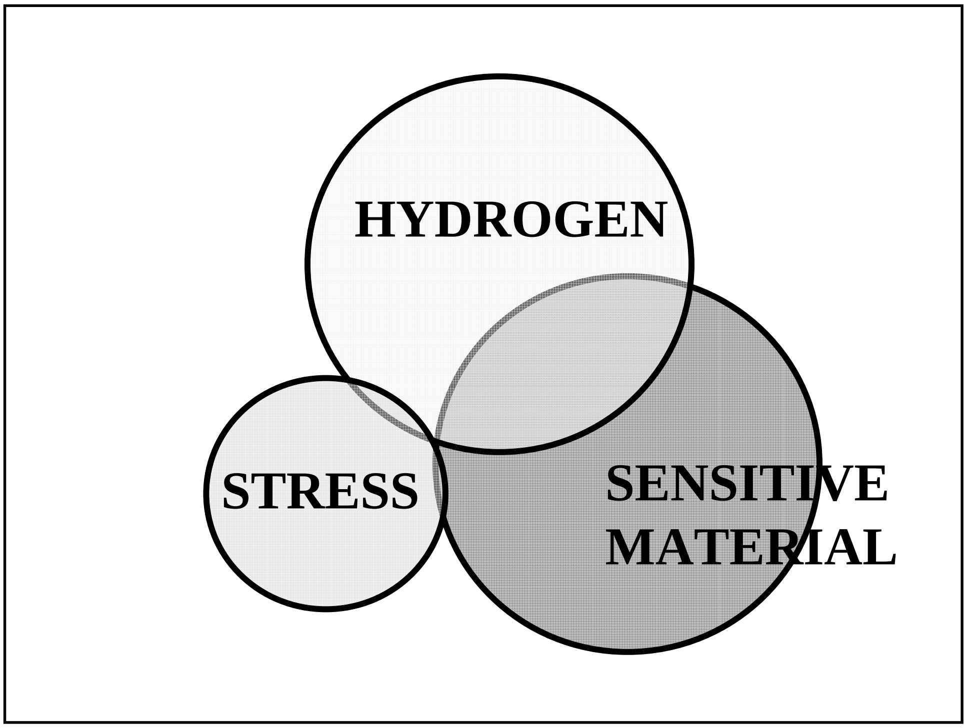
GTAW

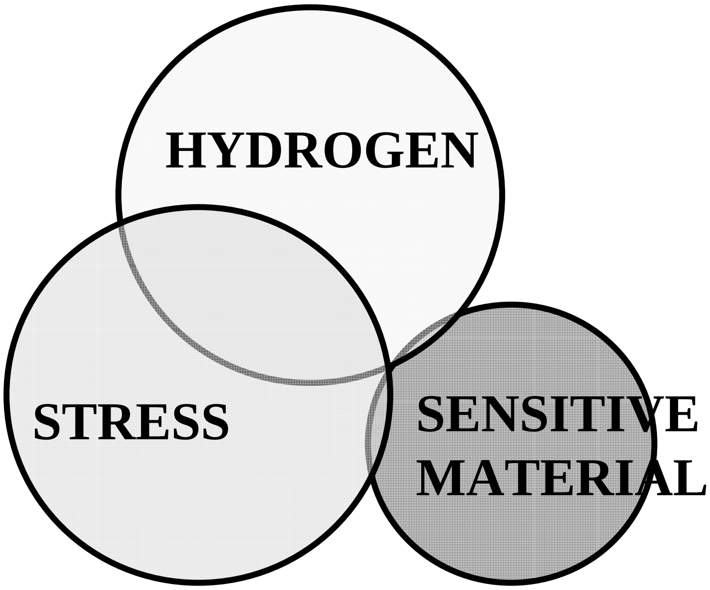
LOW HYDROGEN


0203 TWI © The Welding Institute UK 1975
2mm


HYDROGEN
STRESS
SENSITIVE MATERIAL


HYDROGEN
STRESS
SENSITIVE MATERIAL

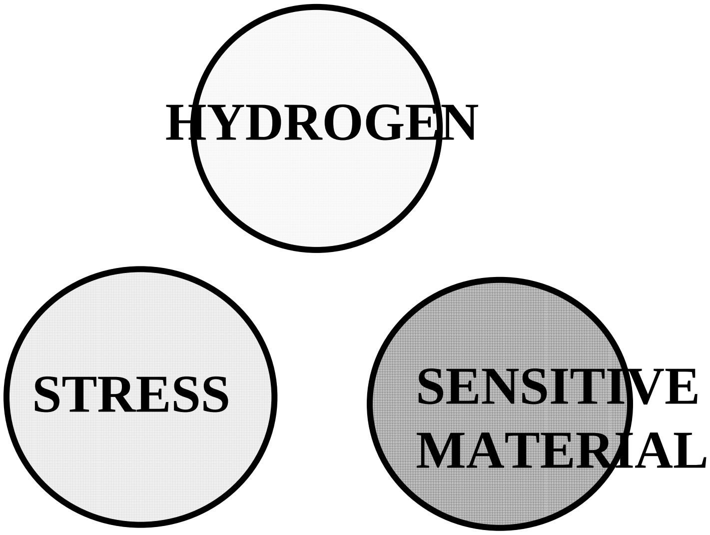

HYDROGEN
STRESS
SENSITIVE MATERIAL



HYDROGEN

STRESS

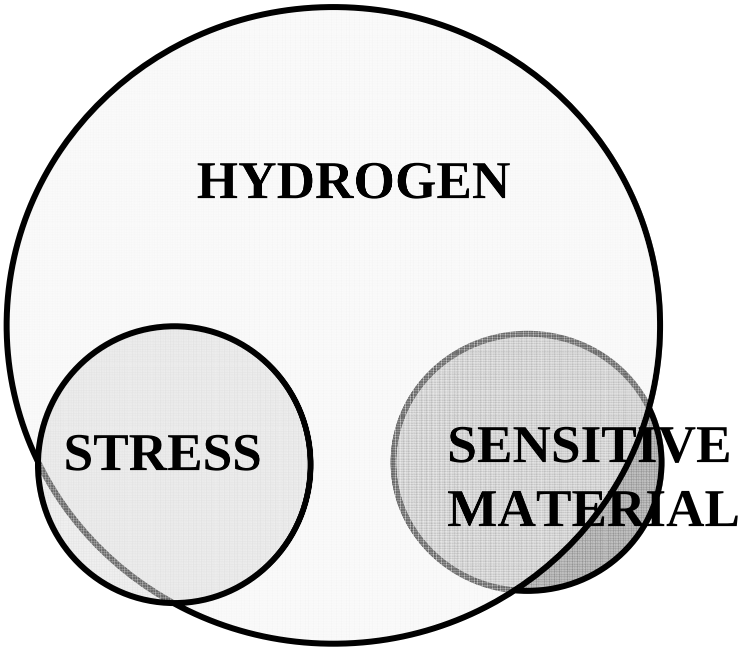
SENSITIVE
MATERIAL



HYDROGEN

STRESS

SENSITIVE
MATERIAL



HYDROGEN

STRESS

SENSITIVE
MATERIAL

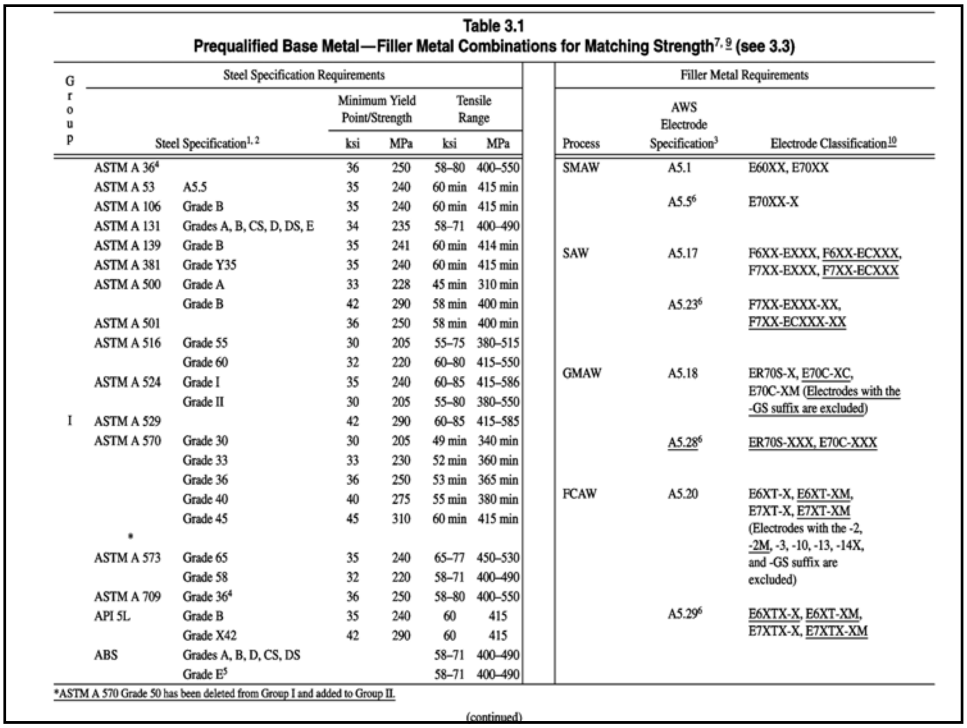


Table 3.1
Prequalified Base Metal—Filler Metal Combinations for Matching Strength[7, 9] (see 3.3)

Group	Steel Specification Requirements							Filler Metal Requirements		
			Minimum Yield Point/Strength		Tensile Range					
	Steel Specification[1, 2]		ksi	MPa	ksi	MPa		Process	AWS Electrode Specification[3]	Electrode Classification[10]
	ASTM A 36[4]		36	250	58–80	400–550		SMAW	A5.1	E60XX, E70XX
	ASTM A 53	A5.5	35	240	60 min	415 min				
	ASTM A 106	Grade B	35	240	60 min	415 min			A5.5[6]	E70XX-X
	ASTM A 131	Grades A, B, CS, D, DS, E	34	235	58–71	400–490				
	ASTM A 139	Grade B	35	241	60 min	414 min		SAW	A5.17	F6XX-EXXX, F6XX-ECXXX, F7XX-EXXX, F7XX-ECXXX
	ASTM A 381	Grade Y35	35	240	60 min	415 min				
	ASTM A 500	Grade A	33	228	45 min	310 min				
		Grade B	42	290	58 min	400 min			A5.23[6]	F7XX-EXXX-XX, F7XX-ECXXX-XX
	ASTM A 501		36	250	58 min	400 min				
	ASTM A 516	Grade 55	30	205	55–75	380–515				
		Grade 60	32	220	60–80	415–550				
	ASTM A 524	Grade I	35	240	60–85	415–586		GMAW	A5.18	ER70S-X, E70C-XC, E70C-XM (Electrodes with the -GS suffix are excluded)
		Grade II	30	205	55–80	380–550				
I	ASTM A 529		42	290	60–85	415–585				
	ASTM A 570	Grade 30	30	205	49 min	340 min			A5.28[6]	ER70S-XXX, E70C-XXX
		Grade 33	33	230	52 min	360 min				
		Grade 36	36	250	53 min	365 min				
		Grade 40	40	275	55 min	380 min		FCAW	A5.20	E6XT-X, E6XT-XM, E7XT-X, E7XT-XM (Electrodes with the -2, -2M, -3, -10, -13, -14X, and -GS suffix are excluded)
		Grade 45	45	310	60 min	415 min				
	*									
	ASTM A 573	Grade 65	35	240	65–77	450–530				
		Grade 58	32	220	58–71	400–490				
	ASTM A 709	Grade 36[4]	36	250	58–80	400–550				
	API 5L	Grade B	35	240	60	415			A5.29[6]	E6XTX-X, E6XT-XM, E7XTX-X, E7XTX-XM
		Grade X42	42	290	60	415				
	ABS	Grades A, B, D, CS, DS			58–71	400–490				
		Grade E[5]			58–71	400–490				

*ASTM A 570 Grade 50 has been deleted from Group I and added to Group II.

(continued)

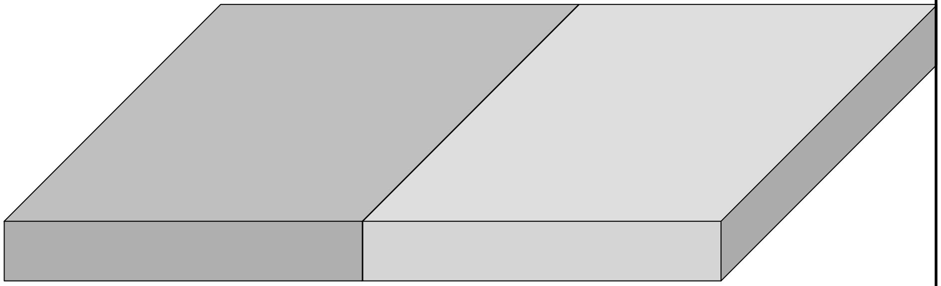
Process Selection/Application

Typically best left to Contractor
SAW: long, big, automatic
FCAW-g: semiauto in shop
FCAW-s: semiauto in field
SMAW: small, miscellaneous,
    repair, tacking
GMAW: semiauto in shop

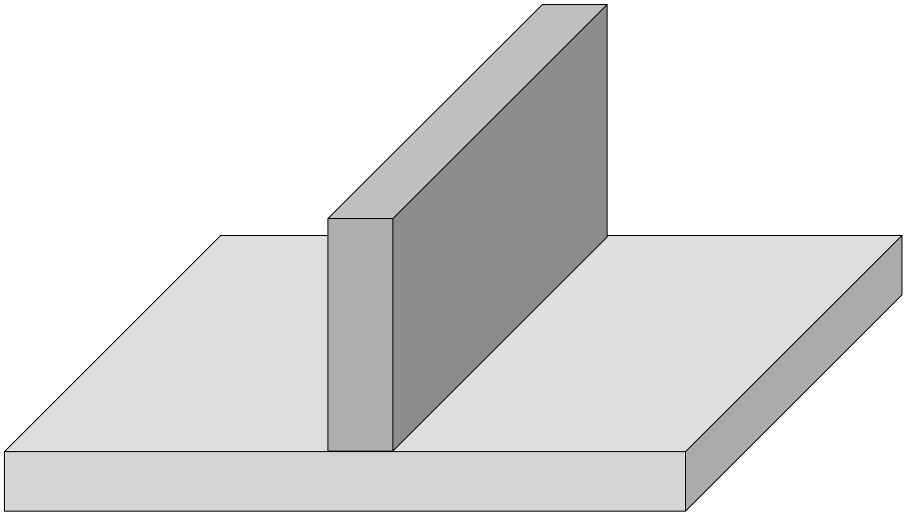
Introduction to Welded Connections

Joints

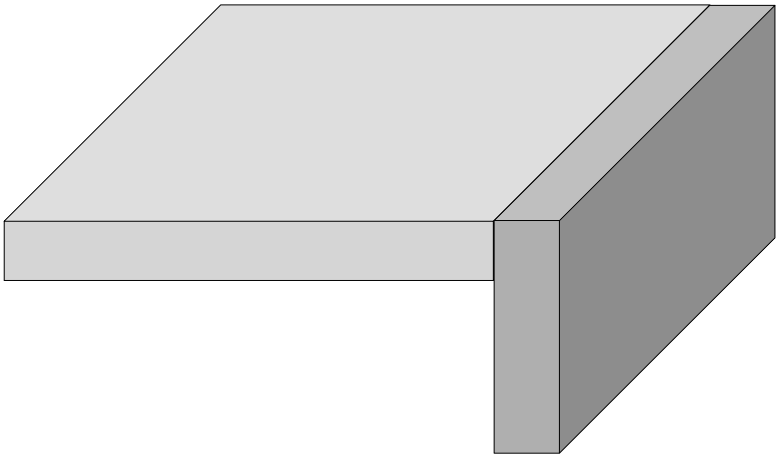
Butt Joint



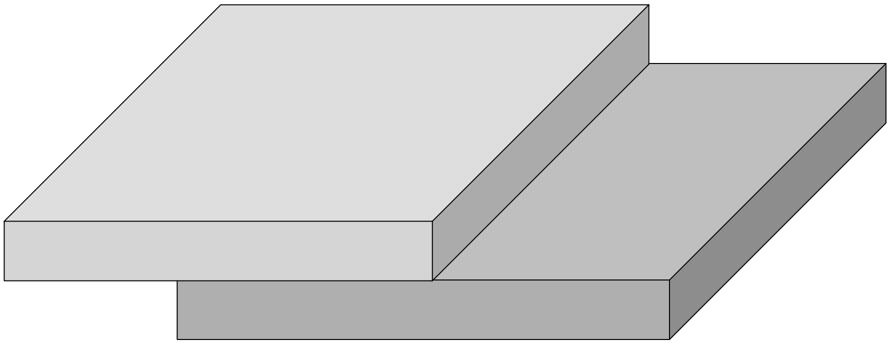
Tee Joint



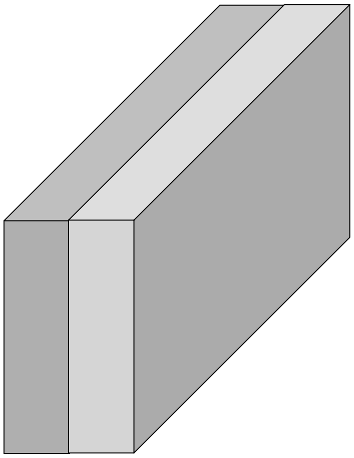
Corner Joint



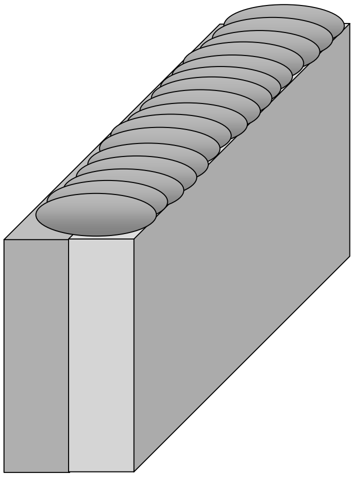
Lap Joint

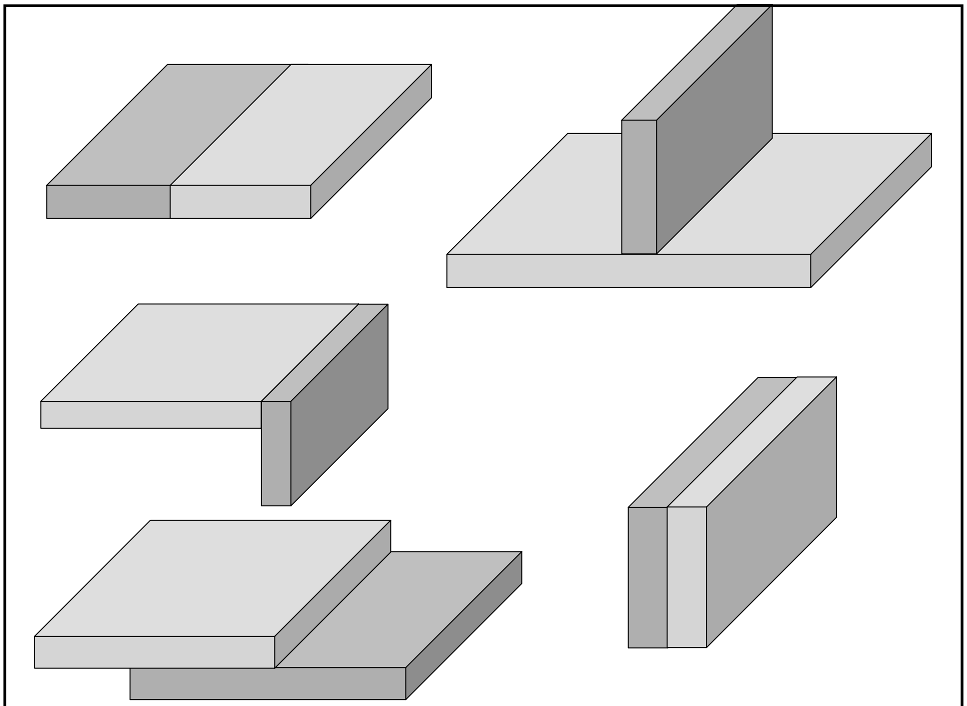


Edge Joint



Edge Joint



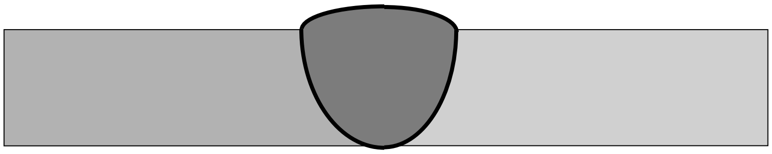


Weld Types

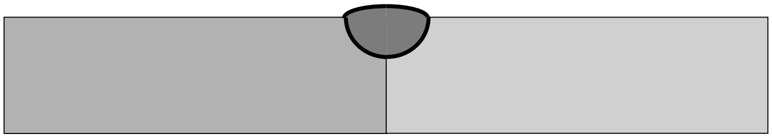
WELD TYPES

- GROOVE WELDS
  - –Complete Joint Penetration (CJP)
  - –Partial Joint Penetration (PJP)
- FILLET WELDS
- PLUG/SLOT

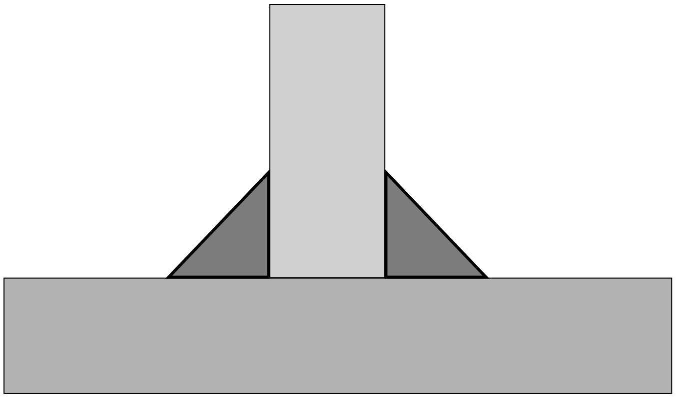
CJP Groove Weld in Butt Joint



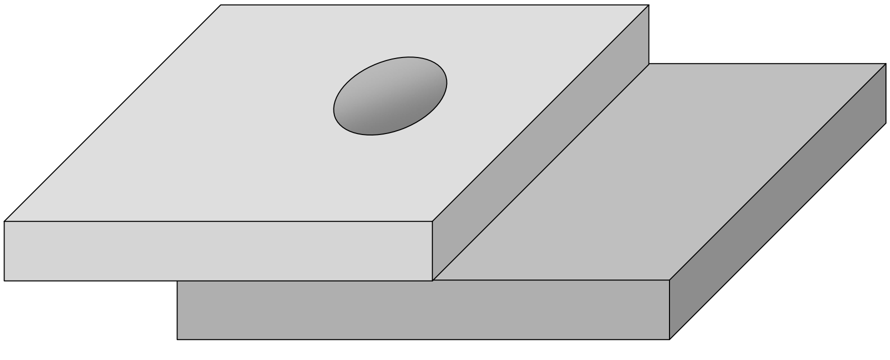
PJP Groove Weld in Butt Joint



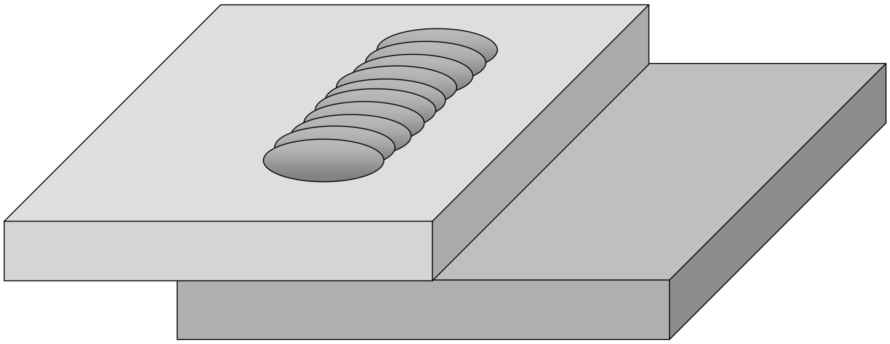
Fillet Welds in a Tee Joint

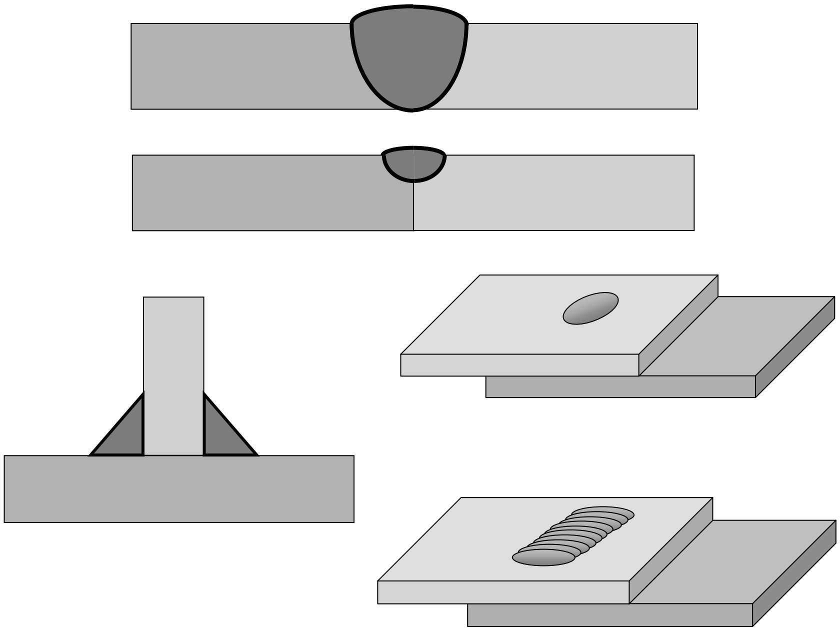


Plug Weld in Lap Joint



Slot Weld in Lap Joint

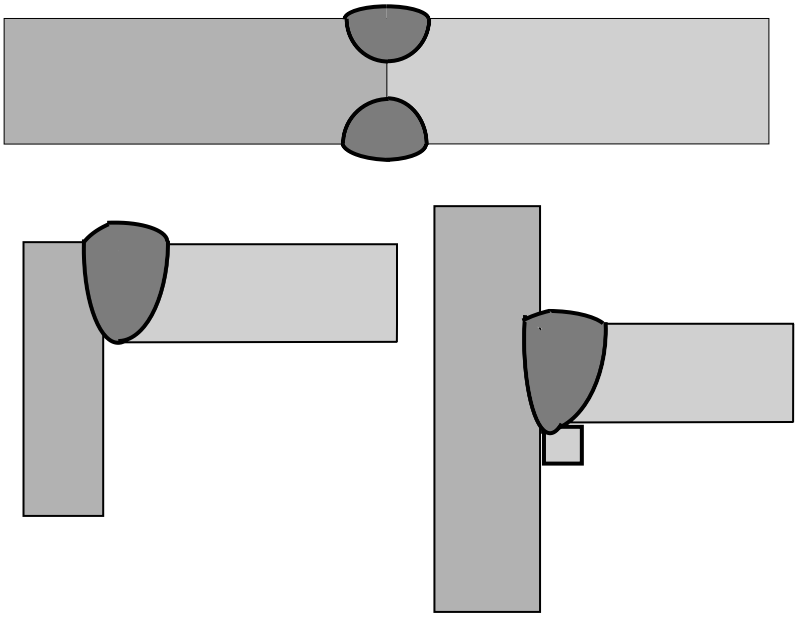




Groove Welds

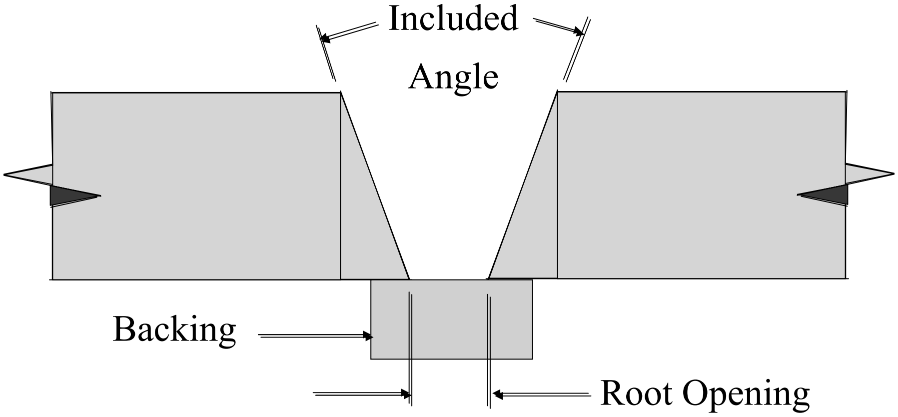
Groove Welds

- Applied to butt, tee, corner joints
- CJP = full strength
- PJP = partial strength
- Tension vs. compression vs. shear



CJP Groove Welds

CJP Groove Weld Terminology



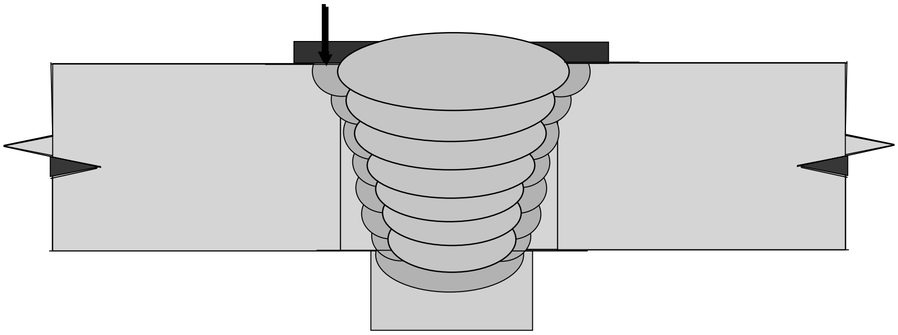
Included Angle

Backing

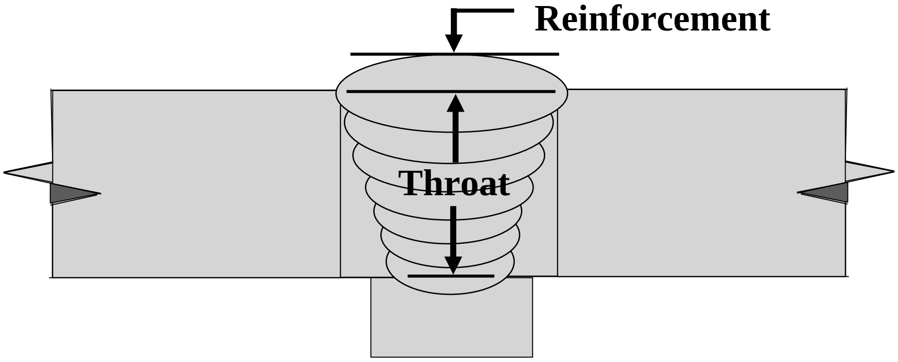
Root Opening

CJP Groove Weld Terminology

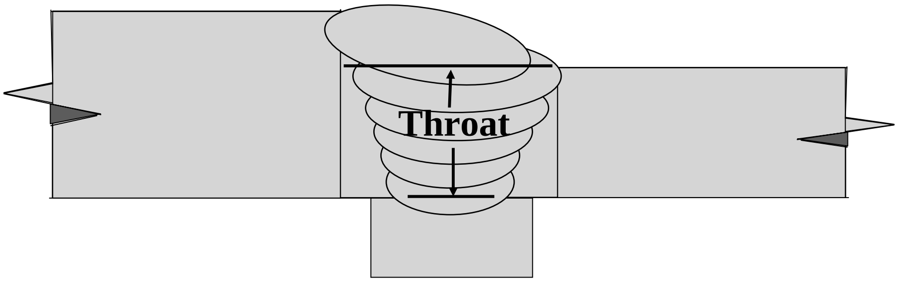
Heat Affected Zone (HAZ)



CJP Groove Weld Terminology



CJP Groove Weld Terminology



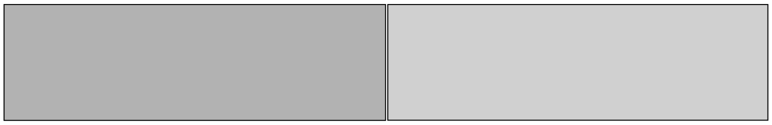
CJP Groove Welds

- Throat = plate thickness
- No design calcs for static
- Same strength, regardless of joint details
- Leave joint details up to Fabricator
- Use "matching strength" weld metal

Groove Weld Types

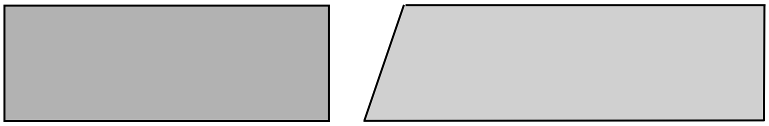
Groove Weld Types:

Square Edge



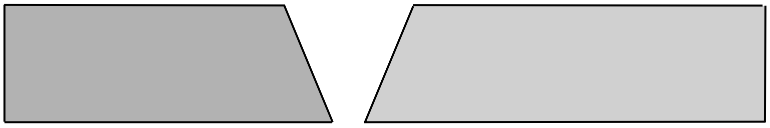
Groove Weld Types:

Bevel Groove



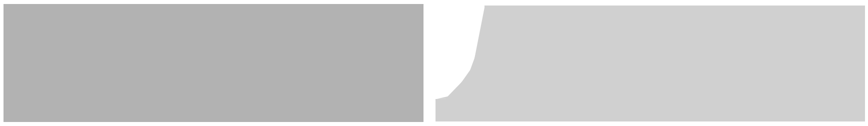
Groove Weld Types:

Vee Groove



Groove Weld Types:

J-Groove

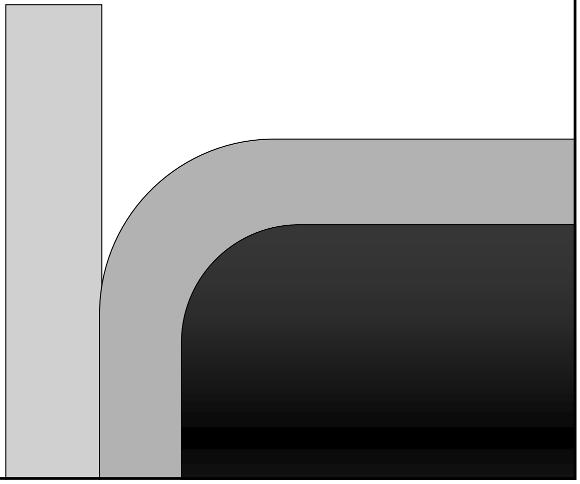


Groove Weld Types:

U-Groove

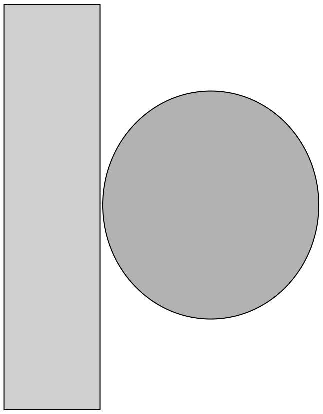
Groove Weld Types:

Flare Bevel Groove



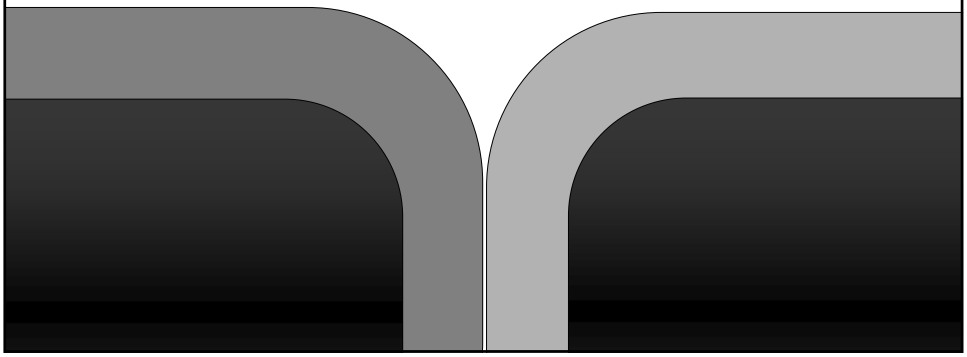
Groove Weld Types:

Flare Bevel Groove



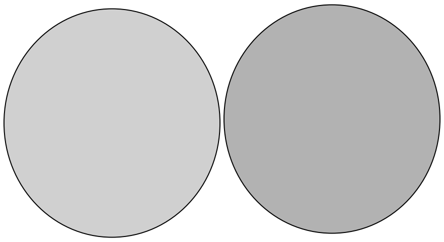
Groove Weld Types:

Flare Vee Groove



Groove Weld Types:

Flare Vee Groove

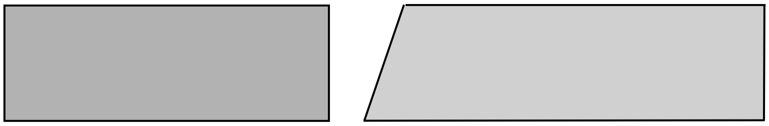


Groove Weld Types:

Single versus Double

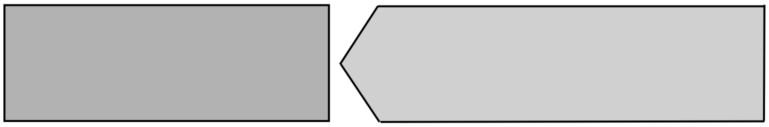
Groove Weld Types:

Single Bevel Groove



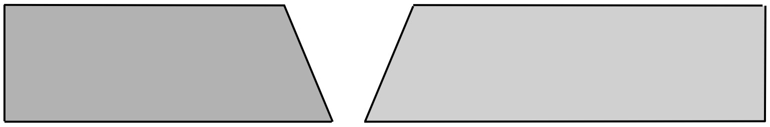
Groove Weld Types:

Double Bevel Groove



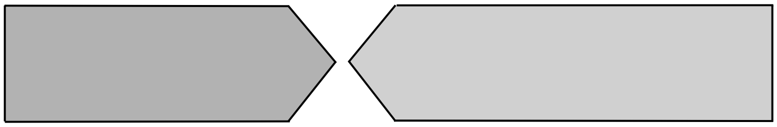
Groove Weld Types:

Single Vee Groove



Groove Weld Types:

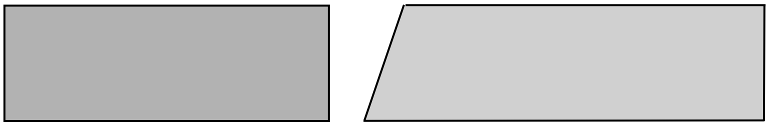
Double Vee Groove



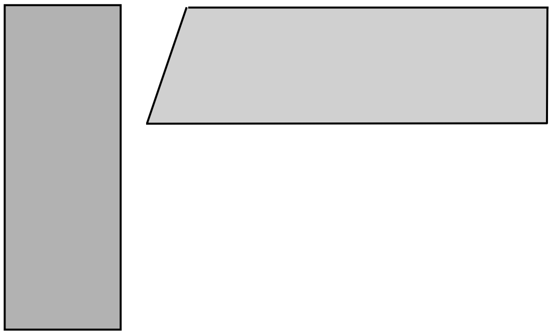
Groove Weld Type and

Joint Type

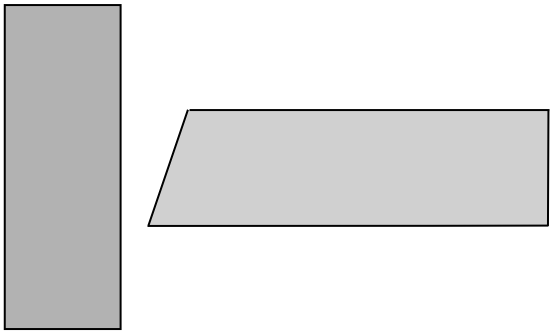
Bevel Groove in Butt Joint



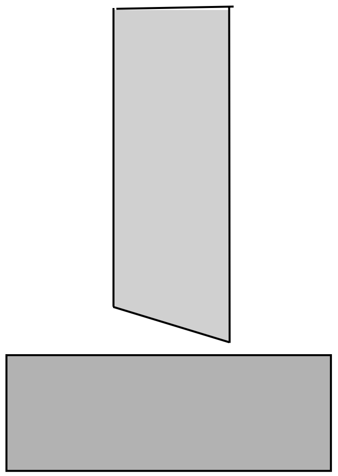
Bevel Groove in Corner Joint



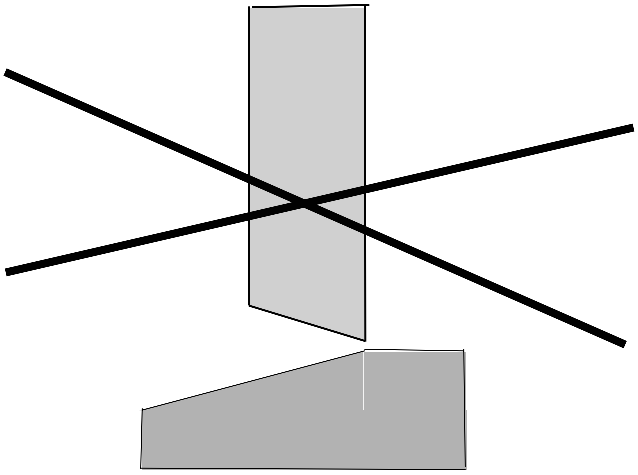
Bevel Groove in Tee Joint



Bevel Groove in Tee Joint

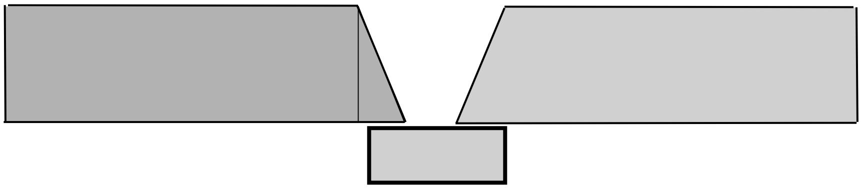


Vee Groove in Tee Joint

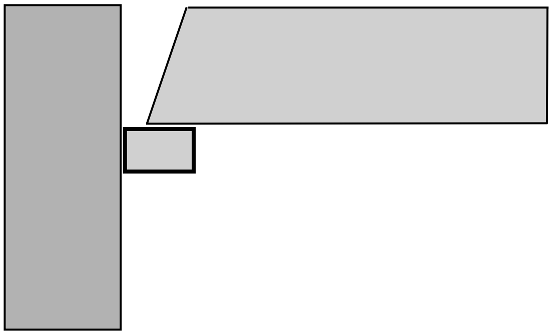


Weld Backing

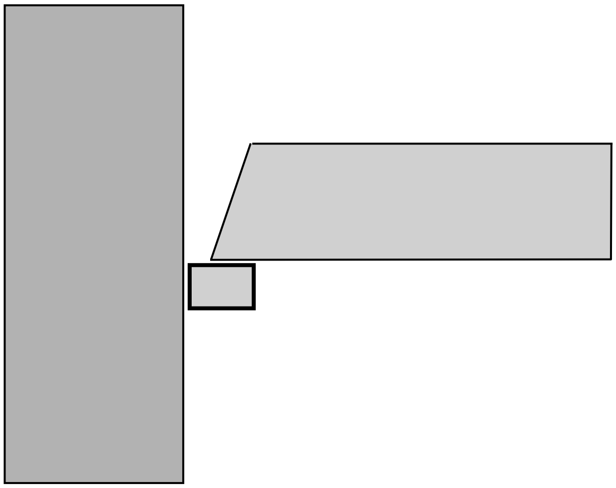
Weld Backing



Weld Backing



Weld Backing



Weld Backing Types:

- Steel
- Copper
- Ceramic

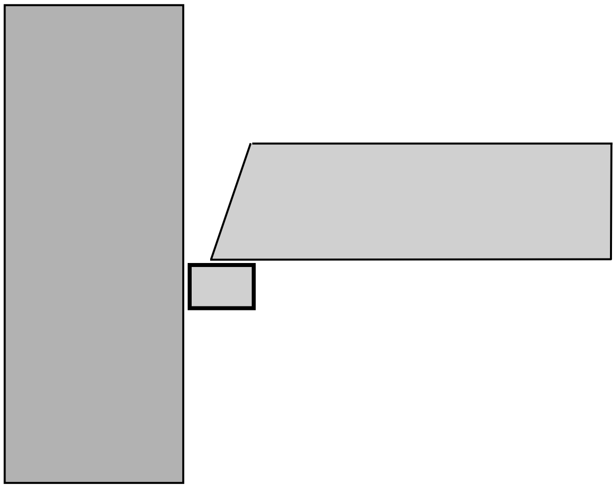
Steel Backing:

Permanent

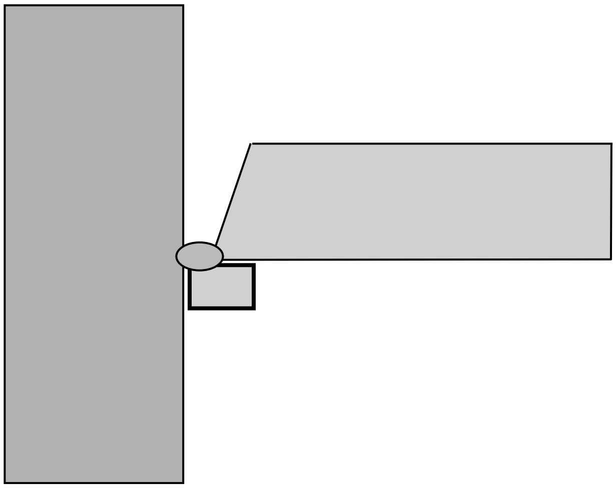
Part of Weldment

Notch Effects

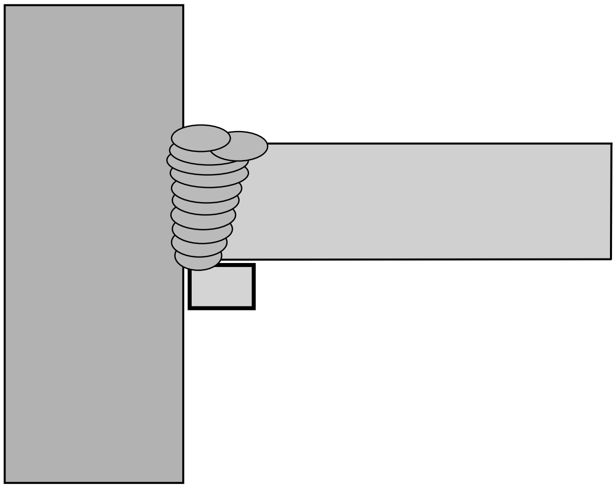
Weld Backing



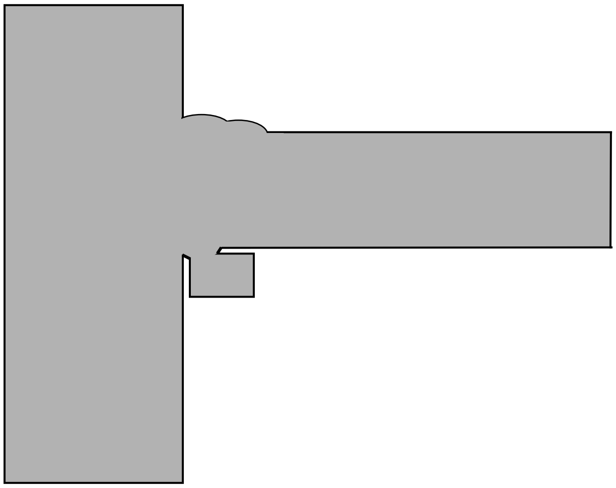
Weld Backing



Weld Backing



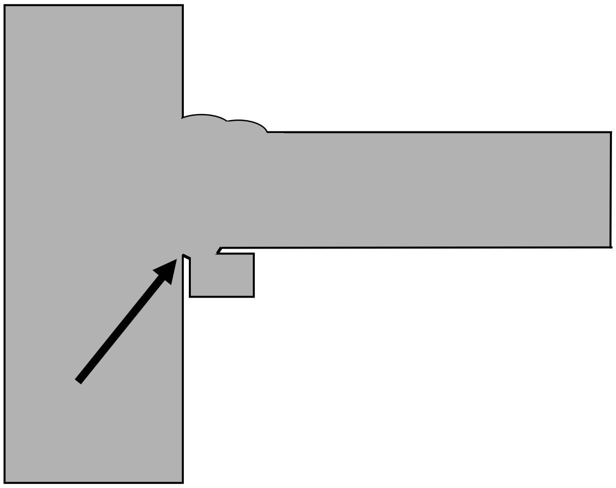
Weld Backing



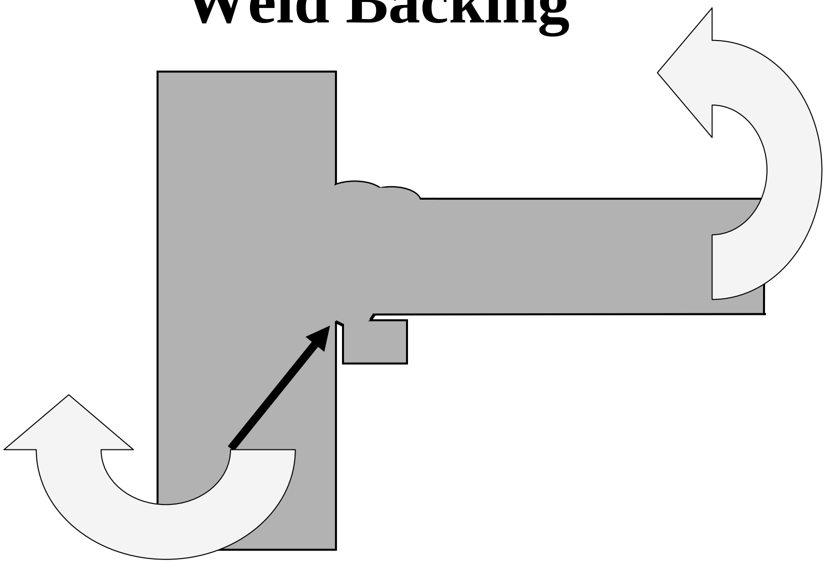
Principle:

There are no secondary members in welded construction.

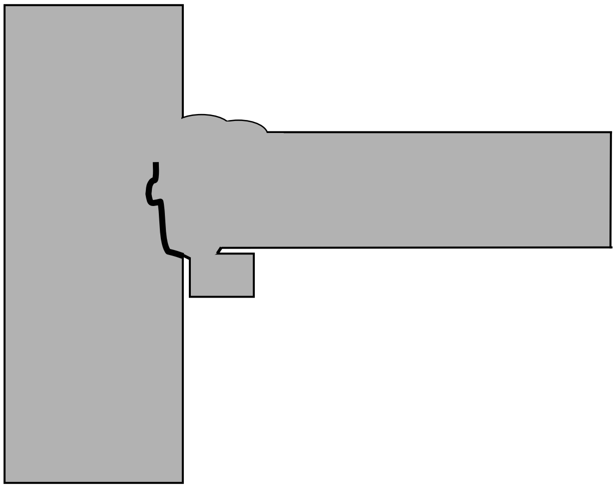
Weld Backing



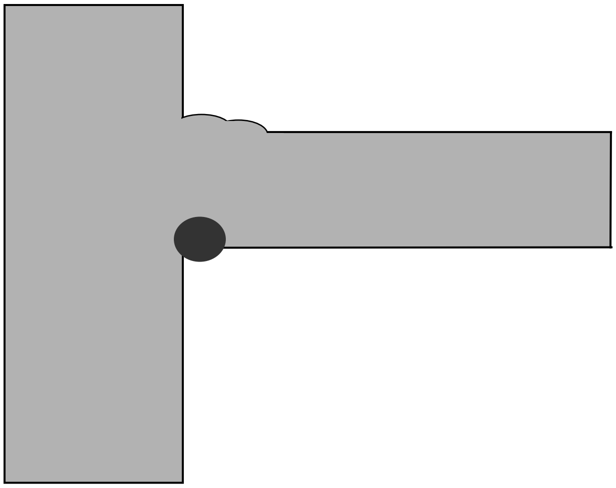
Weld Backing



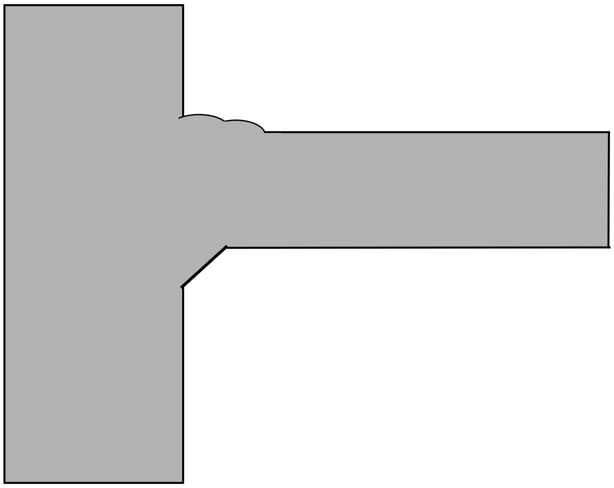
Weld Backing



Weld Backing



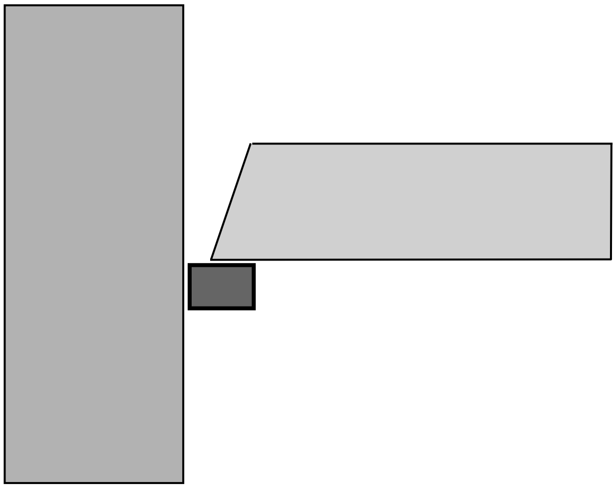
Weld Backing

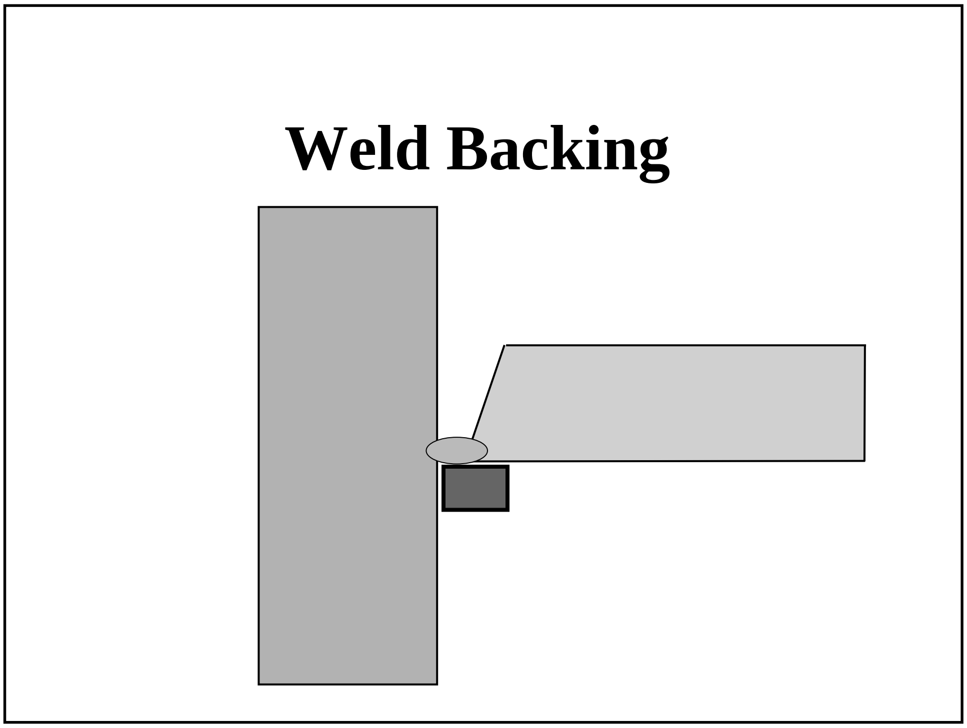


Copper Backing:

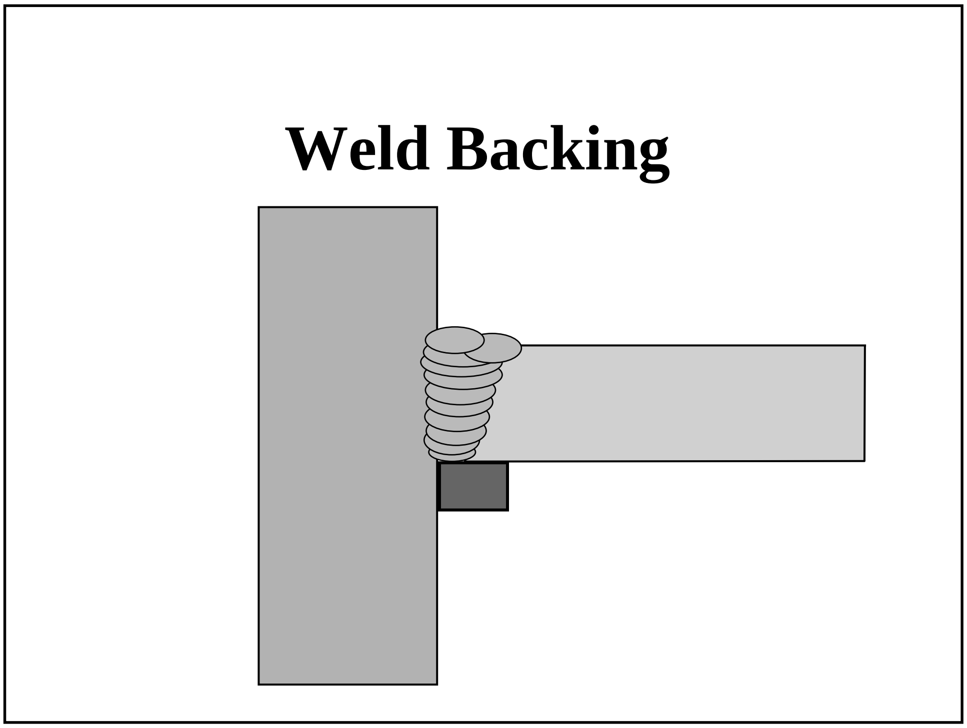
- Removable
- Electrically Conductive
- Metallurgical Effects

Weld Backing



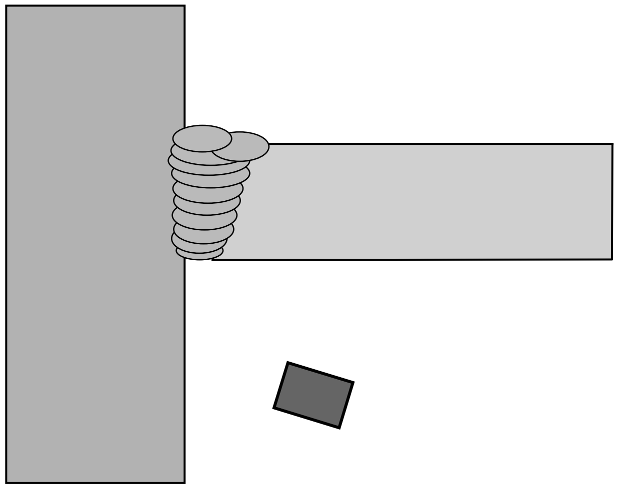


Weld Backing

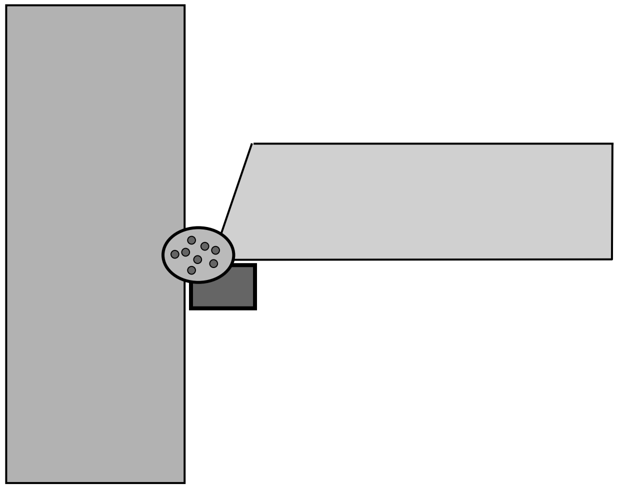


Weld Backing

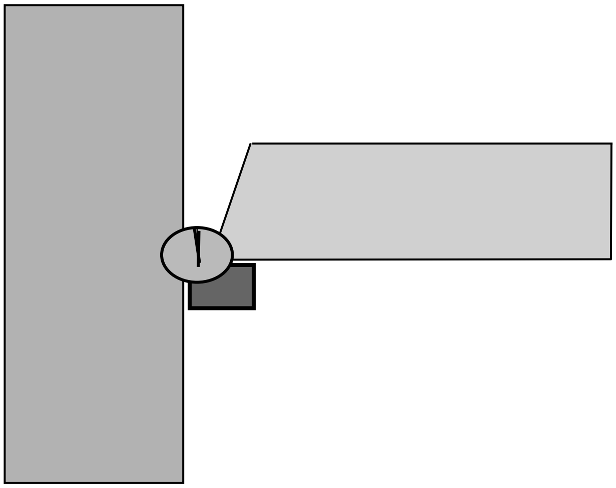
Weld Backing



Weld Backing



Weld Backing

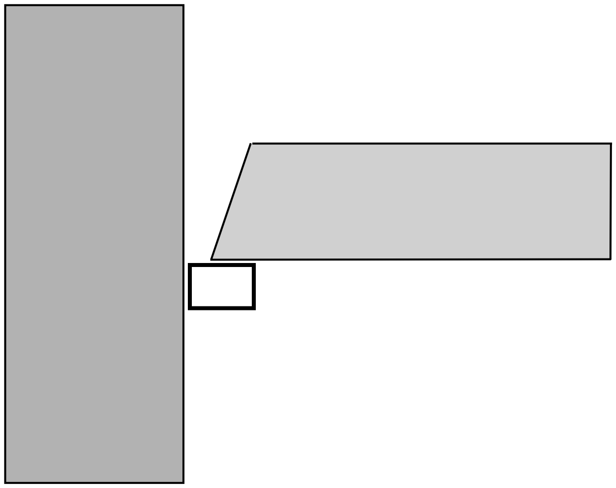


Ceramic Backing:

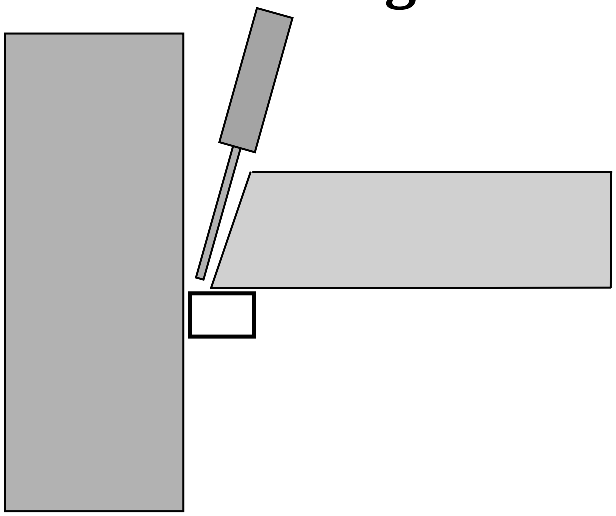
Removable

Electrically Non-conductive

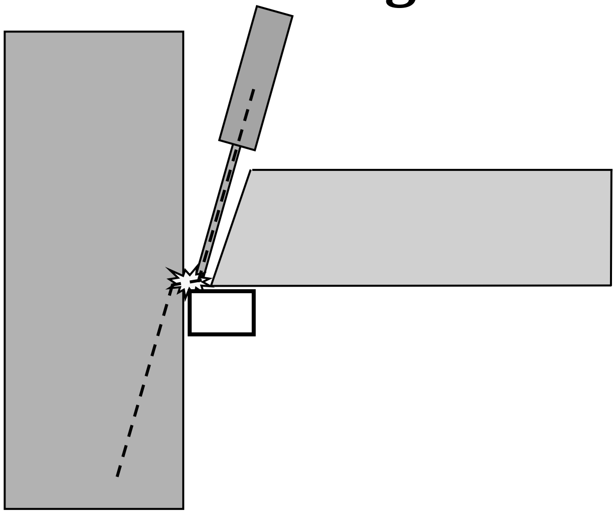
Weld Backing



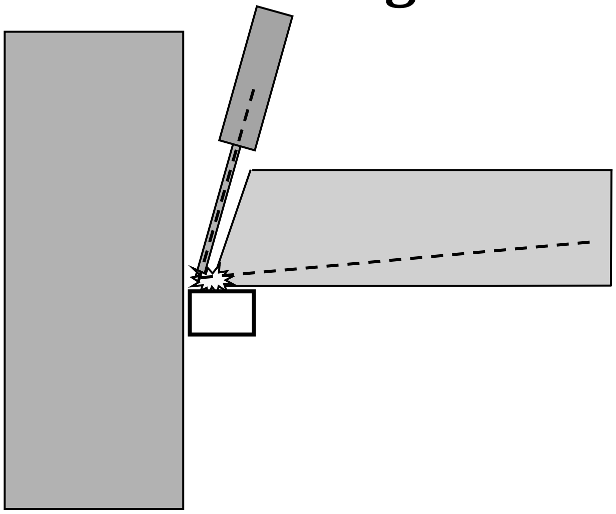
Weld Backing



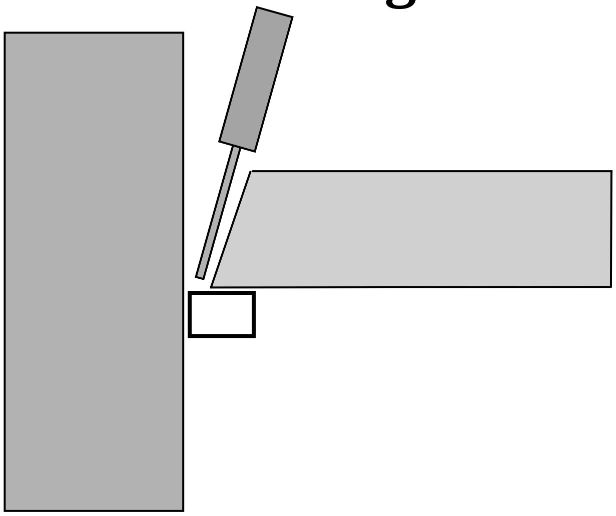
Weld Backing



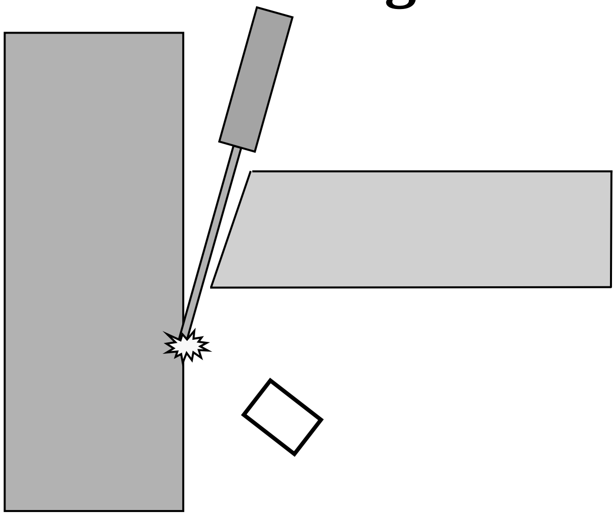
Weld Backing



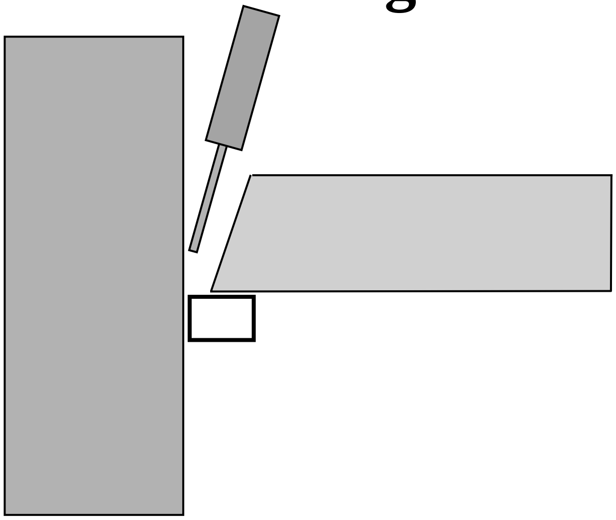
Weld Backing



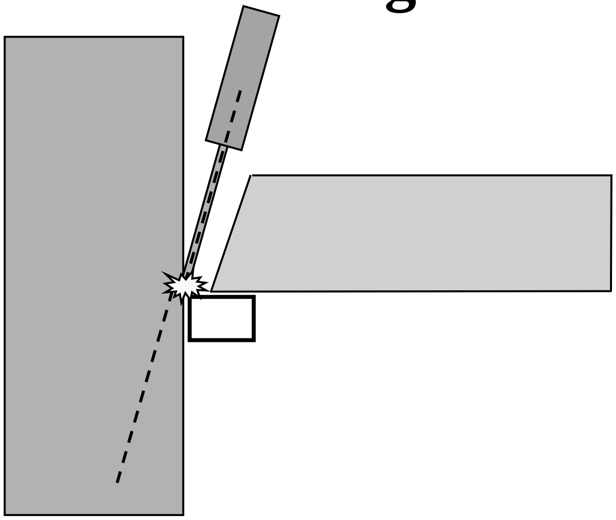
Weld Backing



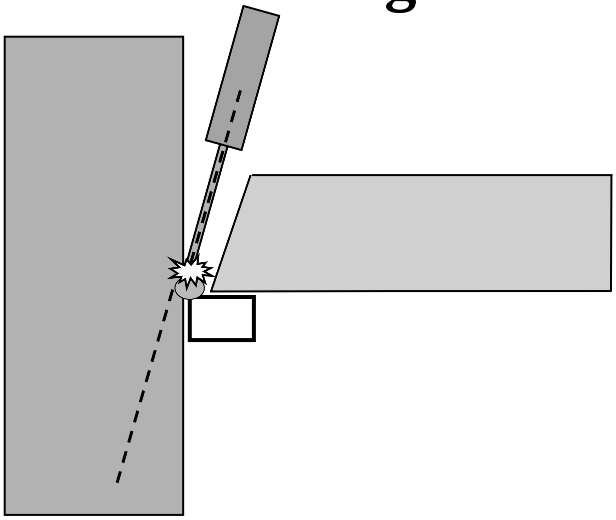
Weld Backing



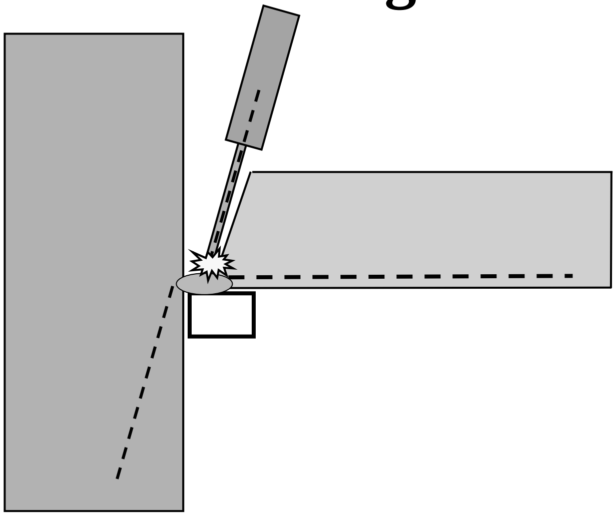
Weld Backing



Weld Backing



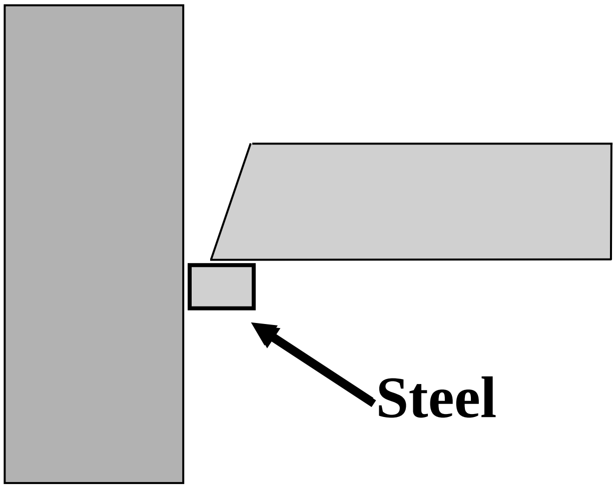
Weld Backing

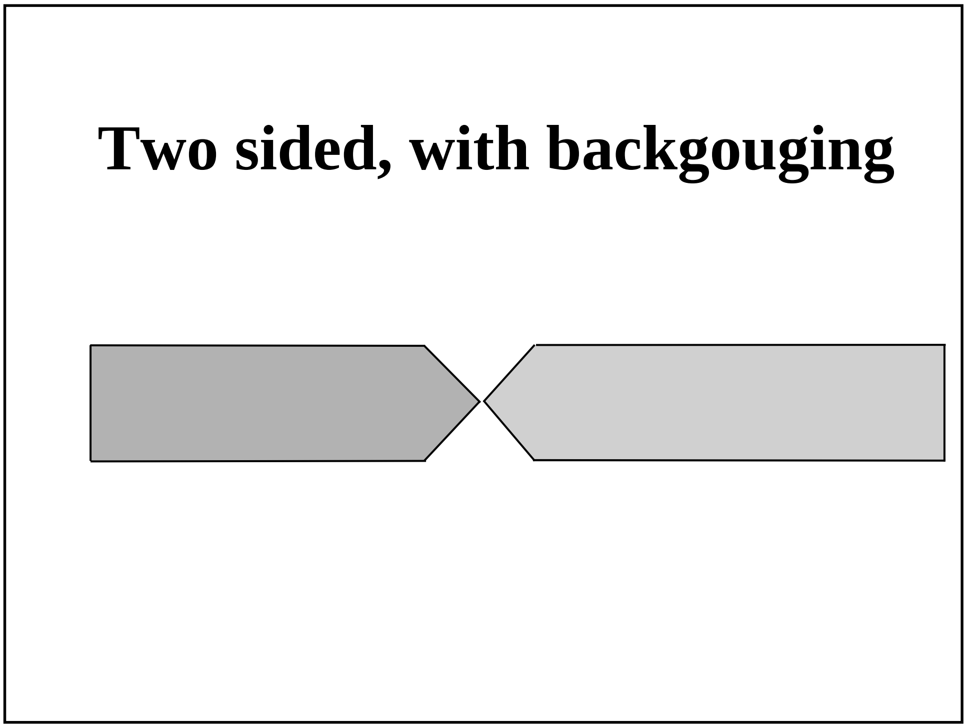


Groove Weld Types:

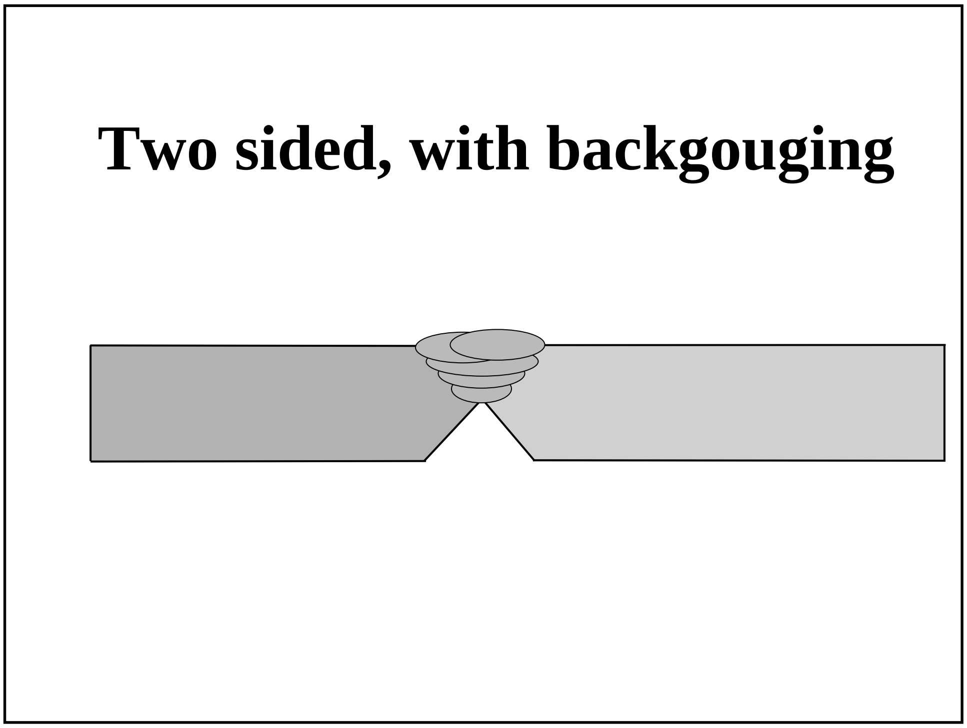
Single versus Double

One sided, with steel backing



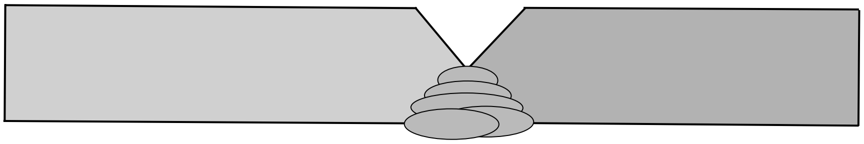


Two sided, with backgouging

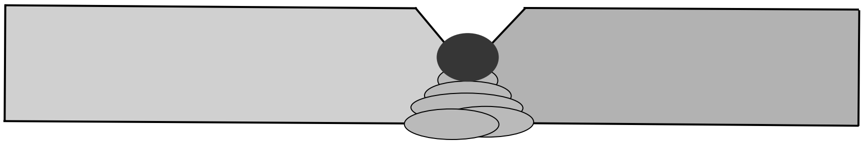


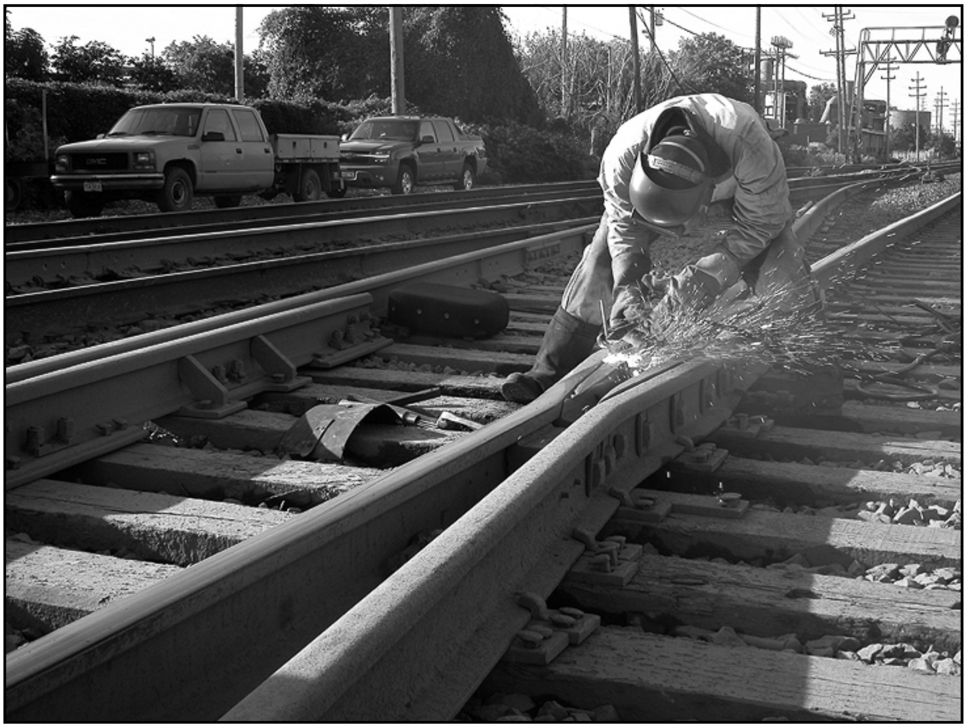
Two sided, with backgouging

Two sided, with backgouging

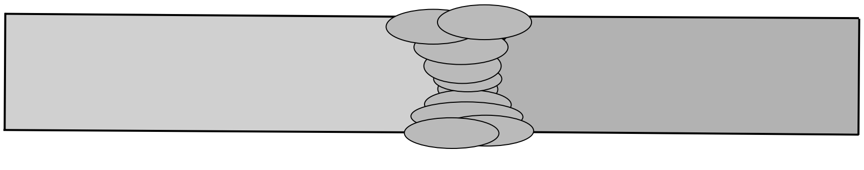


Two sided, with backgouging



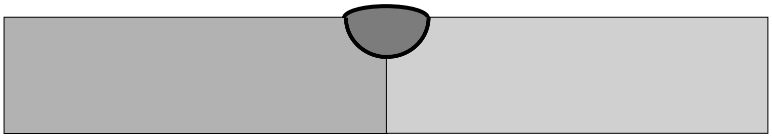


Two sided, with backgouging

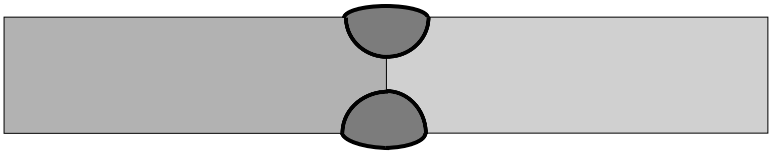


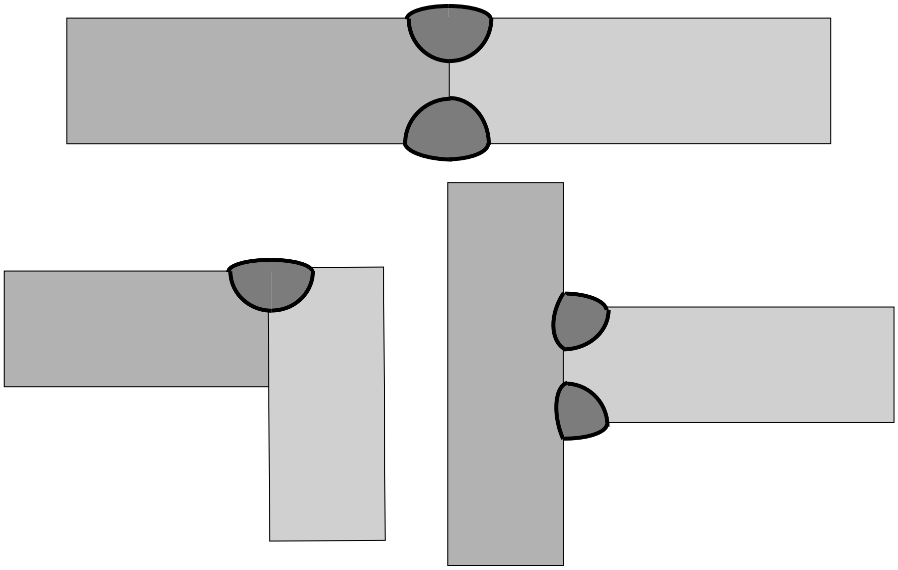
PJP Groove Welds

PJP Groove Weld

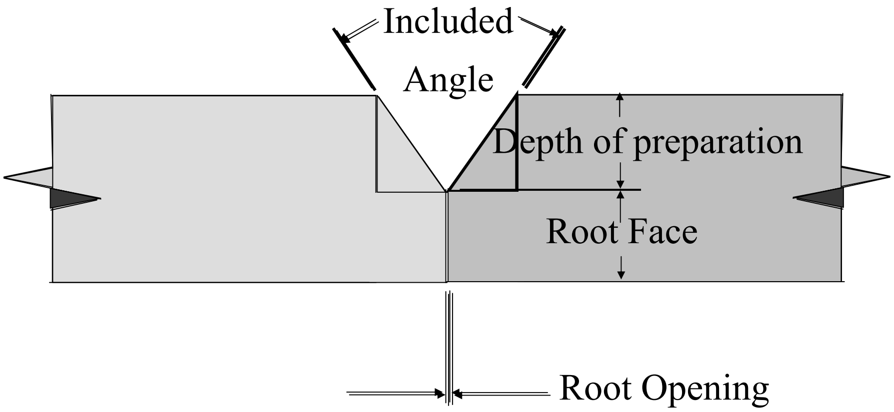


PJP Groove Weld

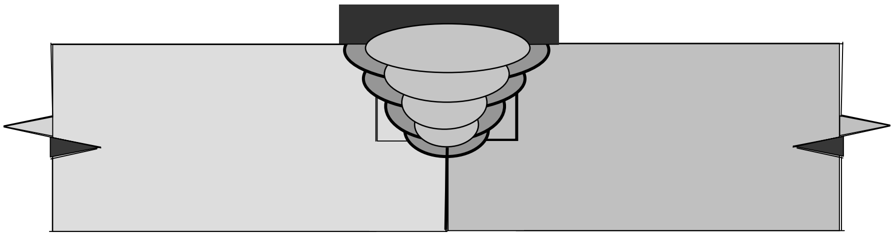




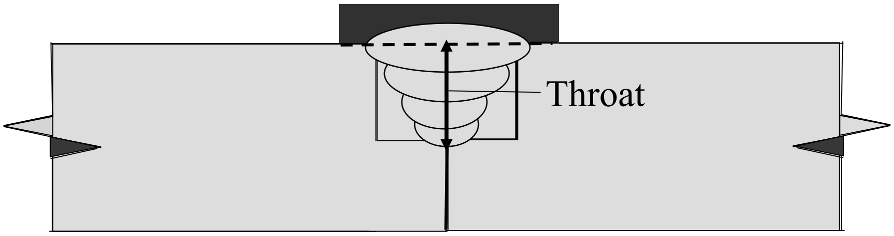
PJP Groove Weld Terminology



PJP Groove Weld Terminology



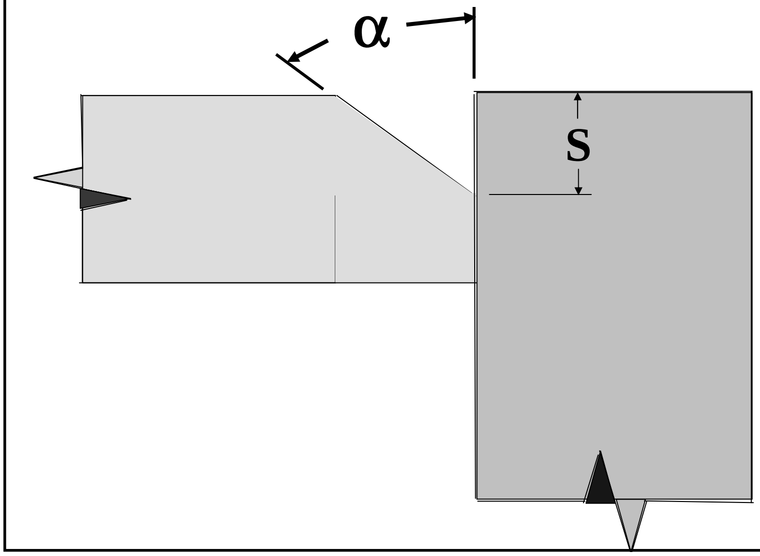
PJP Groove Weld Terminology



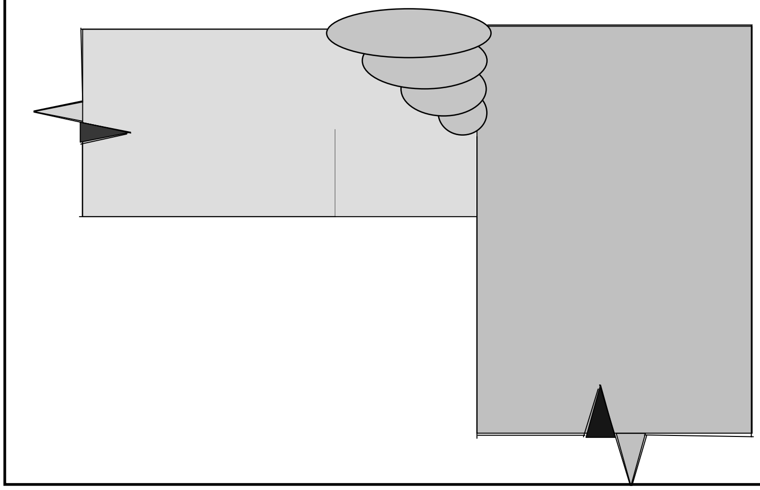
PJP Groove Welds

- Throat < plate thickness
- Must determine throat
- “E” vs. “S” dimension

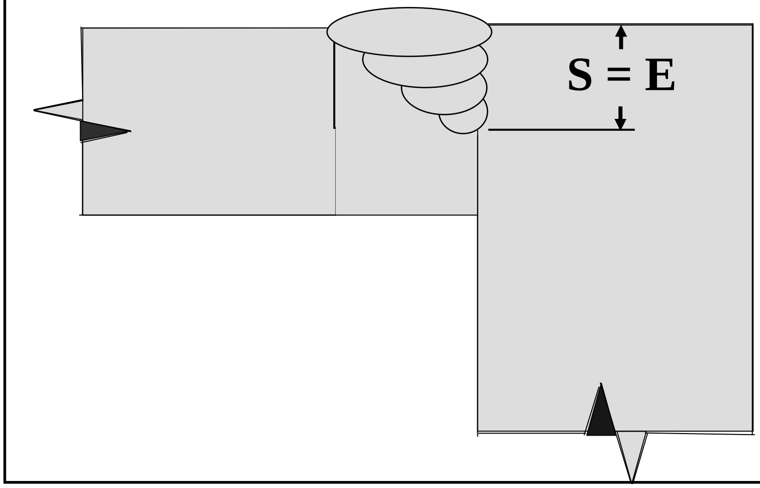
PJP Groove Weld: E vs. S



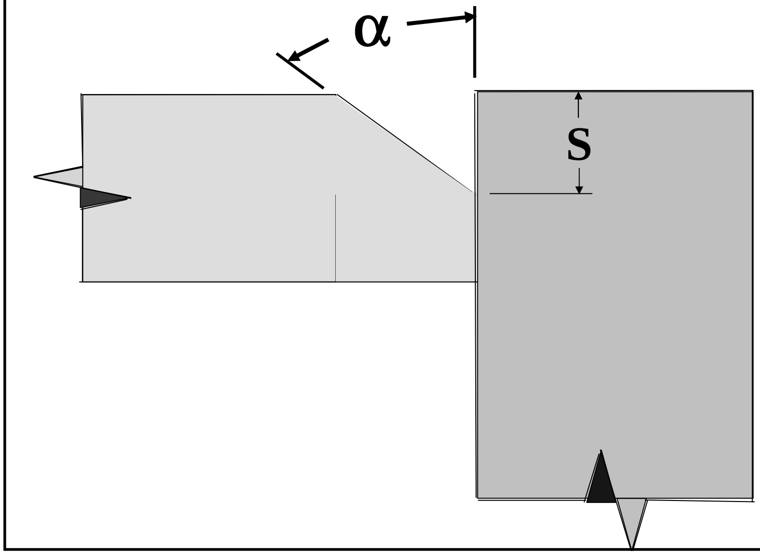
PJP Groove Weld: E vs. S



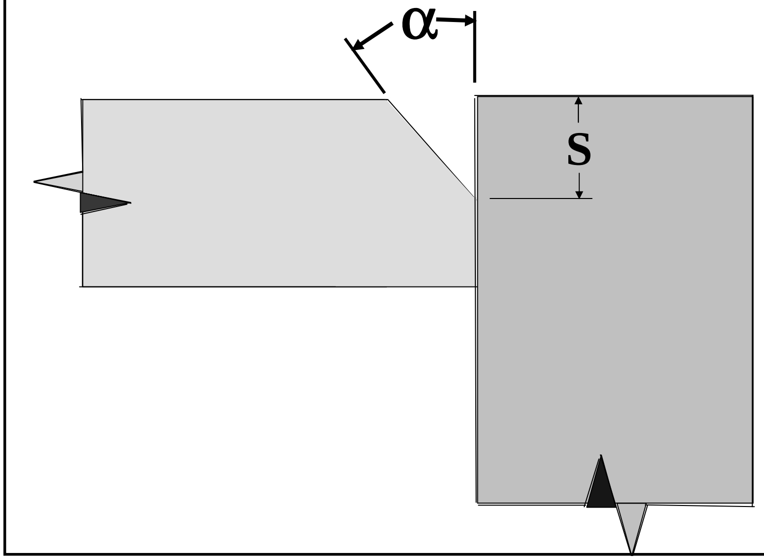
PJP Groove Weld: E vs. S



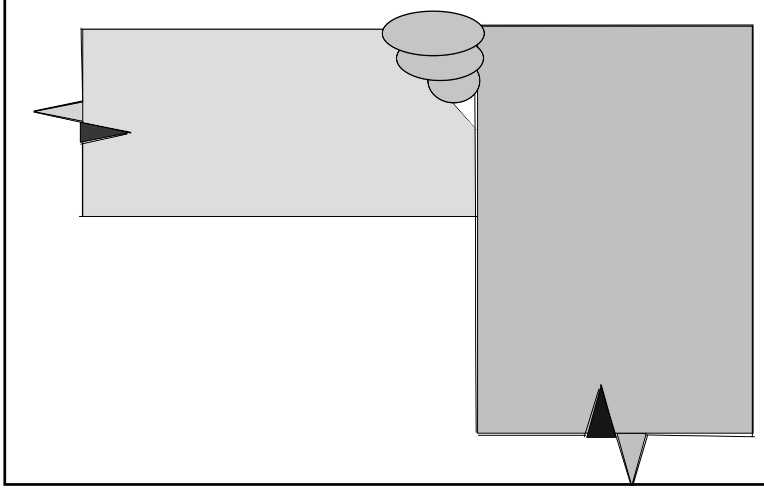
PJP Groove Weld: E vs. S



PJP Groove Weld: E vs. S



PJP Groove Weld: E vs. S



PJP Groove Weld: E vs. S

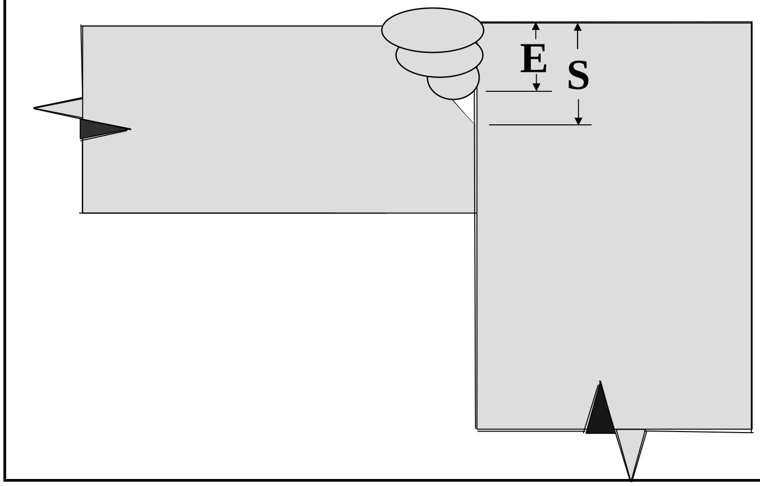


TABLE J 2.1

Effective Throat of Partial Joint Penetration Groove Welds

Welding Process	Welding Position	Groove Type	Effective Throat “E”
SMAW	All	J of U Groove 60° V	E = S
GMAW, FCAW	All		
SAW	F	J or U Groove 60° Bevel or V	
GMAW. FCAW	F, H	45° Bevel	
SMAW	All	45° Bevel	E = S – 1/8”
GMAW, FCAW	V, OH	45° Bevel	

PJP Groove Welds

- Throat < plate thickness
- Must determine throat
- “E” vs. “S” dimension
- Engineer specify “E”
- Leave “S” up to shop
- Could use “matching” or “undermatching”

Minimum Sized PJP Groove Welds

TABLE J2.3

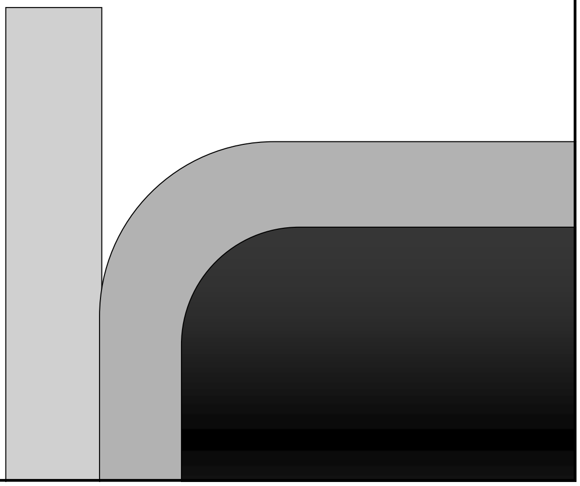
Minimum Effective Throat Thickness of Partial Joint Penetration Groove Welds

Minimum Thickness of Thinner Part Joined	Minimum Effective Throat Thickness
To ¼” inclusive	1/8”
Over ¼” to ½”	3/16”
Over ½” to ¾”	1/4”
Over ¾” to 1 ½”	5/16”
Over 1 ½” to 2 ¼”	3/8”
Over 2 ¼” to 6”	1/2”
Over 6”	5/8”

Flare V and Flare Bevel PJP Groove Welds

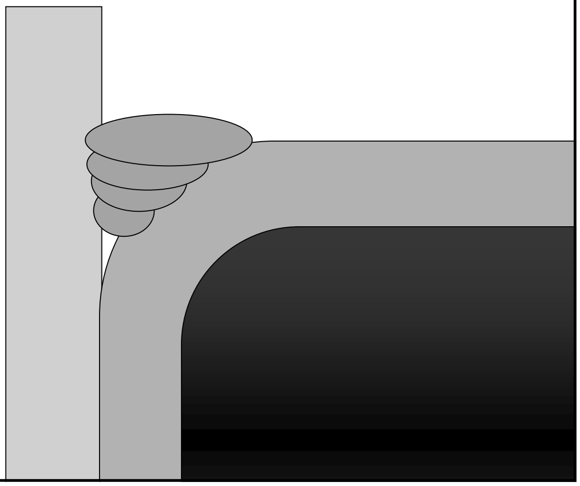
Groove Weld Types:

Flare Bevel Groove



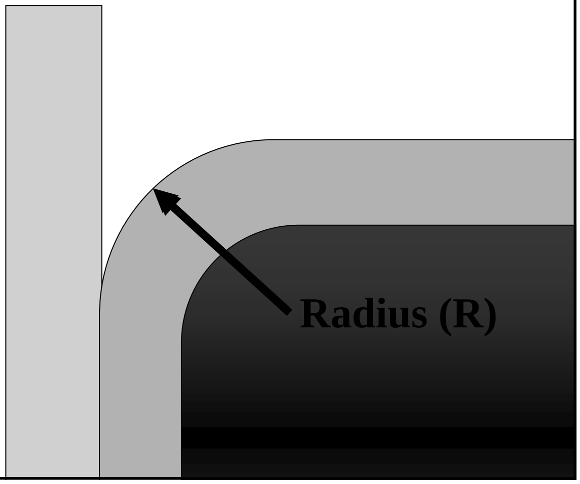
Groove Weld Types:

Flare Bevel Groove



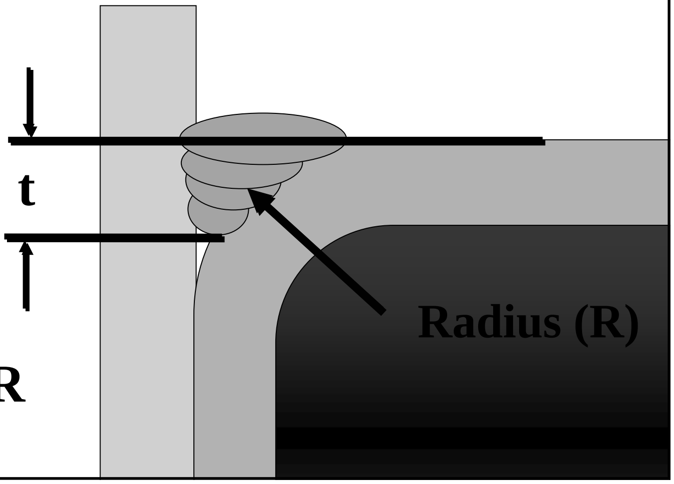
Groove Weld Types:

Flare Bevel Groove



Groove Weld Types:

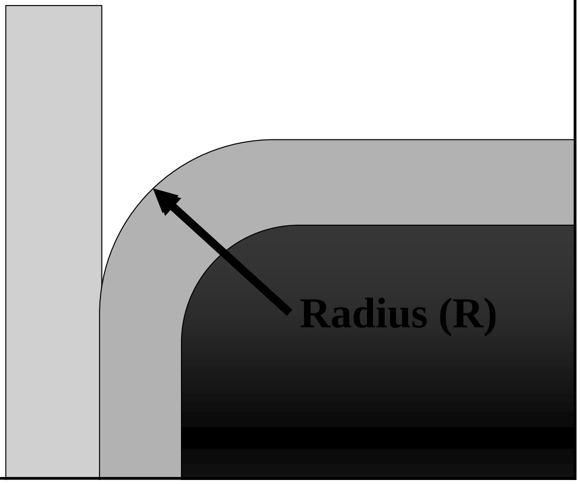
Flare Bevel Groove



t = 5/16 R

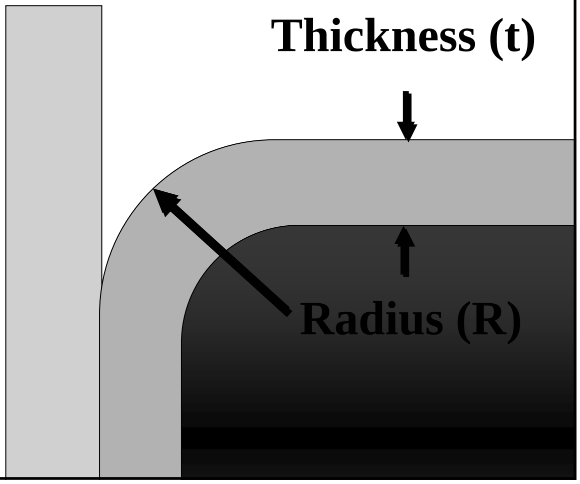
Groove Weld Types:

Flare Bevel Groove



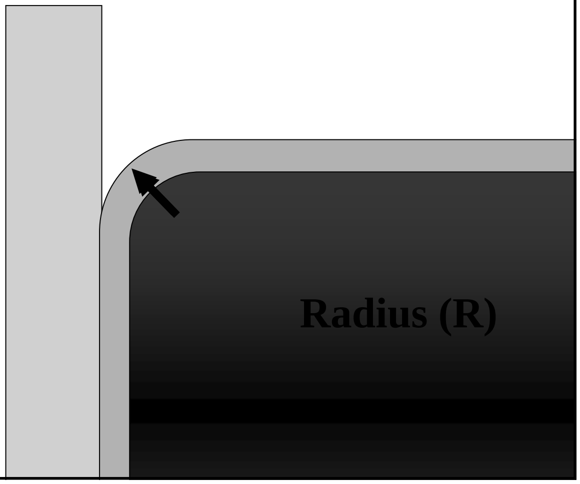
Flare Bevel Groove

$R \doteq 2t$



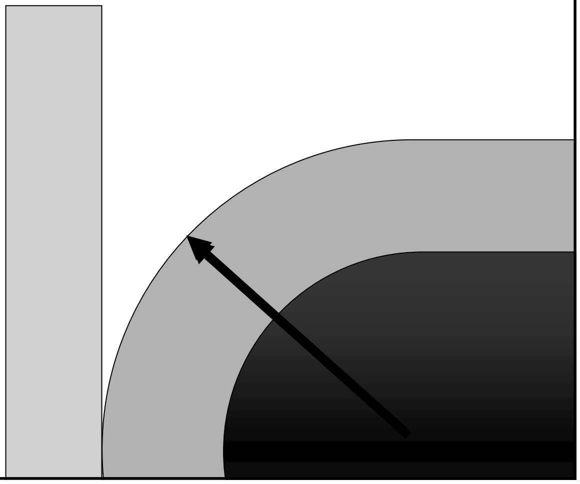
Groove Weld Types:

Flare Bevel Groove



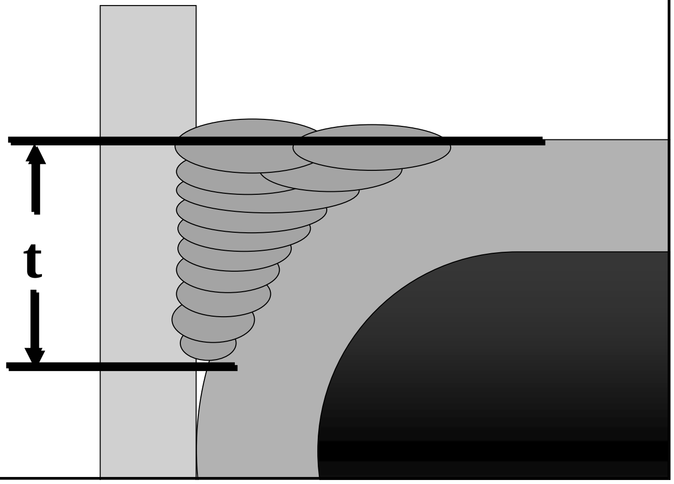
Groove Weld Types:

Flare Bevel Groove



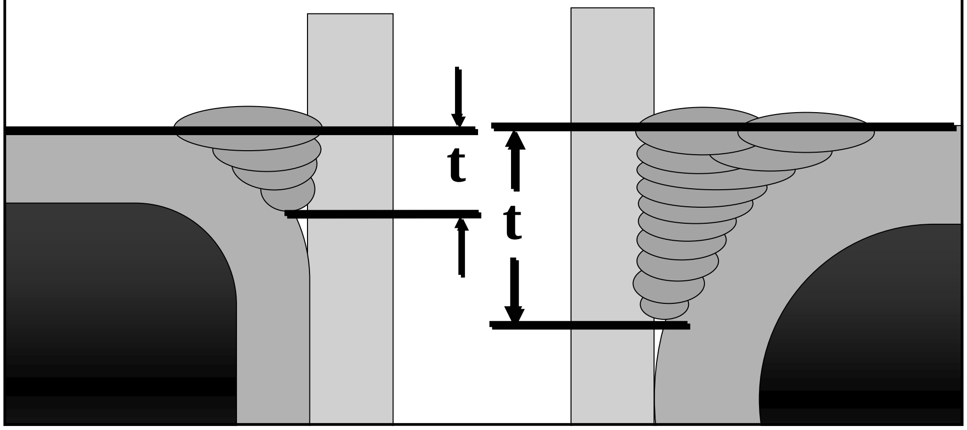
Groove Weld Types:

Flare Bevel Groove



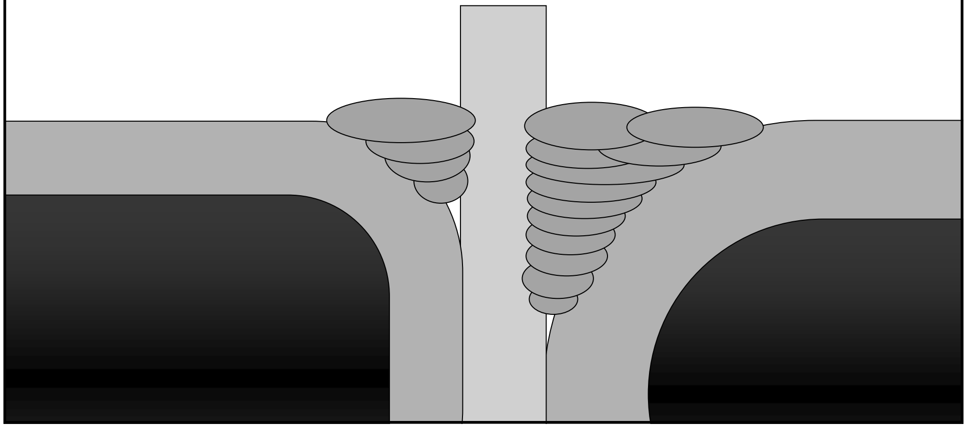
Groove Weld Types:

Flare Bevel Groove



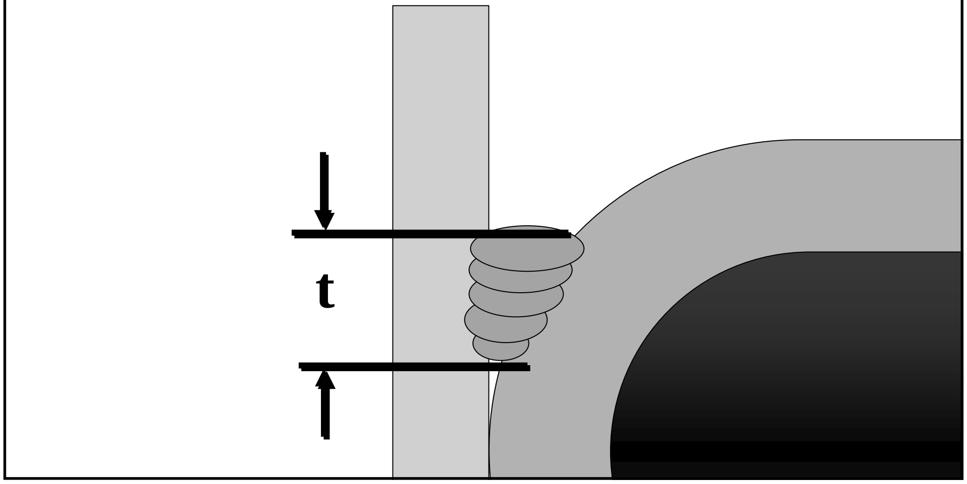
Groove Weld Types:

Flare Bevel Groove



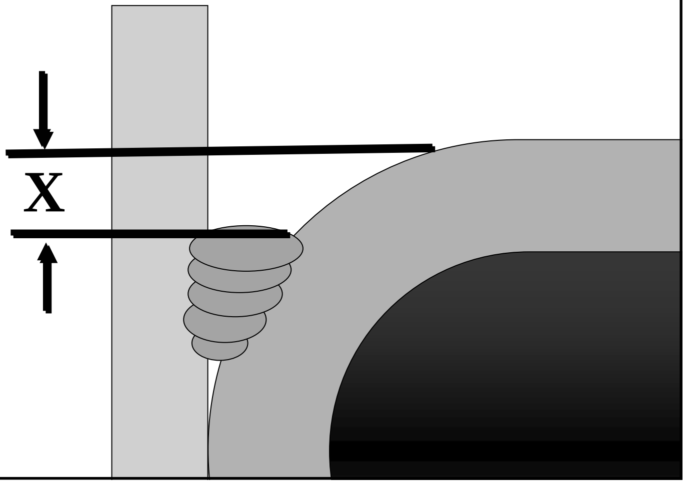
Groove Weld Types:

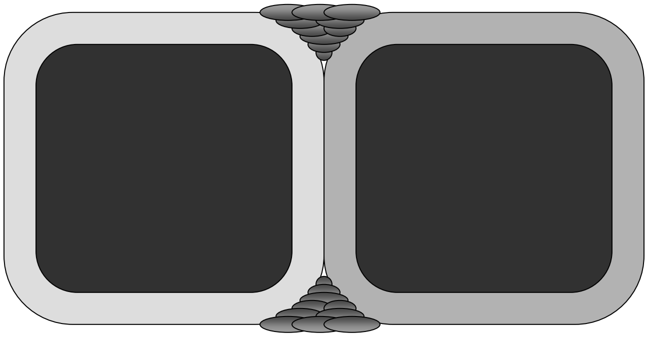
Flare Bevel Groove

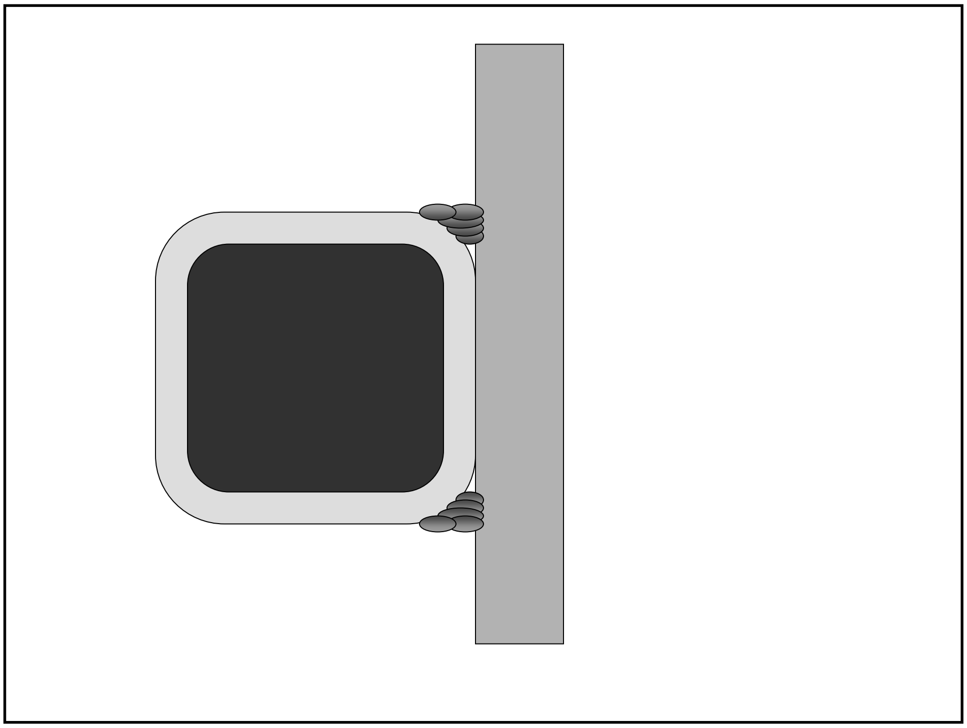


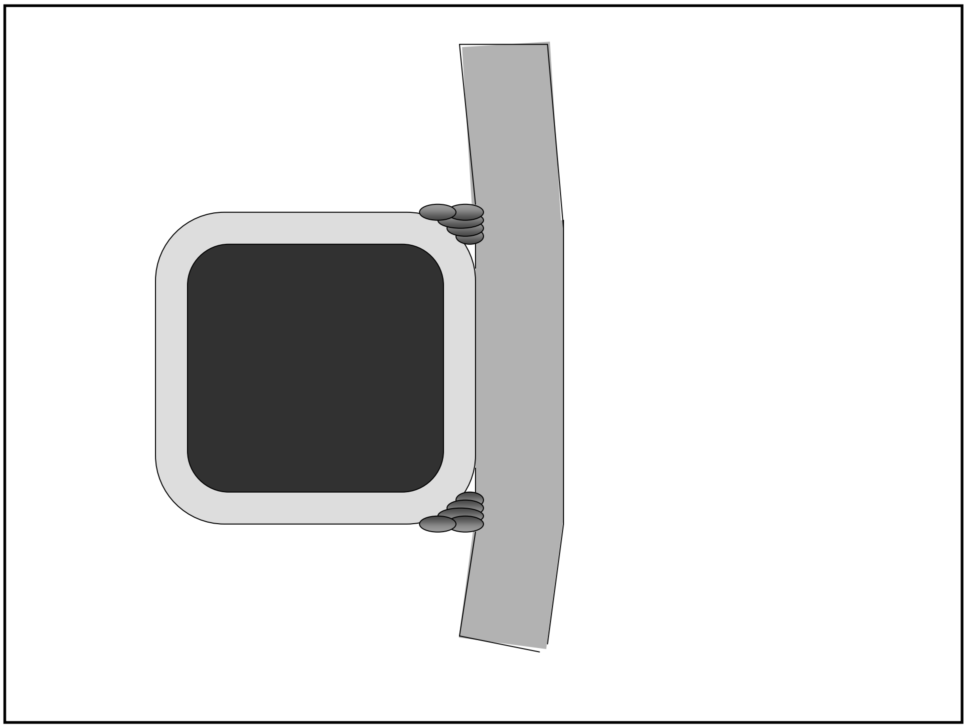
Groove Weld Types:

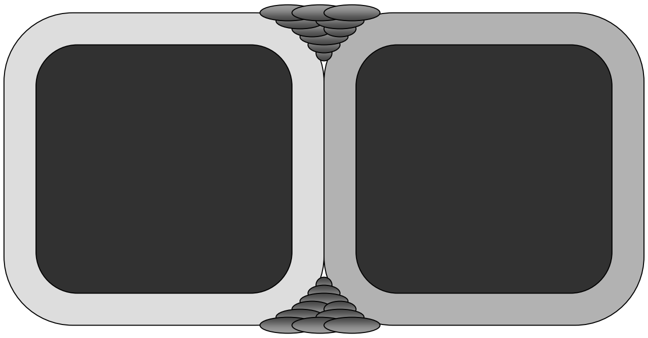
Flare Bevel Groove

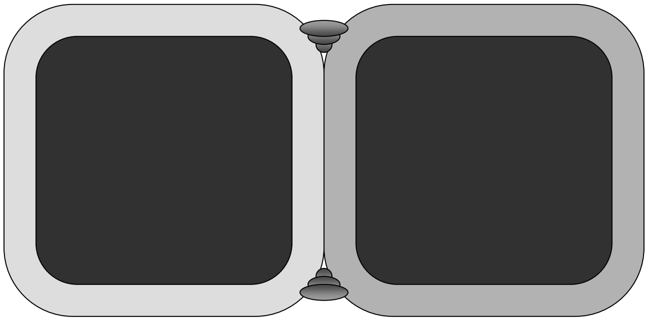












AISC LRFD Table J2.2 (old)

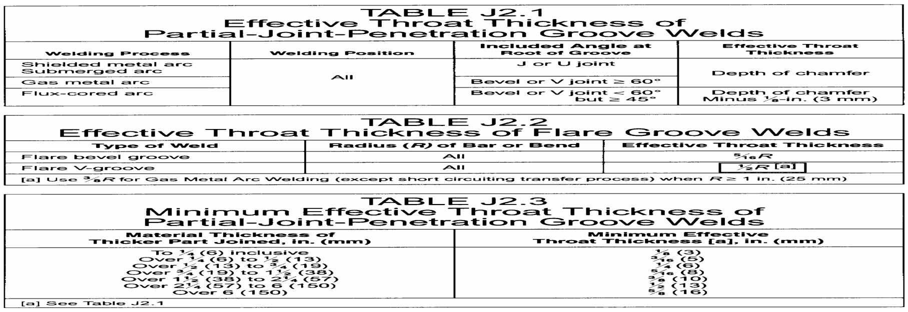


TABLE J2.1
Effective Throat Thickness of
Partial-Joint-Penetration Groove Welds

Welding Process	Welding Position	Included Angle at Root of Groove	Effective Throat Thickness
Shielded metal arc Submerged arc	All	J or U joint	Depth of chamfer
Gas metal arc		Bevel or V joint ≥ 60°	
Flux-cored arc		Bevel or V joint < 60° but ≥ 45°	Depth of chamfer Minus ⅛-in. (3 mm)

TABLE J2.2
Effective Throat Thickness of Flare Groove Welds

Type of Weld	Radius (*R*) of Bar or Bend	Effective Throat Thickness
Flare bevel groove	All	5/16 *R*
Flare V-groove	All	½ *R* [a]

[a] Use ⅜*R* for Gas Metal Arc Welding (except short circuiting transfer process) when *R* ≥ 1 in. (25 mm)

TABLE J2.3
Minimum Effective Throat Thickness of
Partial-Joint-Penetration Groove Welds

Material Thickness of Thicker Part Joined, in. (mm)	Minimum Effective Throat Thickness [a], in. (mm)
To ¼ (6) inclusive	⅛ (3)
Over ¼ (6) to ½ (13)	3/16 (5)
Over ½ (13) to ¾ (19)	¼ (6)
Over ¾ (19) to 1½ (38)	5/16 (8)
Over 1½ (38) to 2¼ (57)	⅜ (10)
Over 2¼ (57) to 6 (150)	½ (13)
Over 6 (150)	⅝ (16)

[a] See Table J2.1

AISC 13th Edition Table J2.2 Effective Weld Sizes of Flare Groove Welds

Welding Process	Flare-Bevel	Flare-Vee
SMAW FCAW-S	5/16 R	5/8 R
GMAW FCAW-G	5/8 R	3/4 R
SAW	5/16 R	1/2 R

AWS D1.1:2006 Table 2.1 Effective Size of Flare-Groove Welds Filled Flush

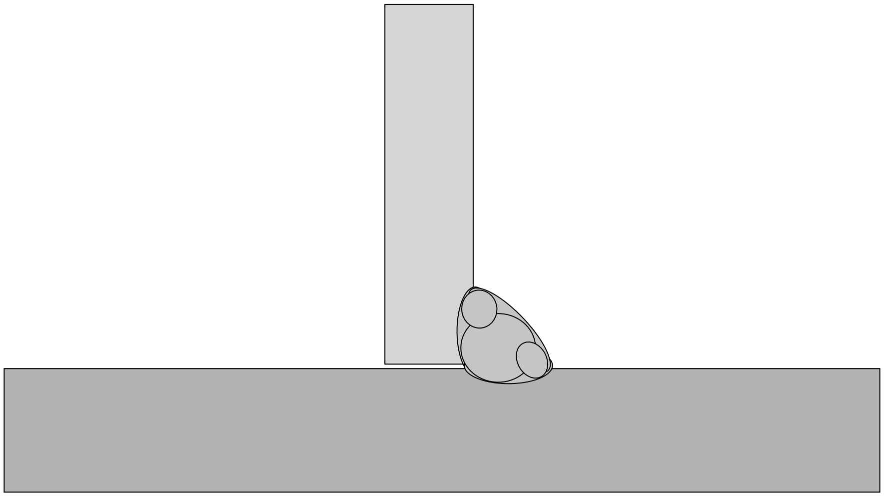
Welding Process	Flare-Bevel	Flare-Vee
SMAW FCAW-S	5/16 R	5/8 R
GMAW FCAW-G	5/8 R	3/4 R
SAW	5/16 R	1/2 R

Since R = 2 x thickness, then the throat is as follows for flare-groove welds filled flush

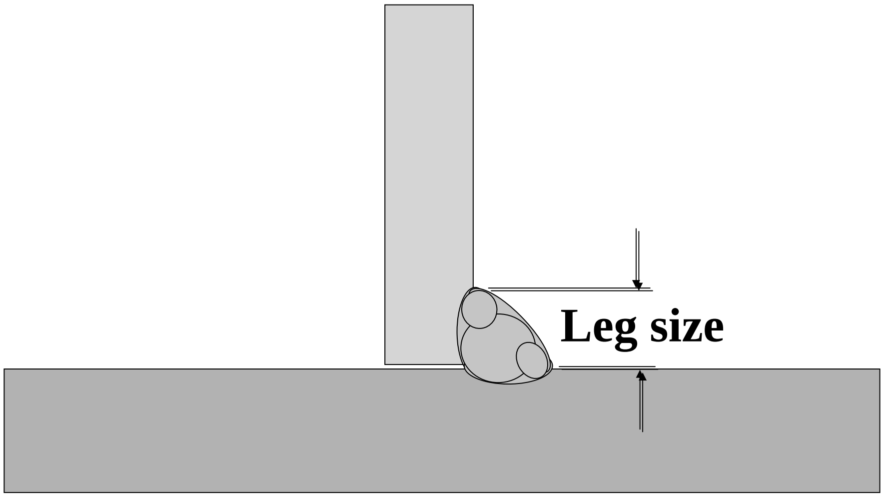
Welding Process	Flare-Bevel	Flare-Vee
SMAW FCAW-S	5/8 t	5/4 t
GMAW FCAW-G	5/4 t	3/2 t
SAW	5/8 t	1/1 t

FILLET WELDS

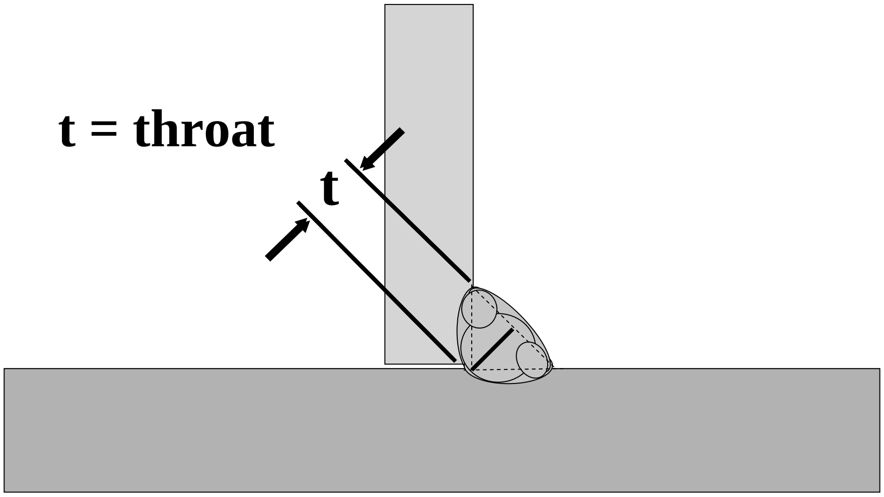
Fillet Weld Terminology



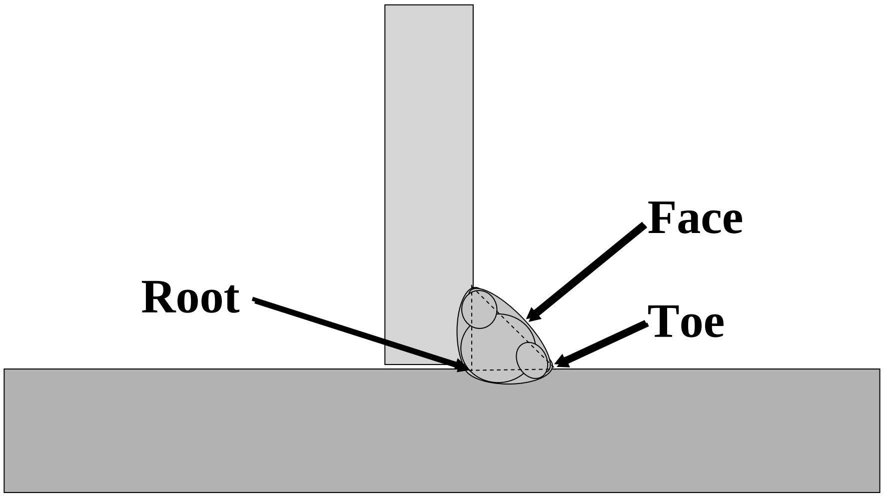
Fillet Weld Terminology



Fillet Weld Terminology

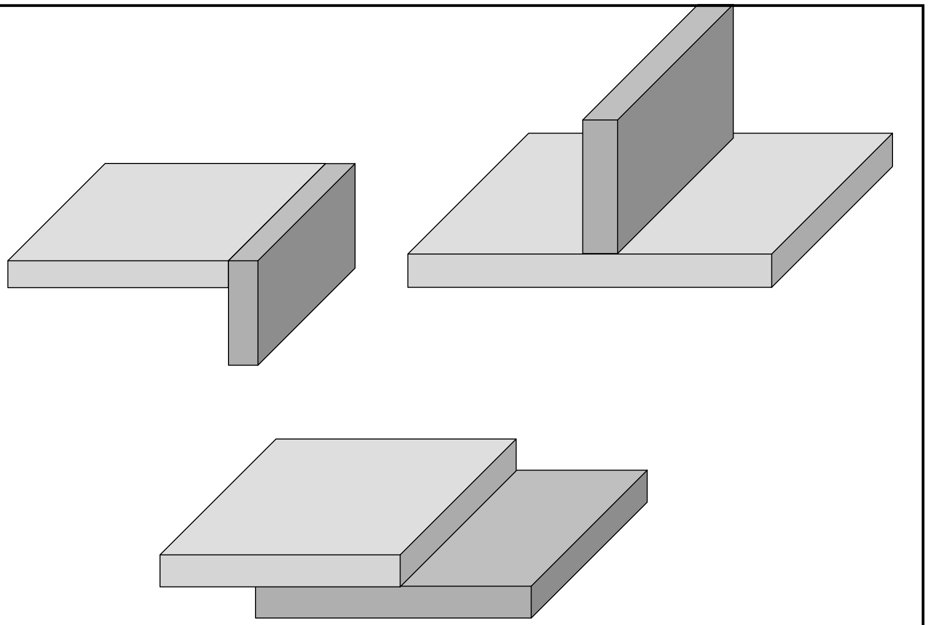

t = throat

Fillet Weld Terminology



FILLET WELDS

- Applied to tee, corner, lap joints



FILLET WELDS

- Applied to tee, corner, lap joints
- Specify throat (leg) dimension
- Specify length
- May use matching, undermatching weld metal

MINIMUM FILLET WELD SIZES

MINIMUM FILLET WELD SIZES

- Has nothing to do with design
- Concern is for practicality and welding heat input/cracking resistance
- Is often the controlling factor for welds subject to shear

AISC LRFD Table J2.4

AISC TABLE J2.4
Minimum Size of Fillet Welds

Material Thickness of Thinner Part Joined	**Minimum Size of Fillet Weld**
To ¼”, inclusive	1/8”
Over ¼” to ½”	3/16”
Over ½” to ¾”	1/4”
Over ¾”	5/16”

AWS Table 5.8
Minimum Fillet Weld Sizes (see 5.14)

Base-Metal Thickness (T)*		Minimum Size of Fillet Weld**	
in.	mm	in.	mm
T $\leq$ 1/4	T $\leq$ 6.4	1/8***	3
1/4 < T $\leq$ 1/2	6.4 < T $\leq$ 12.7	3/16	5
1/2 < T $\leq$ 3/4	12.7 < T $\leq$ 19.0	1/4	6
3/4 < T	19.0 < T	5/16	8

AWS D1.1:2000

Maximum Fillet Weld Size

J2.2b

The maximum size of a fillet weld of connected parts shall be:

(a) Along edges of material less than ¼ in. thick, not greater than the thickness of the material.

(b) Along edges of materials ¼ in. or more in thickness, not greater than the thickness of the material minus 1/16 in, unless the weld is especially designated on the drawings to be built out to obtain full-throat thickness.

Maximum Fillet Size

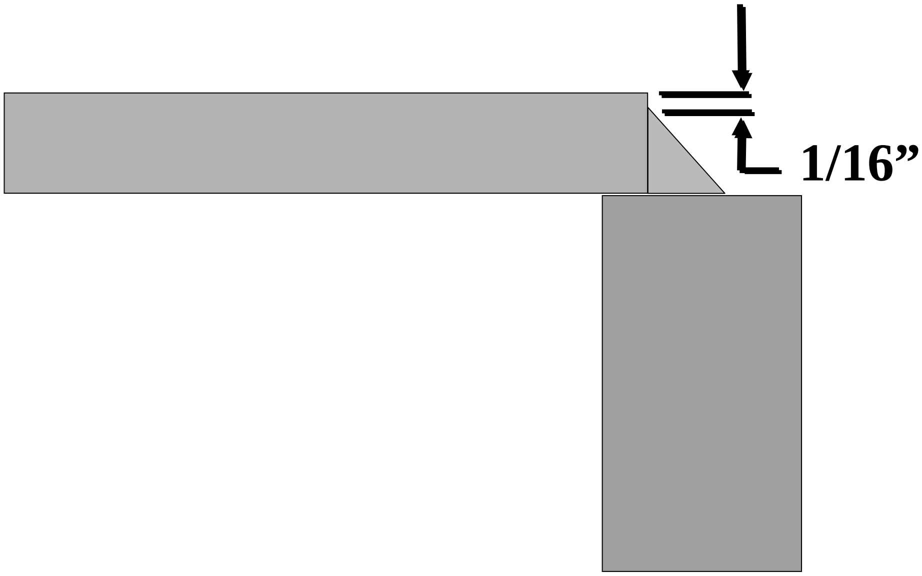
Maximum Fillet Size

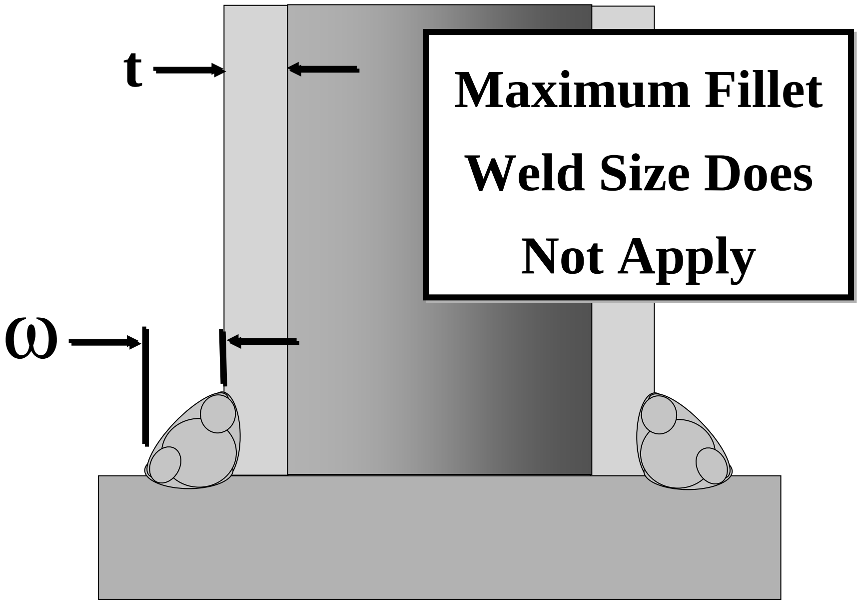
Maximum Fillet Size

Maximum Fillet Size

t ≥ 1/4”

Maximum Fillet Size





Maximum Fillet Weld Size Does Not Apply

Fig C-J2.1

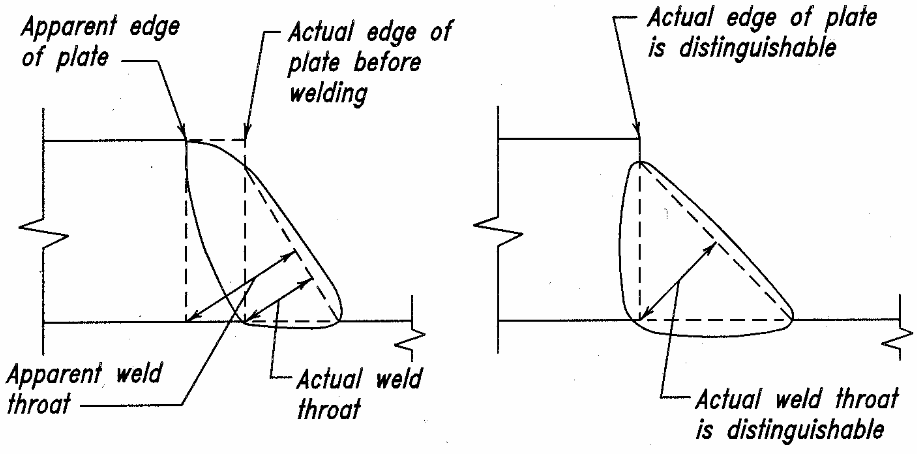
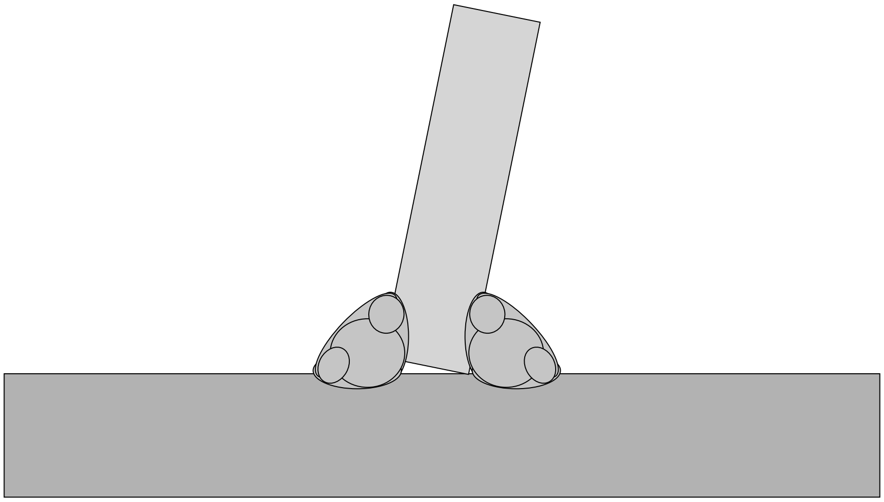
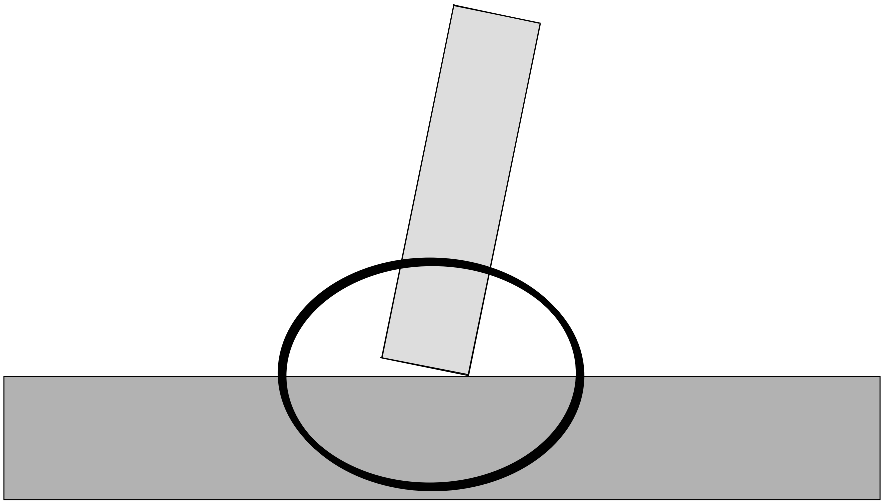


Fig. C-J2.1. Identification of plate edge.

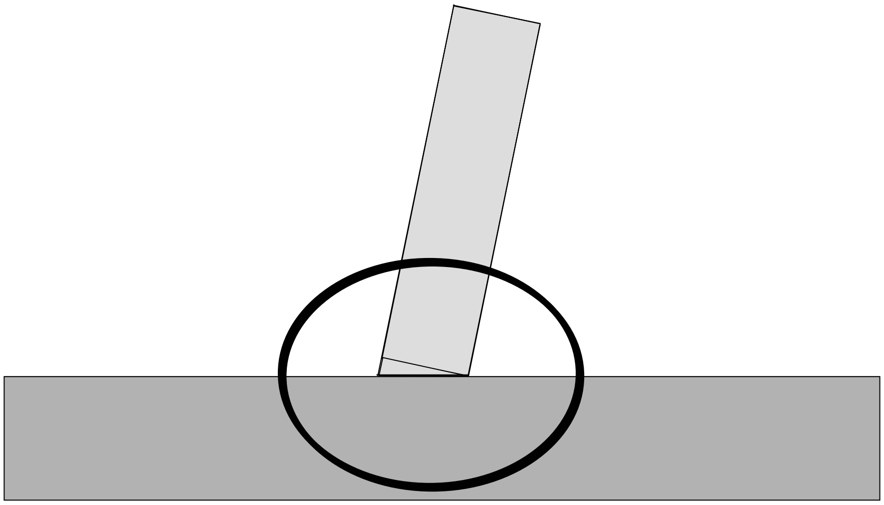
Skewed Tee Joint w/ Fillet Welds



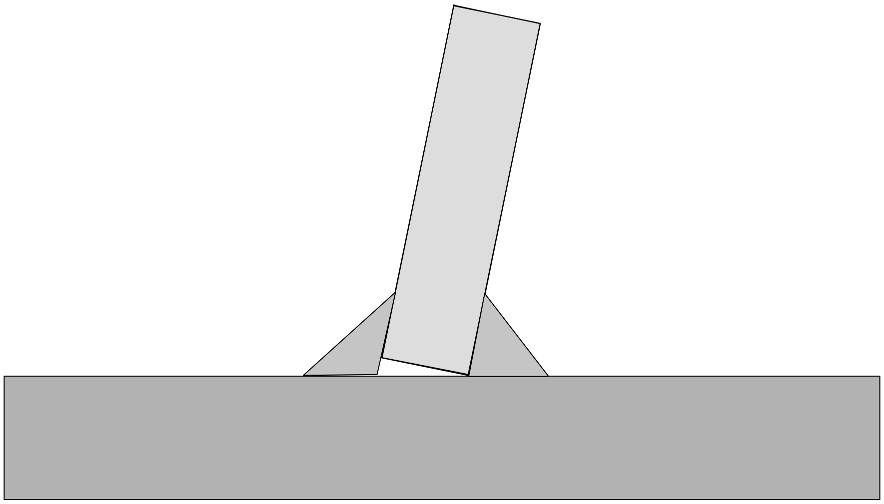
Skewed Tee Joint w/ Fillet Welds

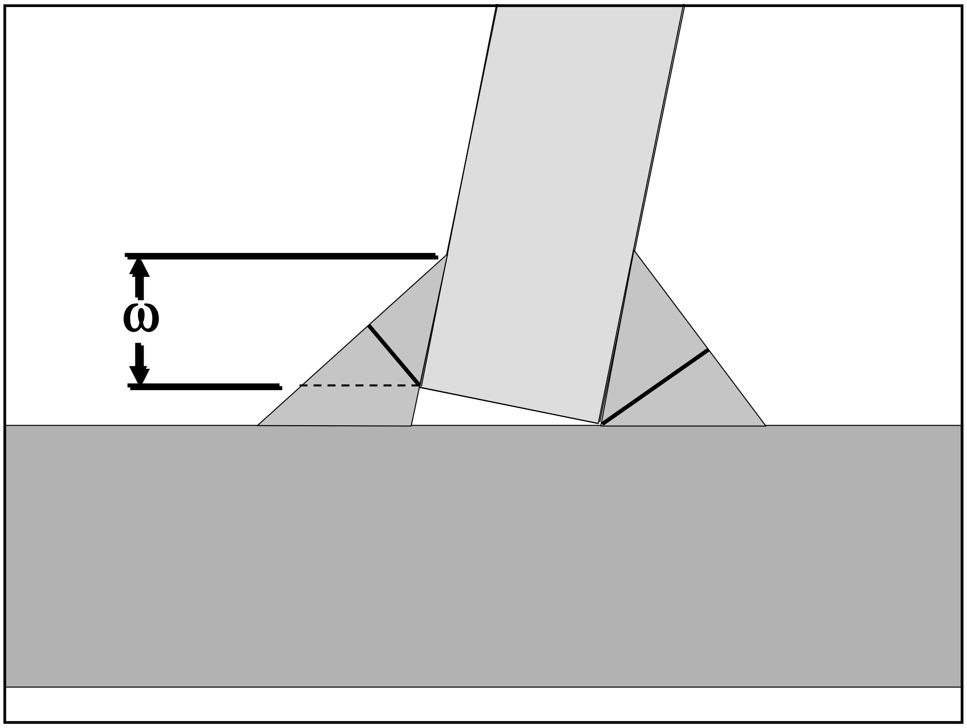


Skewed Tee Joint w/ Fillet Welds



Skewed Tee Joint w/ Fillet Welds

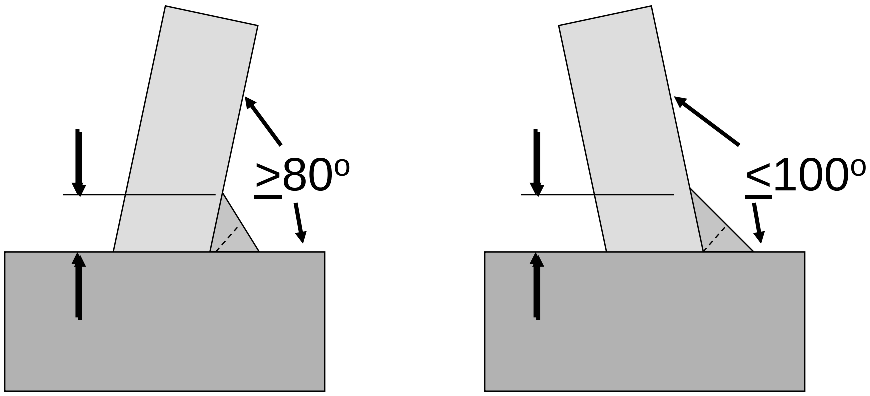




AWS D1.1 2.2.4 Weld Size and Length. (continued) For fillet welds and skewed T-joints, the following shall be provided on the contract documents.

(1) For fillet welds between parts with surfaces meeting at an angle between 80° and 100°, contract documents shall specify the fillet weld leg size.

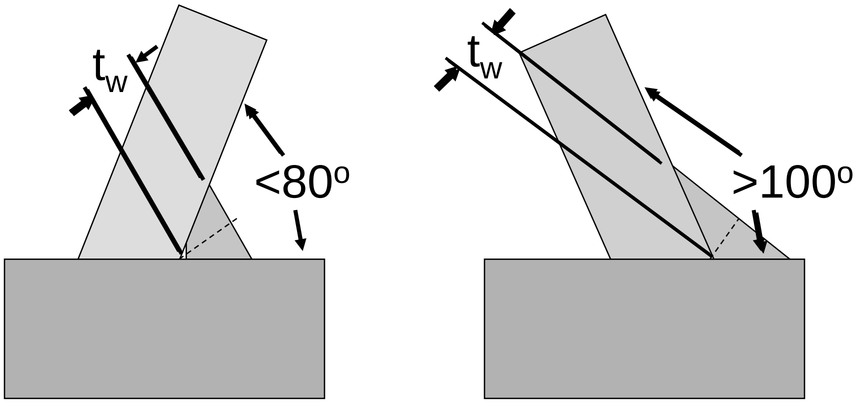
Specify fillet weld leg size within these limits



2.2.4 Weld Size and Length. (continued) For fillet welds and skewed T-joints, the following shall be provided on the contract documents.

(2) For welds between parts with the surfaces meeting at an angle less than 80° or greater than 100°, the contract documents shall specify the effective throat.

Specify fillet weld throat size within these limits



Fillet Weld Terminations

AISC J2.2b

AWS D1.1 2.8.3

AWS D1.1 2.2.4 Weld Size and Length. (continued)

End returns and hold-backs for fillet welds, if required by design, shall be indicated on the contract documents.

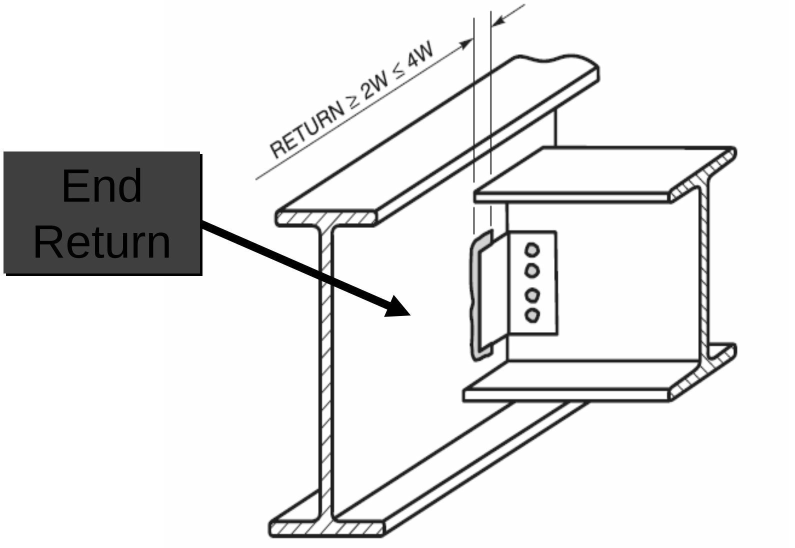
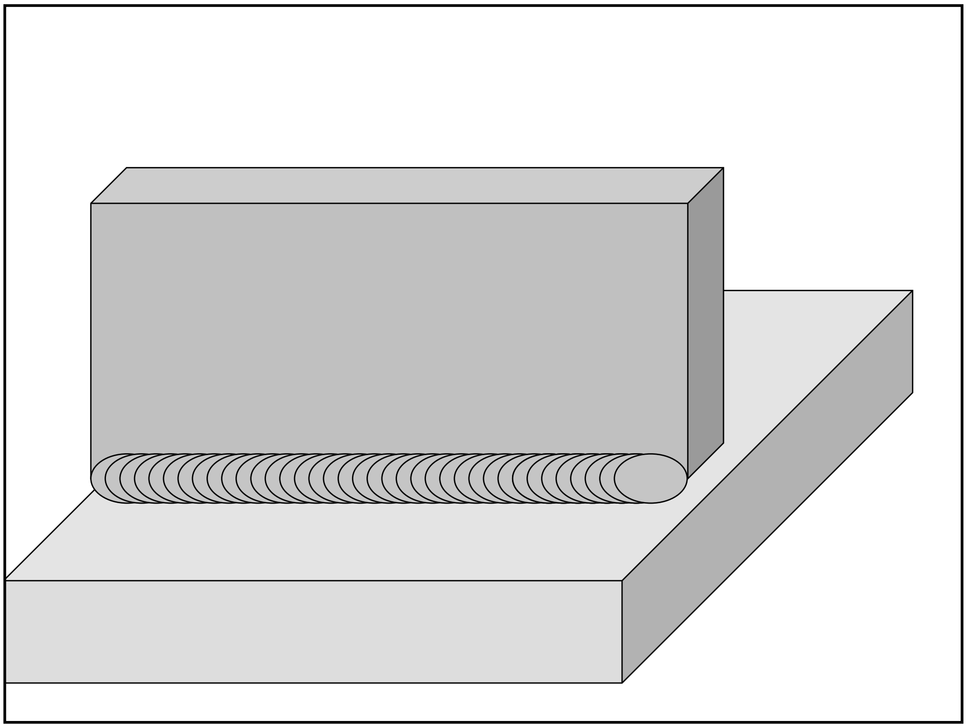


Figure 2.7—End Return at Flexible Connections (see 2.8.3.3)

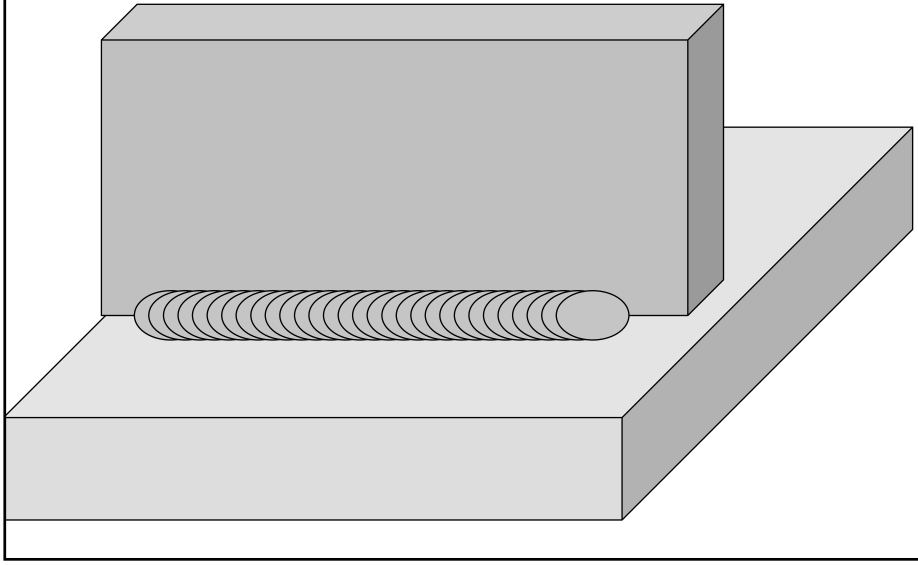
2.8.3 Fillet Weld Terminations

2.8.3.1 General. Fillet weld terminations may extend to the ends or sides of parts or may be stopped short or may have end returns except as limited by the following cases:



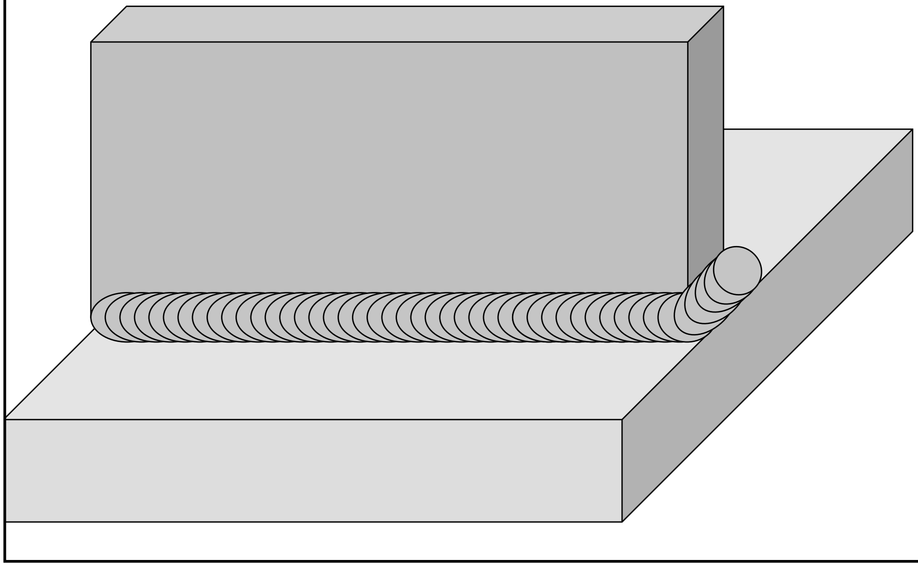
2.8.3 Fillet Weld Terminations

2.8.3.1 General. Fillet weld terminations may extend to the ends or sides of parts or may be stopped short or may have end returns except as limited by the following cases:



2.8.3 Fillet Weld Terminations

2.8.3.1 General. Fillet weld terminations may extend to the ends or sides of parts or may be stopped short or may have end returns except as limited by the following cases:



2.8.3 Fillet Weld Terminations

2.8.3.1 General. Fillet weld terminations may extend to the ends or sides of parts or may be stopped short or may have end returns except as limited by the following cases:

2.8.3.2 Lap Joints Subject to Tension.

In lap joints in which one part extends beyond the edge or side of a part subject to calculated tensile stress, fillet welds shall terminate not less than the size of the weld from the start of the extension (see Figure 2.6).

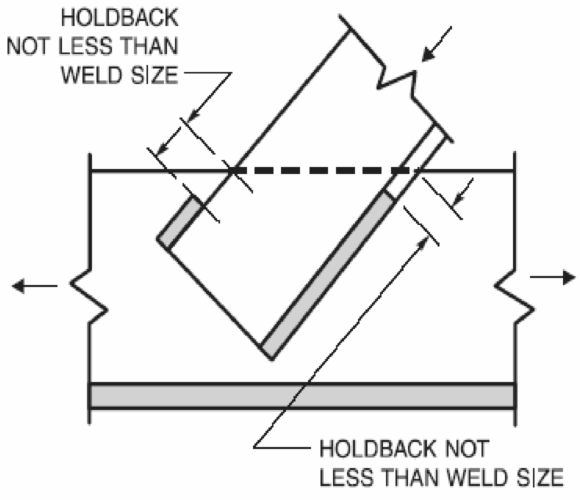


Figure 2.6—Termination of Welds Near Edges Subject to Tension (see 2.8.3.2)

2.8.3.3 Maximum End Return Length. Welded joints shall be arranged to allow the flexibility assumed in the connection design. If the outstanding legs of connection base metal are attached with end returned welds, the length of the end return shall not exceed four times the nominal size of the weld (see Figure 2.7 for examples of flexible connections).

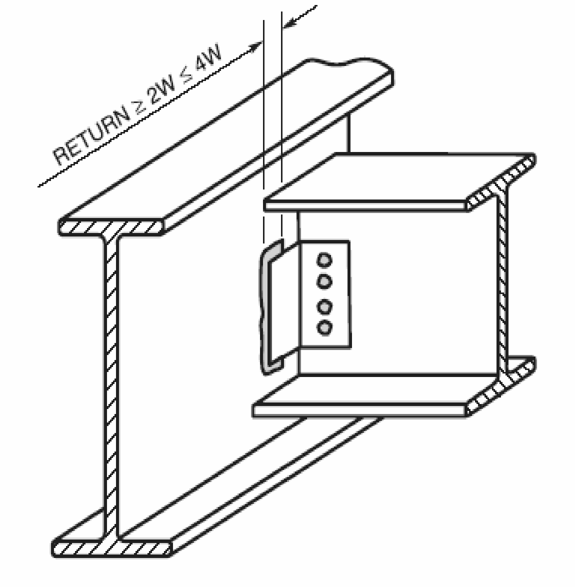
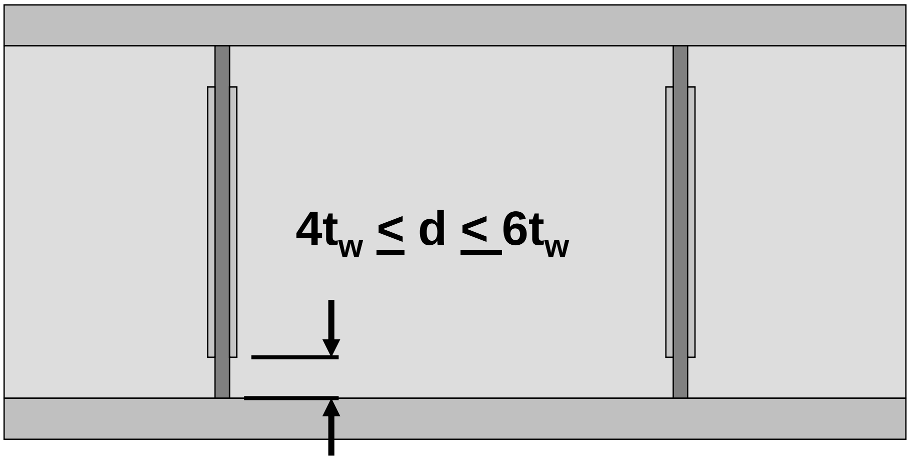


Figure 2.7—End Return at Flexible Connections (see 2.8.3.3)

2.8.3.4 Transverse Stiffener Welds.

Except where the ends of stiffeners are welded to the flange, fillet welds joining transverse stiffeners to girder webs shall start or terminate not less than four times nor more than six times the thickness of the web from the web toe of the web-to-flange welds.



2.8.3.5 Opposite Sides of a Common Plane.

Fillet welds on the opposite sides of a common plane shall be interrupted at the corner common to both welds (see Figure 2.8).

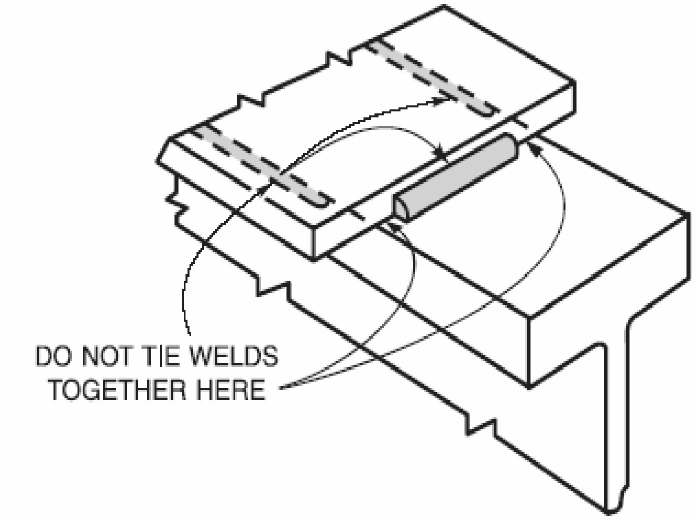
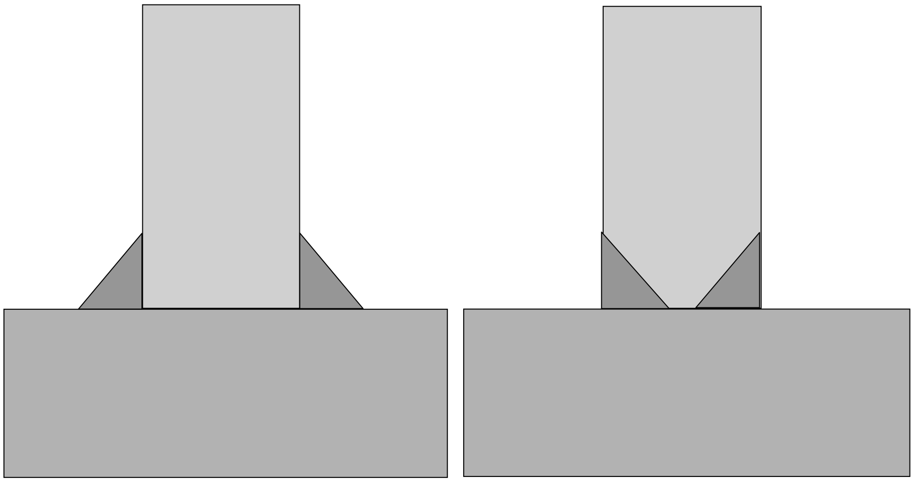


Figure 2.8—Fillet Welds on Opposite Sides of a Common Plane (see 2.8.3.5)

Fillet vs. PJP Groove Weld

- Both used in corner, tee joints

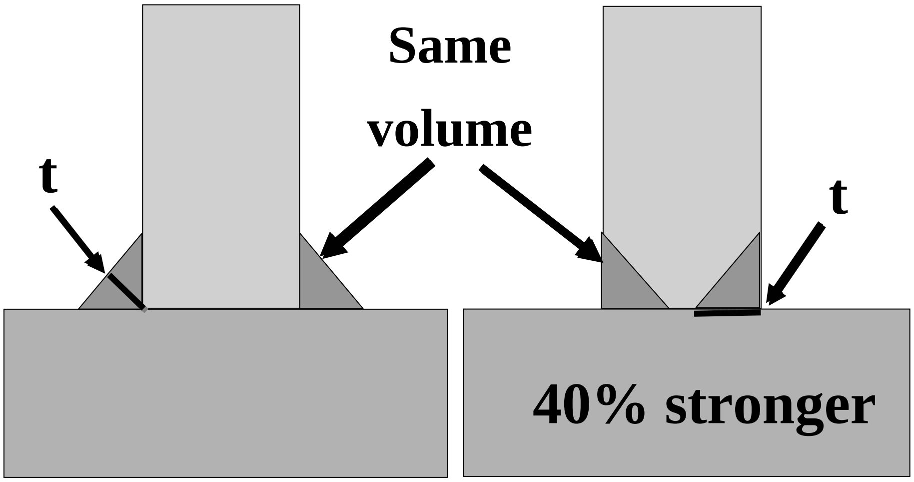
Fillet versus PJP Groove Welds



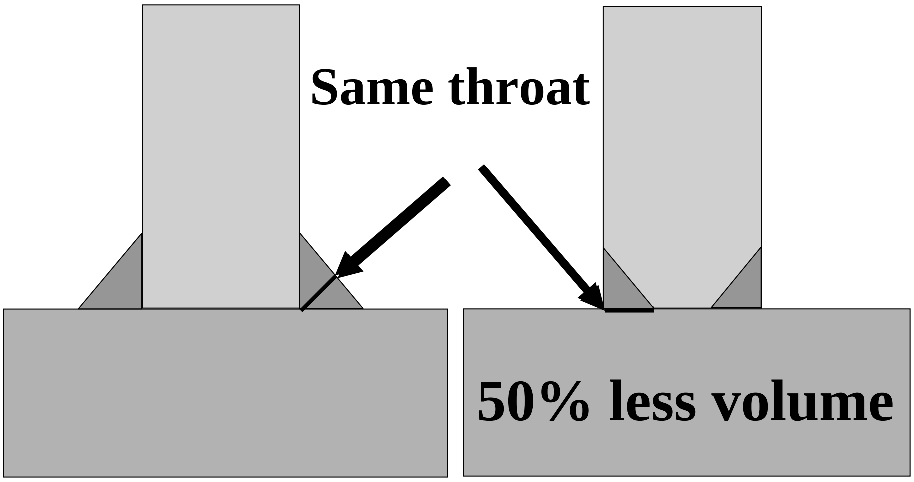
Fillet vs. PJP Groove Weld

- Both used in corner, tee joints
- PJPs more "efficient" in use of weld metal

Fillet versus PJP Groove Welds



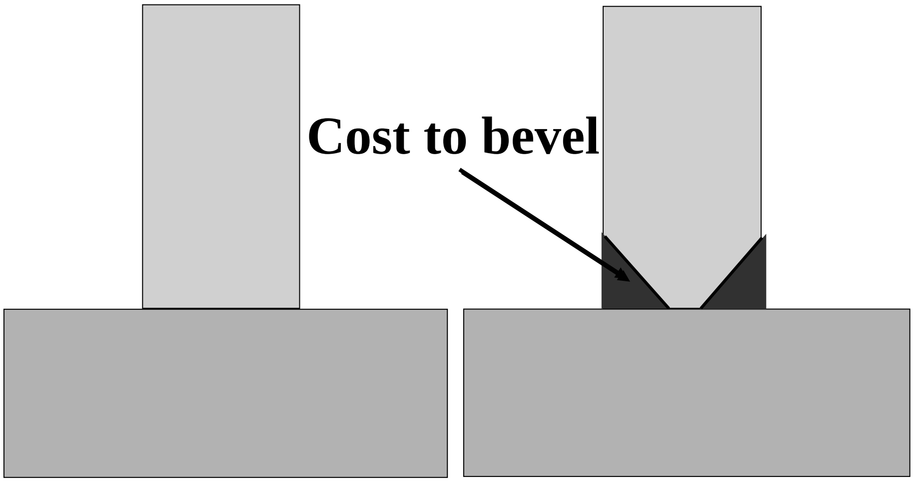
Fillet versus PJP Groove Welds



Same throat

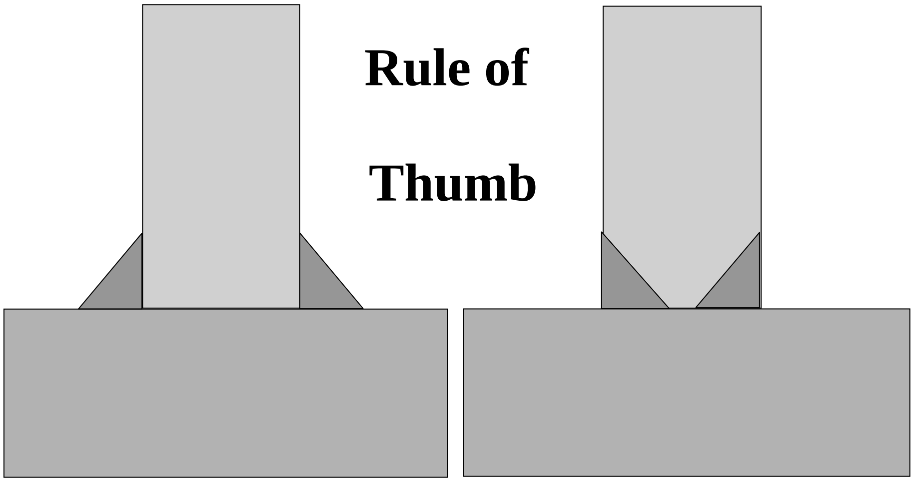
50% less volume

Fillet versus PJP Groove Welds



Cost to bevel

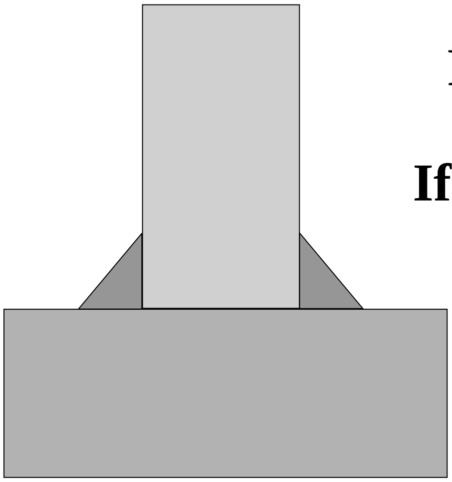
Fillet versus PJP Groove Welds



Rule of

Thumb

Fillet versus PJP Groove Welds



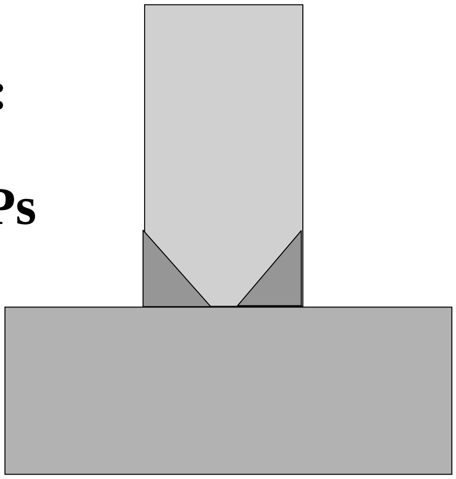
Rule of Thumb:

If t<3/4”, use fillets

Fillet versus PJP Groove Welds

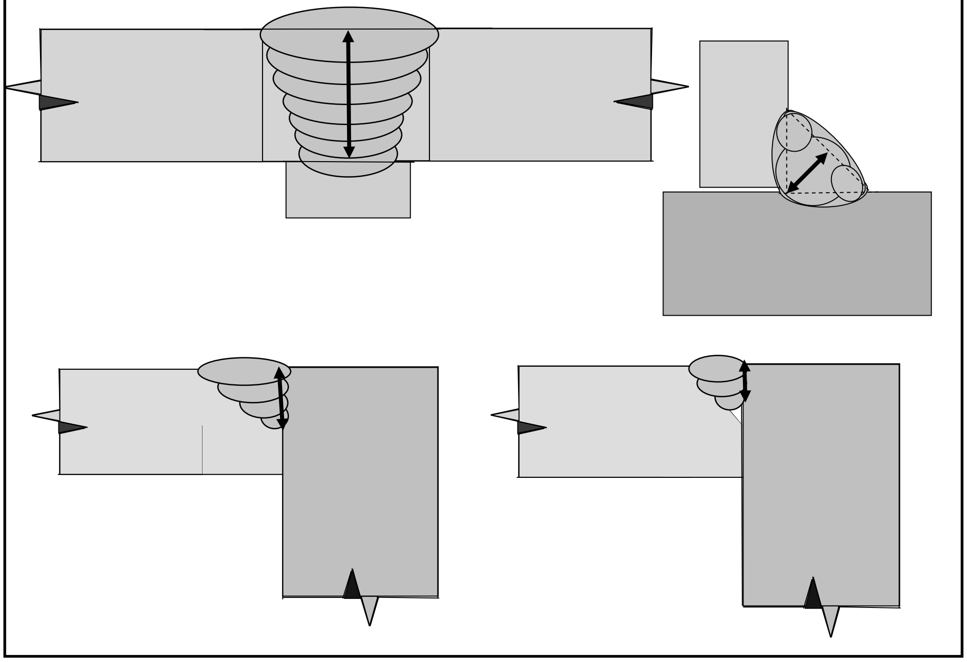
Rule of Thumb:

If t>3/4”, use PJPs

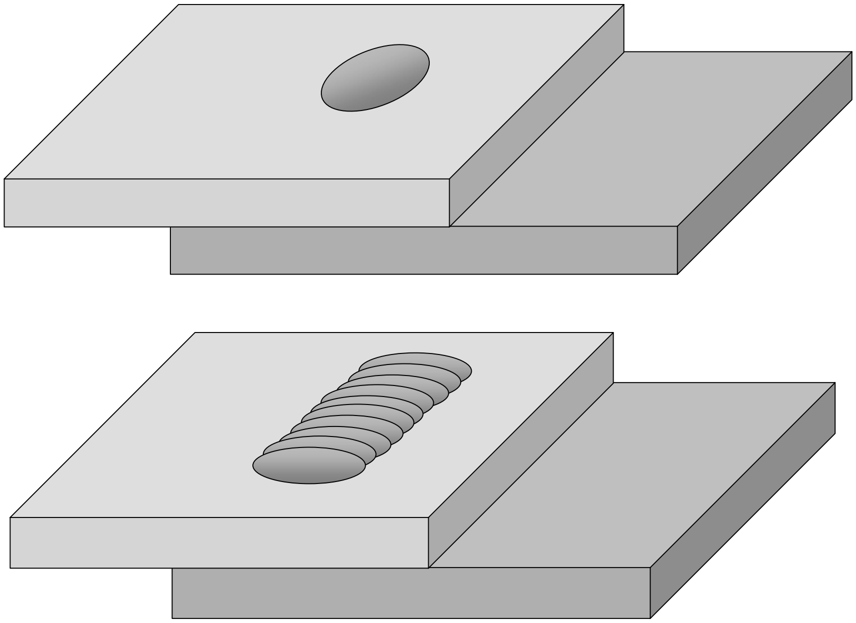


Fillet vs. PJP Groove Weld

- **Both used in corner, tee joints**
- **PJPs more “efficient” in use of weld metal**
- **Fillets don’t require joint prep**

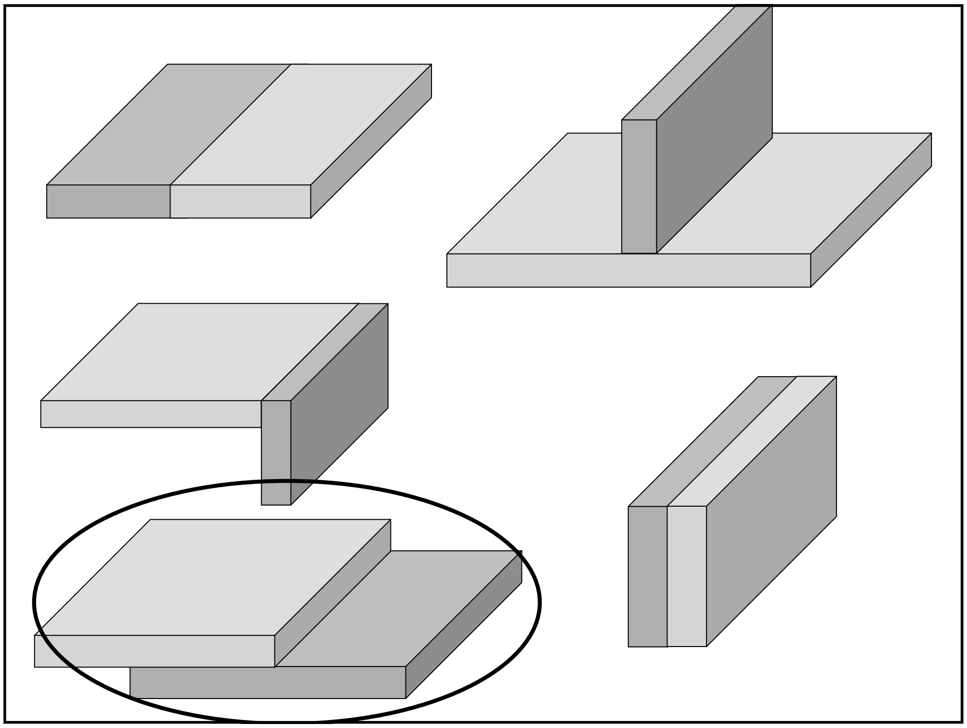


Plug and Slot Welds



Plug and Slot Welds

- **Applied to lap joints**



Plug and Slot Welds

- Applied to lap joints
- Not often applied in structures
- Restricted in dynamically loaded structures
- Not a good substitution for misplaced bolt holes

Weld Metal Strength

- Matching
- Undermatching
- Overmatching

MATCHING STRENGTH

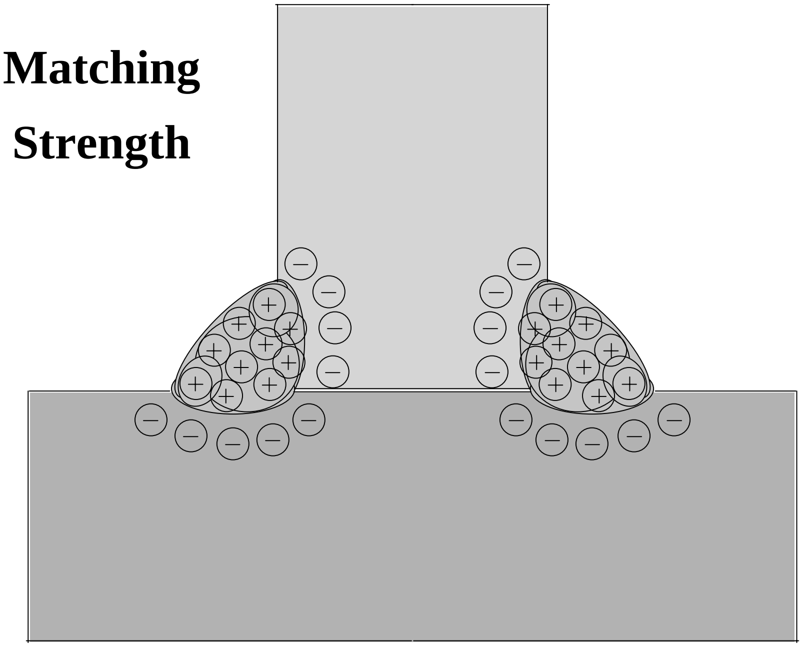
- Only require for CJP in tension
- OK for all welds
- Usually used for groove welds
- Compares minimum specified values
- Fy/Fu ratios = different

UNDERMATCHING STRENGTH

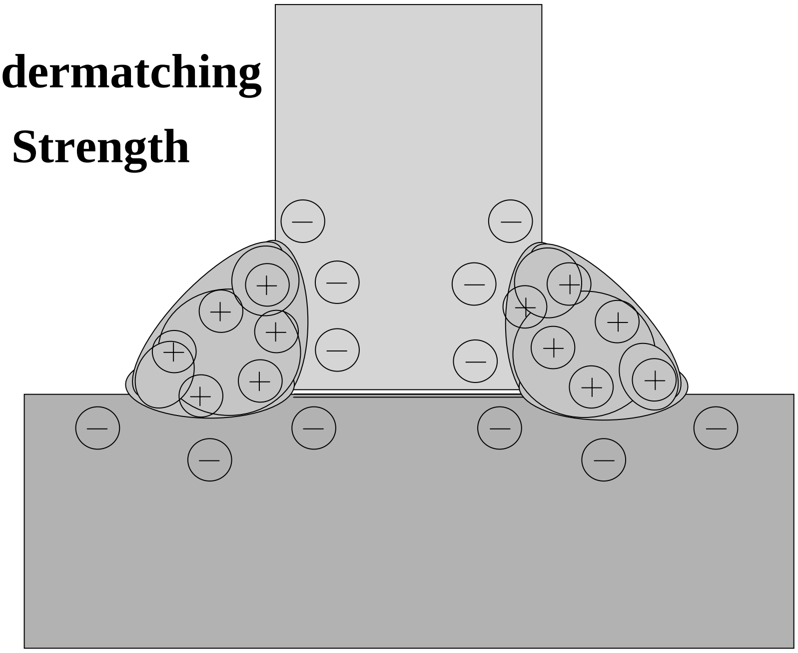
- Typical application is fillets, PJPs on higher strength steel
- "Optimized Weld Metal"
- More crack resistant
- Weld size often controlled by minimum size

Matching

Strength

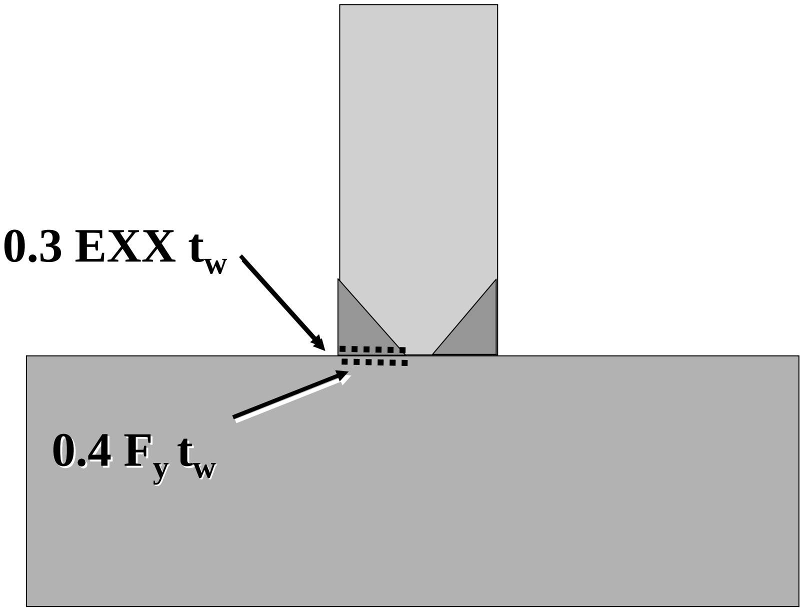


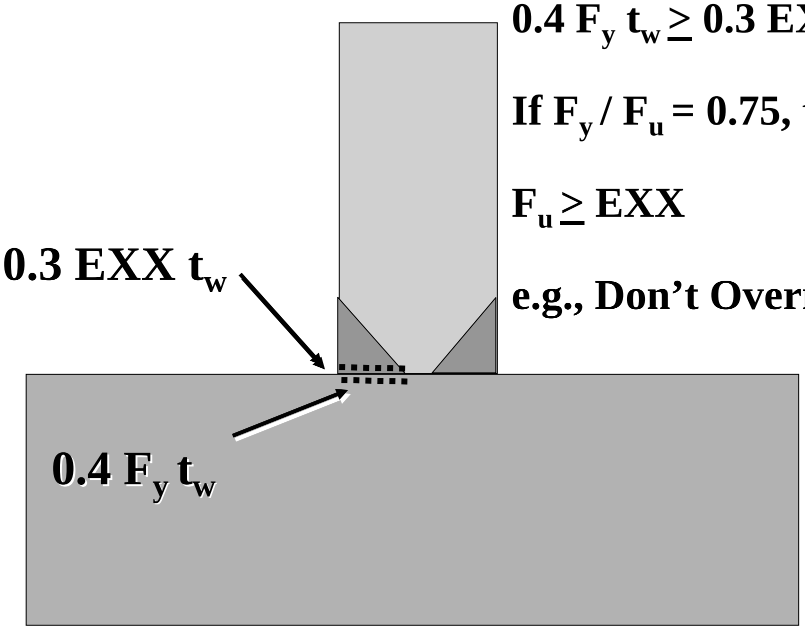
Undermatching Strength



OVERMATCHING STRENGTH

- Never required in D1.1, AISC
- Naturally occurs with lower strength steels, alloy electrodes
- If deliberately considered in design, may be non-conservative





0.4 F_y $t_w \geq$ 0.3 EXX t_w

If F_y / F_u = 0.75, then

$F_u \geq$ EXX

e.g., Don’t Overmatch

Table J2.5

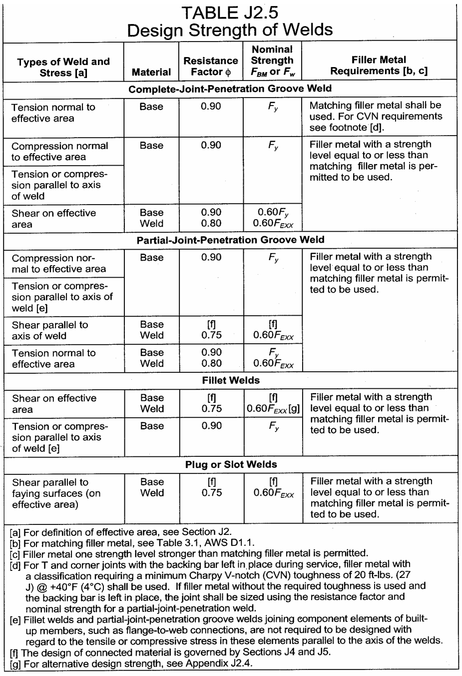


TABLE J2.5
Design Strength of Welds

Types of Weld and Stress [a]	Material	Resistance Factor φ	Nominal Strength F_{BM} or F_w	Filler Metal Requirements [b, c]
Complete-Joint-Penetration Groove Weld				
Tension normal to effective area	Base	0.90	F_y	Matching filler metal shall be used. For CVN requirements see footnote [d].
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld				
Shear on effective area	Base Weld	0.90 0.80	$0.60F_y$ $0.60F_{EXX}$	
Partial-Joint-Penetration Groove Weld				
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]				
Shear parallel to axis of weld	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	
Tension normal to effective area	Base Weld	0.90 0.80	F_y $0.60F_{EXX}$	
Fillet Welds				
Shear on effective area	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$ [g]	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]	Base	0.90	F_y	
Plug or Slot Welds				
Shear parallel to faying surfaces (on effective area)	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.

[a] For definition of effective area, see Section J2.
[b] For matching filler metal, see Table 3.1, AWS D1.1.
[c] Filler metal one strength level stronger than matching filler metal is permitted.
[d] For T and corner joints with the backing bar left in place during service, filler metal with a classification requiring a minimum Charpy V-notch (CVN) toughness of 20 ft-lbs. (27 J) @ +40°F (4°C) shall be used. If filler metal without the required toughness is used and the backing bar is left in place, the joint shall be sized using the resistance factor and nominal strength for a partial-joint-penetration weld.
[e] Fillet welds and partial-joint-penetration groove welds joining component elements of built-up members, such as flange-to-web connections, are not required to be designed with regard to the tensile or compressive stress in these elements parallel to the axis of the welds.
[f] The design of connected material is governed by Sections J4 and J5.
[g] For alternative design strength, see Appendix J2.4.

CJP Groove Weld

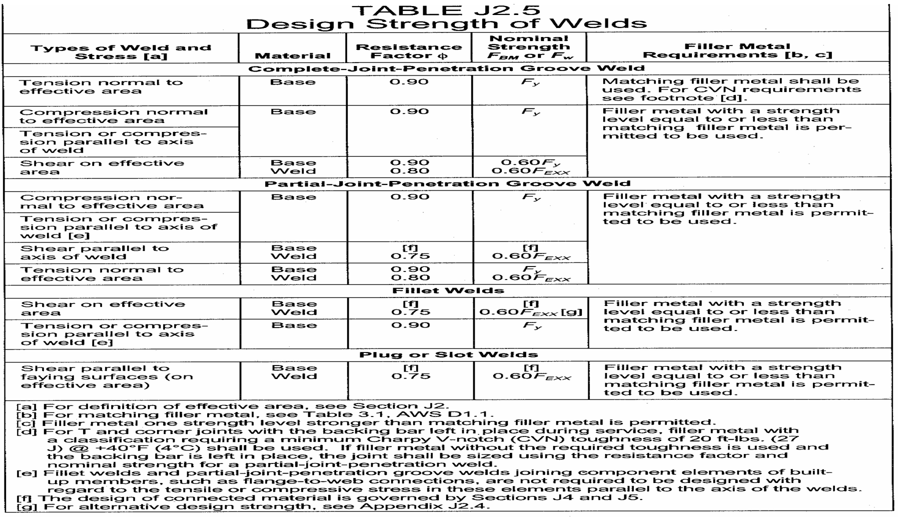
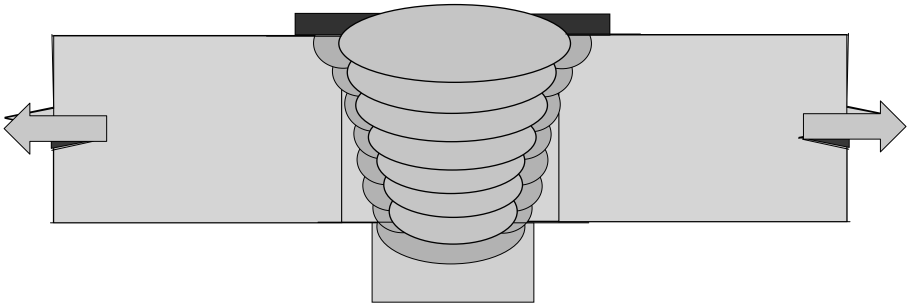


TABLE J2.5
Design Strength of Welds

Types of Weld and Stress [a]	Material	Resistance Factor φ	Nominal Strength F_{BM} or F_w	Filler Metal Requirements [b, c]
Complete-Joint-Penetration Groove Weld				
Tension normal to effective area	Base	0.90	F_y	Matching filler metal shall be used. For CVN requirements see footnote [d].
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld				
Shear on effective area	Base Weld	0.90 0.80	$0.60F_y$ $0.60F_{EXX}$	
Partial-Joint-Penetration Groove Weld				
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]				
Shear parallel to axis of weld	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	
Tension normal to effective area	Base Weld	0.90 0.80	F_y $0.60F_{EXX}$	
Fillet Welds				
Shear on effective area	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$ [g]	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]	Base	0.90	F_y	
Plug or Slot Welds				
Shear parallel to faying surfaces (on effective area)	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.

[a] For definition of effective area, see Section J2.
[b] For matching filler metal, see Table 3.1, AWS D1.1.
[c] Filler metal one strength level stronger than matching filler metal is permitted.
[d] For T and corner joints with the backing bar left in place during service, filler metal with a classification requiring a minimum Charpy V-notch (CVN) toughness of 20 ft-lbs. (27 J) @ +40°F (4°C) shall be used. If filler metal without the required toughness is used and the backing bar is left in place, the joint shall be sized using the resistance factor and nominal strength for a partial-joint-penetration weld.
[e] Fillet welds and partial-joint-penetration groove welds joining component elements of built-up members, such as flange-to-web connections, are not required to be designed with regard to the tensile or compressive stress in these elements parallel to the axis of the welds.
[f] The design of connected material is governed by Sections J4 and J5.
[g] For alternative design strength, see Appendix J2.4.

CJP Groove Weld in Tension



CJP Groove Weld

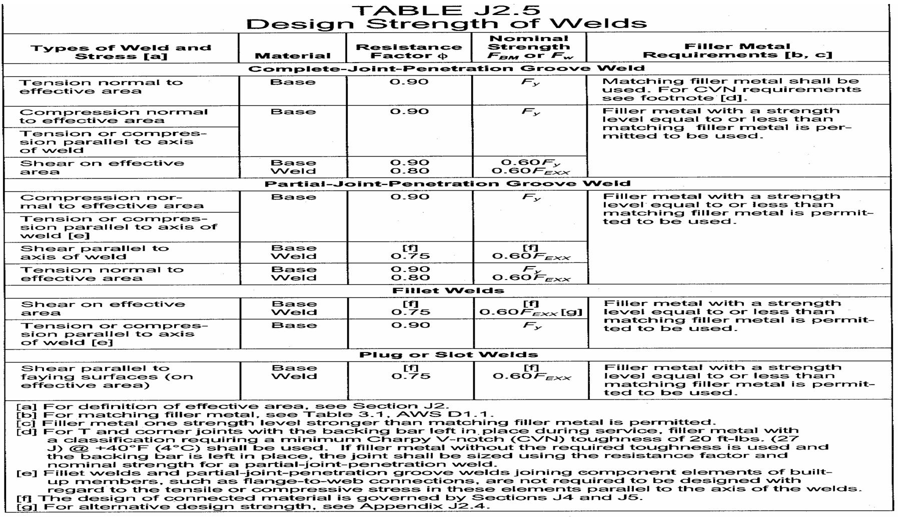
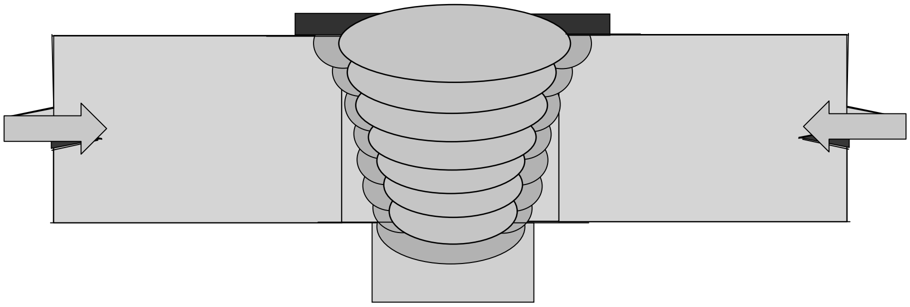


TABLE J2.5
Design Strength of Welds

Types of Weld and Stress [a]	Material	Resistance Factor ϕ	Nominal Strength F_{BM} or F_w	Filler Metal Requirements [b, c]
Complete-Joint-Penetration Groove Weld				
Tension normal to effective area	Base	0.90	F_y	Matching filler metal shall be used. For CVN requirements see footnote [d].
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld				
Shear on effective area	Base Weld	0.90 0.80	$0.60F_y$ $0.60F_{EXX}$	
Partial-Joint-Penetration Groove Weld				
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]				
Shear parallel to axis of weld	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	
Tension normal to effective area	Base Weld	0.90 0.80	F_y $0.60F_{EXX}$	
Fillet Welds				
Shear on effective area	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$ [g]	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]	Base	0.90	F_y	
Plug or Slot Welds				
Shear parallel to faying surfaces (on effective area)	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.

[a] For definition of effective area, see Section J2.
[b] For matching filler metal, see Table 3.1, AWS D1.1.
[c] Filler metal one strength level stronger than matching filler metal is permitted.
[d] For T and corner joints with the backing bar left in place during service, filler metal with a classification requiring a minimum Charpy V-notch (CVN) toughness of 20 ft-lbs. (27 J) @ +40°F (4°C) shall be used. If filler metal without the required toughness is used and the backing bar is left in place, the joint shall be sized using the resistance factor and nominal strength for a partial-joint-penetration weld.
[e] Fillet welds and partial-joint-penetration groove welds joining component elements of built-up members, such as flange-to-web connections, are not required to be designed with regard to the tensile or compressive stress in these elements parallel to the axis of the welds.
[f] The design of connected material is governed by Sections J4 and J5.
[g] For alternative design strength, see Appendix J2.4.

CJP Groove Weld in Compression



CJP Groove Weld

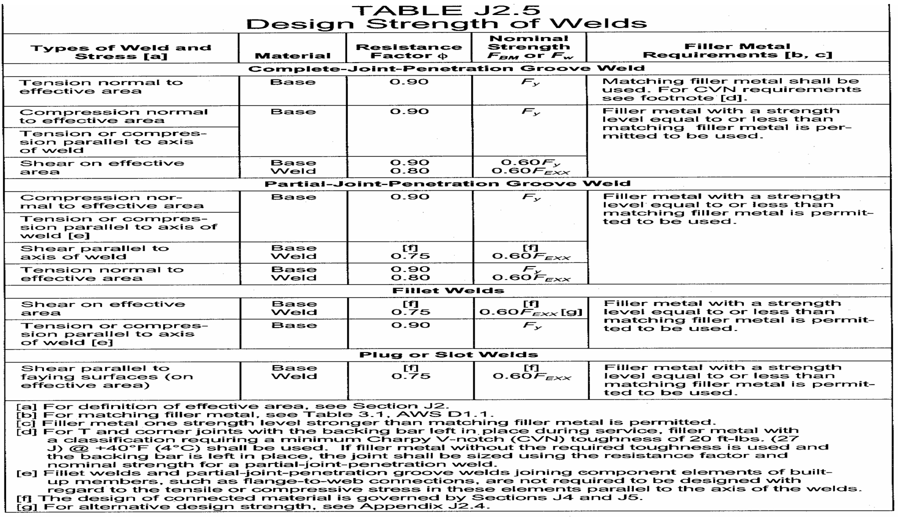
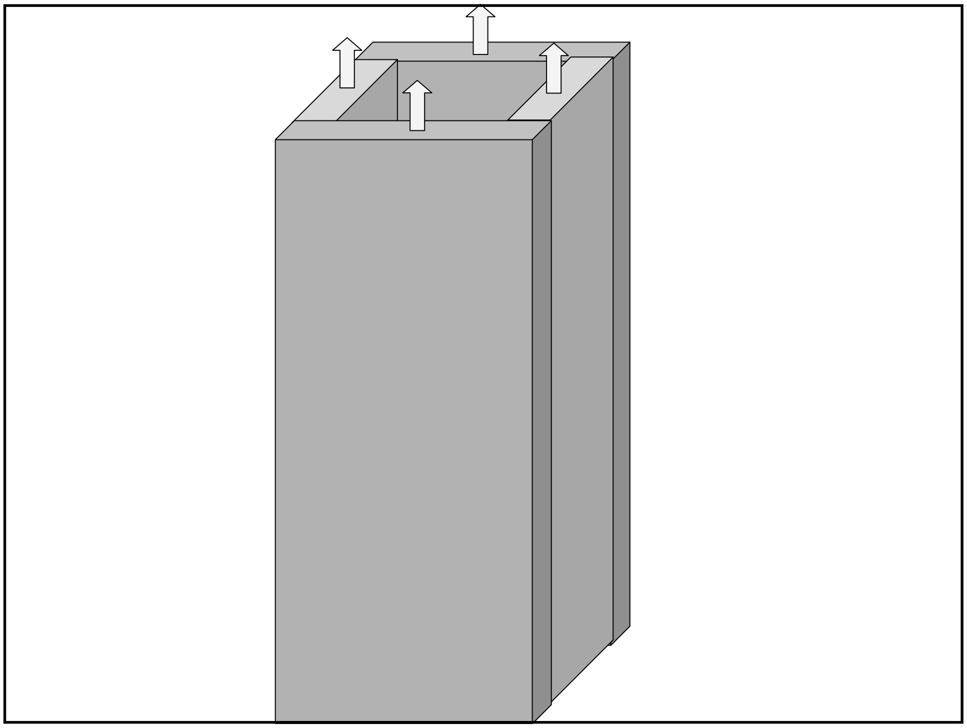
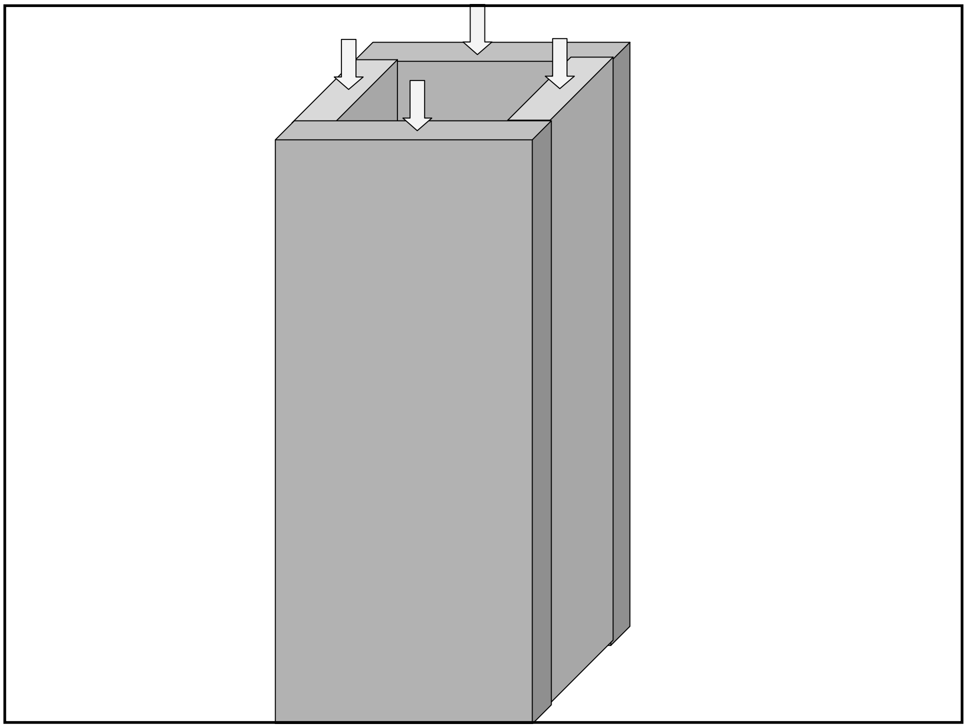


TABLE J2.5
Design Strength of Welds

Types of Weld and Stress [a]	Material	Resistance Factor ϕ	Nominal Strength F_{BM} or F_w	Filler Metal Requirements [b, c]
Complete-Joint-Penetration Groove Weld				
Tension normal to effective area	Base	0.90	F_y	Matching filler metal shall be used. For CVN requirements see footnote [d].
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld				
Shear on effective area	Base Weld	0.90 0.80	$0.60F_y$ $0.60F_{EXX}$	
Partial-Joint-Penetration Groove Weld				
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]				
Shear parallel to axis of weld	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	
Tension normal to effective area	Base Weld	0.90 0.80	F_y $0.60F_{EXX}$	
Fillet Welds				
Shear on effective area	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$ [g]	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]	Base	0.90	F_y	
Plug or Slot Welds				
Shear parallel to faying surfaces (on effective area)	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.

[a] For definition of effective area, see Section J2.
[b] For matching filler metal, see Table 3.1, AWS D1.1.
[c] Filler metal one strength level stronger than matching filler metal is permitted.
[d] For T and corner joints with the backing bar left in place during service, filler metal with a classification requiring a minimum Charpy V-notch (CVN) toughness of 20 ft-lbs. (27 J) @ +40°F (4°C) shall be used. If filler metal without the required toughness is used and the backing bar is left in place, the joint shall be sized using the resistance factor and nominal strength for a partial-joint-penetration weld.
[e] Fillet welds and partial-joint-penetration groove welds joining component elements of built-up members, such as flange-to-web connections, are not required to be designed with regard to the tensile or compressive stress in these elements parallel to the axis of the welds.
[f] The design of connected material is governed by Sections J4 and J5.
[g] For alternative design strength, see Appendix J2.4.





CJP Groove Weld

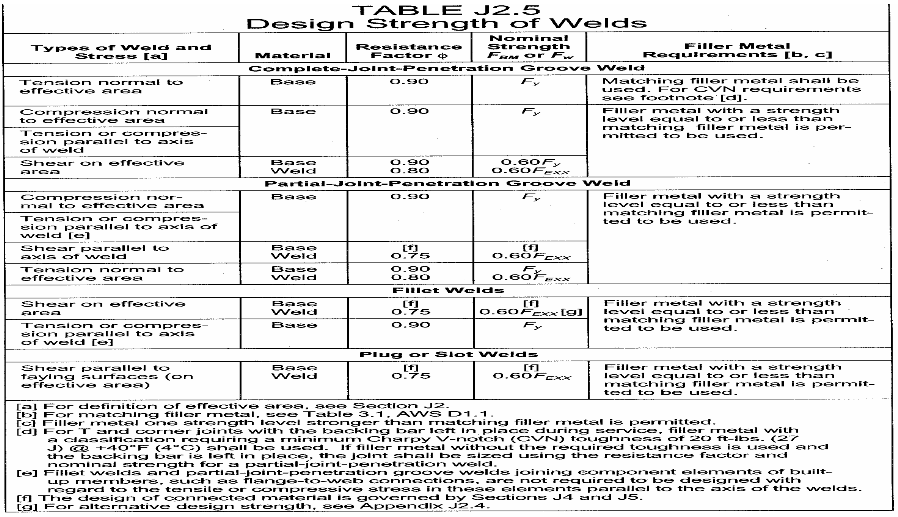
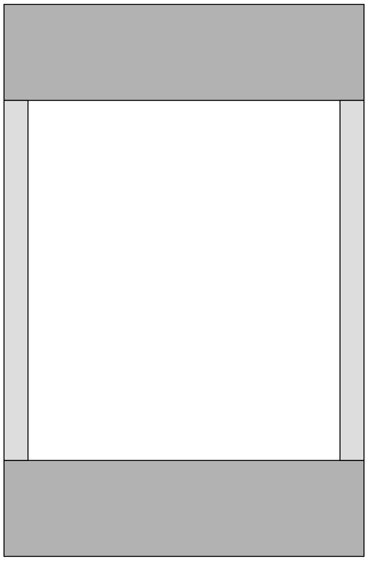
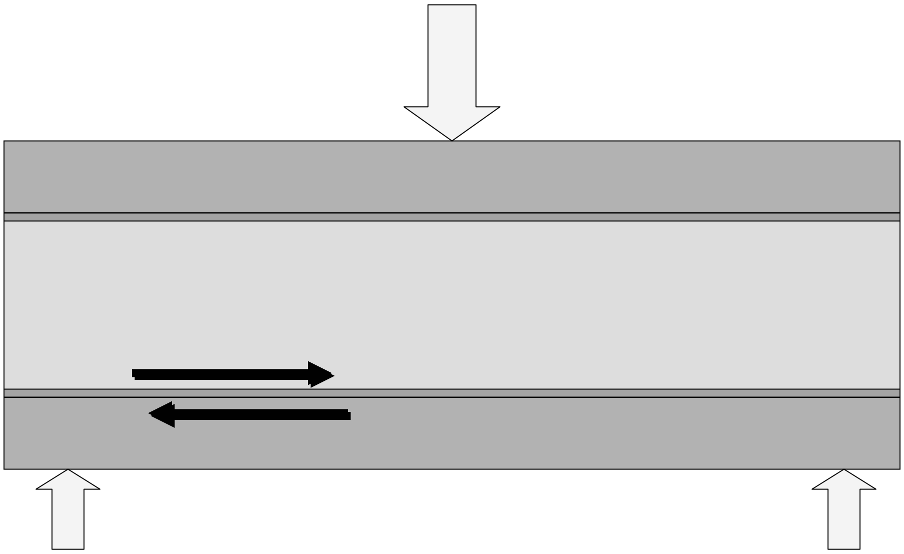


TABLE J2.5
Design Strength of Welds

Types of Weld and Stress [a]	Material	Resistance Factor ϕ	Nominal Strength F_{BM} or F_w	Filler Metal Requirements [b, c]
Complete-Joint-Penetration Groove Weld				
Tension normal to effective area	Base	0.90	F_y	Matching filler metal shall be used. For CVN requirements see footnote [d].
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld				
Shear on effective area	Base Weld	0.90 0.80	$0.60F_y$ $0.60F_{EXX}$	
Partial-Joint-Penetration Groove Weld				
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]				
Shear parallel to axis of weld	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	
Tension normal to effective area	Base Weld	0.90 0.80	F_y $0.60F_{EXX}$	
Fillet Welds				
Shear on effective area	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$ [g]	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]	Base	0.90	F_y	
Plug or Slot Welds				
Shear parallel to faying surfaces (on effective area)	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.

[a] For definition of effective area, see Section J2.
[b] For matching filler metal, see Table 3.1, AWS D1.1.
[c] Filler metal one strength level stronger than matching filler metal is permitted.
[d] For T and corner joints with the backing bar left in place during service, filler metal with a classification requiring a minimum Charpy V-notch (CVN) toughness of 20 ft-lbs. (27 J) @ +40°F (4°C) shall be used. If filler metal without the required toughness is used and the backing bar is left in place, the joint shall be sized using the resistance factor and nominal strength for a partial-joint-penetration weld.
[e] Fillet welds and partial-joint-penetration groove welds joining component elements of built-up members, such as flange-to-web connections, are not required to be designed with regard to the tensile or compressive stress in these elements parallel to the axis of the welds.
[f] The design of connected material is governed by Sections J4 and J5.
[g] For alternative design strength, see Appendix J2.4.





CJP Groove Weld

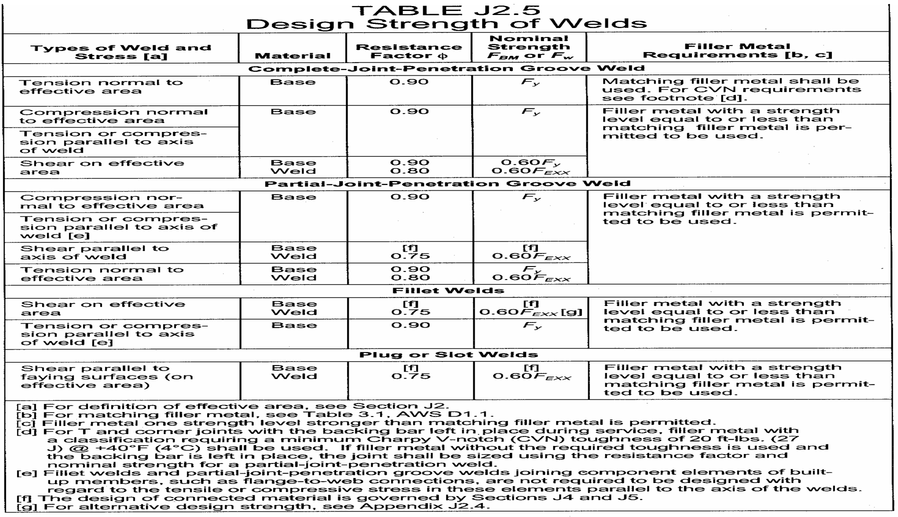
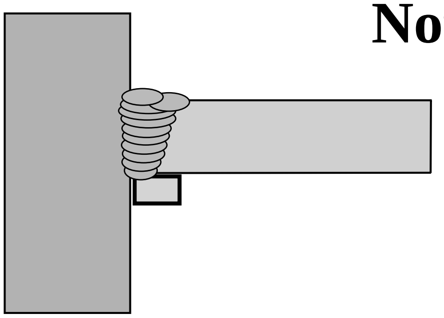


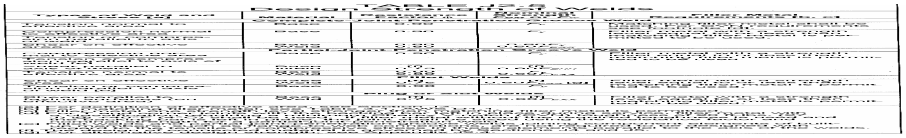
TABLE J2.5
Design Strength of Welds

Types of Weld and Stress [a]	Material	Resistance Factor ϕ	Nominal Strength F_{BM} or F_w	Filler Metal Requirements [b, c]
Complete-Joint-Penetration Groove Weld				
Tension normal to effective area	Base	0.90	F_y	Matching filler metal shall be used. For CVN requirements see footnote [d].
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld				
Shear on effective area	Base Weld	0.90 0.80	$0.60F_y$ $0.60F_{EXX}$	
Partial-Joint-Penetration Groove Weld				
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]				
Shear parallel to axis of weld	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	
Tension normal to effective area	Base Weld	0.90 0.80	F_y $0.60F_{EXX}$	
Fillet Welds				
Shear on effective area	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$ [g]	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]	Base	0.90	F_y	
Plug or Slot Welds				
Shear parallel to faying surfaces (on effective area)	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.

[a] For definition of effective area, see Section J2.
[b] For matching filler metal, see Table 3.1, AWS D1.1.
[c] Filler metal one strength level stronger than matching filler metal is permitted.
[d] For T and corner joints with the backing bar left in place during service, filler metal with a classification requiring a minimum Charpy V-notch (CVN) toughness of 20 ft-lbs. (27 J) @ +40°F (4°C) shall be used. If filler metal without the required toughness is used and the backing bar is left in place, the joint shall be sized using the resistance factor and nominal strength for a partial-joint-penetration weld.
[e] Fillet welds and partial-joint-penetration groove welds joining component elements of built-up members, such as flange-to-web connections, are not required to be designed with regard to the tensile or compressive stress in these elements parallel to the axis of the welds.
[f] The design of connected material is governed by Sections J4 and J5.
[g] For alternative design strength, see Appendix J2.4.

Notes





PJP Groove Weld

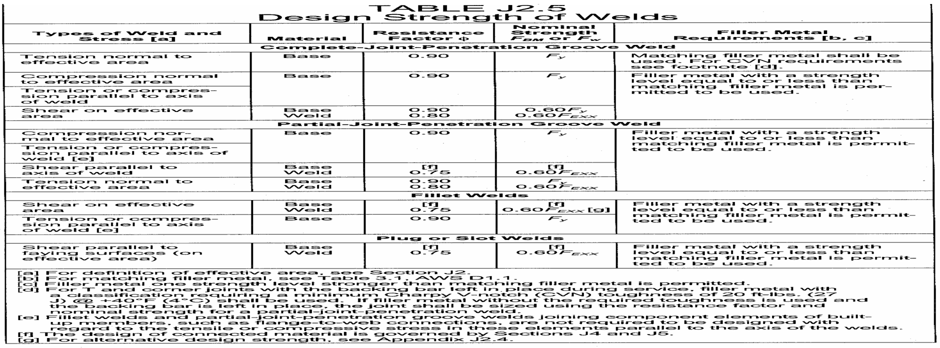


TABLE J2.5
Design Strength of Welds

Types of Weld and Stress [a]	Material	Resistance Factor ϕ	Nominal Strength F_{BM} or F_w	Filler Metal Requirements [b, c]
Complete-Joint-Penetration Groove Weld				
Tension normal to effective area	Base	0.90	F_y	Matching filler metal shall be used. For CVN requirements see footnote [d].
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld				
Shear on effective area	Base Weld	0.90 0.80	$0.60F_y$ $0.60F_{EXX}$	
Partial-Joint-Penetration Groove Weld				
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]				
Shear parallel to axis of weld	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	
Tension normal to effective area	Base Weld	0.90 0.80	F_y $0.60F_{EXX}$	
Fillet Welds				
Shear on effective area	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$ [g]	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]	Base	0.90	F_y	
Plug or Slot Welds				
Shear parallel to faying surfaces (on effective area)	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.

[a] For definition of effective area, see Section J2.
[b] For matching filler metal, see Table 3.1, AWS D1.1.
[c] Filler metal one strength level stronger than matching filler metal is permitted.
[d] For T and corner joints with the backing bar left in place during service, filler metal with a classification requiring a minimum Charpy V-notch (CVN) toughness of 20 ft-lbs. (27 J) @ +40°F (4°C) shall be used. If filler metal without the required toughness is used and the backing bar is left in place, the joint shall be sized using the resistance factor and nominal strength for a partial-joint-penetration weld.
[e] Fillet welds and partial-joint-penetration groove welds joining component elements of built-up members, such as flange-to-web connections, are not required to be designed with regard to the tensile or compressive stress in these elements parallel to the axis of the welds.
[f] The design of connected material is governed by Sections J4 and J5.
[g] For alternative design strength, see Appendix J2.4.

Fillet Welds

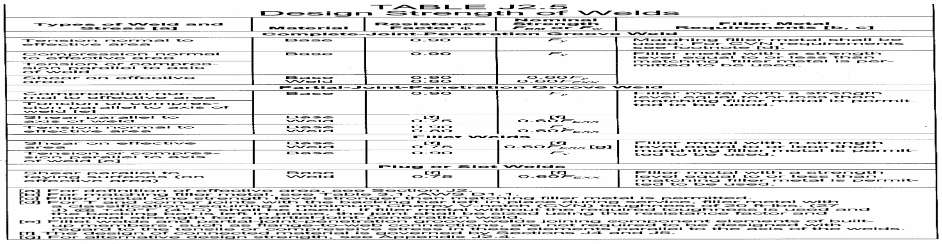


TABLE J2.5
Design Strength of Welds

Types of Weld and Stress [a]	Material	Resistance Factor ϕ	Nominal Strength F_{BM} or F_w	Filler Metal Requirements [b, c]
Complete-Joint-Penetration Groove Weld				
Tension normal to effective area	Base	0.90	F_y	Matching filler metal shall be used. For CVN requirements see footnote [d].
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld				
Shear on effective area	Base Weld	0.90 0.80	$0.60F_y$ $0.60F_{EXX}$	
Partial-Joint-Penetration Groove Weld				
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]				
Shear parallel to axis of weld	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	
Tension normal to effective area	Base Weld	0.90 0.80	F_y $0.60F_{EXX}$	
Fillet Welds				
Shear on effective area	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$ [g]	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]	Base	0.90	F_y	
Plug or Slot Welds				
Shear parallel to faying surfaces (on effective area)	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.

[a] For definition of effective area, see Section J2.
[b] For matching filler metal, see Table 3.1, AWS D1.1.
[c] Filler metal one strength level stronger than matching filler metal is permitted.
[d] For T and corner joints with the backing bar left in place during service, filler metal with a classification requiring a minimum Charpy V-notch (CVN) toughness of 20 ft-lbs. (27 J) @ +40°F (4°C) shall be used. If filler metal without the required toughness is used and the backing bar is left in place, the joint shall be sized using the resistance factor and nominal strength for a partial-joint-penetration weld.
[e] Fillet welds and partial-joint-penetration groove welds joining component elements of built-up members, such as flange-to-web connections, are not required to be designed with regard to the tensile or compressive stress in these elements parallel to the axis of the welds.
[f] The design of connected material is governed by Sections J4 and J5.
[g] For alternative design strength, see Appendix J2.4.

Plug or Slot Welds

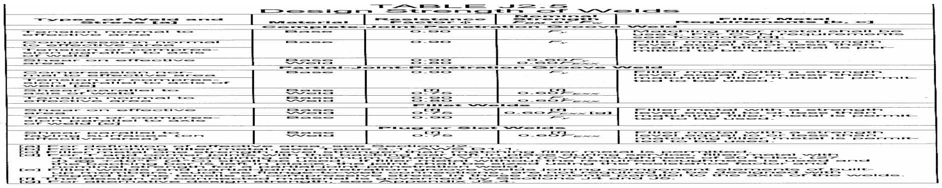


TABLE J2.5
Design Strength of Welds

Types of Weld and Stress [a]	Material	Resistance Factor ϕ	Nominal Strength F_{BM} or F_w	Filler Metal Requirements [b, c]
Complete-Joint-Penetration Groove Weld				
Tension normal to effective area	Base	0.90	F_y	Matching filler metal shall be used. For CVN requirements see footnote [d].
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld				
Shear on effective area	Base Weld	0.90 0.80	$0.60F_y$ $0.60F_{EXX}$	
Partial-Joint-Penetration Groove Weld				
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]				
Shear parallel to axis of weld	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	
Tension normal to effective area	Base Weld	0.90 0.80	F_y $0.60F_{EXX}$	
Fillet Welds				
Shear on effective area	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$ [g]	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]	Base	0.90	F_y	
Plug or Slot Welds				
Shear parallel to faying surfaces (on effective area)	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.

[a] For definition of effective area, see Section J2.
[b] For matching filler metal, see Table 3.1, AWS D1.1.
[c] Filler metal one strength level stronger than matching filler metal is permitted.
[d] For T and corner joints with the backing bar left in place during service, filler metal with a classification requiring a minimum Charpy V-notch (CVN) toughness of 20 ft-lbs. (27 J) @ +40°F (4°C) shall be used. If filler metal without the required toughness is used and the backing bar is left in place, the joint shall be sized using the resistance factor and nominal strength for a partial-joint-penetration weld.
[e] Fillet welds and partial-joint-penetration groove welds joining component elements of built-up members, such as flange-to-web connections, are not required to be designed with regard to the tensile or compressive stress in these elements parallel to the axis of the welds.
[f] The design of connected material is governed by Sections J4 and J5.
[g] For alternative design strength, see Appendix J2.4.

Notes

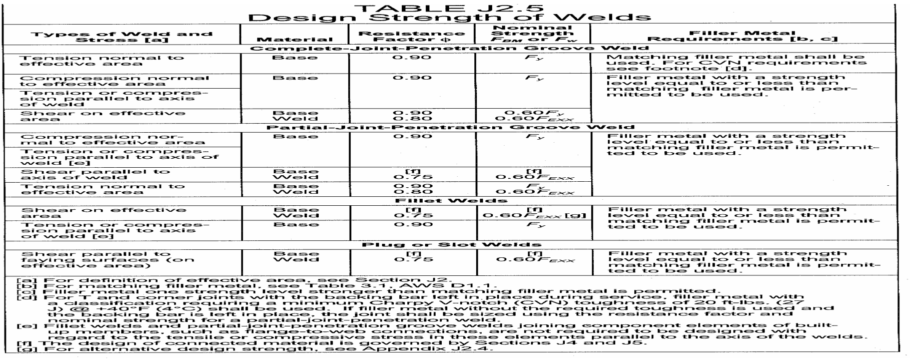


TABLE J2.5
Design Strength of Welds

Types of Weld and Stress [a]	Material	Resistance Factor ϕ	Nominal Strength F_{BM} or F_w	Filler Metal Requirements [b, c]
Complete-Joint-Penetration Groove Weld				
Tension normal to effective area	Base	0.90	F_y	Matching filler metal shall be used. For CVN requirements see footnote [d].
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld				
Shear on effective area	Base Weld	0.90 0.80	$0.60F_y$ $0.60F_{EXX}$	
Partial-Joint-Penetration Groove Weld				
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]				
Shear parallel to axis of weld	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	
Tension normal to effective area	Base Weld	0.90 0.80	F_y $0.60F_{EXX}$	
Fillet Welds				
Shear on effective area	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$[g]	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]	Base	0.90	F_y	
Plug or Slot Welds				
Shear parallel to faying surfaces (on effective area)	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.

[a] For definition of effective area, see Section J2.
[b] For matching filler metal, see Table 3.1, AWS D1.1.
[c] Filler metal one strength level stronger than matching filler metal is permitted.
[d] For T and corner joints with the backing bar left in place during service, filler metal with a classification requiring a minimum Charpy V-notch (CVN) toughness of 20 ft-lbs. (27 J) @ +40°F (4°C) shall be used. If filler metal without the required toughness is used and the backing bar is left in place, the joint shall be sized using the resistance factor and nominal strength for a partial-joint-penetration weld.
[e] Fillet welds and partial-joint-penetration groove welds joining component elements of built-up members, such as flange-to-web connections, are not required to be designed with regard to the tensile or compressive stress in these elements parallel to the axis of the welds.
[f] The design of connected material is governed by Sections J4 and J5.
[g] For alternative design strength, see Appendix J2.4.

Table J2.5

Matching Strength

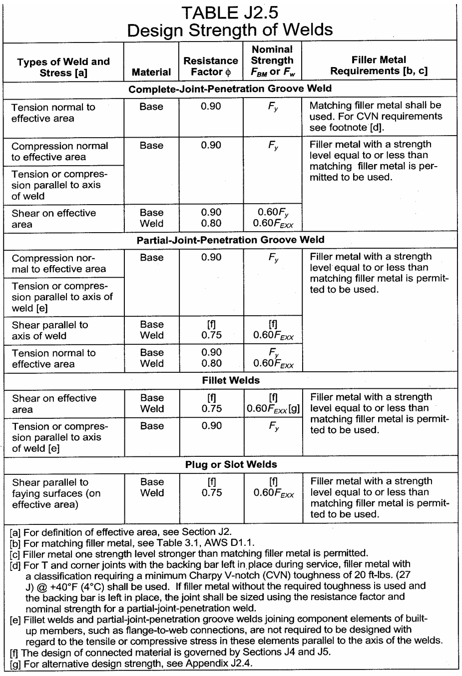


TABLE J2.5
Design Strength of Welds

Types of Weld and Stress [a]	Material	Resistance Factor ϕ	Nominal Strength F_{BM} or F_w	Filler Metal Requirements [b, c]
Complete-Joint-Penetration Groove Weld				
Tension normal to effective area	Base	0.90	F_y	Matching filler metal shall be used. For CVN requirements see footnote [d].
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld				
Shear on effective area	Base Weld	0.90 0.80	$0.60F_y$ $0.60F_{EXX}$	
Partial-Joint-Penetration Groove Weld				
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]				
Shear parallel to axis of weld	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	
Tension normal to effective area	Base Weld	0.90 0.80	F_y $0.60F_{EXX}$	
Fillet Welds				
Shear on effective area	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$[g]	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]	Base	0.90	F_y	
Plug or Slot Welds				
Shear parallel to faying surfaces (on effective area)	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.

[a] For definition of effective area, see Section J2.
[b] For matching filler metal, see Table 3.1, AWS D1.1.
[c] Filler metal one strength level stronger than matching filler metal is permitted.
[d] For T and corner joints with the backing bar left in place during service, filler metal with a classification requiring a minimum Charpy V-notch (CVN) toughness of 20 ft-lbs. (27 J) @ +40°F (4°C) shall be used. If filler metal without the required toughness is used and the backing bar is left in place, the joint shall be sized using the resistance factor and nominal strength for a partial-joint-penetration weld.
[e] Fillet welds and partial-joint-penetration groove welds joining component elements of built-up members, such as flange-to-web connections, are not required to be designed with regard to the tensile or compressive stress in these elements parallel to the axis of the welds.
[f] The design of connected material is governed by Sections J4 and J5.
[g] For alternative design strength, see Appendix J2.4.

Table J2.5

Undermatching

Permitted

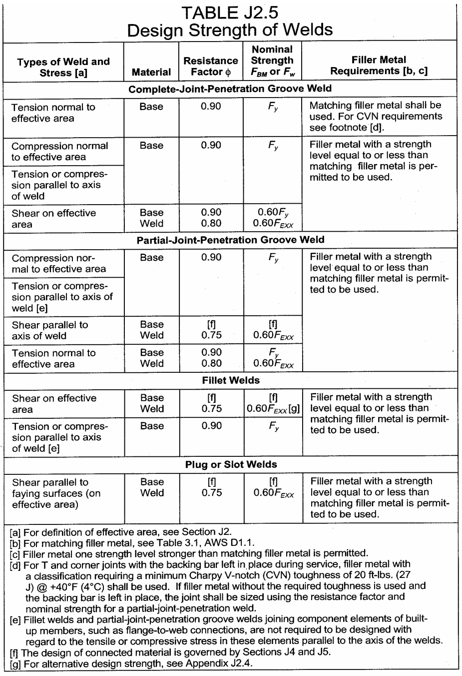


TABLE J2.5
Design Strength of Welds

Types of Weld and Stress [a]	Material	Resistance Factor ϕ	Nominal Strength F_{BM} or F_w	Filler Metal Requirements [b, c]
Complete-Joint-Penetration Groove Weld				
Tension normal to effective area	Base	0.90	F_y	Matching filler metal shall be used. For CVN requirements see footnote [d].
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld				
Shear on effective area	Base Weld	0.90 0.80	$0.60F_y$ $0.60F_{EXX}$	
Partial-Joint-Penetration Groove Weld				
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]				
Shear parallel to axis of weld	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	
Tension normal to effective area	Base Weld	0.90 0.80	F_y $0.60F_{EXX}$	
Fillet Welds				
Shear on effective area	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$[g]	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]	Base	0.90	F_y	
Plug or Slot Welds				
Shear parallel to faying surfaces (on effective area)	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.

[a] For definition of effective area, see Section J2.
[b] For matching filler metal, see Table 3.1, AWS D1.1.
[c] Filler metal one strength level stronger than matching filler metal is permitted.
[d] For T and corner joints with the backing bar left in place during service, filler metal with a classification requiring a minimum Charpy V-notch (CVN) toughness of 20 ft-lbs. (27 J) @ +40°F (4°C) shall be used. If filler metal without the required toughness is used and the backing bar is left in place, the joint shall be sized using the resistance factor and nominal strength for a partial-joint-penetration weld.
[e] Fillet welds and partial-joint-penetration groove welds joining component elements of built-up members, such as flange-to-web connections, are not required to be designed with regard to the tensile or compressive stress in these elements parallel to the axis of the welds.
[f] The design of connected material is governed by Sections J4 and J5.
[g] For alternative design strength, see Appendix J2.4.

Table J2.5--10 KSI Overmatch permitted

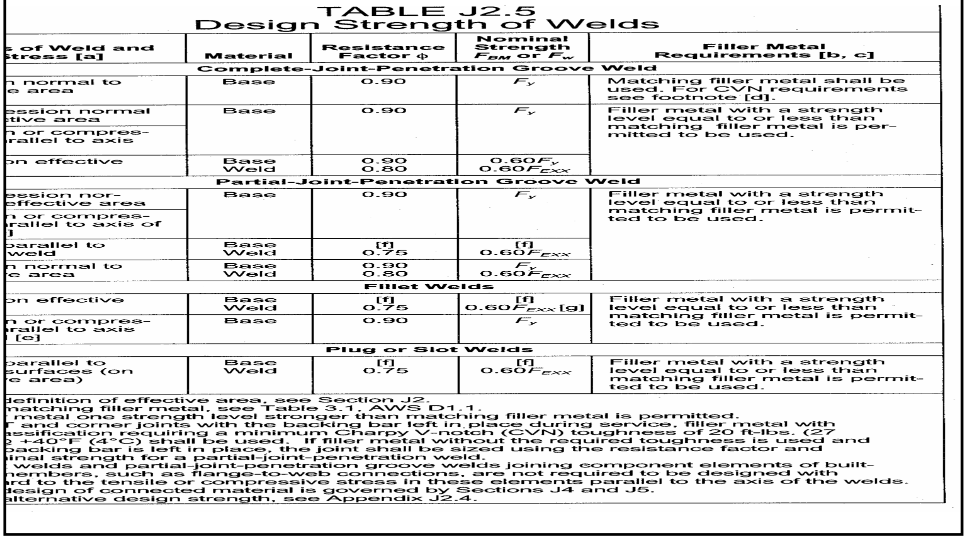


TABLE J2.5
Design Strength of Welds

s of Weld and tress [a]	Material	Resistance Factor ϕ	Nominal Strength F_{BM} or F_w	Filler Metal Requirements [b, c]
Complete-Joint-Penetration Groove Weld				
n normal to e area	Base	0.90	F_y	Matching filler metal shall be used. For CVN requirements see footnote [d].
ession normal tive area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
n or compres- rallel to axis				
on effective	Base Weld	0.90 0.80	$0.60F_y$ $0.60F_{EXX}$	
Partial-Joint-Penetration Groove Weld				
ession nor- effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
n or compres- rallel to axis of]				
parallel to weld	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	
n normal to e area	Base Weld	0.90 0.80	F_y $0.60F_{EXX}$	
Fillet Welds				
on effective	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$ [g]	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
n or compres- rallel to axis [e]	Base	0.90	F_y	
Plug or Slot Welds				
parallel to surfaces (on e area)	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.

definition of effective area, see Section J2.
natching filler metal, see Table 3.1, AWS D1.1.
metal one strength level stronger than matching filler metal is permitted.
T and corner joints with the backing bar left in place during service, filler metal with
ssification requiring a minimum Charpy V-notch (CVN) toughness of 20 ft-lbs. (27
+40°F (4°C) shall be used. If filler metal without the required toughness is used and
acking bar is left in place, the joint shall be sized using the resistance factor and
inal strength for a partial-joint-penetration weld.
welds and partial-joint-penetration groove welds joining component elements of built-
nembers, such as flange-to-web connections, are not required to be designed with
rd to the tensile or compressive stress in these elements parallel to the axis of the welds.
design of connected material is governed by Sections J4 and J5.
lternative design strength, see Appendix J2.4.

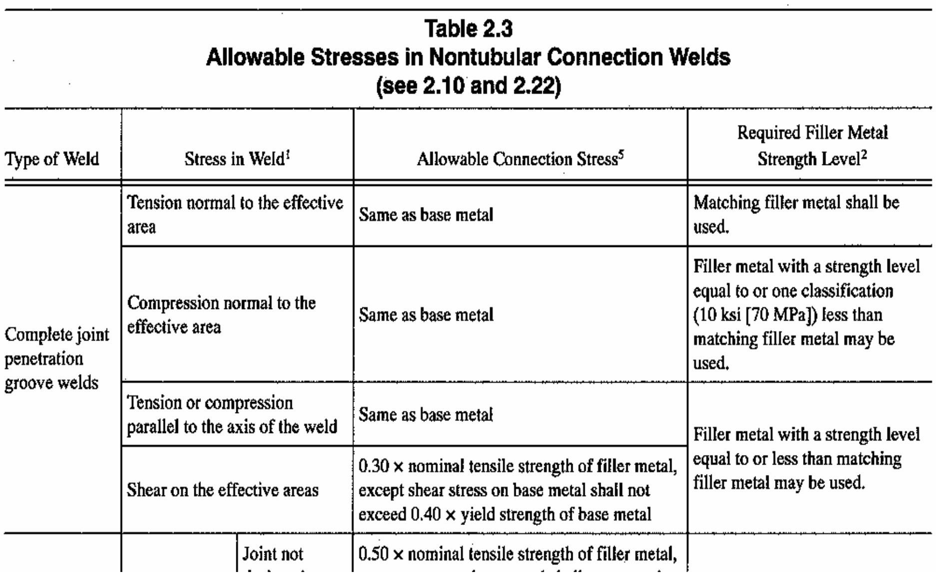
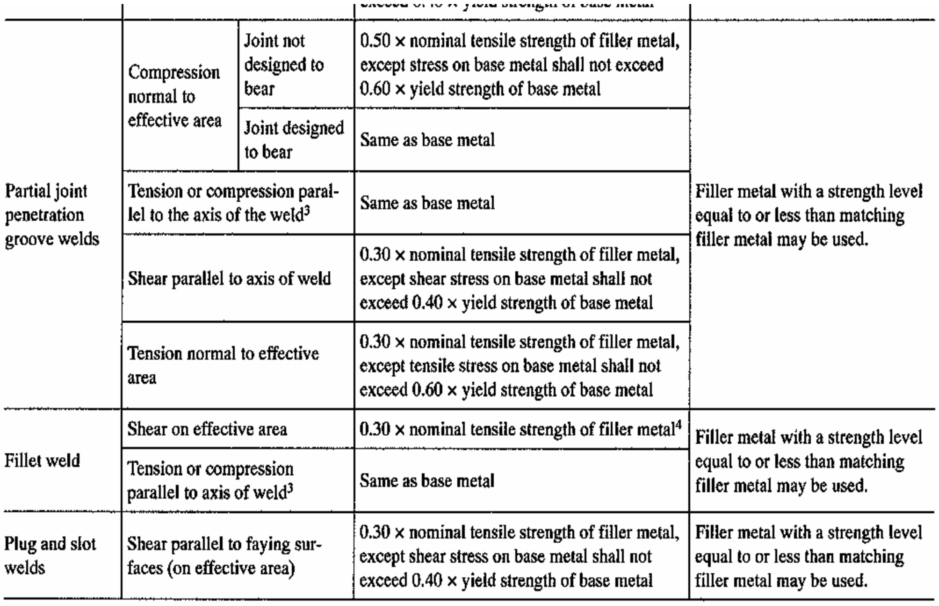


Table 2.3
Allowable Stresses in Nontubular Connection Welds
(see 2.10 and 2.22)

Type of Weld	Stress in Weld[1]		Allowable Connection Stress[5]	Required Filler Metal Strength Level[2]
Complete joint penetration groove welds	Tension normal to the effective area		Same as base metal	Matching filler metal shall be used.
	Compression normal to the effective area		Same as base metal	Filler metal with a strength level equal to or one classification (10 ksi [70 MPa]) less than matching filler metal may be used.
	Tension or compression parallel to the axis of the weld		Same as base metal	Filler metal with a strength level equal to or less than matching filler metal may be used.
	Shear on the effective areas		0.30 × nominal tensile strength of filler metal, except shear stress on base metal shall not exceed 0.40 × yield strength of base metal	
		Joint not	0.50 × nominal tensile strength of filler metal,	

AWS D1.1:2000

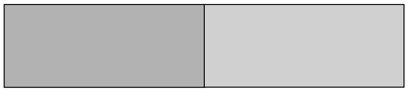


Partial joint penetration groove welds	Compression normal to effective area	Joint not designed to bear	0.50 × nominal tensile strength of filler metal, except stress on base metal shall not exceed 0.60 × yield strength of base metal	Filler metal with a strength level equal to or less than matching filler metal may be used.
		Joint designed to bear	Same as base metal	
	Tension or compression parallel to the axis of the weld[3]		Same as base metal	
	Shear parallel to axis of weld		0.30 × nominal tensile strength of filler metal, except shear stress on base metal shall not exceed 0.40 × yield strength of base metal	
	Tension normal to effective area		0.30 × nominal tensile strength of filler metal, except tensile stress on base metal shall not exceed 0.60 × yield strength of base metal	
Fillet weld	Shear on effective area		0.30 × nominal tensile strength of filler metal[4]	Filler metal with a strength level equal to or less than matching filler metal may be used.
	Tension or compression parallel to axis of weld[3]		Same as base metal	
Plug and slot welds	Shear parallel to faying surfaces (on effective area)		0.30 × nominal tensile strength of filler metal, except shear stress on base metal shall not exceed 0.40 × yield strength of base metal	Filler metal with a strength level equal to or less than matching filler metal may be used.

AWS D1.1:2000

Selecting Weld Types

BUTT JOINTS



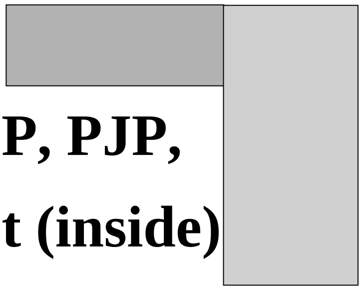
Tension → CJP, PJP

Shear → PJP

Compression → PJP (Bear?)

Selecting Weld Types

CORNER JOINTS

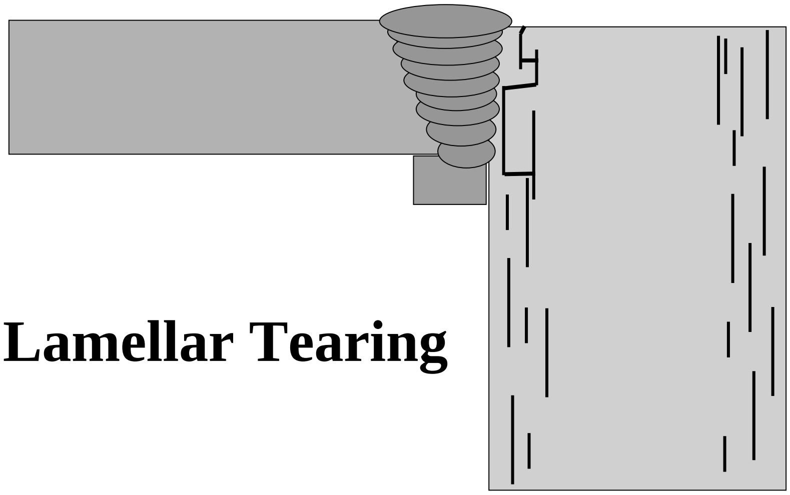


Tension → CJP, PJP, Fillet (inside)

Shear → PJP, Fillet (inside)

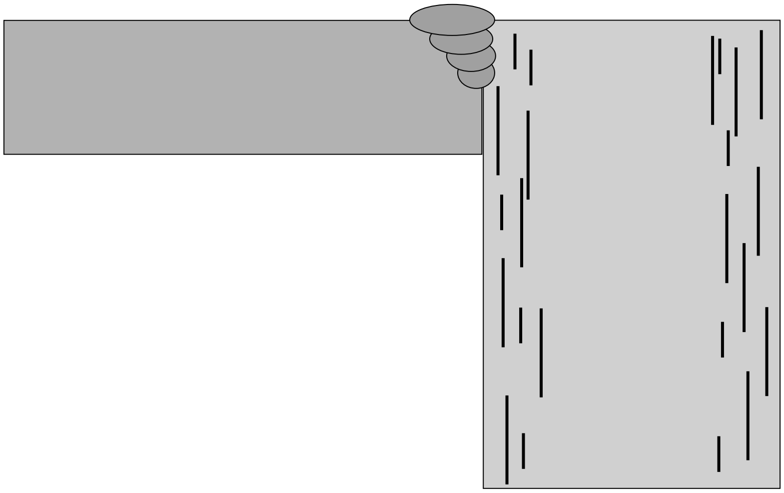
Compression → PJP, Fillet (inside)

CORNER JOINTS

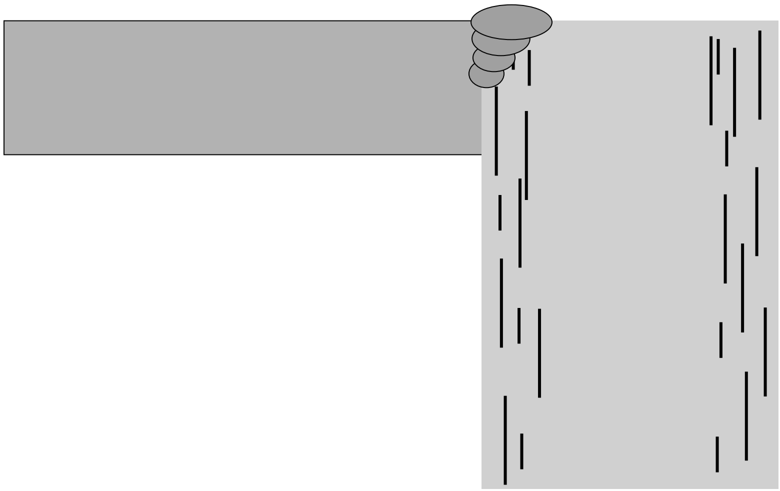


Lamellar Tearing

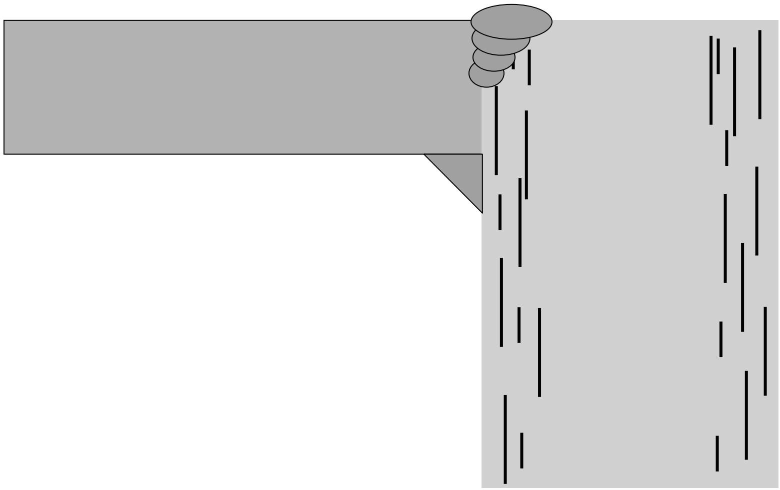
CORNER JOINTS--PJP



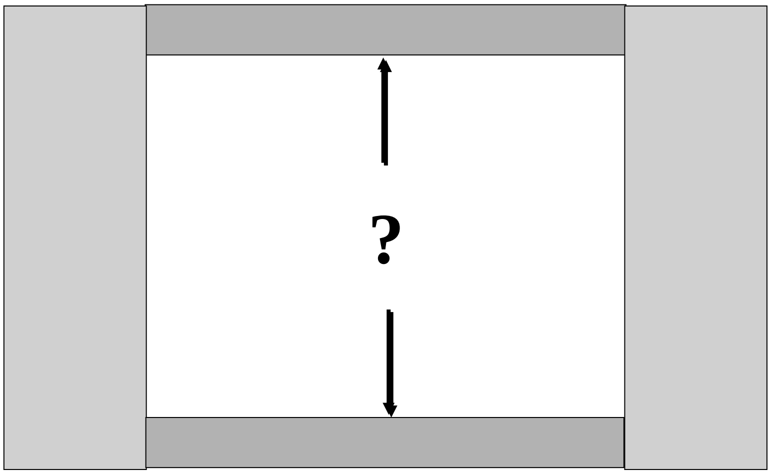
CORNER JOINTS--PJP



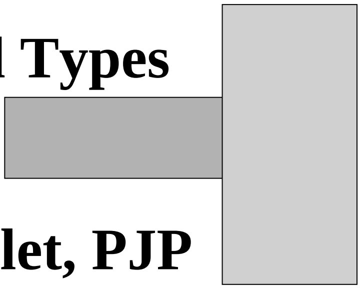
PJP AND FILLET



CORNER JOINTS



Selecting Weld Types



TEE JOINTS

Tension → Fillet, PJP

Shear → Fillet, PJP

Compression → Fillet, PJP

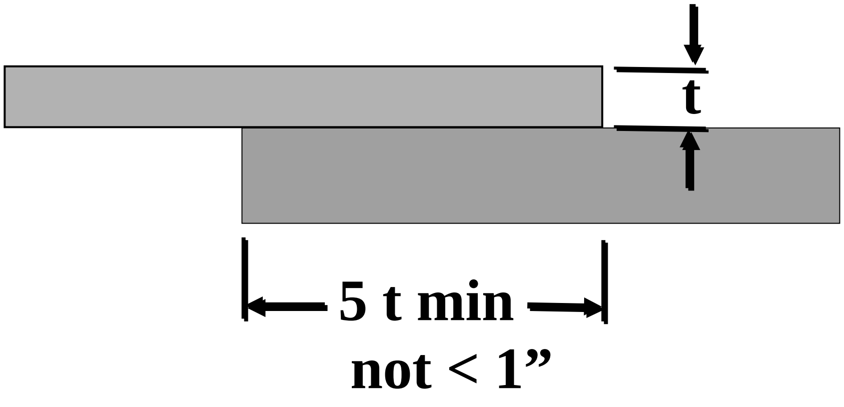
Selecting Weld Types

LAP JOINTS

Tension → Fillet, Plug, Slot

Compression → Fillet, Plug, Slot

LAP JOINTS



AISC LRFD J2b

Fig C-J2.3

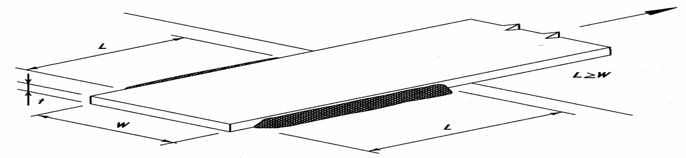


Fig.C-J2.2. Longitudinal fillet welds.

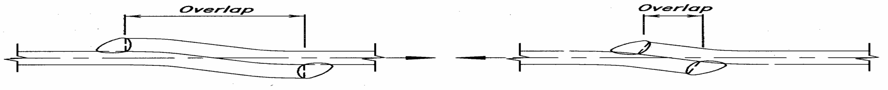


Fig. C-J2.3. Minimum lap.

Fig C-J2.2

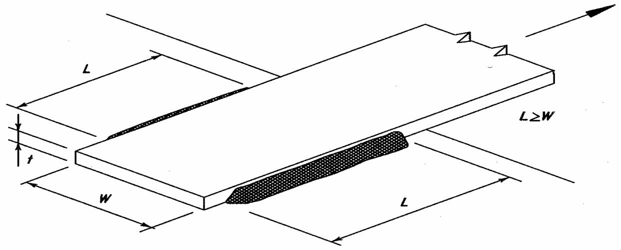


Fig.C-J2.2. Longitudinal fillet welds.

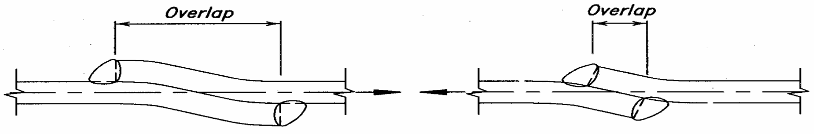


Fig. C-J2.3. Minimum lap.

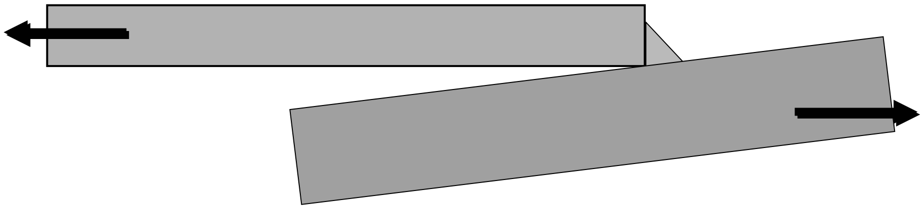
LAP JOINTS

AISC LRFD J2b

LAP JOINTS

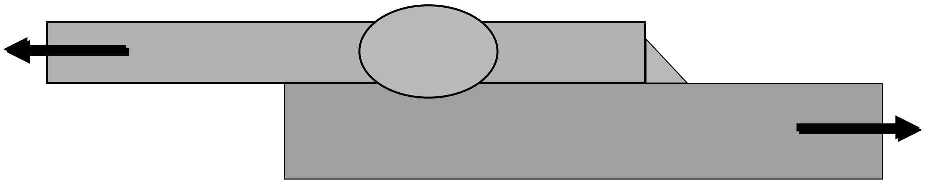
AISC LRFD J2b

LAP JOINTS



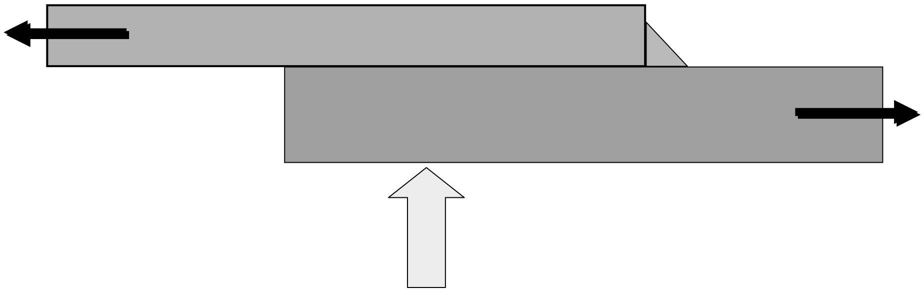
AISC LRFD J2b

LAP JOINTS



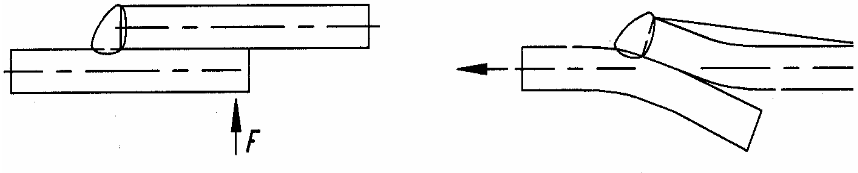
AISC LRFD J2b

LAP JOINTS



AISC LRFD J2b

Fig C-J2.4



(a) Restrained

(b) Unrestrained

Fig. C-J2.4. Restraint of lap joints.

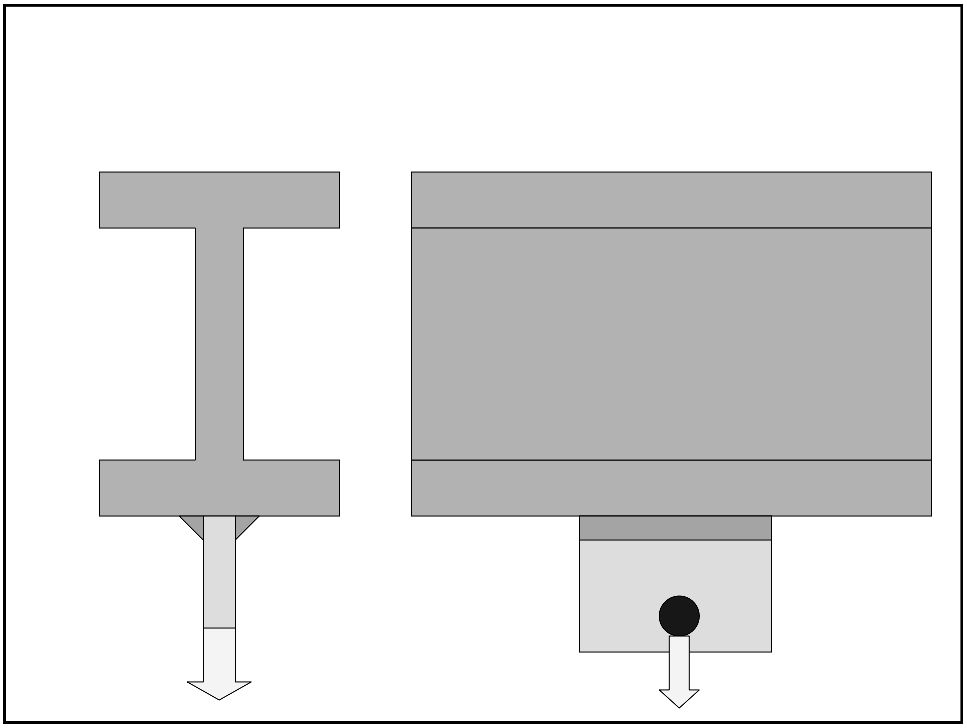
INTRODUCTION TO WELDED CONNECTIONS

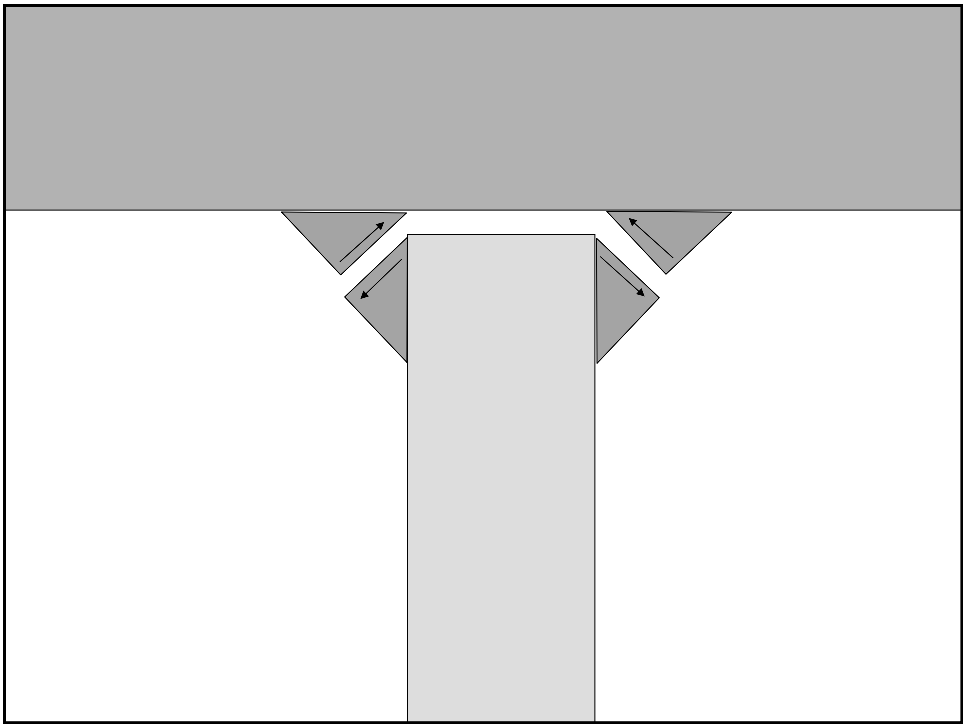
Calculating Weld Sizes

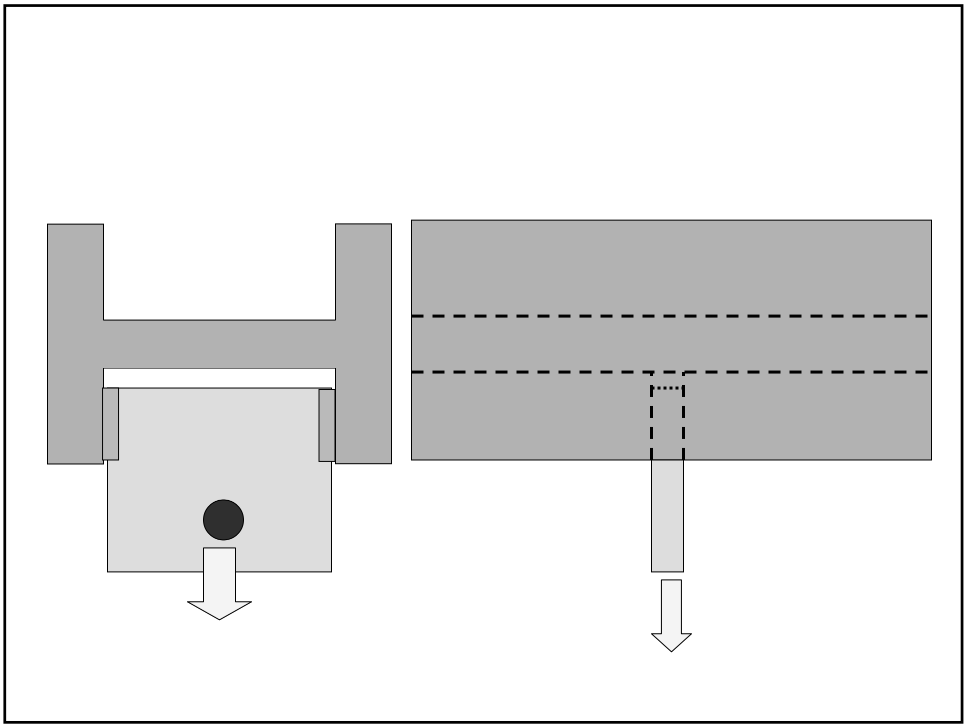
Two Approaches

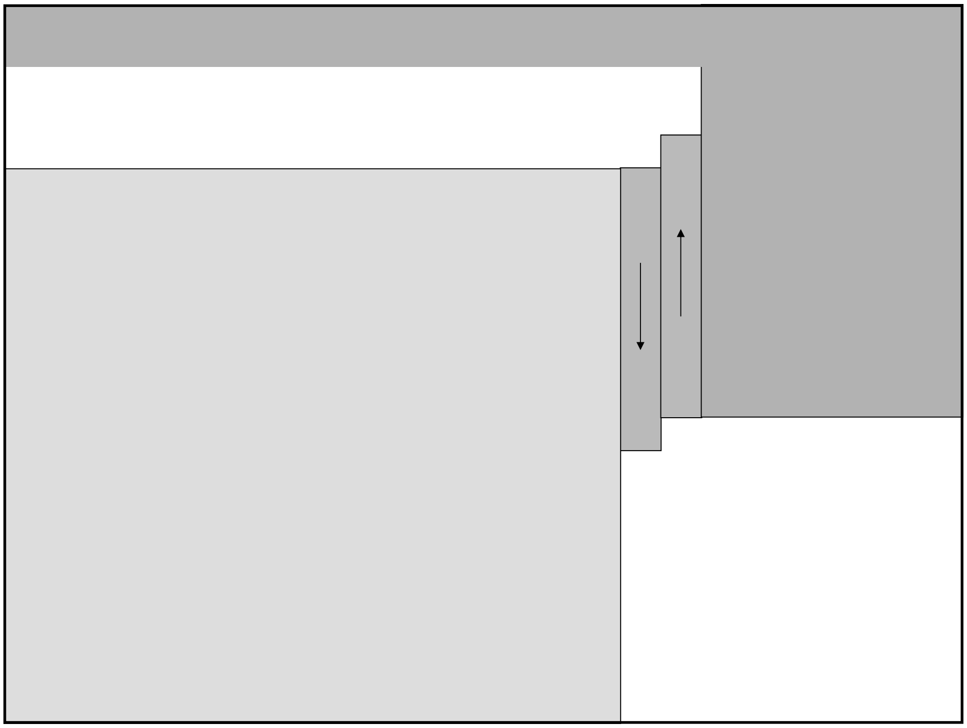
- Fillet welds
- Weld groups (bending & torsion)

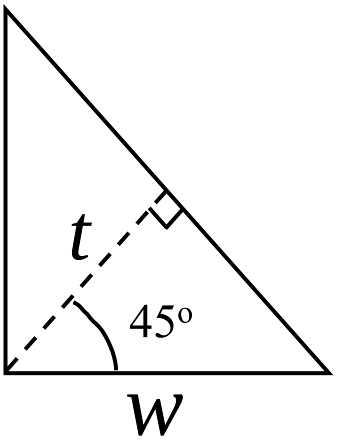
Fillet Welds:
Direct Loading











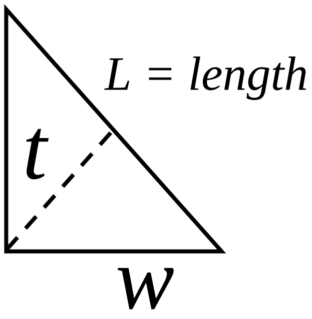
cos 45^{o} = t / w

t = w (cos 45^{o})

t = 0.707 w

Shear Stress on Throat

$$\tau = \frac{F}{A} = \frac{F}{t \times L}$$



$$\tau = \frac{F}{(0.707w)L}$$

Allowable Stresses on Welds

$$\tau_{allowable} = 0.30 \times Exx$$

E6010, *Exx* = 60 ksi (430 MPa)

E71T-1, *Exx* = 70 ksi (480 MPa)

E81T1-K2 *Exx* = 80 ksi (550 MPa)

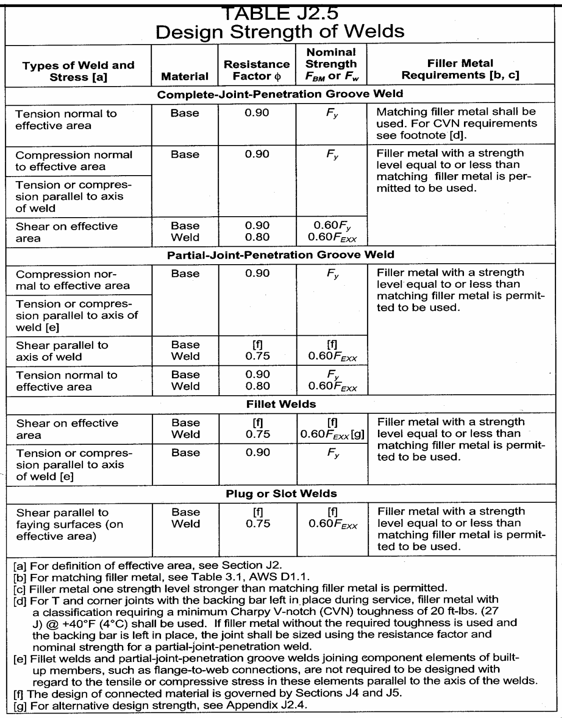


TABLE J2.5
Design Strength of Welds

Types of Weld and Stress [a]	Material	Resistance Factor ϕ	Nominal Strength F_{BM} or F_w	Filler Metal Requirements [b, c]
Complete-Joint-Penetration Groove Weld				
Tension normal to effective area	Base	0.90	F_y	Matching filler metal shall be used. For CVN requirements see footnote [d].
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld				
Shear on effective area	Base Weld	0.90 0.80	$0.60F_y$ $0.60F_{EXX}$	
Partial-Joint-Penetration Groove Weld				
Compression normal to effective area	Base	0.90	F_y	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]				
Shear parallel to axis of weld	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	
Tension normal to effective area	Base Weld	0.90 0.80	F_y $0.60F_{EXX}$	
Fillet Welds				
Shear on effective area	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$[g]	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.
Tension or compression parallel to axis of weld [e]	Base	0.90	F_y	
Plug or Slot Welds				
Shear parallel to faying surfaces (on effective area)	Base Weld	[f] 0.75	[f] $0.60F_{EXX}$	Filler metal with a strength level equal to or less than matching filler metal is permitted to be used.

[a] For definition of effective area, see Section J2.

[b] For matching filler metal, see Table 3.1, AWS D1.1.

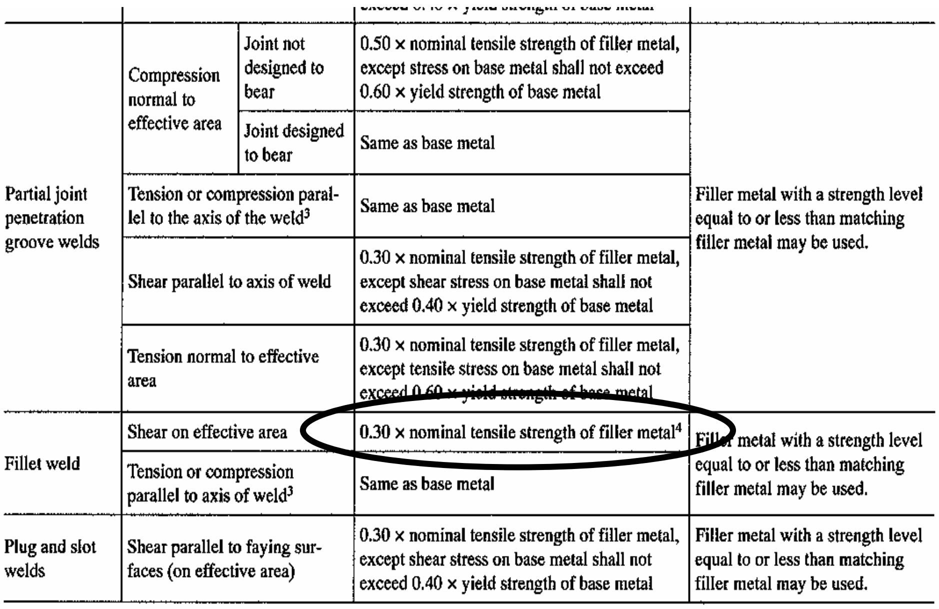
[c] Filler metal one strength level stronger than matching filler metal is permitted.

[d] For T and corner joints with the backing bar left in place during service, filler metal with a classification requiring a minimum Charpy V-notch (CVN) toughness of 20 ft-lbs. (27 J) @ +40°F (4°C) shall be used. If filler metal without the required toughness is used and the backing bar is left in place, the joint shall be sized using the resistance factor and nominal strength for a partial-joint-penetration weld.

[e] Fillet welds and partial-joint-penetration groove welds joining component elements of built-up members, such as flange-to-web connections, are not required to be designed with regard to the tensile or compressive stress in these elements parallel to the axis of the welds.

[f] The design of connected material is governed by Sections J4 and J5.

[g] For alternative design strength, see Appendix J2.4.



			exceed 0.40 × yield strength of base metal	
Partial joint penetration groove welds	Compression normal to effective area	Joint not designed to bear	0.50 × nominal tensile strength of filler metal, except stress on base metal shall not exceed 0.60 × yield strength of base metal	Filler metal with a strength level equal to or less than matching filler metal may be used.
		Joint designed to bear	Same as base metal	
	Tension or compression parallel to the axis of the weld[3]		Same as base metal	
	Shear parallel to axis of weld		0.30 × nominal tensile strength of filler metal, except shear stress on base metal shall not exceed 0.40 × yield strength of base metal	
	Tension normal to effective area		0.30 × nominal tensile strength of filler metal, except tensile stress on base metal shall not exceed 0.60 × yield strength of base metal	
Fillet weld	Shear on effective area		0.30 × nominal tensile strength of filler metal[4]	Filler metal with a strength level equal to or less than matching filler metal may be used.
	Tension or compression parallel to axis of weld[3]		Same as base metal	
Plug and slot welds	Shear parallel to faying surfaces (on effective area)		0.30 × nominal tensile strength of filler metal, except shear stress on base metal shall not exceed 0.40 × yield strength of base metal	Filler metal with a strength level equal to or less than matching filler metal may be used.

AWS D1.1:2000

$$\tau = \frac{F}{(0.707w)L} = 0.3Exx = \tau_{allowable}$$

Solving for *w*...

w = F / (0.212 Exx L)

$$\tau_{allowable} = \frac{F}{(0.707w)\,L} = 0.3Exx$$

Solving for $F_{allowable...}$

$$\mathbf{F_{allowable} = 0.212\ Exx\ w\ L}$$

$$f = \frac{F}{L} \quad \text{(Unit force, lbf/linear in)}$$

$$w = \frac{\text{actual force/in.}}{\text{allowable force/in.}} = \frac{f}{0.212 \times Exx}$$

$$f_{allowable} = 0.212 \times Exx \times w$$

Leg size, *w* (in)	Allowable unit force, kips/linear in		

Lincoln Procedure Handbook, 13th Ed., p. 2.3-3

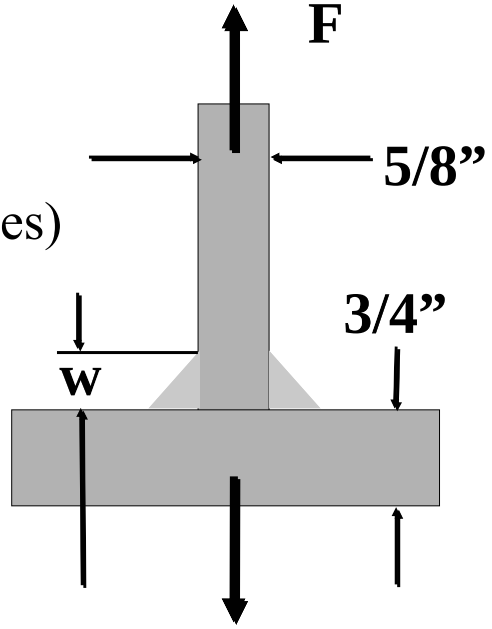
Example

F = 45,000 lbf

L = 12.0 in (2 sides)

E7018

w = ?



Example

$$w = \frac{F}{0.212 \times Exx \times L}$$

$w=$

$$= \frac{\textbf{45,000 lbf}}{\textbf{0.212 X 70,000 lbf/in}^2\textbf{ X 12 inch X 2 welds}}$$

= 0.126 inch   USE 3/16”

Example

F = 45,000 lbf

L = 12.0 in (2 sides)

E7018

w = ?

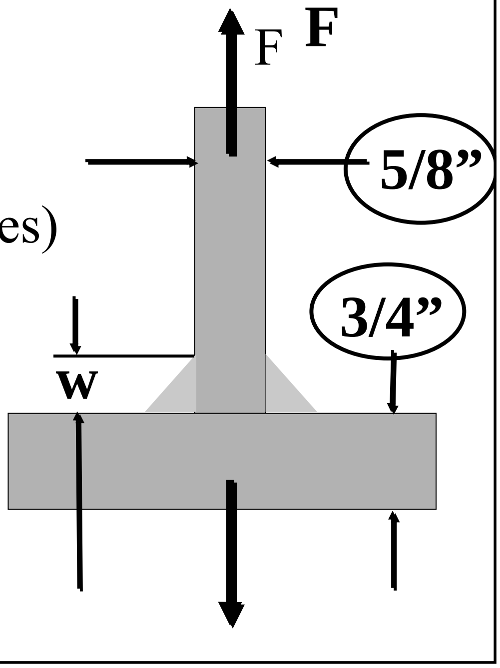


Table 5.8
Minimum Fillet Weld Sizes (see 5.14)

Base-Metal Thickness (T)*		Minimum Size of Fillet Weld**	
in.	mm	in.	mm
T ≤ 1/4	T ≤ 6.4	1/8***	3
1/4 < T ≤ 1/2	6.4 < T ≤ 12.7	3/16	5
1/2 < T ≤ 3/4	12.7 < T ≤ 19.0	1/4	6
3/4 < T	19.0 < T	5/16	8

AWS D1.1:2000

Table 5.8
Minimum Fillet Weld Sizes (see 5.14)

Base-Metal Thickness (T)*		Minimum Size of Fillet Weld**	
in.	mm	in.	mm
T ≤ 1/4	T ≤ 6.4	1/8***	3
1/4 < T ≤ 1/2	6.4 < T ≤ 12.7	3/16	5
1/2 < T ≤ 3/4	12.7 < T ≤ 19.0	1/4	6
3/4 < T	19.0 < T	5/16	8

AWS D1.1:2000

Table 5.8 Notes

* For non-low hydrogen processes without preheat calculated in accordance with 3.5.2, T equals thickness of the thicker part joined; single-pass welds shall be used.

For non-low hydrogen processes using procedures established to prevent cracking in accordance with 3.5.2 and for low hydrogen processes, T equals thickness of the thinner part joined; single-pass requirement does not apply.

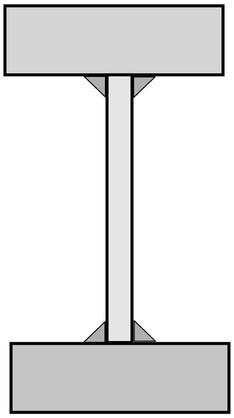
Table 5.8 Notes

** Except that the weld size need not exceed the thickness of the thinner part joined.

*** Minimum size for cyclically loaded structures is 3/16 in. (5 mm).

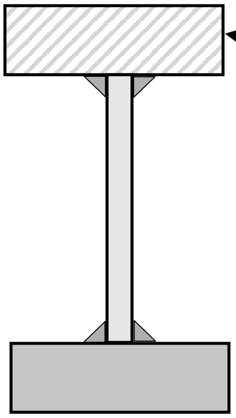
Fillet Welds:
Indirect Loading

Shear Due to Bending



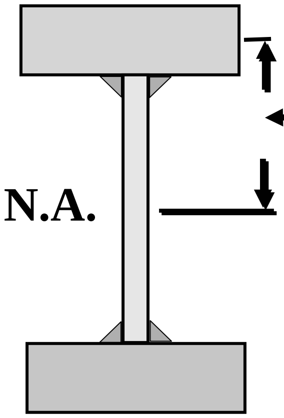
$$f = \frac{V \cdot A \cdot y}{I \cdot n}$$

Shear Due to Bending



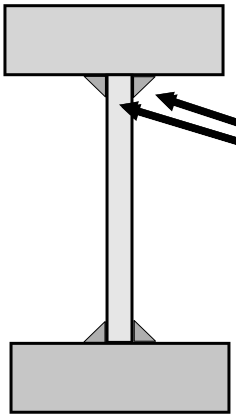
$$f = \frac{V \cdot \textcircled{A} \cdot y}{I \cdot n}$$

Shear Due to Bending



$$f = \frac{V \cdot A \cdot \textcircled{y}}{I \cdot n}$$

Shear Due to Bending



$$f = \frac{V \cdot A \cdot y}{I \cdot n}$$

f **= force on weld, lbf/linear in.(kN/linear mm)**

V **= shear on section at given point, lbf (kN)**

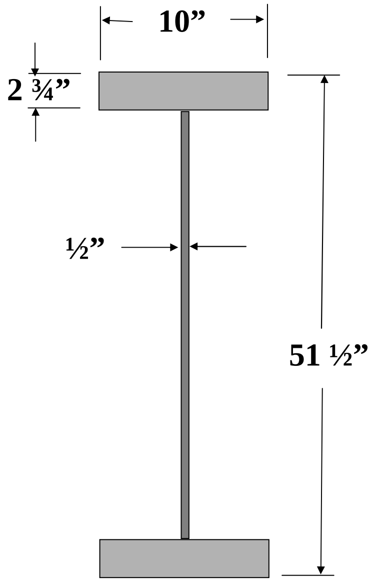
A **= area held by the weld, in^2 (mm^2)**

y **= distance from CG of area held to NA, in (mm)**

I **= moment of inertia of whole section, in^4 (mm^4)**

n **= number of welds holding area**

Example: Horizontal Shear



V = 189,000 lbf

I = 36,768 in^4

A = 27.5 in^2

y = 24.375 in

n = 2 welds (E70)

w = ?

$$f = \frac{V \cdot A \cdot y}{I \cdot n}$$

$$= \frac{(189{,}000)(27.5)(24.375)}{(36{,}768)(2)}$$

$$= 1720 \ \text{lbf/in.}$$

$$w = \frac{\text{actual force/in.}}{\text{allowable force/in}} = \frac{f}{0.212 \times Exx}$$

.

$$w = \frac{1720}{0.212 \times 70{,}000} = 0.116 \text{ in.}$$

Use minimum weld size… 3/16 in

Table 5.8
Minimum Fillet Weld Sizes (see 5.14)

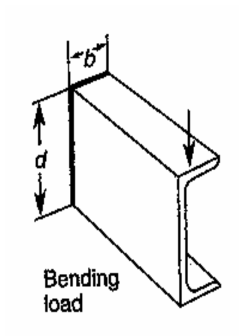
Base-Metal Thickness (T)*		Minimum Size of Fillet Weld**	
in.	mm	in.	mm
T ≤ 1/4	T ≤ 6.4	1/8***	3
1/4 < T ≤ 1/2	6.4 < T ≤ 12.7	3/16	5
1/2 < T ≤ 3/4	12.7 < T ≤ 19.0	1/4	6
3/4 < T	19.0 < T	5/16	8

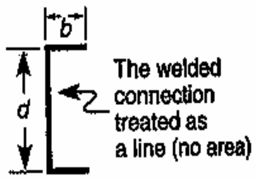
AWS D1.1:2000

Weld Groups

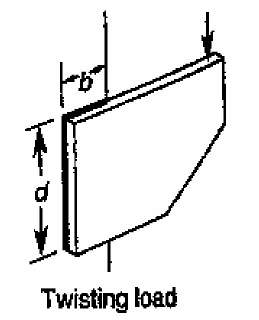
Treating the weld as a line

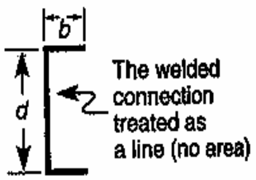
Bending $\sigma = \dfrac{M}{S} \rightarrow \sigma = \dfrac{M}{S_w}$





Treating the weld as a line





Torsion

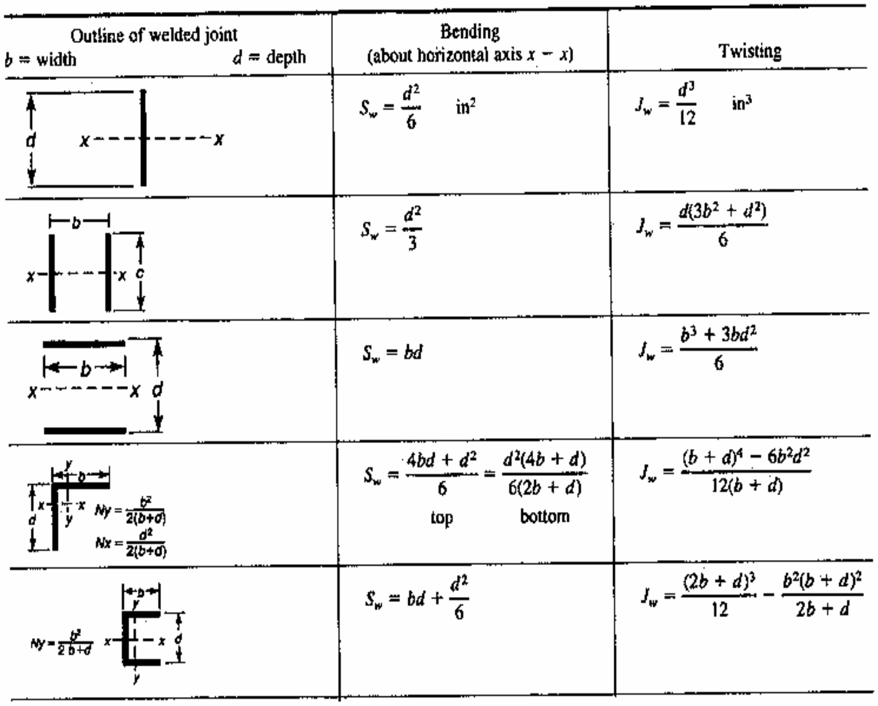
$$\sigma = \frac{Tc}{J} \rightarrow \sigma = \frac{Tc}{J_w}$$

---

1. **Find properties of the weld (Sw, Jw, Aw)**
2. **Find forces on weld using these properties**
3. **Calculate resultant force, *f***
4. **Calculate weld size, *w***

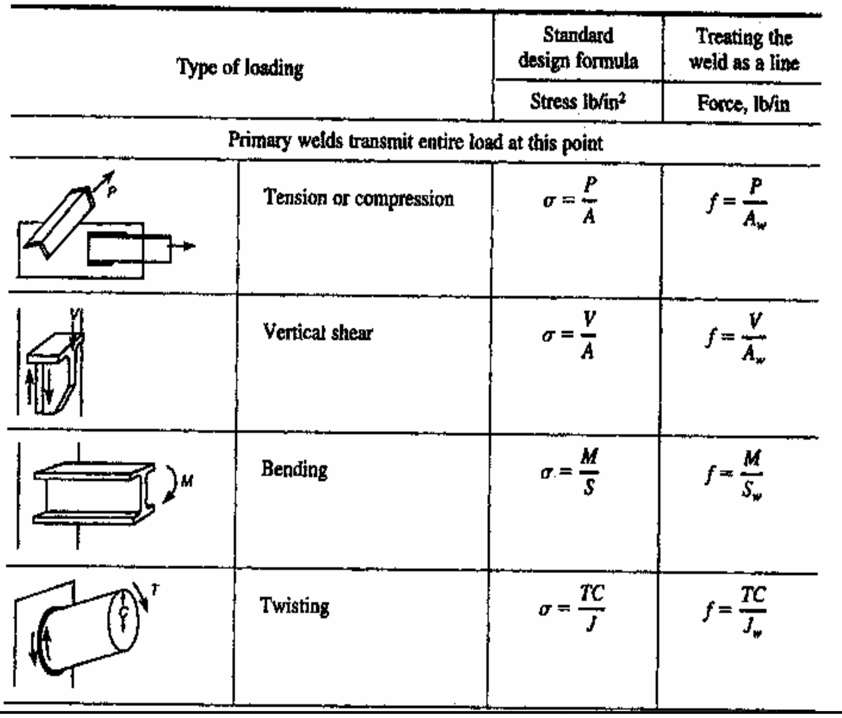
$$w = \frac{\textbf{actual force/in.}}{\textbf{allowable force/in.}} = \frac{f}{0.212 \times Exx}$$

Step 1: Determine Properties



Outline of welded joint b = width d = depth	Bending (about horizontal axis x − x)	Twisting
d, x, x	$S_w = \frac{d^2}{6}$ in^2	$J_w = \frac{d^3}{12}$ in^3
b, x, x, c	$S_w = \frac{d^2}{3}$	$J_w = \frac{d(3b^2 + d^2)}{6}$
b, x, x, d	$S_w = bd$	$J_w = \frac{b^3 + 3bd^2}{6}$
y, b, x, x, y, d $Ny = \frac{b^2}{2(b+d)}$ $Nx = \frac{d^2}{2(b+d)}$	$S_w = \frac{4bd + d^2}{6} = \frac{d^2(4b + d)}{6(2b + d)}$ top bottom	$J_w = \frac{(b + d)^4 - 6b^2d^2}{12(b + d)}$
b, y, x, x, d, y $Ny = \frac{b^2}{2b+d}$	$S_w = bd + \frac{d^2}{6}$	$J_w = \frac{(2b + d)^3}{12} - \frac{b^2(b + d)^2}{2b + d}$

Step 2: Calculate the forces



Type of loading		Standard design formula Stress lb/in²	Treating the weld as a line Force, lb/in
Primary welds transmit entire load at this point			
	Tension or compression	$\sigma = \frac{P}{A}$	$f = \frac{P}{A_w}$
	Vertical shear	$\sigma = \frac{V}{A}$	$f = \frac{V}{A_w}$
	Bending	$\sigma = \frac{M}{S}$	$f = \frac{M}{S_w}$
	Twisting	$\sigma = \frac{TC}{J}$	$f = \frac{TC}{J_w}$

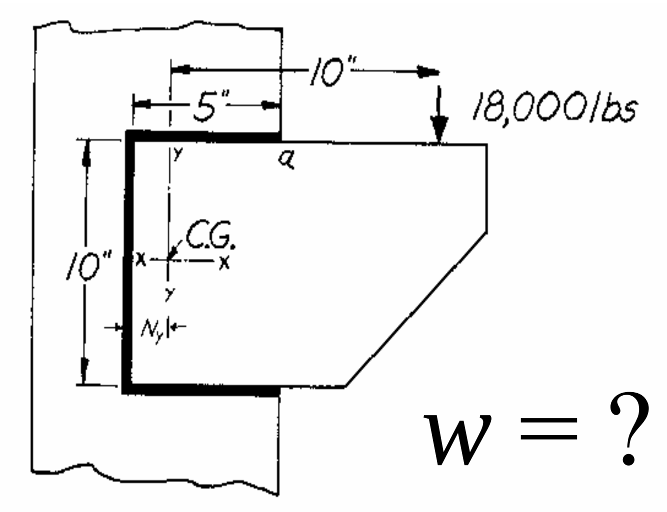
Step 3: Calculate the resultant force

$$f_r = \sqrt{f_1^2 + f_2^2 + f_n^2}$$

Step 4: Calculate the weld size

$$w = \frac{\text{actual force/in.}}{\text{allowable force/in}} = \frac{f_r}{0.212 \times Exx}$$

Example: weld as a line



$$w = ?$$

Step 1: Determine Properties

$$N_y = \frac{b^2}{2b+d} = 1.25\text{in}$$

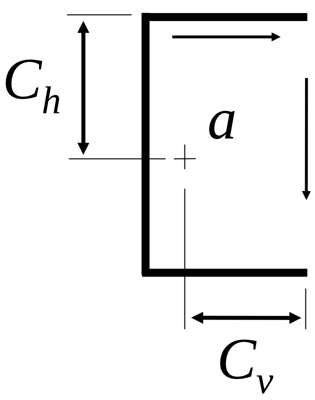
$$J_w = \frac{(2b+d)^3}{12} - \frac{b^2(b+d)^2}{2b+d} = 386\text{in}^3$$

Step 1: Determine Properties

$$A_w = L = 20\text{in (ignoring throat)}$$

Step 2: Calculate the forces

Combined forces are maximum at point a



C_v = 3.75 in

C_h = 5.0 in

Step 2: Calculate the forces

***Torque* = *T* = 18,000 lbf x 10 in.**

Twisting (horizontal component):

$$f_h = \frac{T \cdot c_h}{J_w} = \frac{(180{,}000) \cdot (5)}{386} = 2340 \text{lbf/in}$$

Step 2: Calculate the forces

Twisting (vertical component):

$$f_v = \frac{T \cdot c_v}{J_w} = \frac{(180{,}000) \cdot (3.75)}{386} =$$

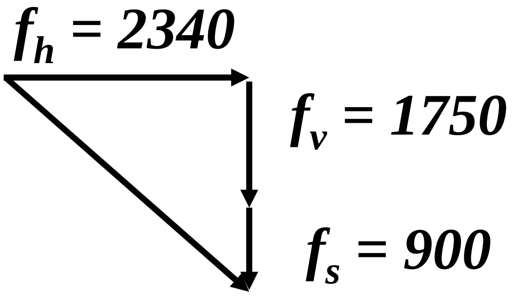
$$= 1750 \text{ lbf/in}$$

Step 2: Calculate the forces

Vertical Shear:

$$f_s = \frac{P}{A_w} = \frac{18{,}000}{20} = 900 \text{ lbf/in}$$

Step 3:
Calculate the resultant force



$$f_r = \sqrt{f_h^2 + \left(f_v + f_s\right)^2} = 3540 \text{ lbf/in.}$$

Step 4: Calculate the weld size

$$w = \frac{\text{actual force/in.}}{\text{allowable force/in.}} = \frac{f_r}{0.212 \times Exx}$$

using Exx = 70,000

$$w = \frac{3540}{0.212 \times 70{,}000} = .238\text{in (use 1/4in)}$$

Weld Properties

Weld Capacity

Weld Size (throat) +

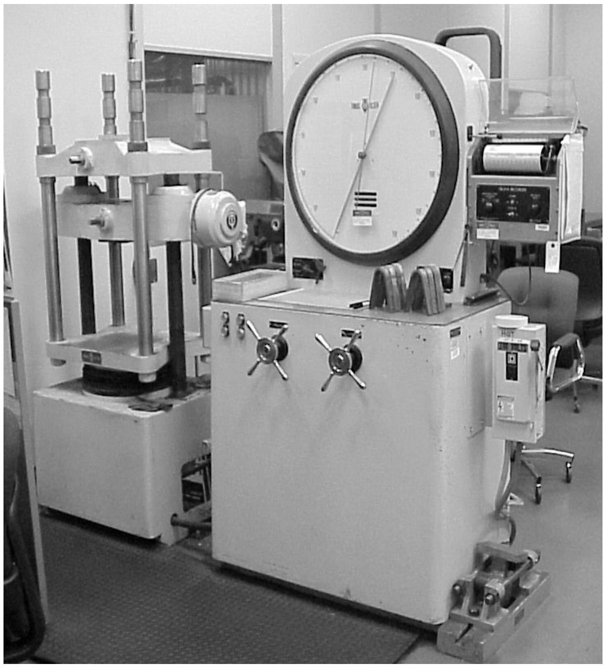
Deposited Weld Strength

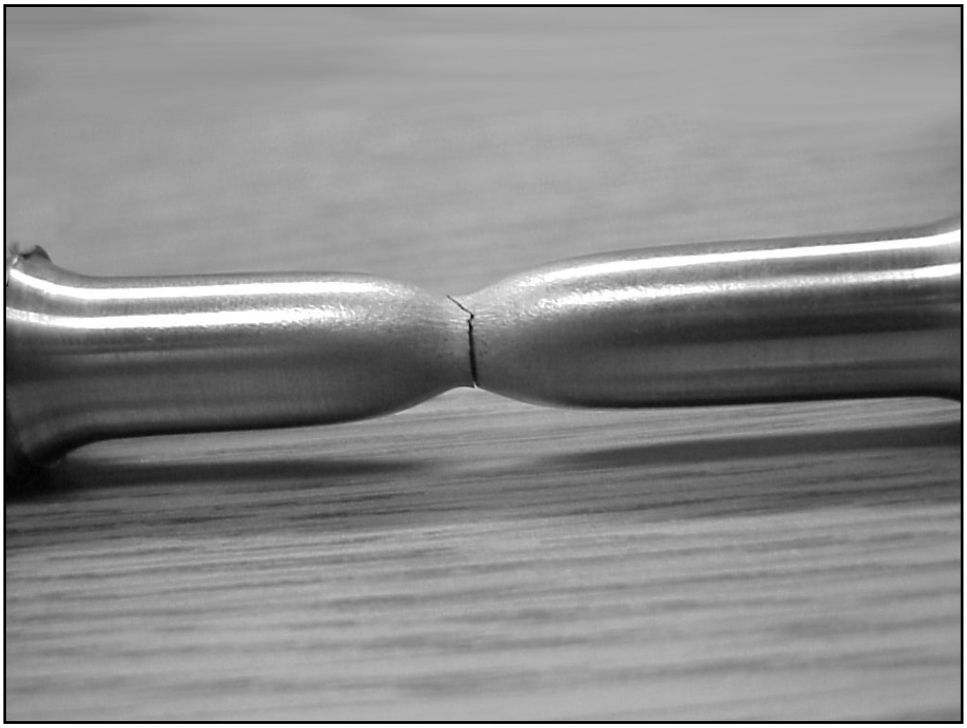
Mechanical Properties

- Ultimate Tensile Strength
- Yield Strength
- Elongation
- Modulus of Elasticity
- Compressive Strength
- Shear Strength
- Fatigue Strength
- Fracture Toughness
- Hardness

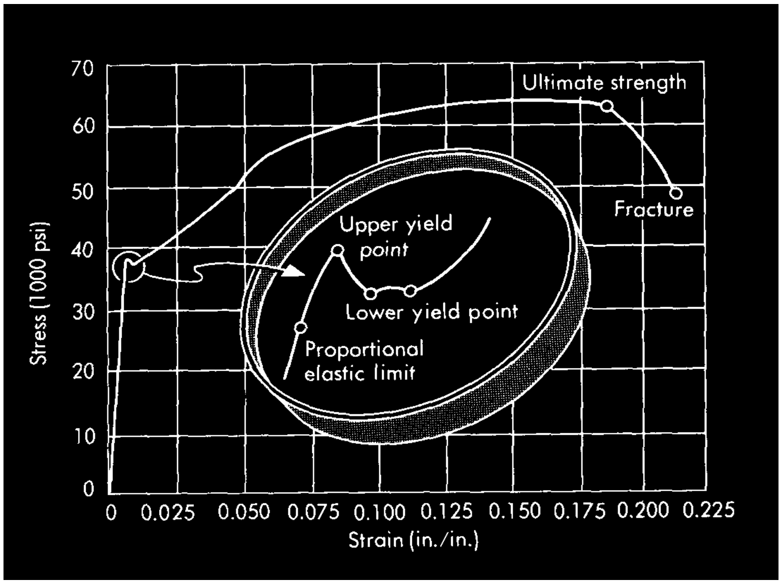
Mechanical Properties

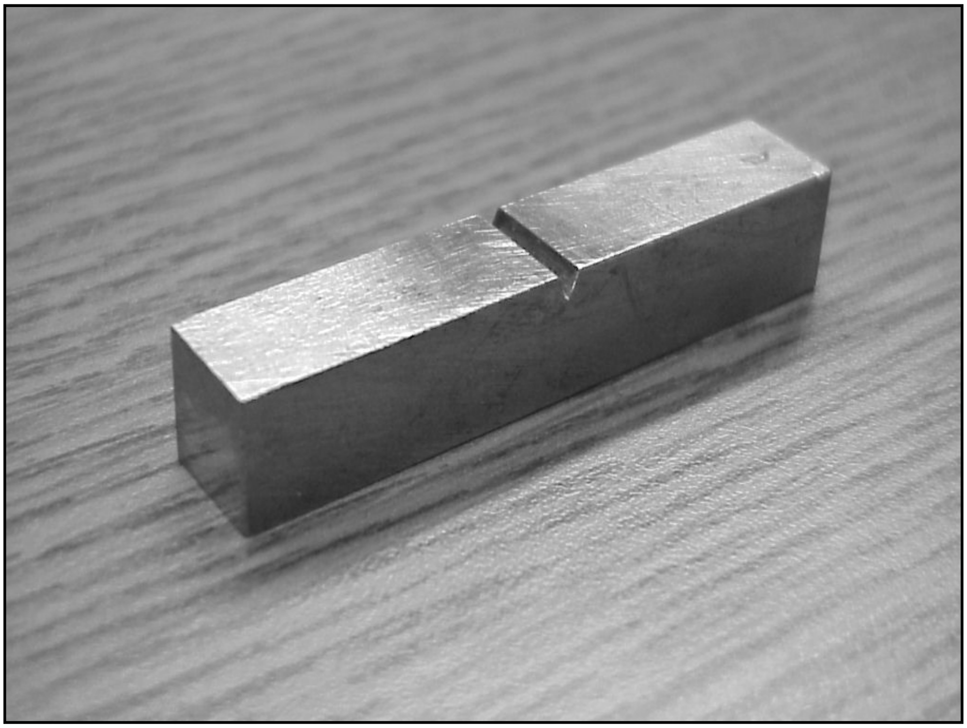
- Ultimate Tensile Strength
- Yield Strength
- Elongation
- Modulus of Elasticity
- Compressive Strength
- Shear Strength
- Fatigue Strength
- Fracture Toughness
- Hardness

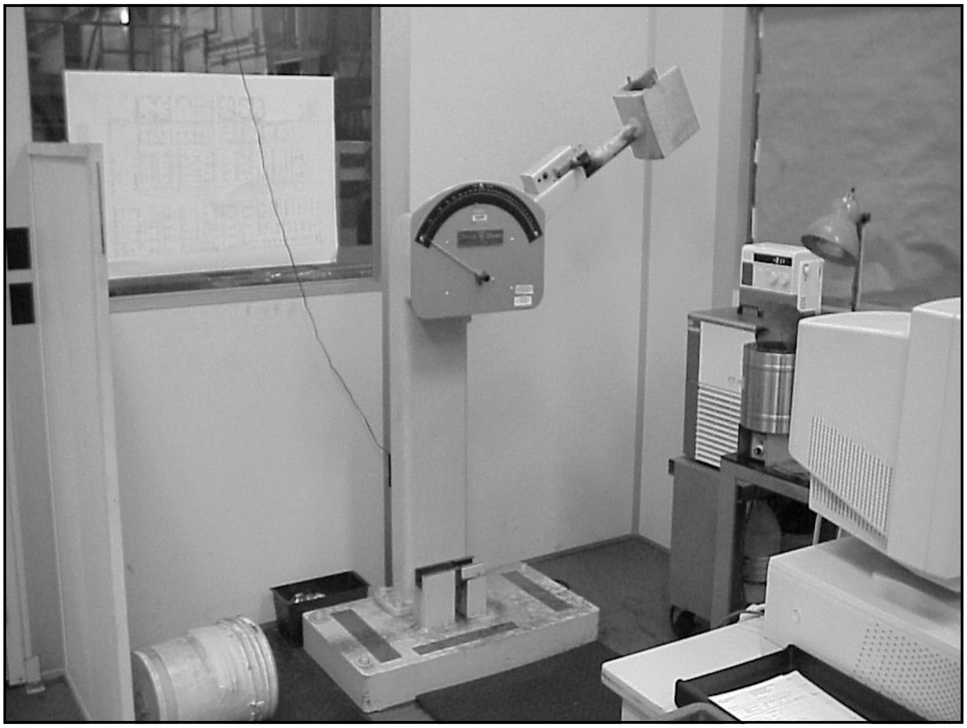




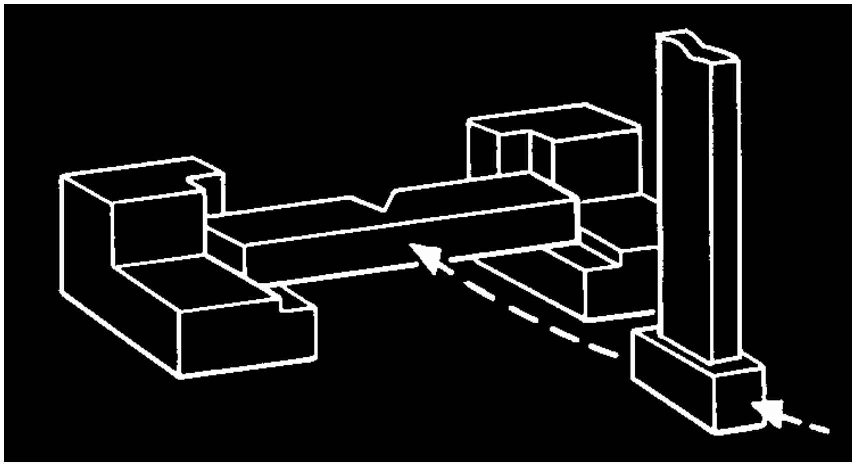
Tensile Test Results



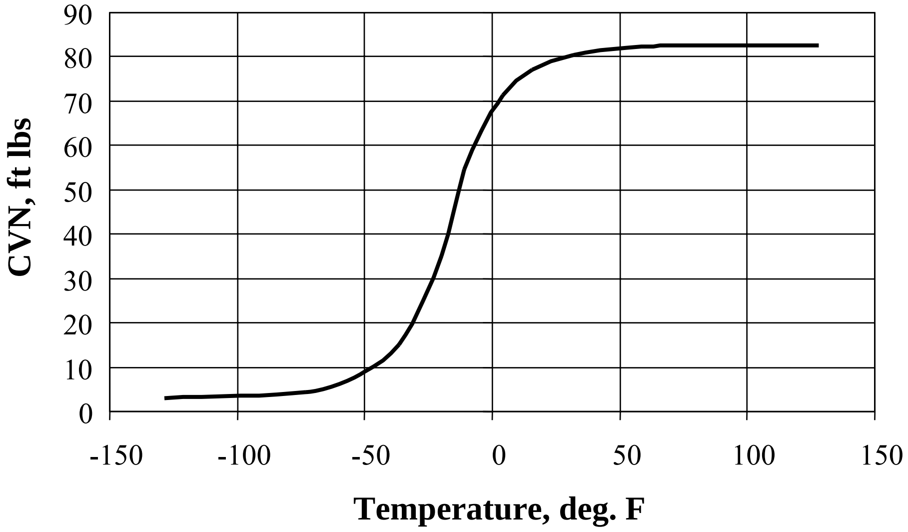




CVN Specimen



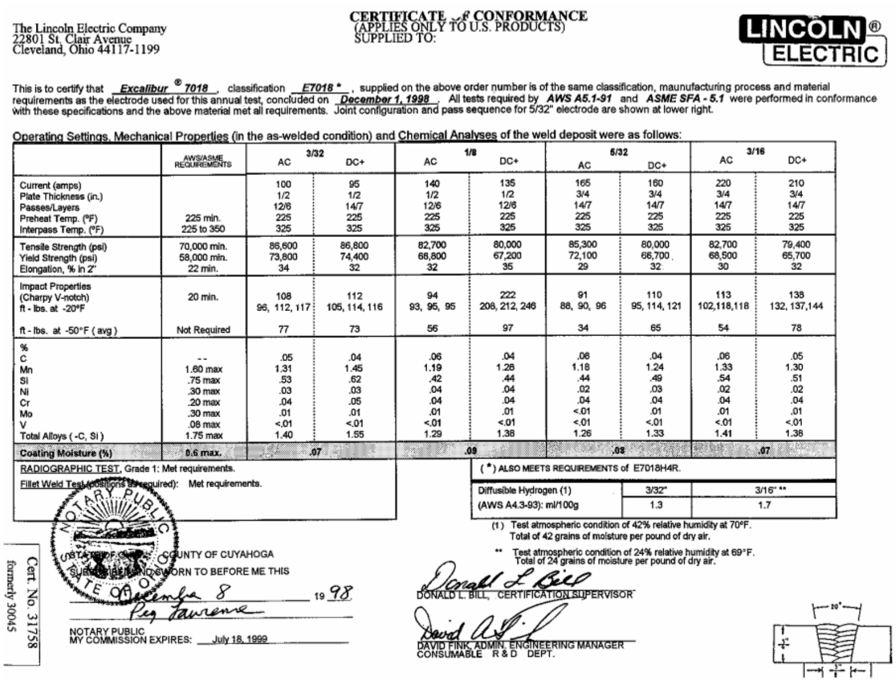
Charpy V-Notch Test (CVN)



Mechanical Property Requirements

E7018

Yield: 58 ksi min.
Tensile: 70 ksi min.
Elong.: 22% min.
CVN: 20 ft lb @ -20 deg. F



The Lincoln Electric Company
22801 St. Clair Avenue
Cleveland, Ohio 44117-1199

CERTIFICATE of CONFORMANCE
(APPLIES ONLY TO U.S. PRODUCTS)
SUPPLIED TO:

LINCOLN® ELECTRIC

This is to certify that ***Excalibur® 7018***, classification ***E7018 ****, supplied on the above order number is of the same classification, maunufacturing process and material requirements as the electrode used for this annual test, concluded on ***December 1, 1998***. All tests required by ***AWS A5.1-91*** and ***ASME SFA - 5.1*** were performed in conformance with these specifications and the above material met all requirements. Joint configuration and pass sequence for 5/32" electrode are shown at lower right.

Operating Settings, Mechanical Properties (in the as-welded condition) and Chemical Analyses of the weld deposit were as follows:

	AWS/ASME REQUIREMENTS	3/32		1/8		5/32		3/16	
		AC	DC+	AC	DC+	AC	DC+	AC	DC+
Current (amps)		100	95	140	135	165	160	220	210
Plate Thickness (in.)		1/2	1/2	1/2	1/2	3/4	3/4	3/4	3/4
Passes/Layers		12/6	14/7	12/6	12/6	14/7	14/7	14/7	14/7
Preheat Temp. (°F)	225 min.	225	225	225	225	225	225	225	225
Interpass Temp. (°F)	225 to 350	325	325	325	325	325	325	325	325
Tensile Strength (psi)	70,000 min.	86,600	86,800	82,700	80,000	85,300	80,000	82,700	79,400
Yield Strength (psi)	58,000 min.	73,800	74,400	68,800	67,200	72,100	66,700	68,500	65,700
Elongation, % in 2"	22 min.	34	32	32	35	29	32	30	32
Impact Properties (Charpy V-notch) ft - lbs. at -20°F	20 min.	108 96, 112, 117	112 105, 114, 116	94 93, 95, 95	222 208, 212, 246	91 88, 90, 96	110 95, 114, 121	113 102,118,118	138 132, 137,144
ft - lbs. at -50°F (avg)	Not Required	77	73	56	97	34	65	54	78
%									
C	- -	.05	.04	.06	.04	.06	.04	.06	.05
Mn	1.60 max	1.31	1.45	1.19	1.26	1.16	1.24	1.33	1.30
Si	.75 max	.53	.62	.42	.44	.44	.49	.54	.51
Ni	.30 max	.03	.03	.04	.04	.02	.03	.02	.02
Cr	.20 max	.04	.05	.04	.04	.04	.04	.04	.04
Mo	.30 max	.01	.01	.01	.01	<.01	.01	.01	.01
V	.08 max	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Total Alloys (-C, Si)	1.75 max	1.40	1.55	1.29	1.38	1.26	1.33	1.41	1.38
Coating Moisture (%)	**0.6 max.**	**.07**		**.09**		**.08**		**.07**	

RADIOGRAPHIC TEST, Grade 1: Met requirements.

Fillet Weld Test (positions as required): Met requirements.

(*) ALSO MEETS REQUIREMENTS of E7018H4R.

	3/32"	3/16" **
Diffusible Hydrogen (1) (AWS A4.3-93): ml/100g	1.3	1.7

(1) Test atmospheric condition of 42% relative humidity at 70°F.
Total of 42 grains of moisture per pound of dry air.

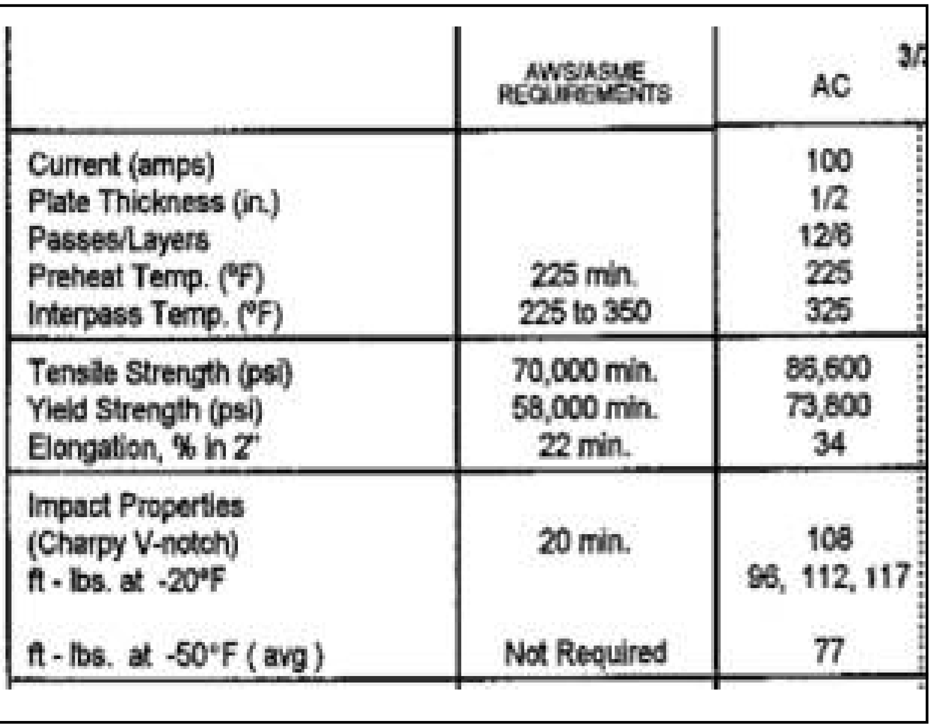
** Test atmospheric condition of 24% relative humidity at 69°F.
Total of 24 grains of moisture per pound of dry air.

STATE OF OHIO, COUNTY OF CUYAHOGA
SUBSCRIBED AND SWORN TO BEFORE ME THIS
December 8 19 98
Peg Lawrence
NOTARY PUBLIC
MY COMMISSION EXPIRES: July 18, 1999

Cert. No. 31758
formerly 30045

Donald L Bill
DONALD L. BILL, CERTIFICATION SUPERVISOR

David A
DAVID FINK, ADMIN. ENGINEERING MANAGER
CONSUMABLE R & D DEPT.



	AWS/ASME REQUIREMENTS	AC
Current (amps)		100
Plate Thickness (in.)		1/2
Passes/Layers		12/6
Preheat Temp. (°F)	225 min.	225
Interpass Temp. (°F)	225 to 350	325
Tensile Strength (psi)	70,000 min.	86,600
Yield Strength (psi)	58,000 min.	73,800
Elongation, % in 2"	22 min.	34
Impact Properties		
(Charpy V-notch)	20 min.	108
ft - lbs. at -20°F		96, 112, 117
ft - lbs. at -50°F (avg)	Not Required	77

REMEMBER: Steel properties typically based on minimum specified yield strength. Weld metal is typically based on tensile strength.

Resources:

- **-AISC Solutions Center (aisc.org)**
- **-James F Lincoln Arc Welding Foundation (jflf.org)**
- **-The Lincoln Electric Company (lincolnelectric.com)**

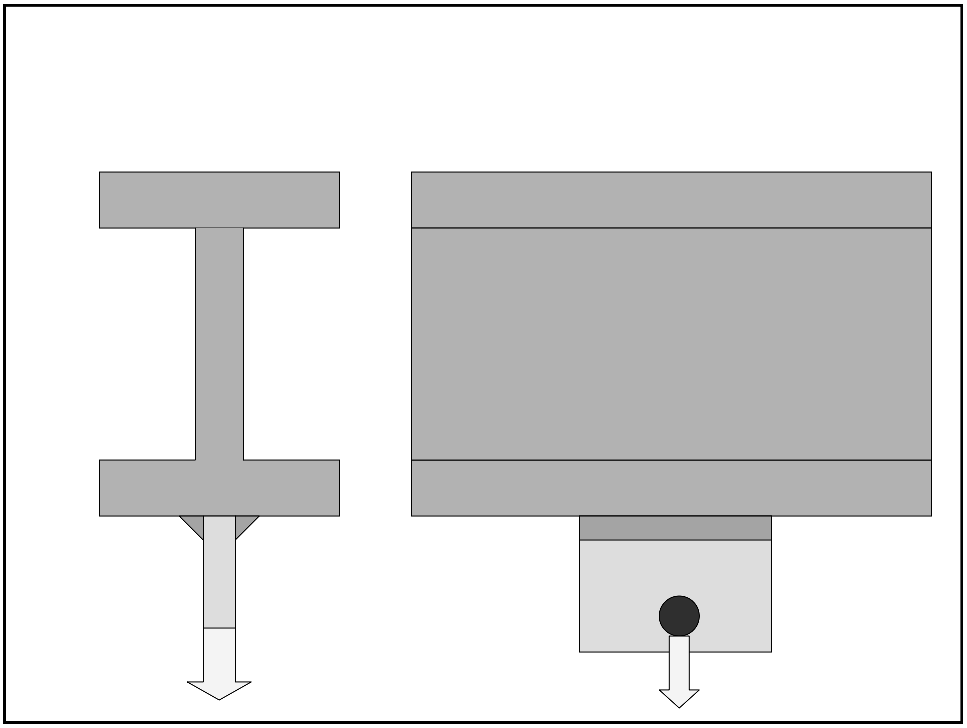
PRINCIPLES
OF
CONNECTION
DESIGN

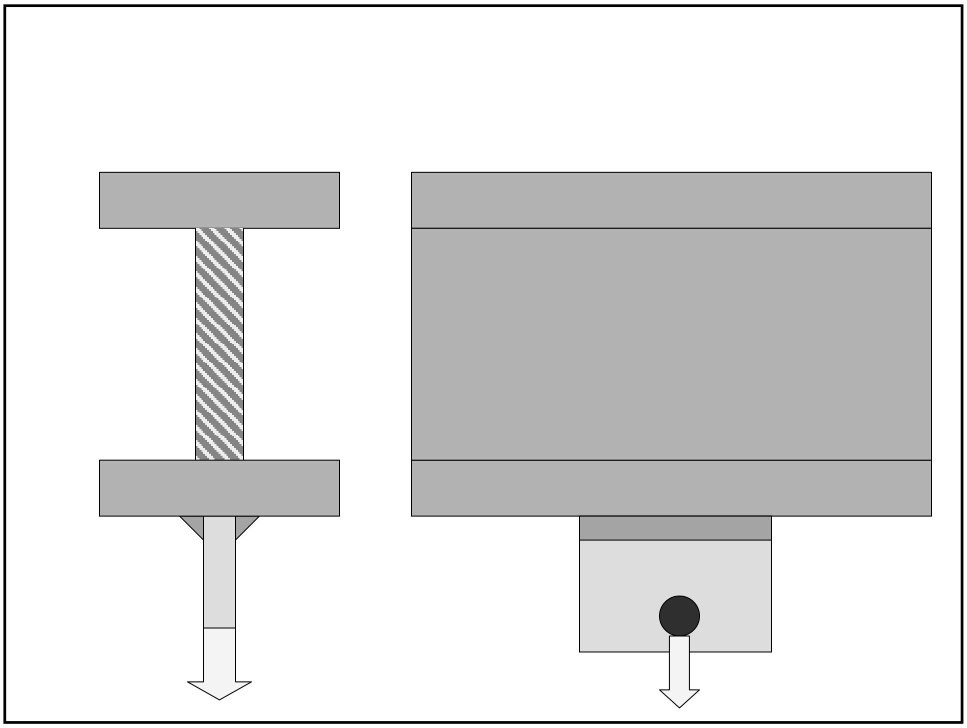
Principle 1

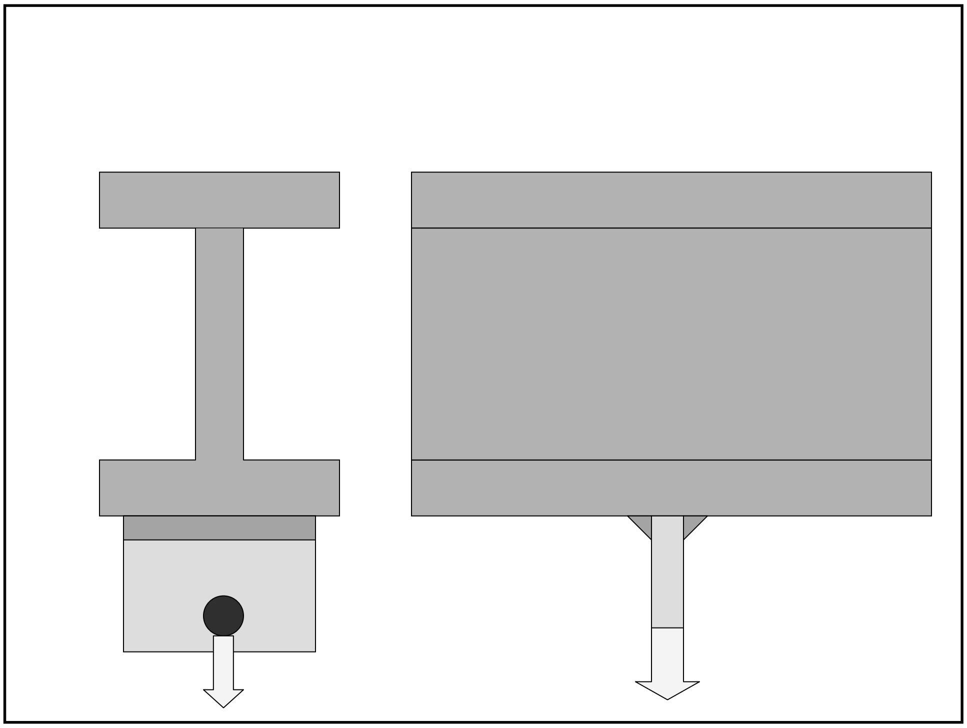
PROVIDE A PATH FOR THE FORCE TO ENTER INTO THE SECTION THAT LIES PARALLEL

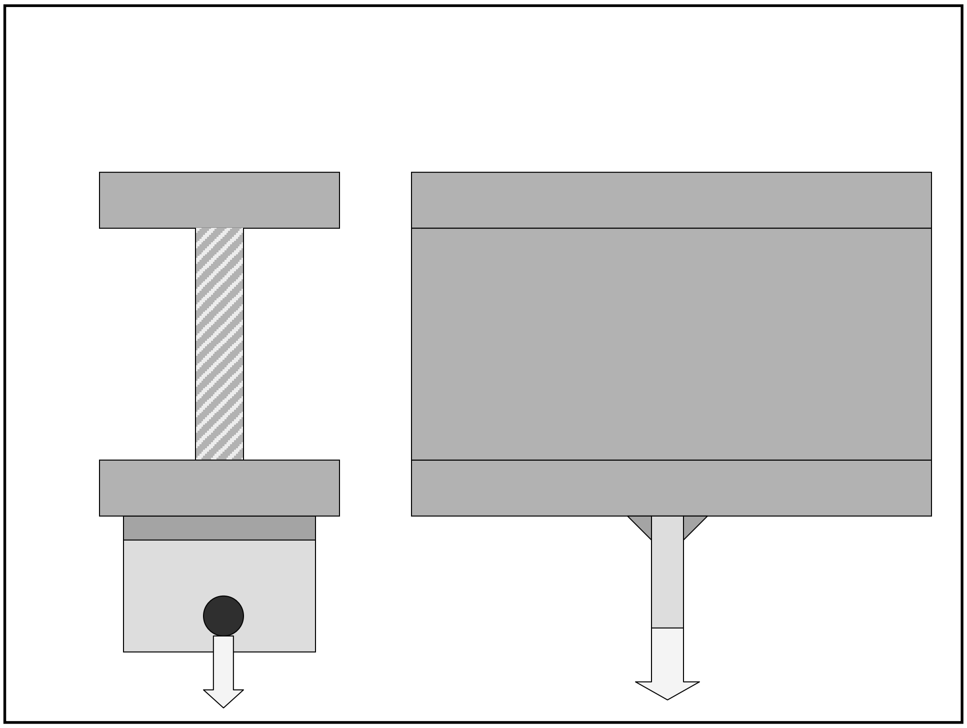
"THE FORCE GOES TO THE STIFF PART."

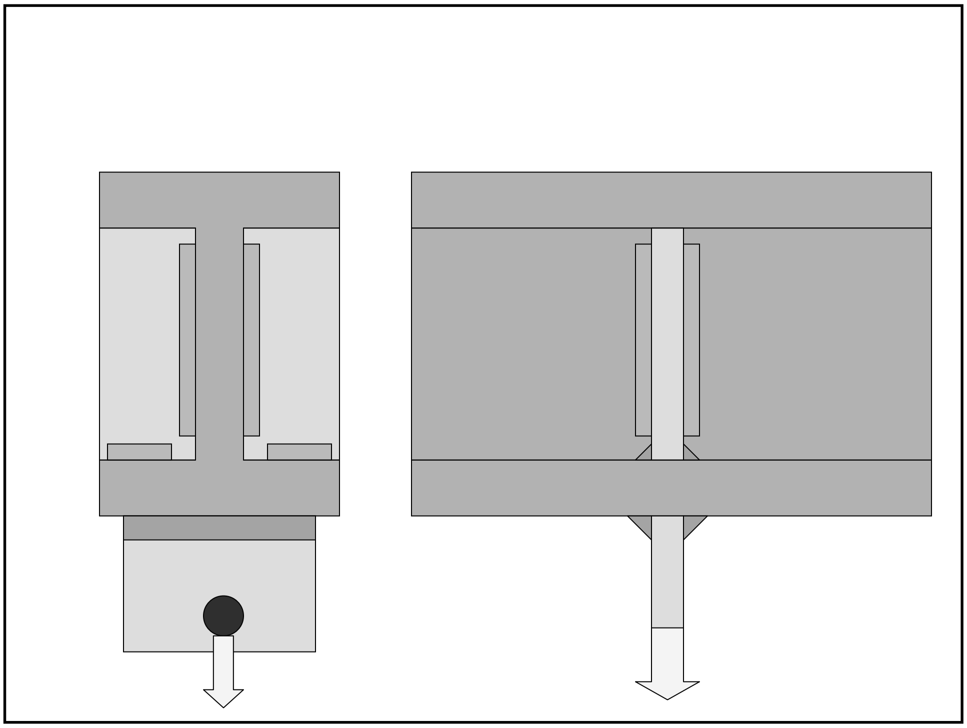
Bill Milek,
Vice President, AISC (Retired)

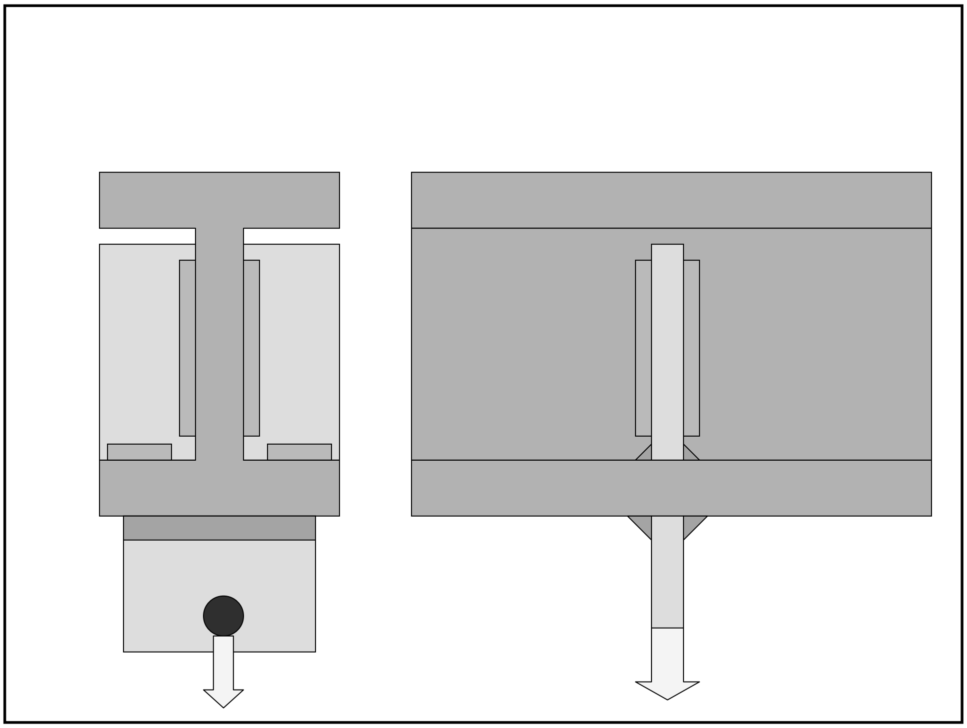


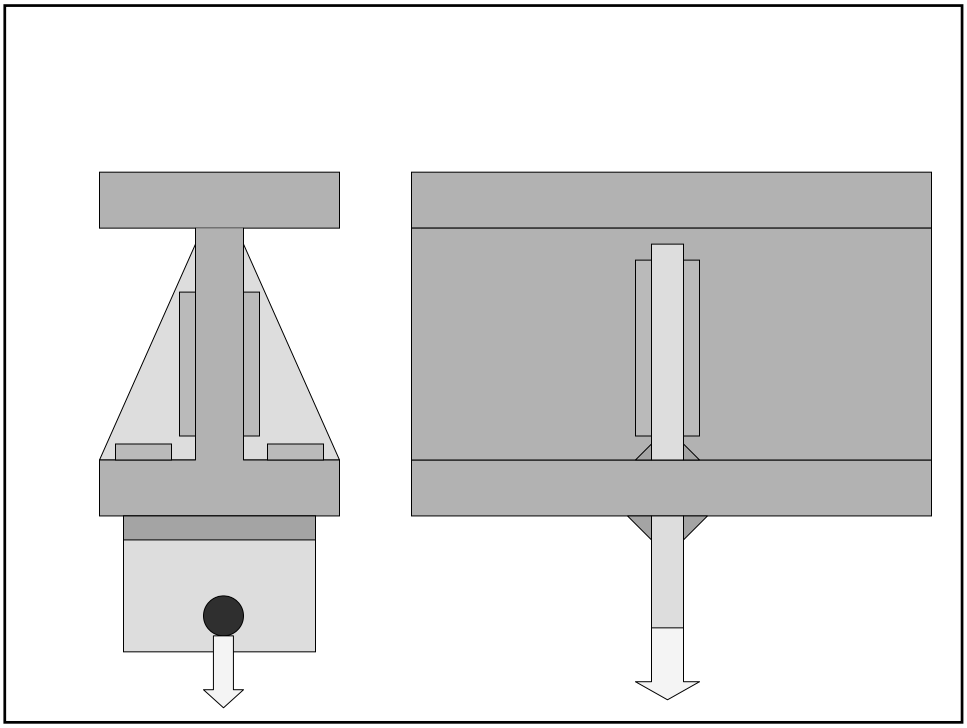


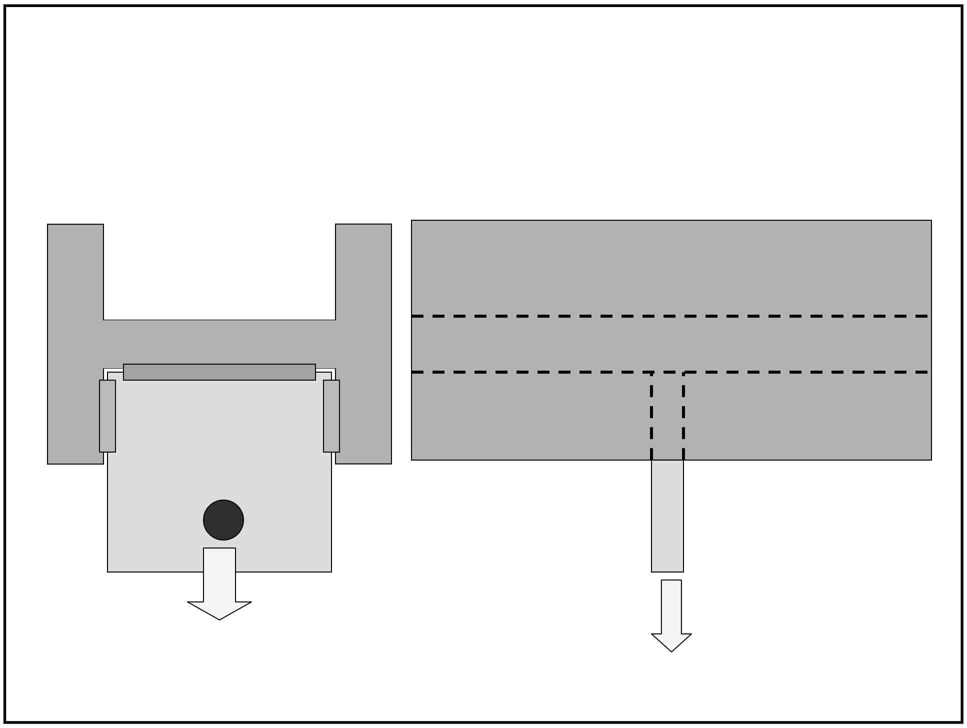


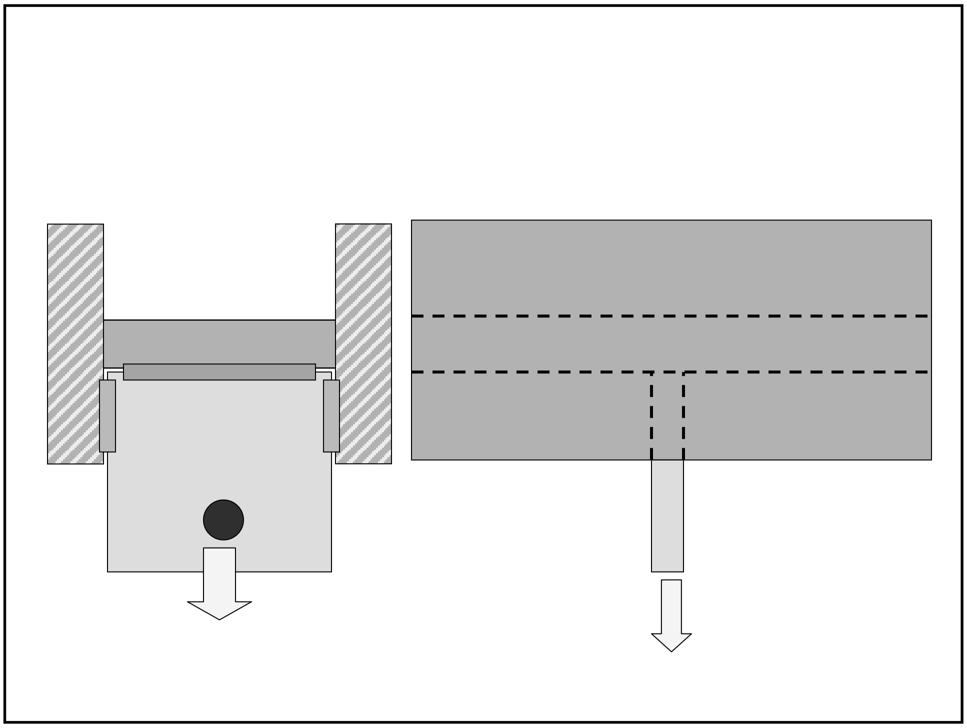


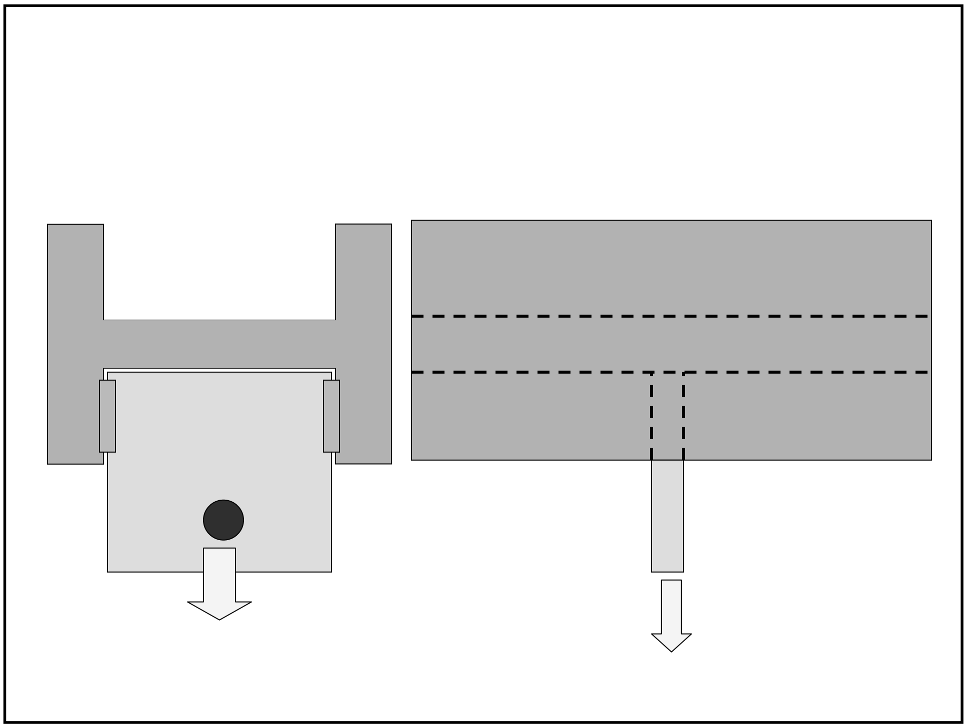


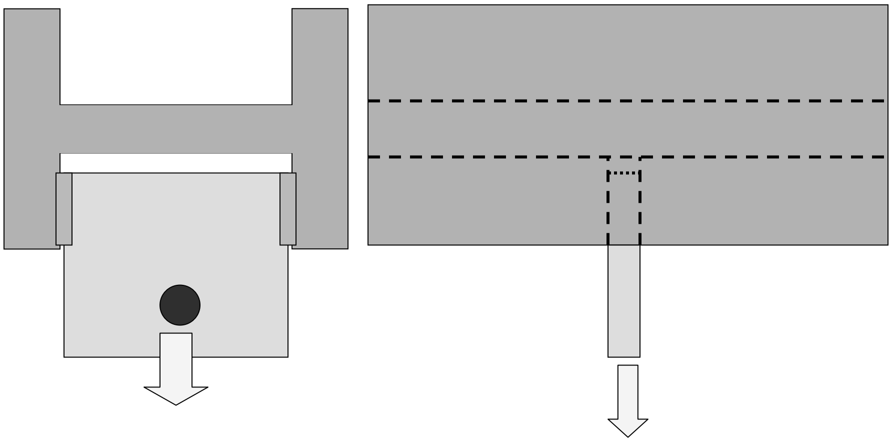




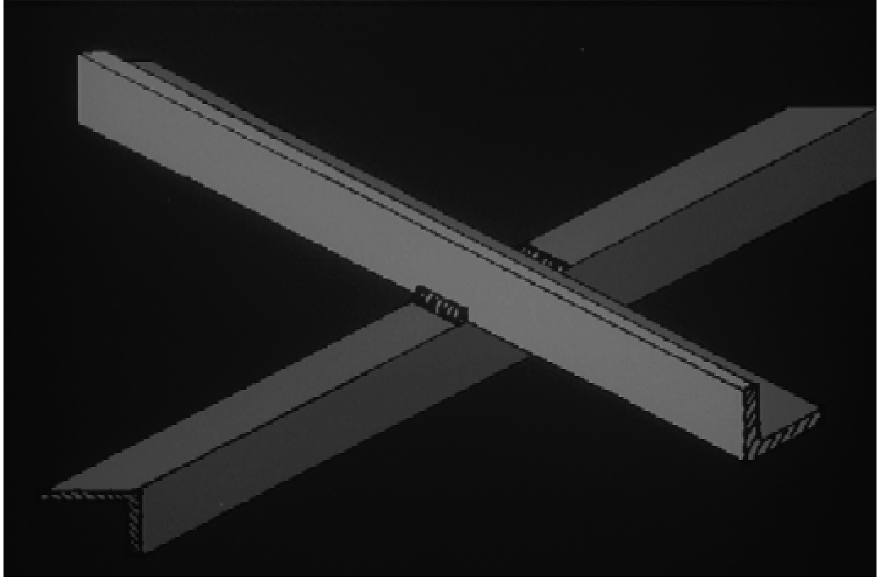


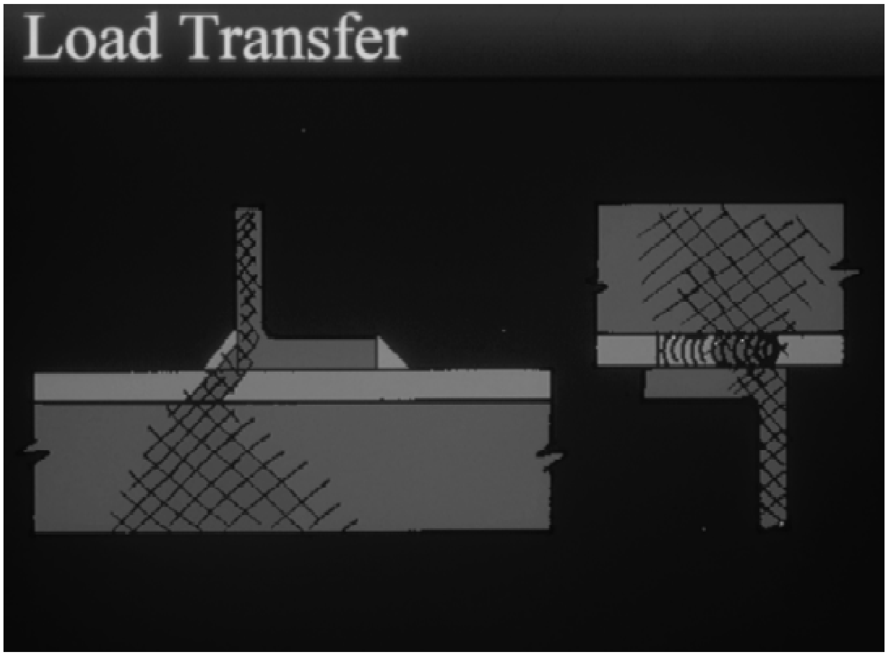




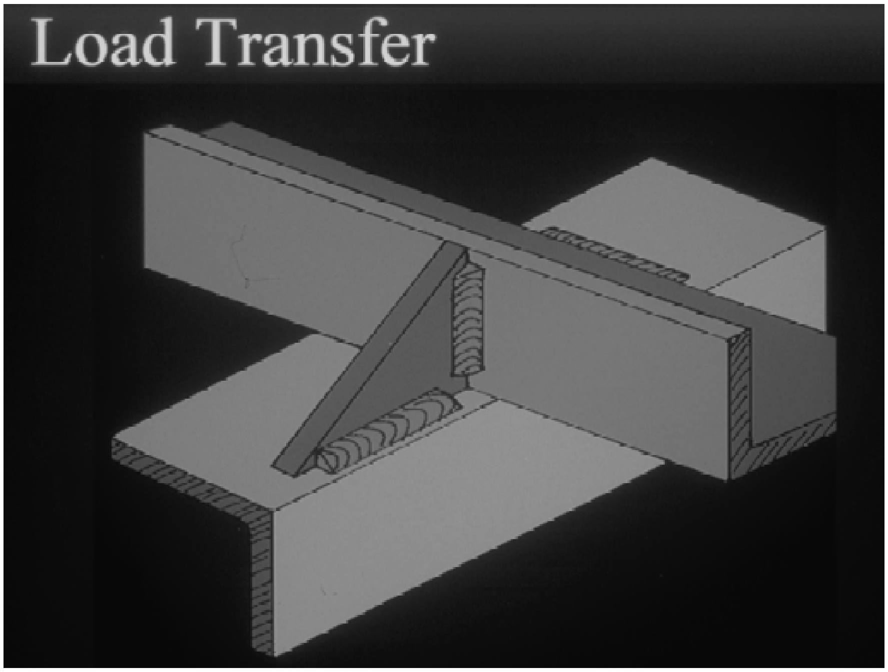


Load Transfer

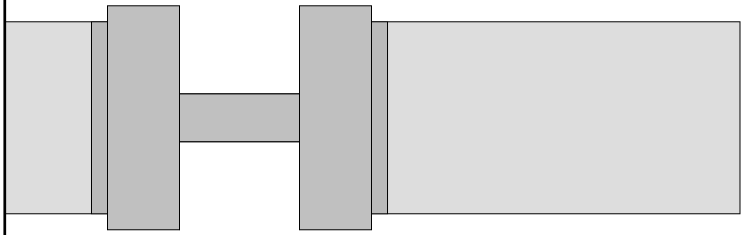


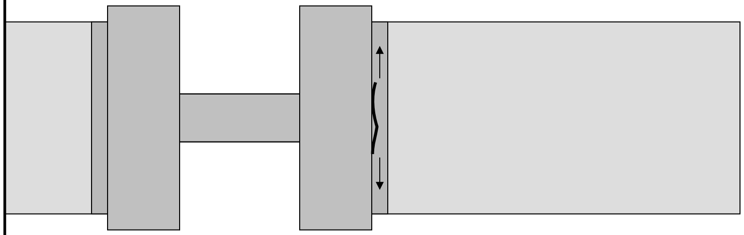


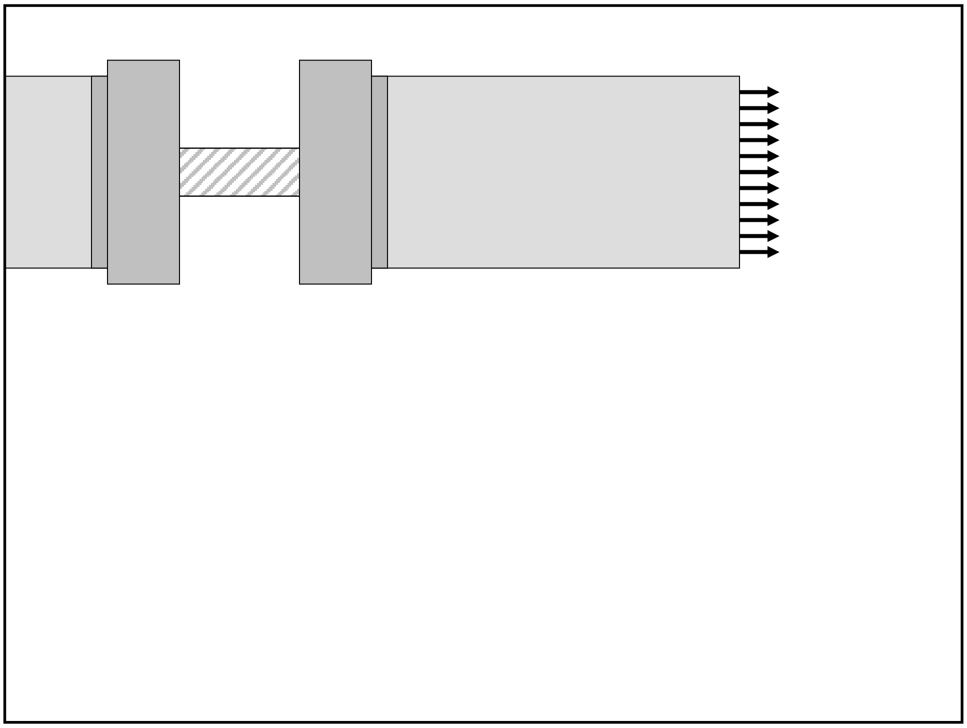
Load Transfer

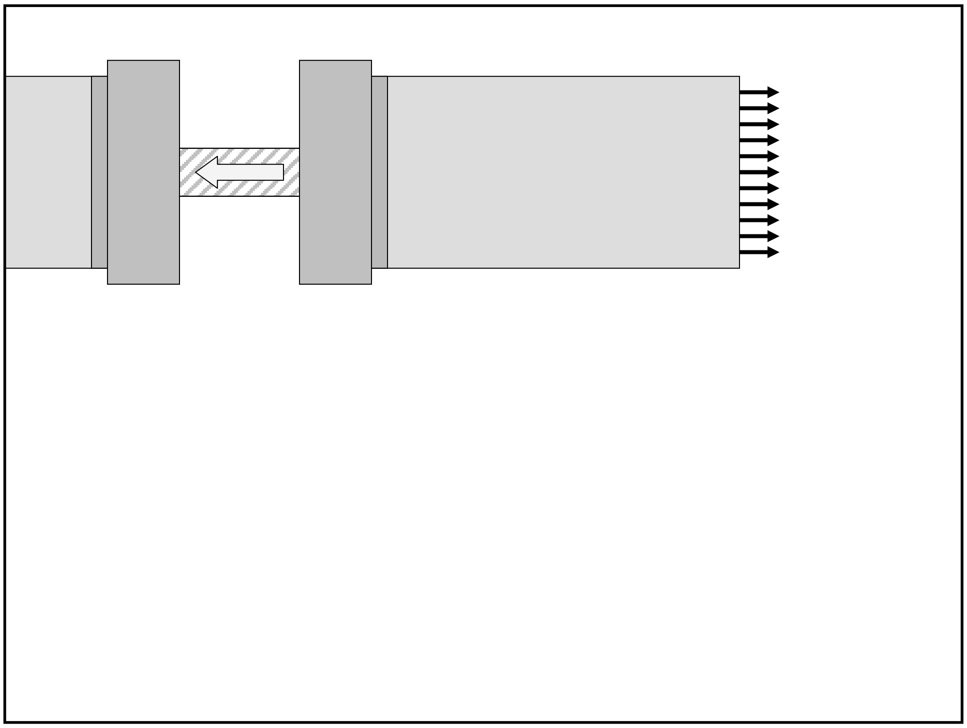


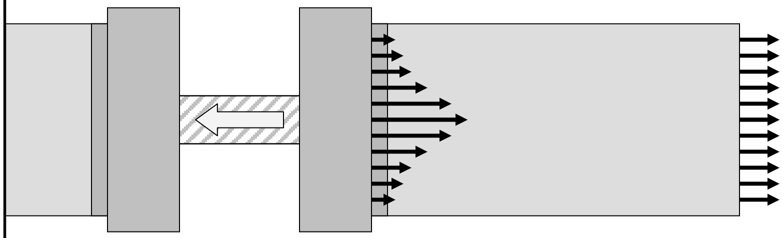
Load Transfer

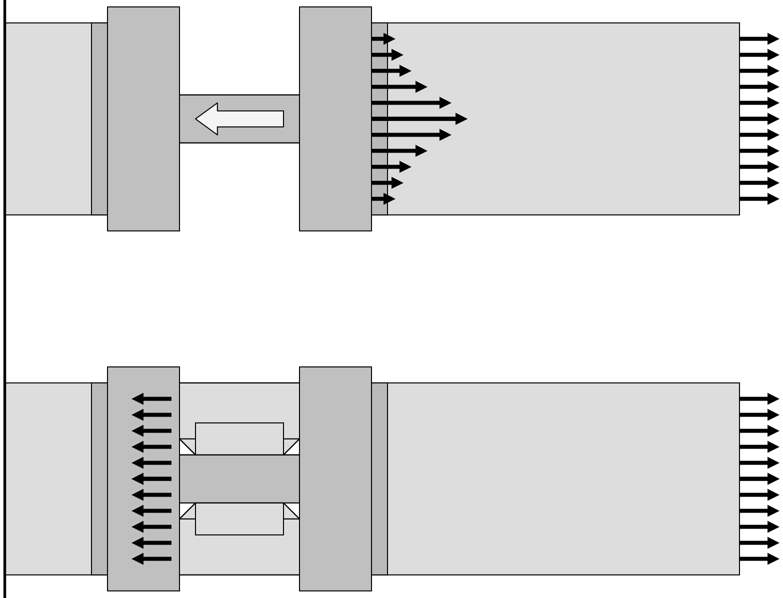


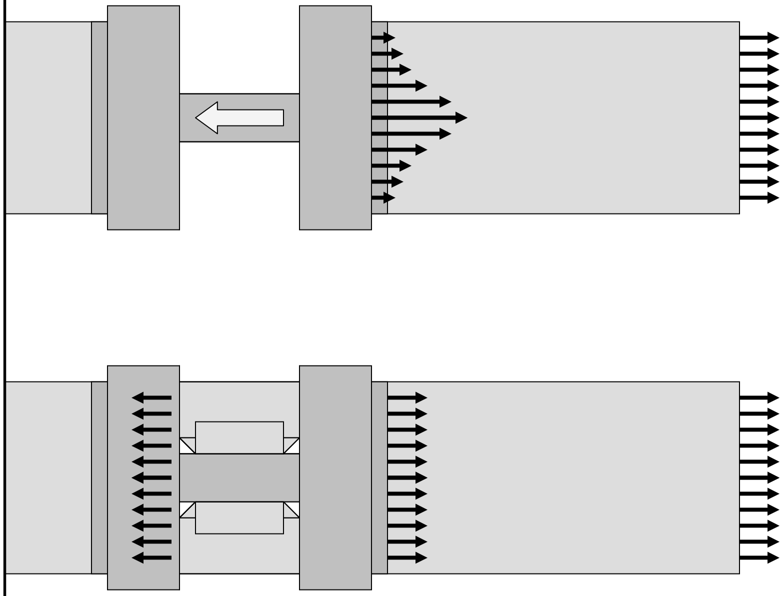


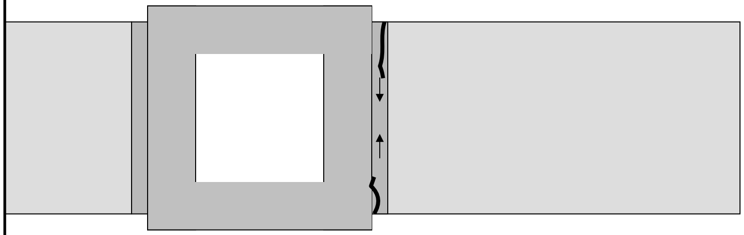


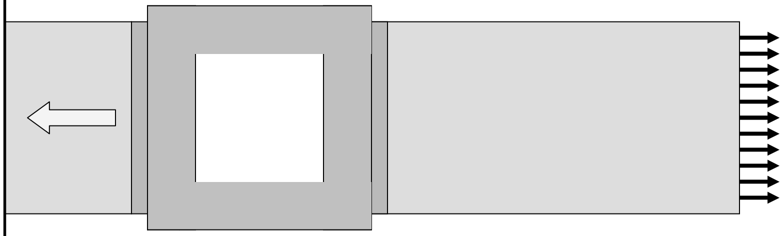


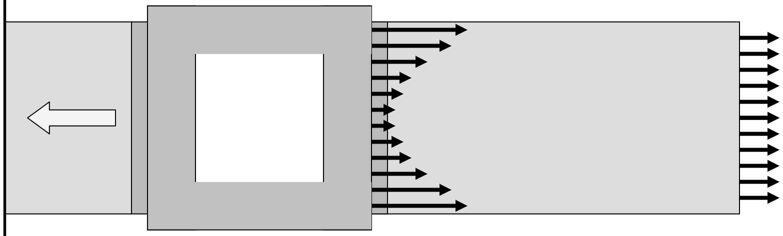


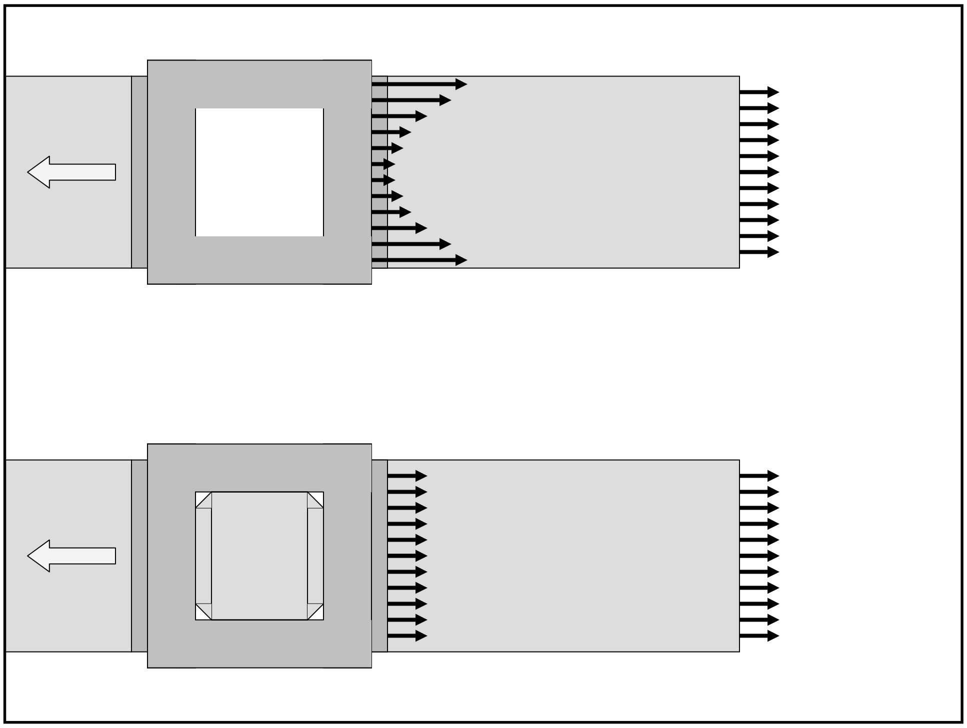


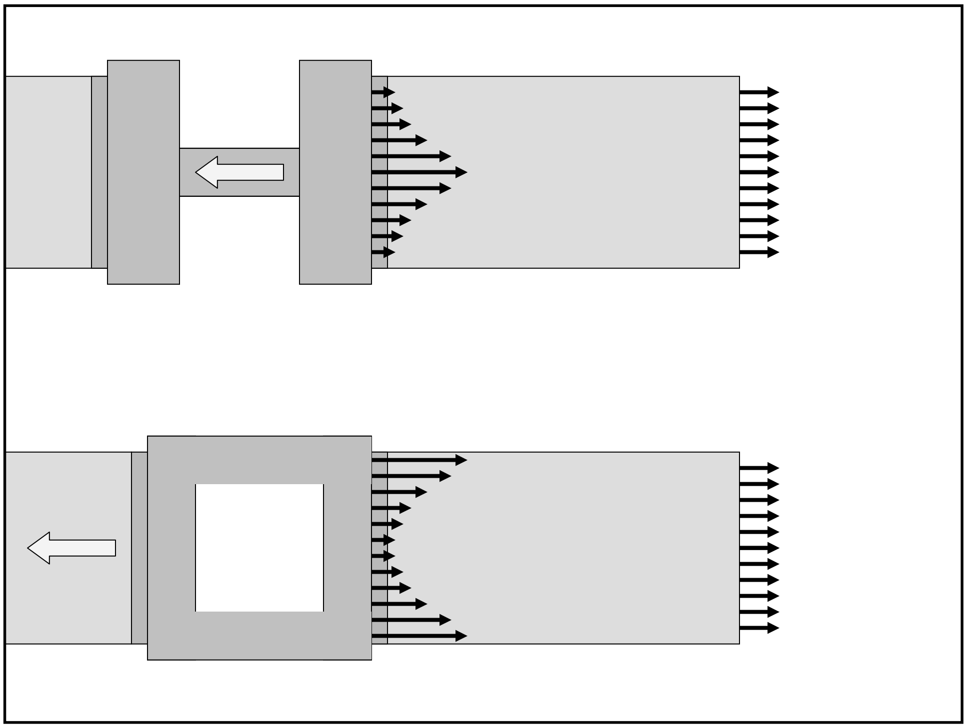


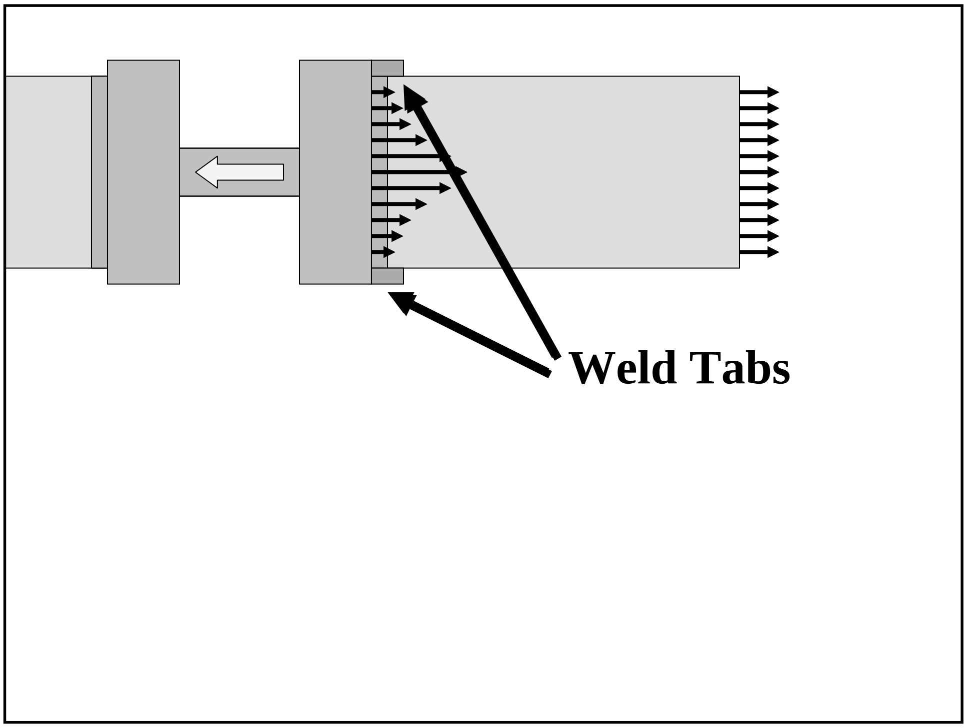


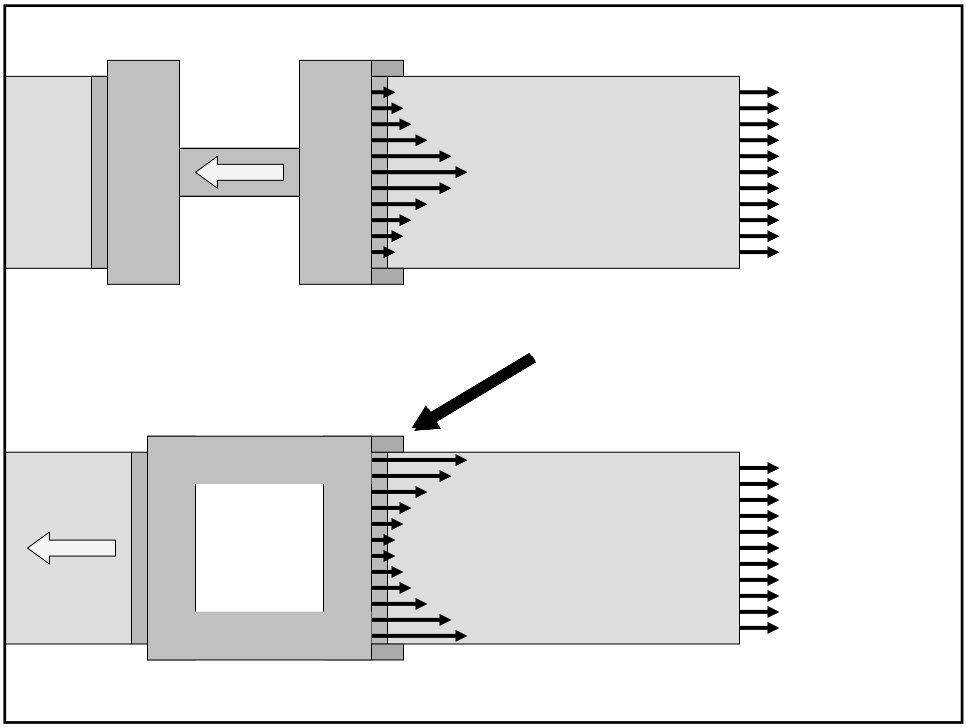


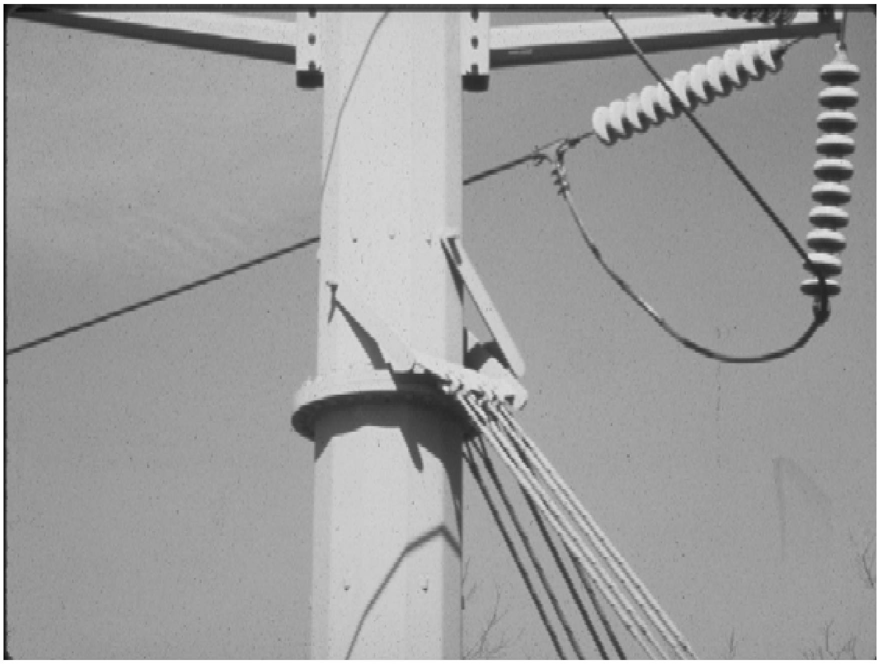


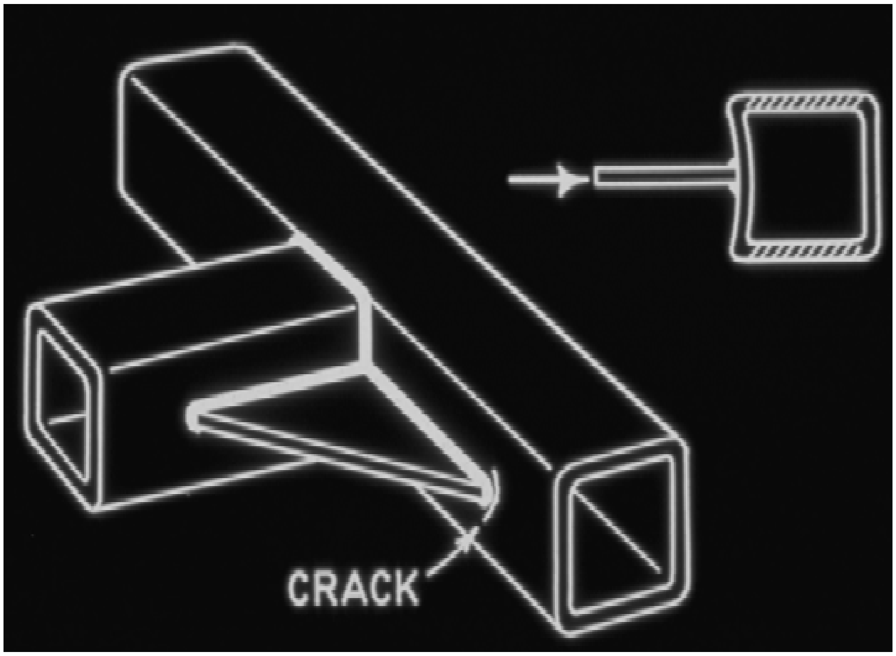


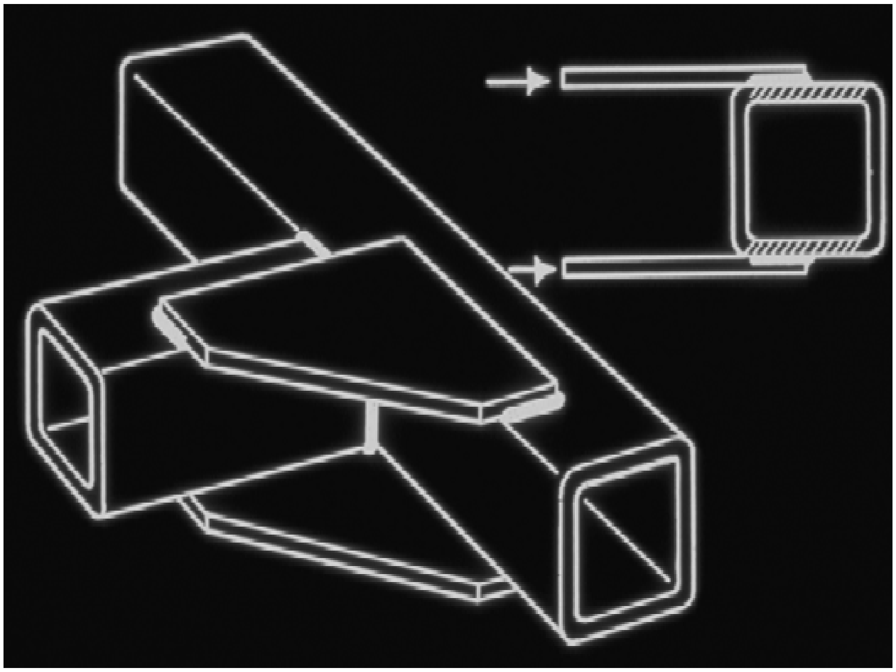


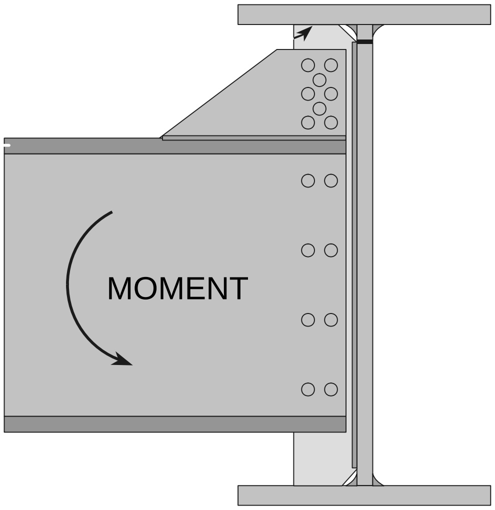

Weld Tabs






CRACK

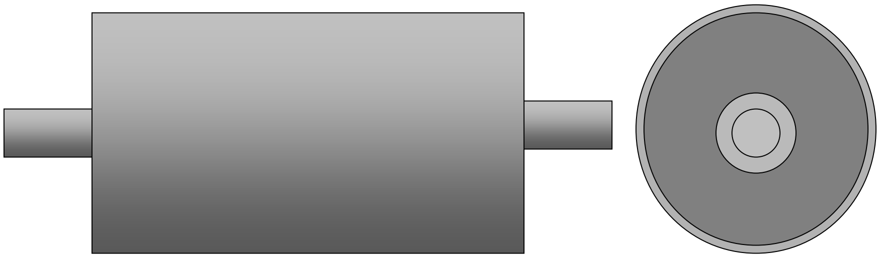


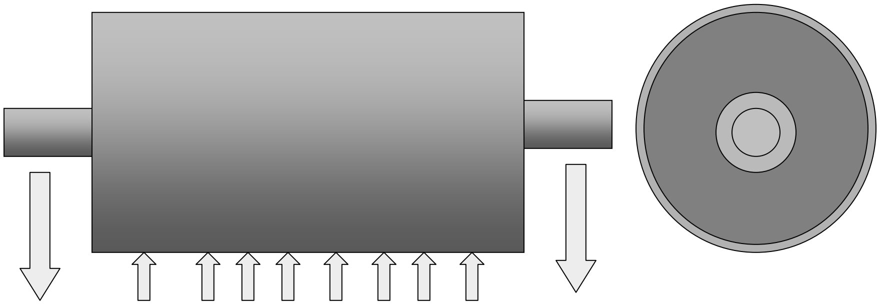


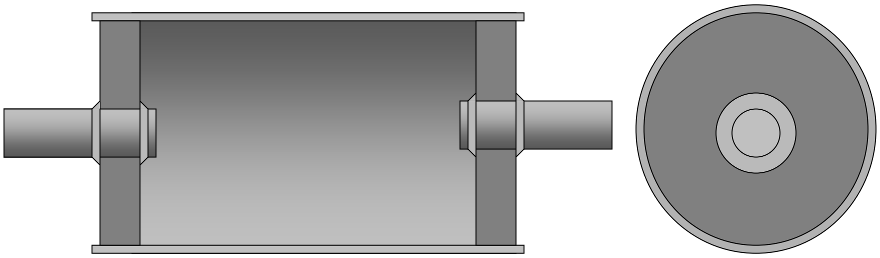
Principle 2

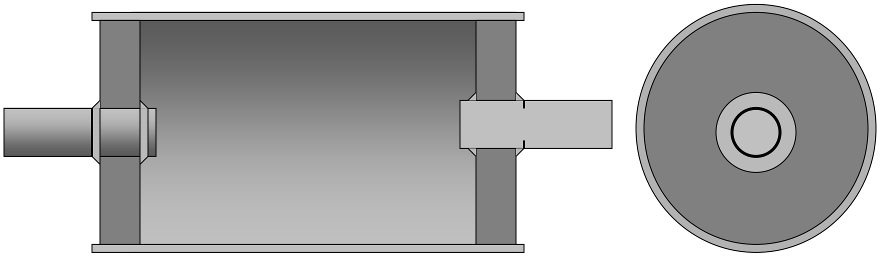
DON’T PUT WELD IN BENDING

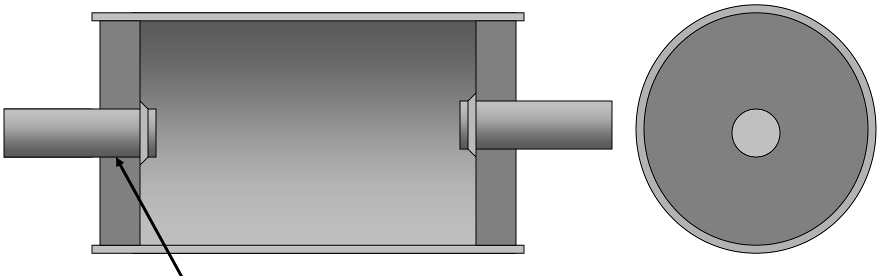
Linoleum Roll



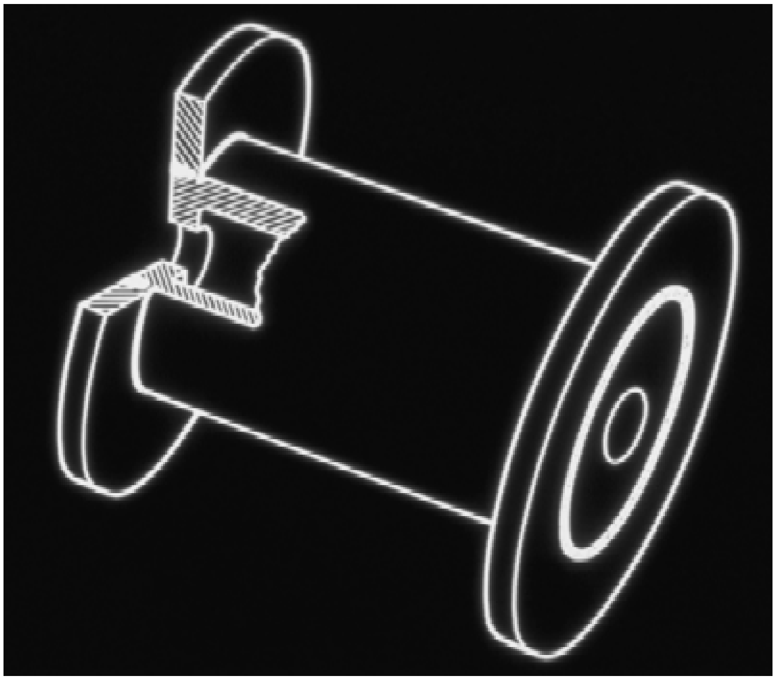




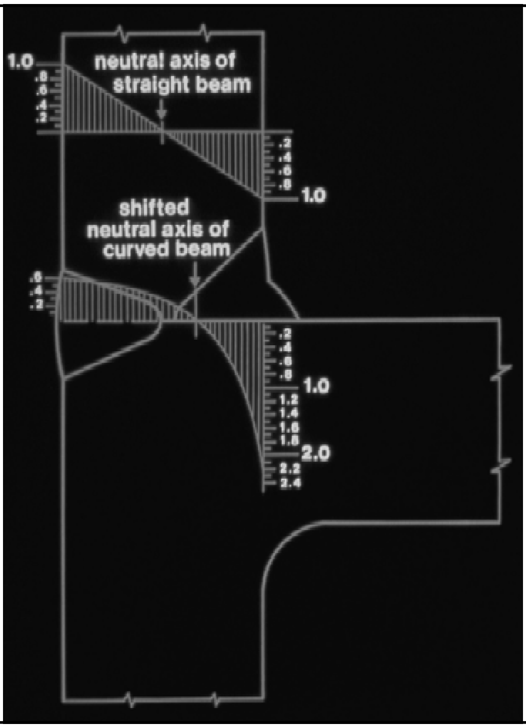


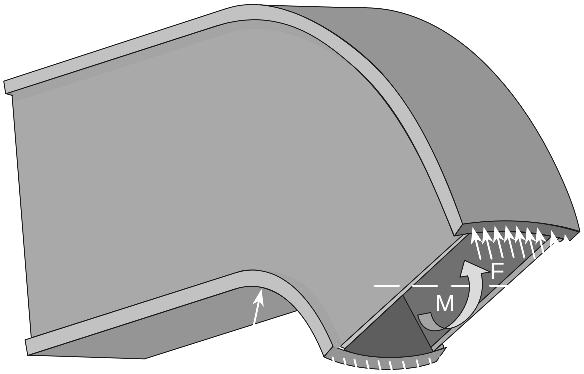


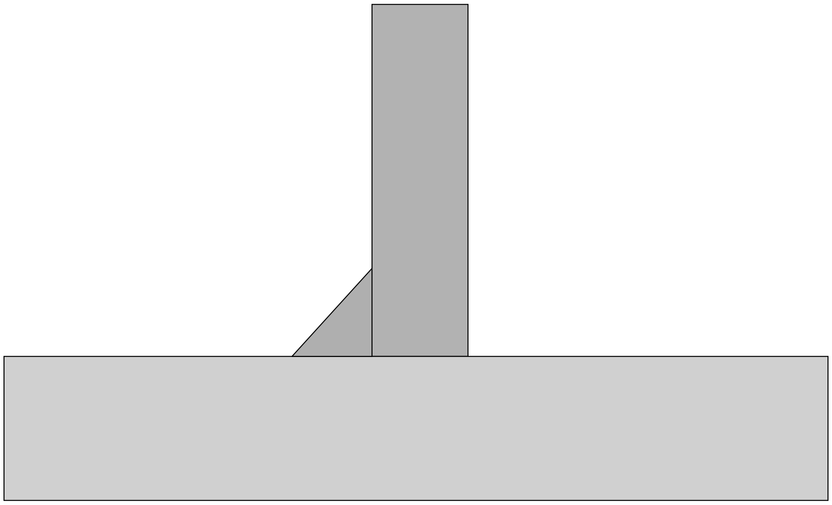
Press Fit

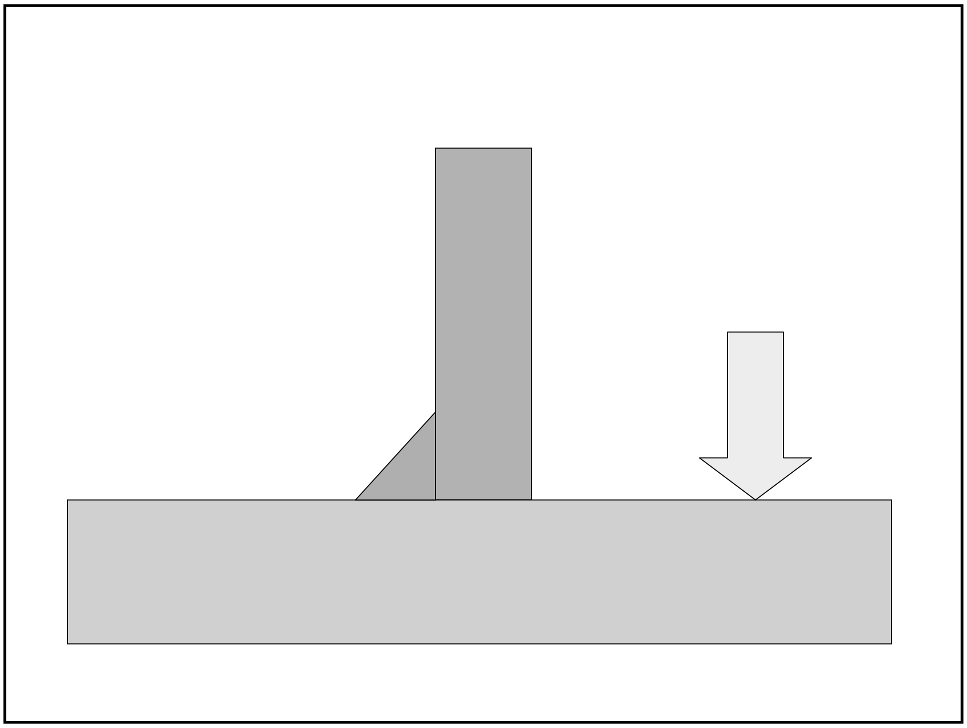


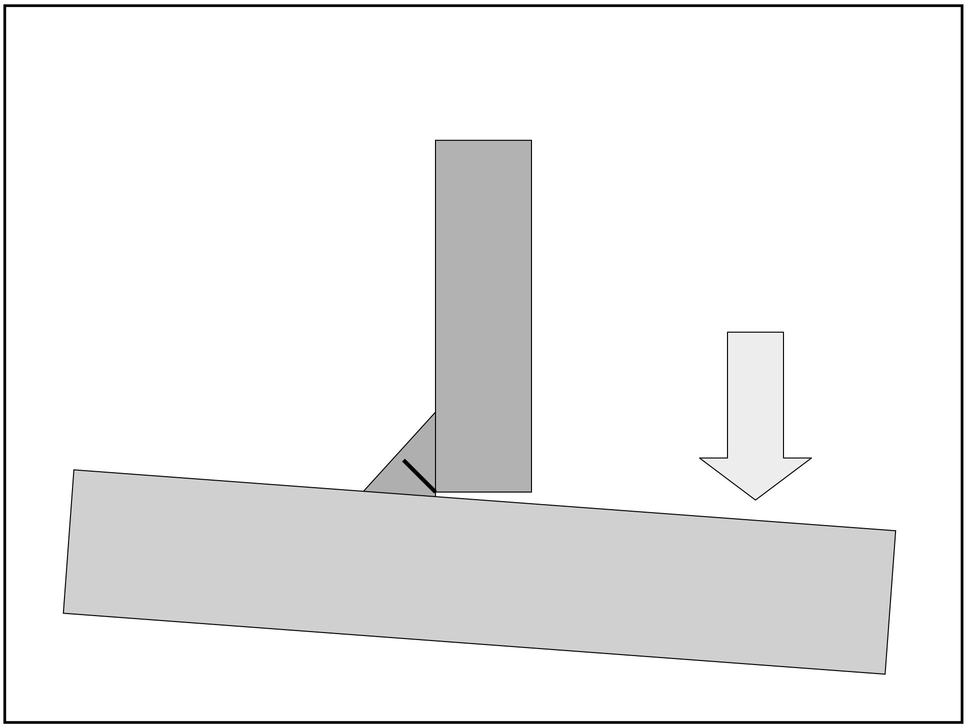

1.0
.8
.6
.4
.2
neutral axis of straight beam
.2
.4
.6
.8
1.0
shifted neutral axis of curved beam
.6
.4
.2
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4


1.0
.8
.6
.4
.2
neutral axis of straight beam
.2
.4
.6
.8
1.0
shifted neutral axis of curved beam
.6
.4
.2
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4

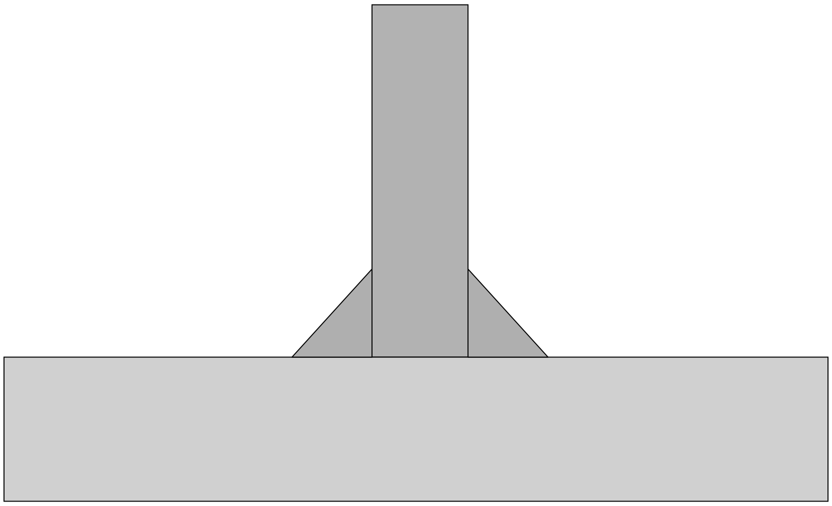

F
M



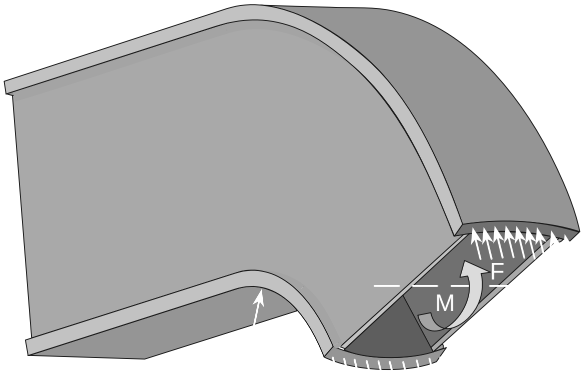


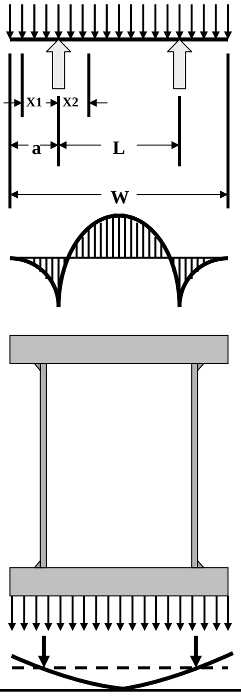


The Welder's Solution



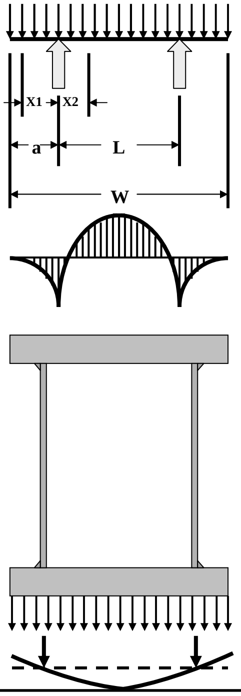
The Engineer's Solution



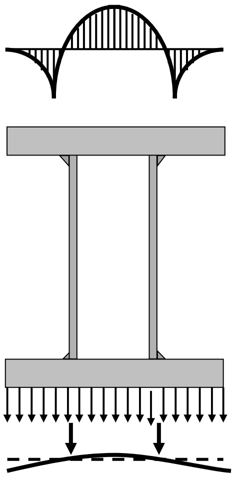


$$\theta = \frac{(wL)}{24EI}(L^2 - 6a^2)$$

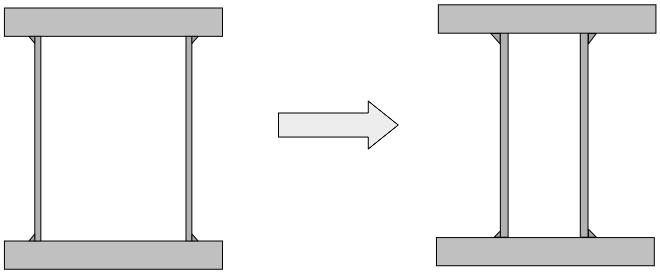
$$a = 0.225\ w$$



$$\theta = \frac{(wL)}{24EI}(L^2 - 6a^2)$$



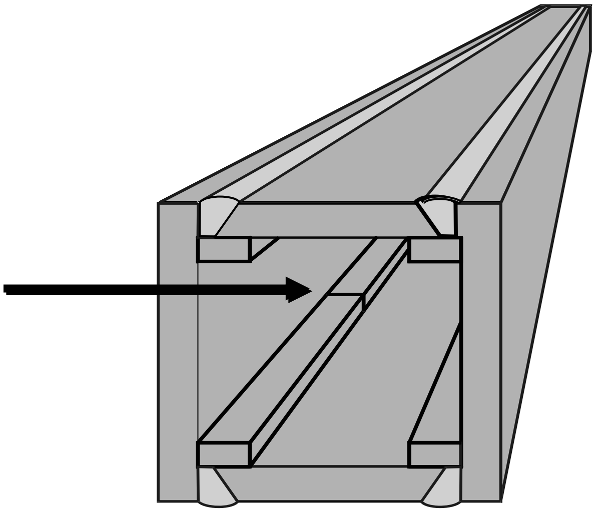
The Engineer's Solution

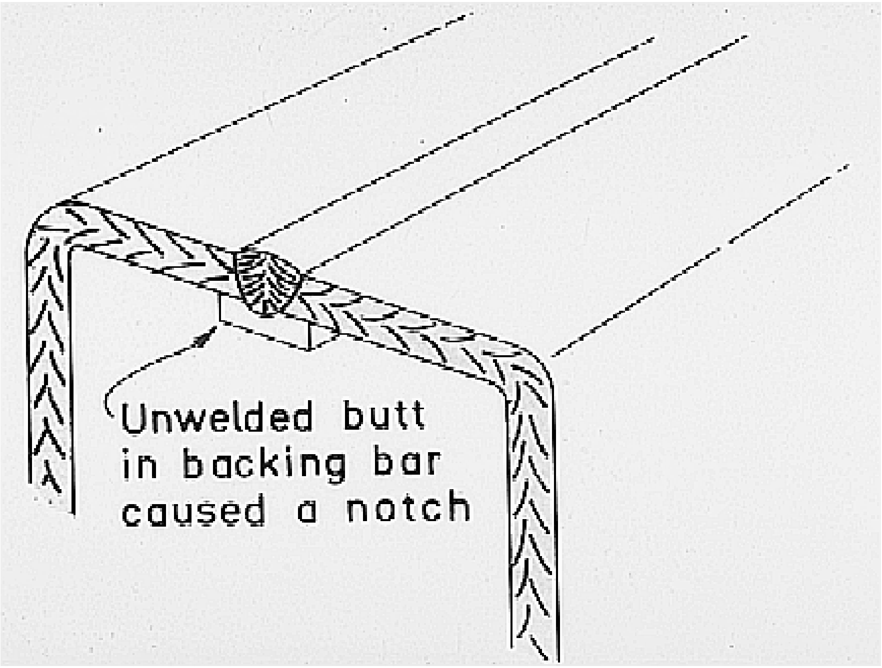


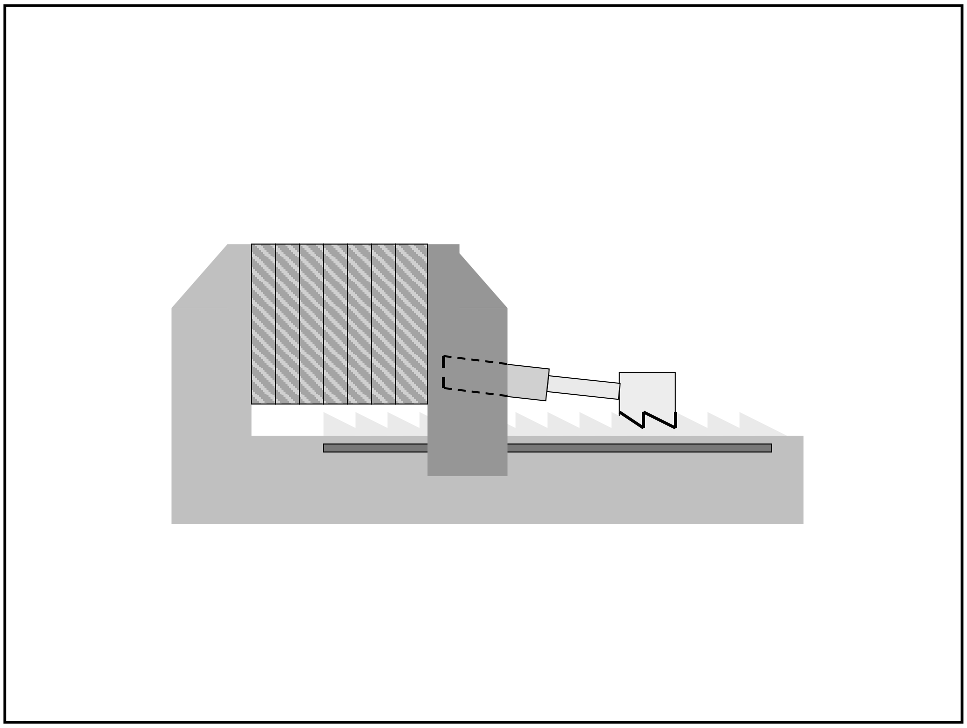
Principle 3

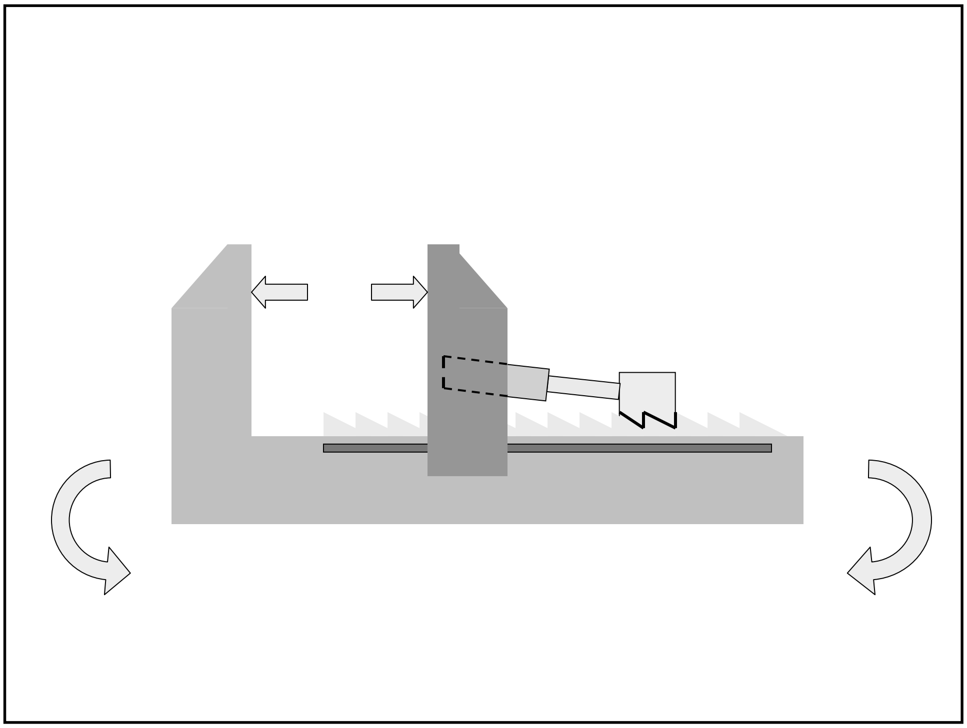
THERE ARE NO SECONDARY MEMBERS IN WELDED CONSTRUCTION

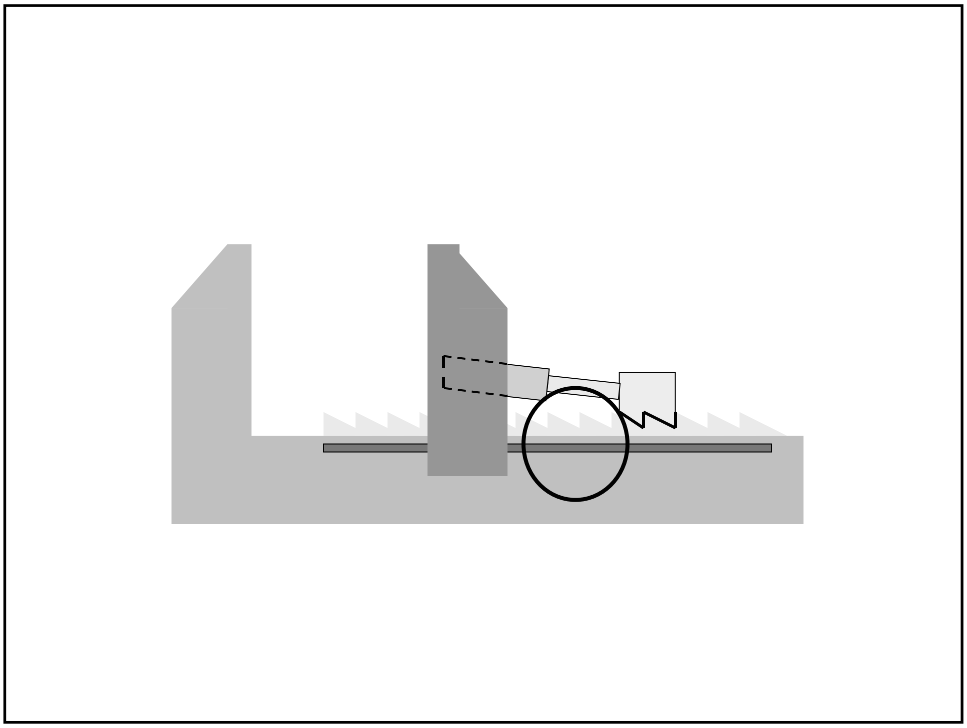
Box Girder

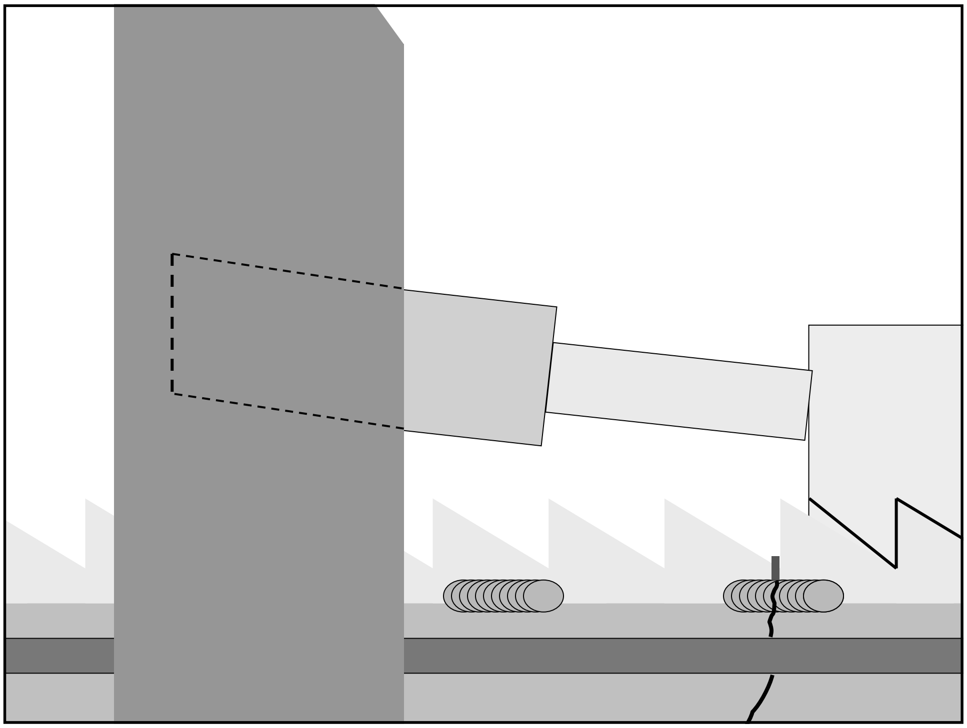






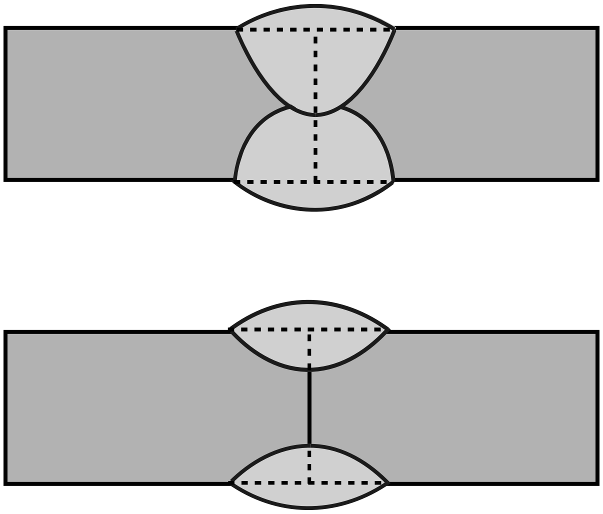






Principle 4

NOTHIN' WELDS ARE
GOOD FOR NOTHIN'

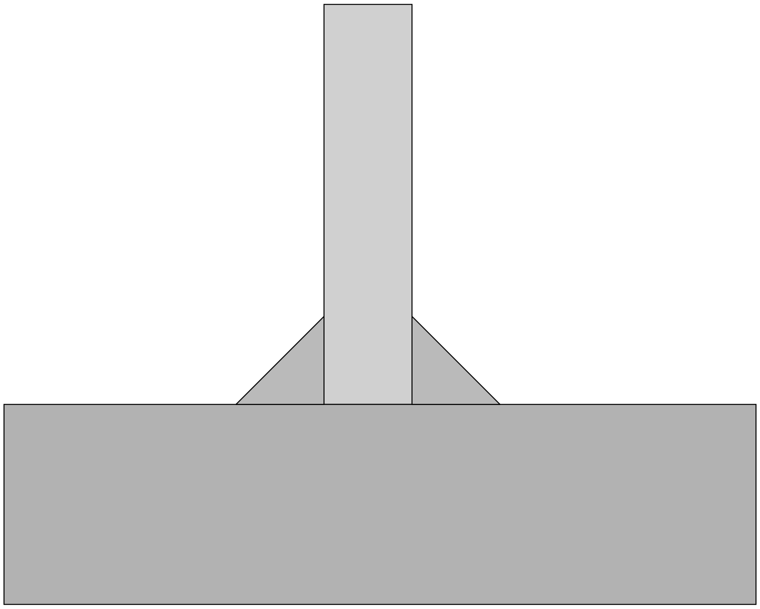


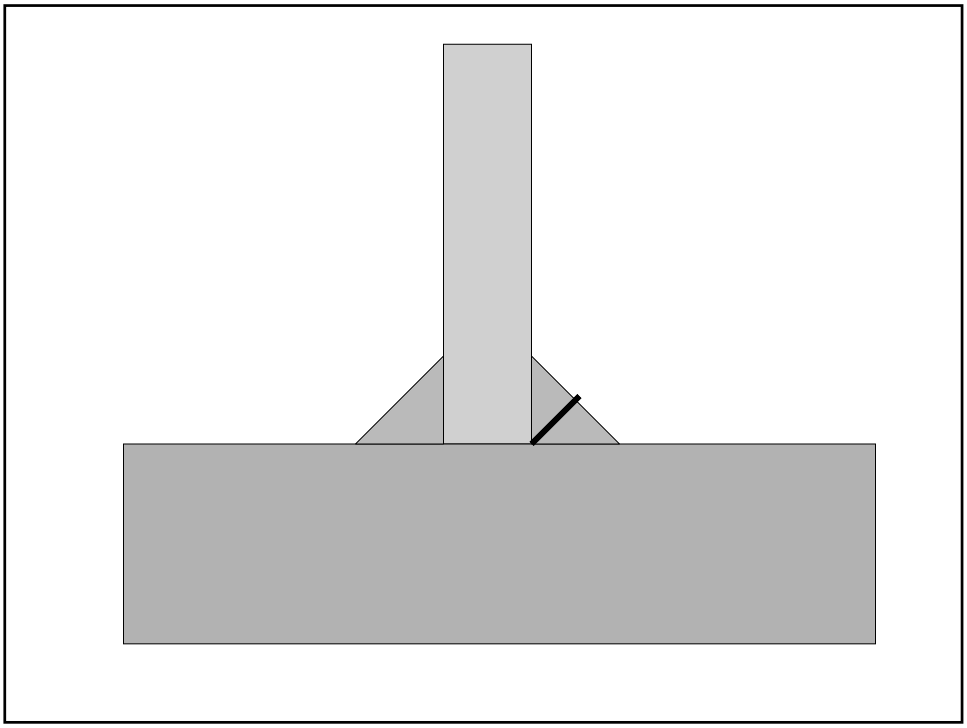
Maximum Fillet Size

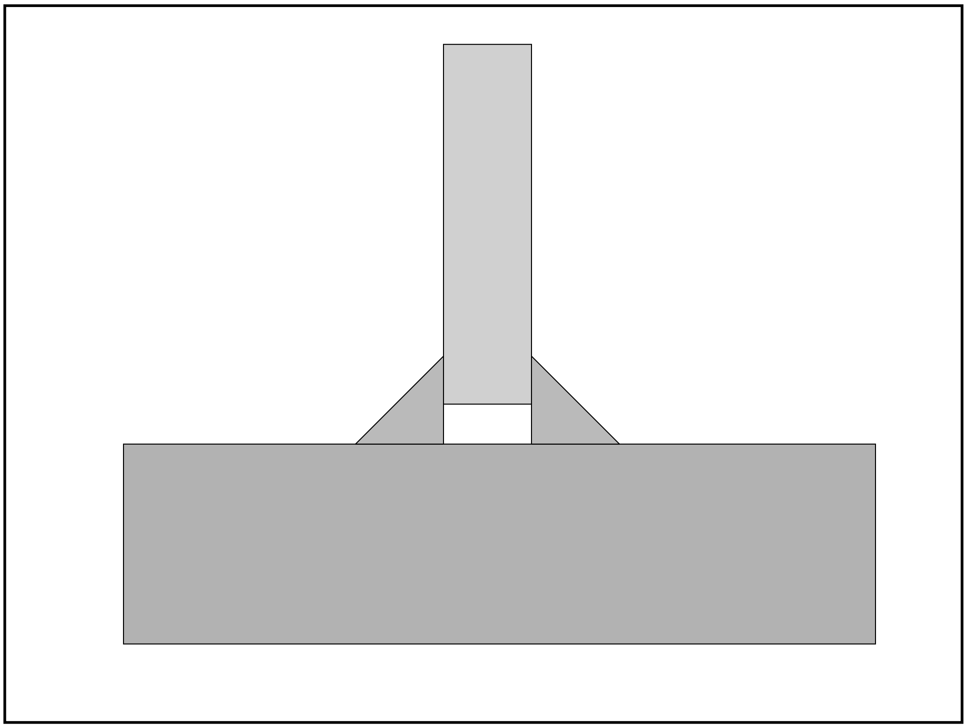
Maximum Fillet Size

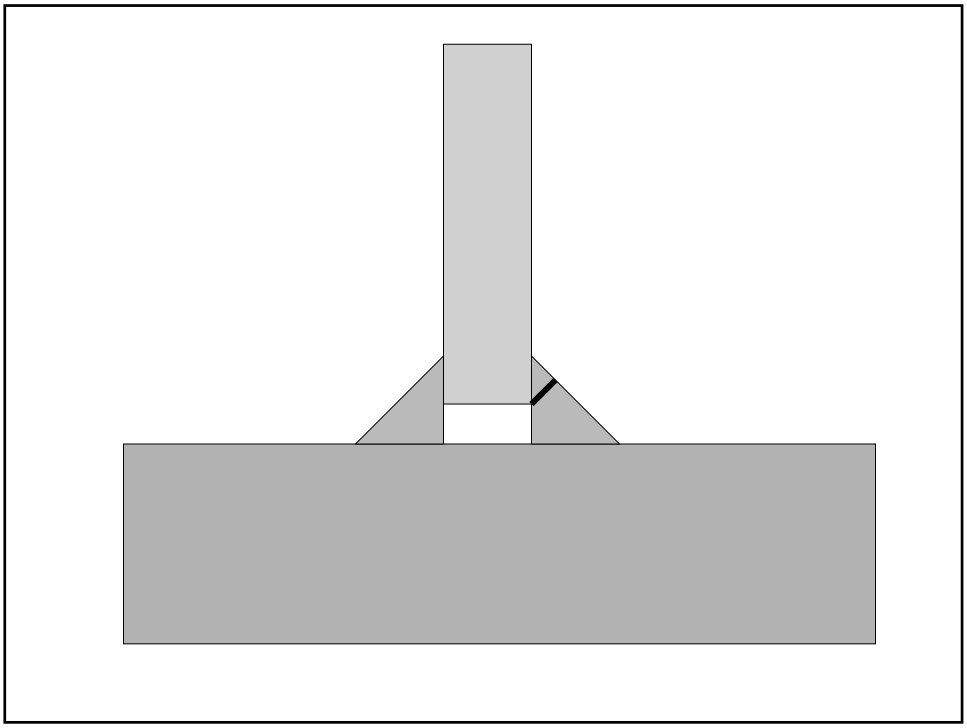
t ≥ 1/4”

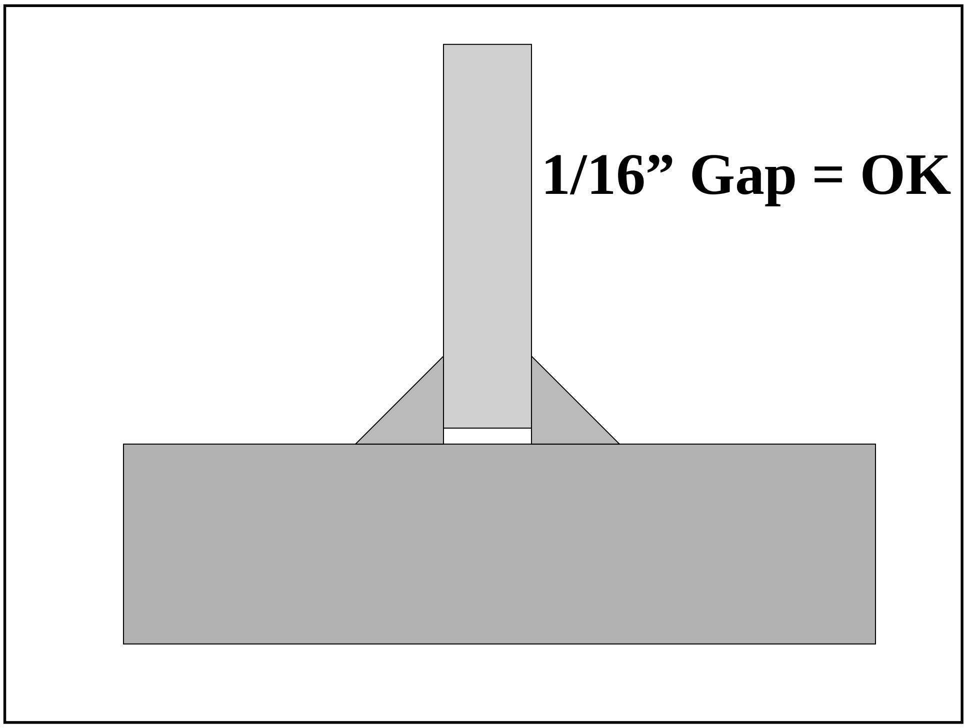
Maximum Fillet Size



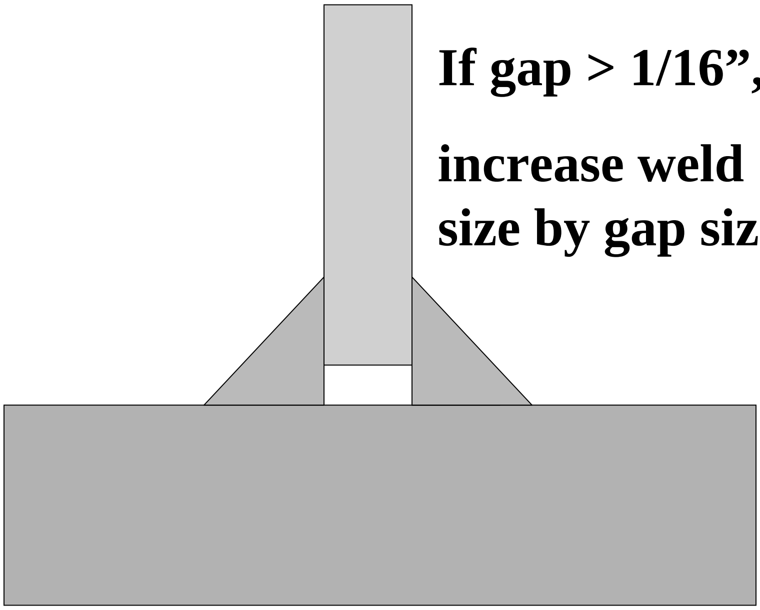






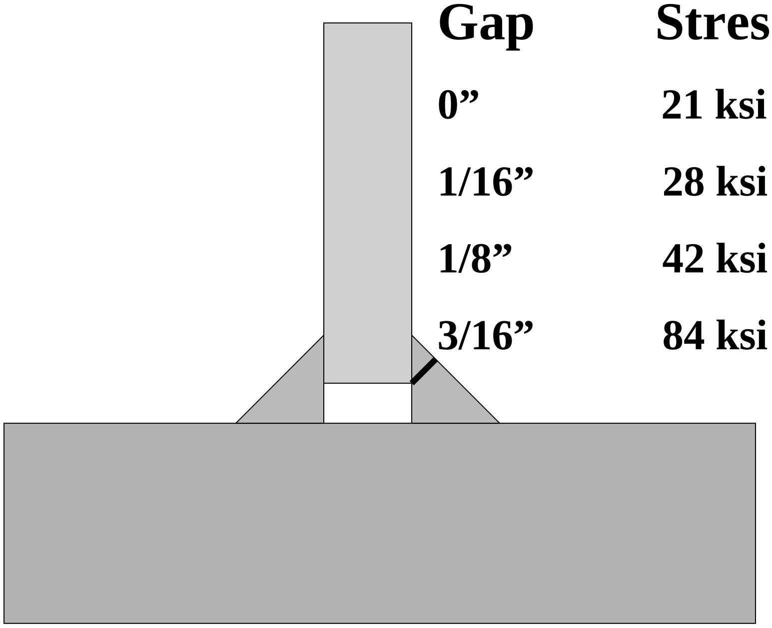


1/16” Gap = OK

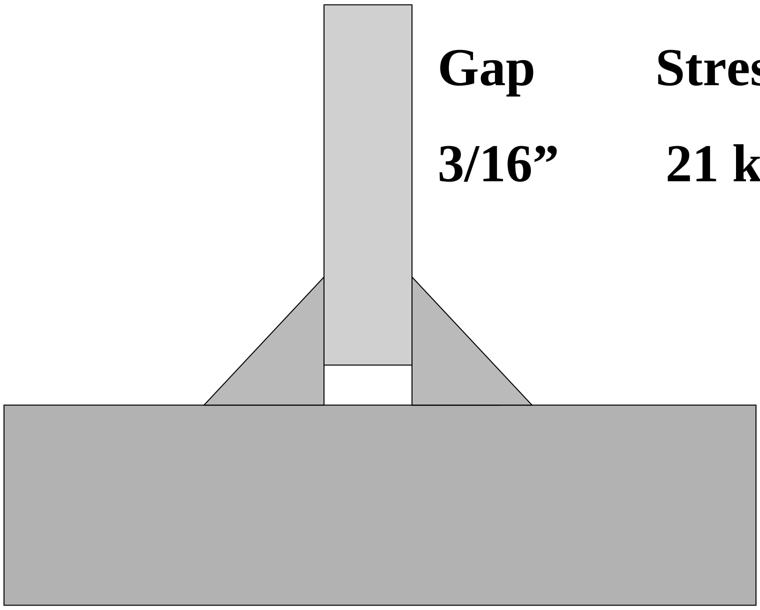


If gap > 1/16”,

increase weld size by gap size



Gap	**Stress**
0”	21 ksi
1/16”	28 ksi
1/8”	42 ksi
3/16”	84 ksi

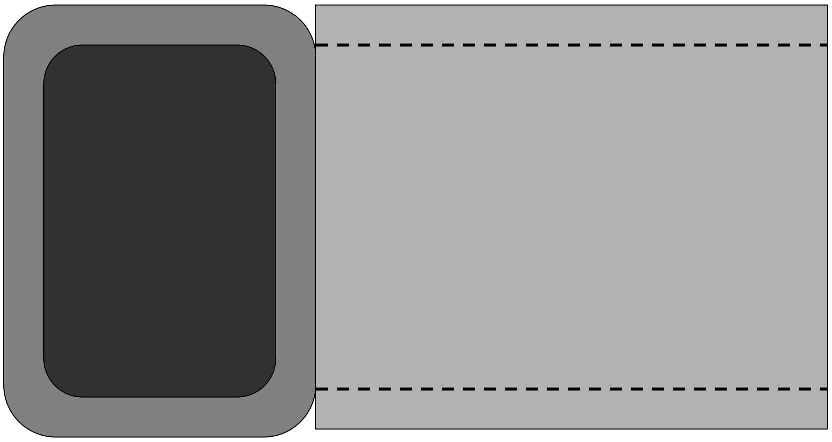


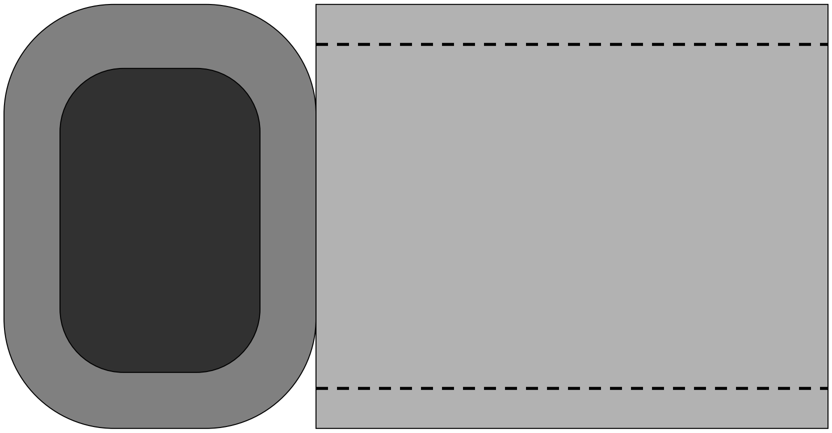
Gap	Stress
3/16”	21 ksi

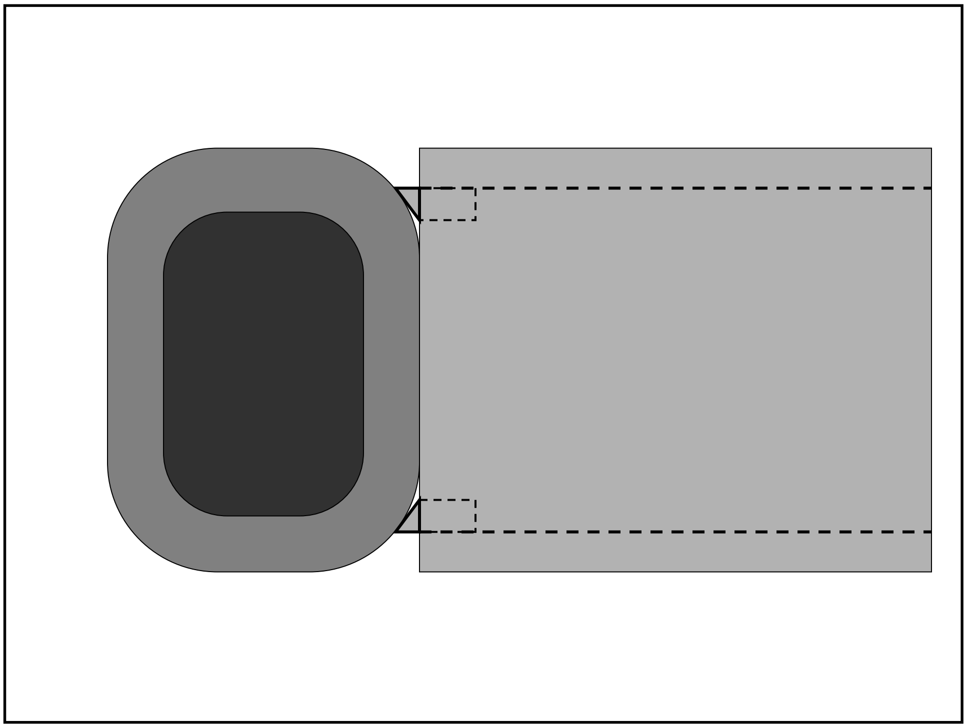
Principle 5

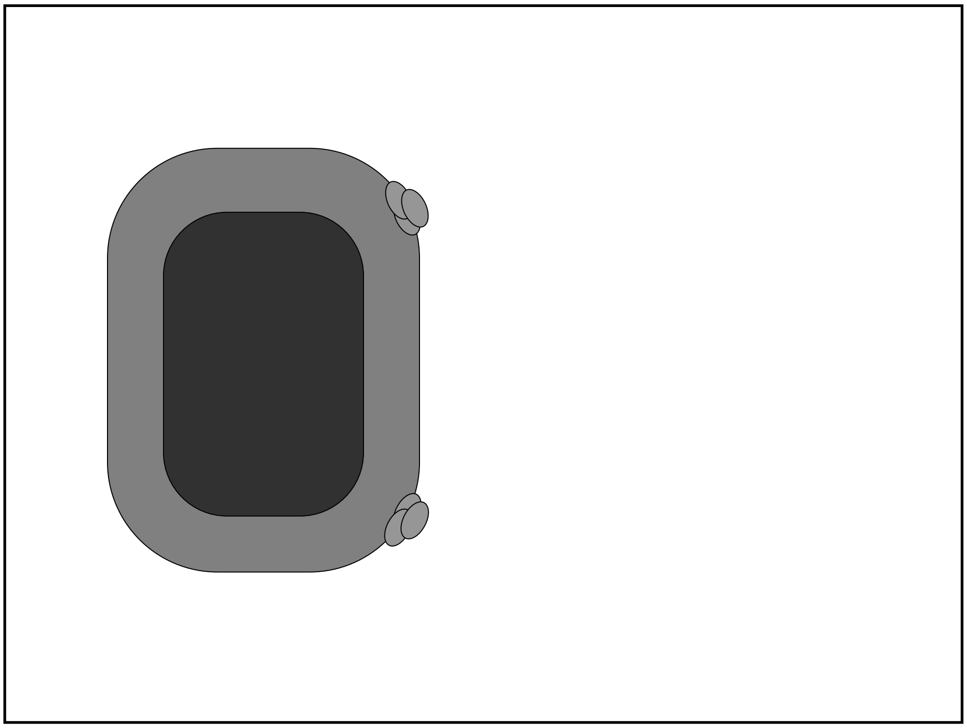
AVOID A JOINT WHERE THE STRENGTH AND PERFORMACE OF THE JOINT DEPENDS ON THE SKILL OF THE WELDER

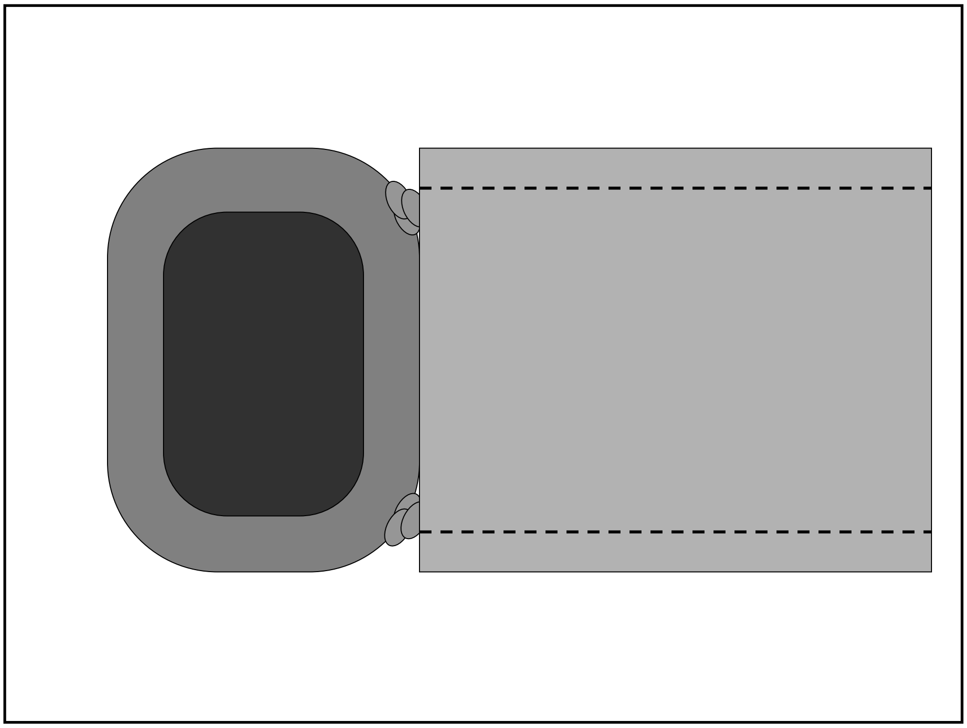
Matched Connection

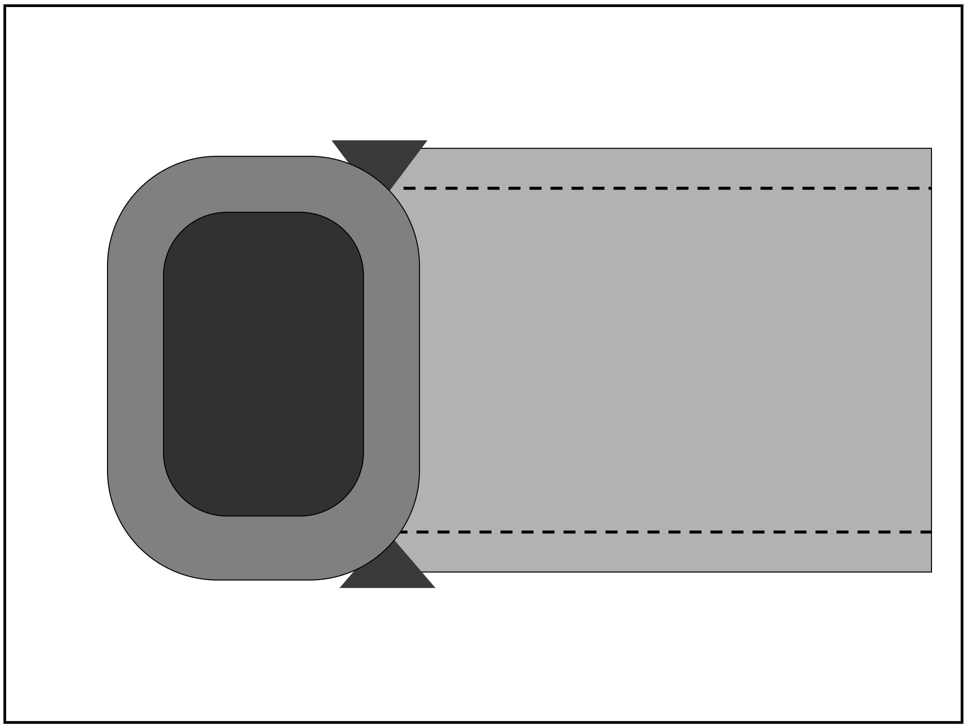




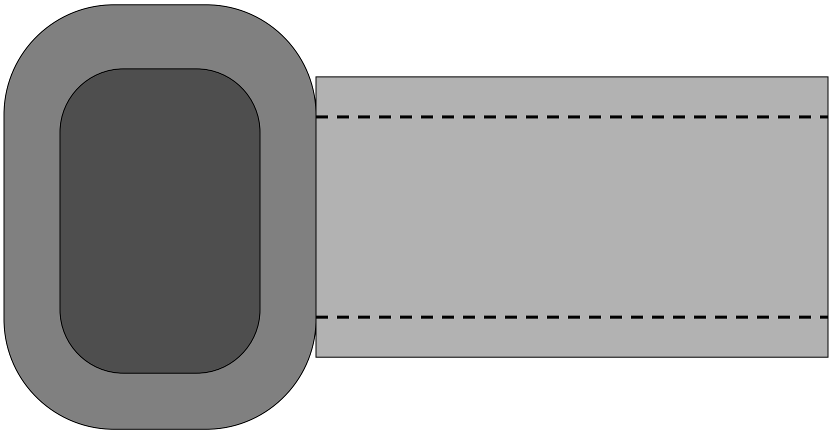


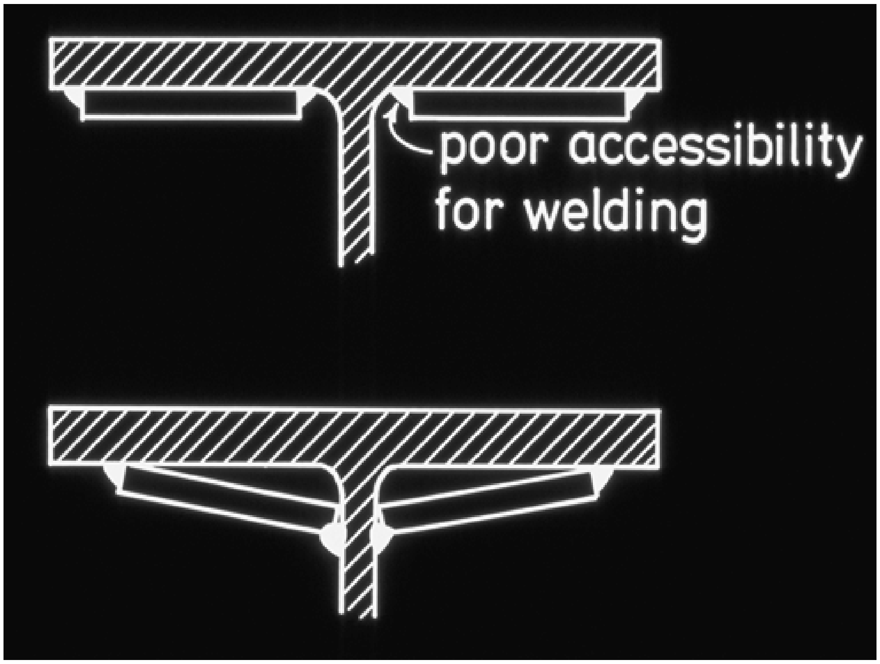






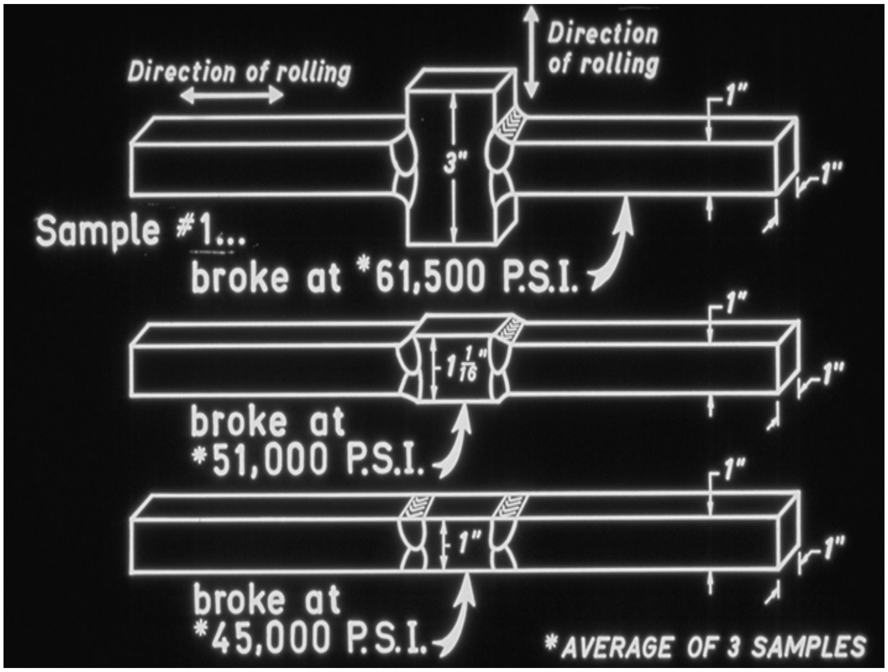
Stepped Connection

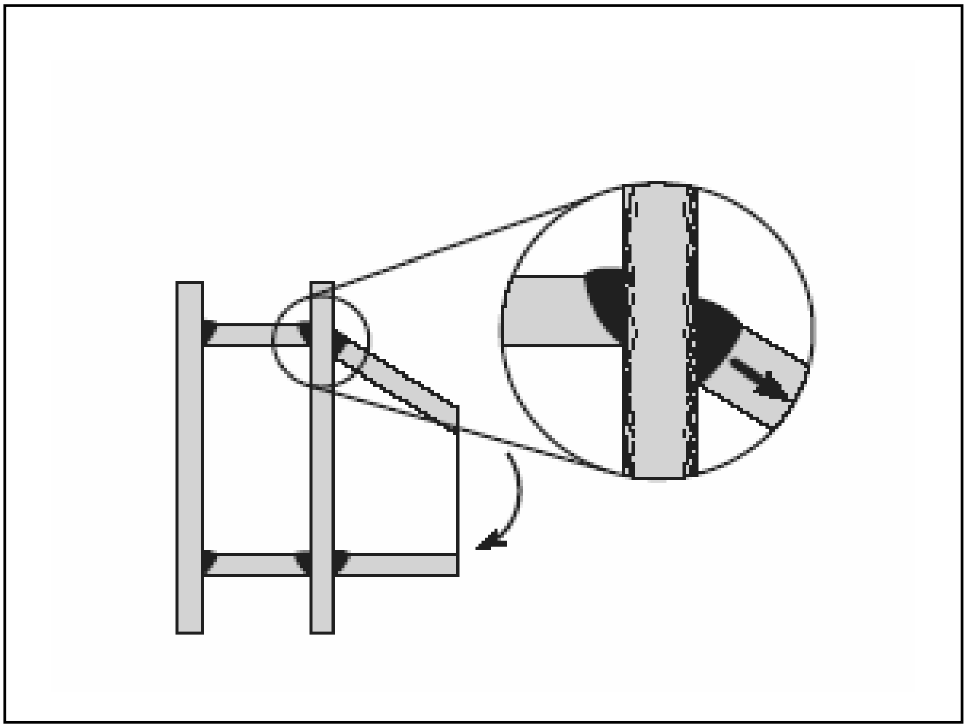


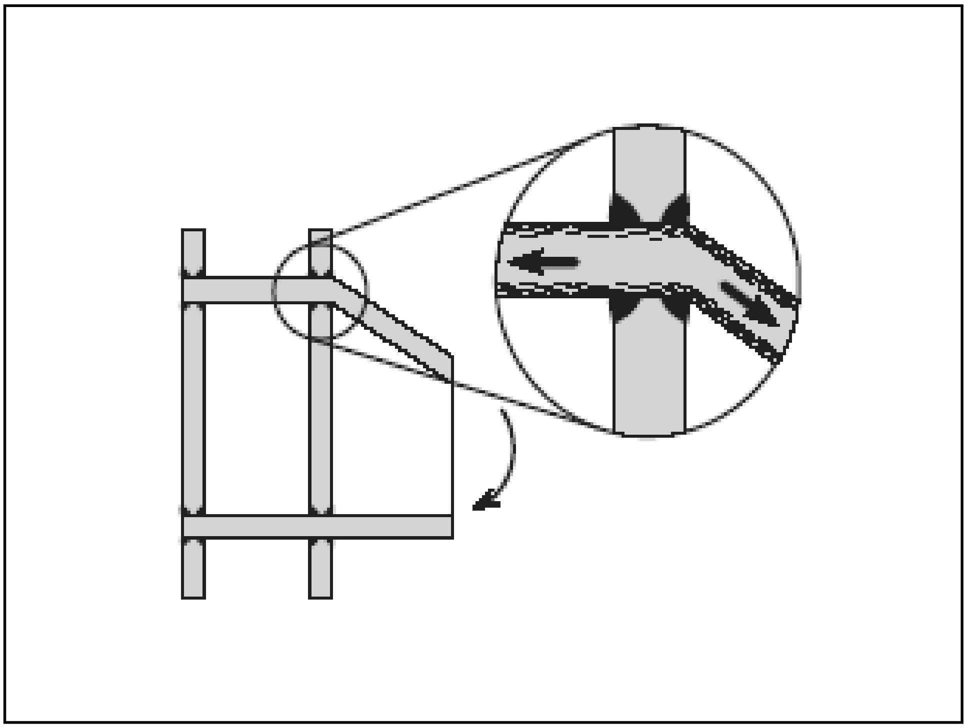


Principle 9

WHEN POSSIBLE, DON'T PASS MAJOR LOADS THROUGH THE THICKNESS OF THE STEEL

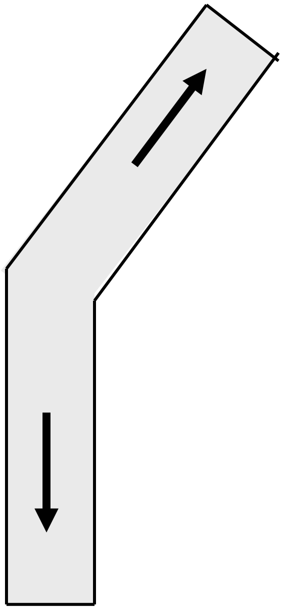


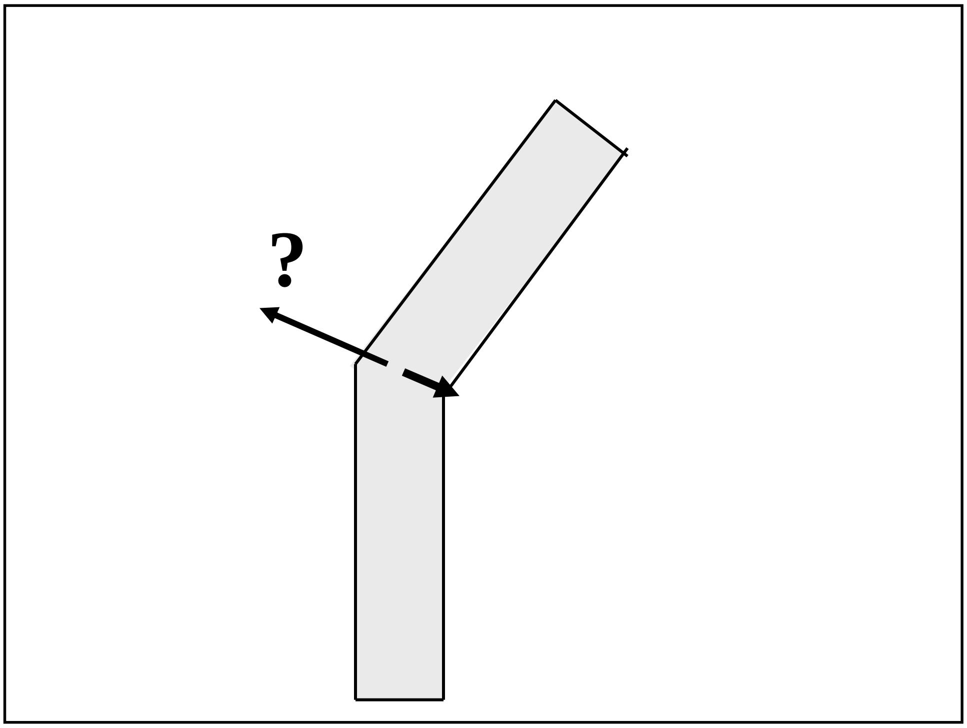


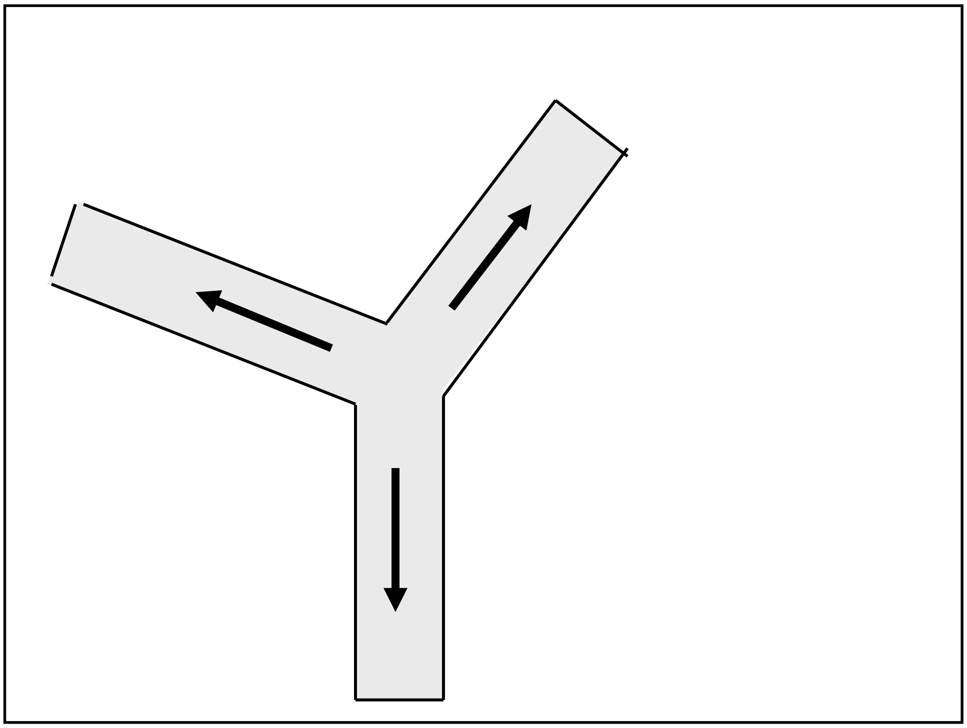


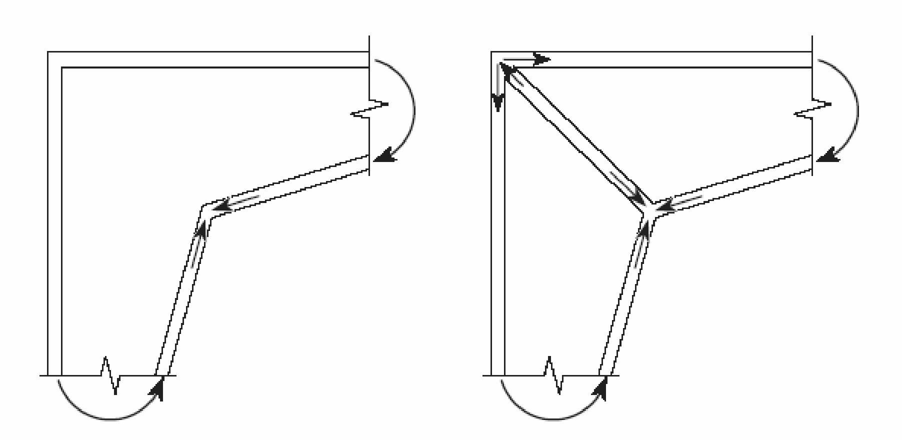
Principle 10

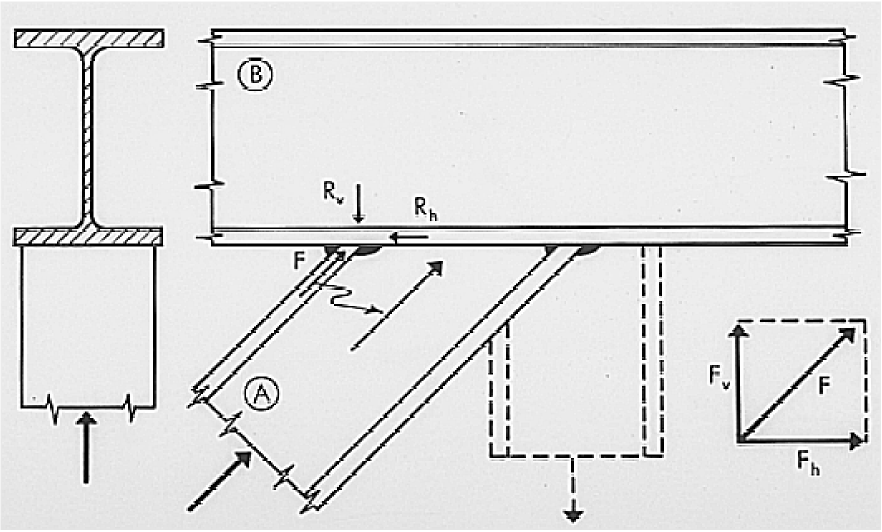
PROVIDE A MEMBER WHEN FORCES CHANGE DIRECTION





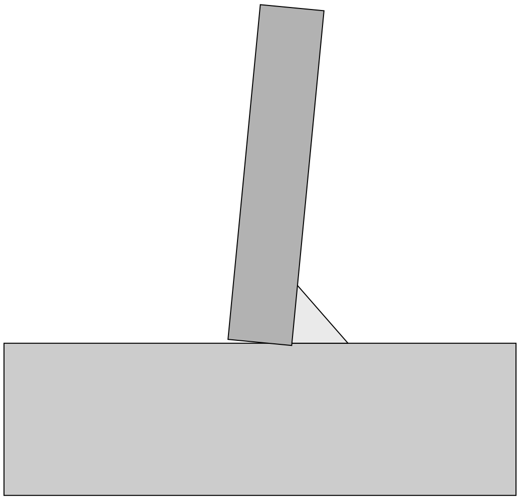




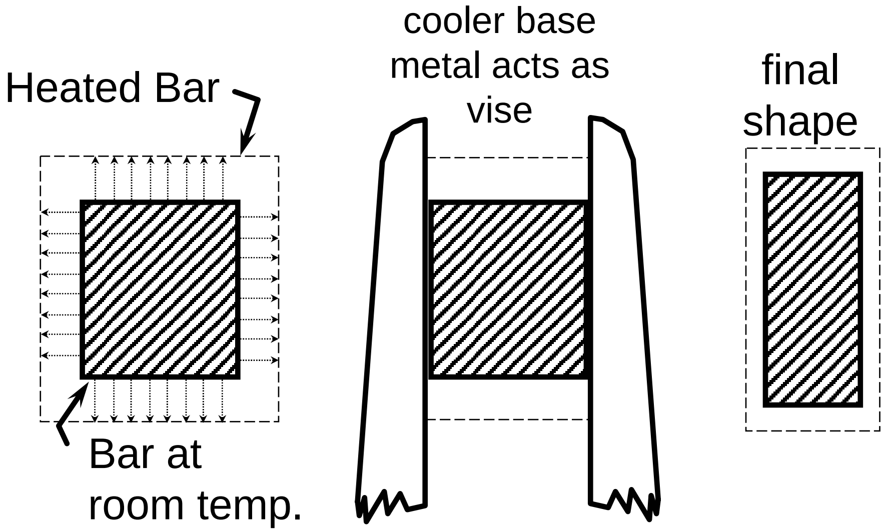

B
R_v
R_h
F
A
F_v
F
F_h

Controlling Distortion

After Welding



Volumetric Expansion



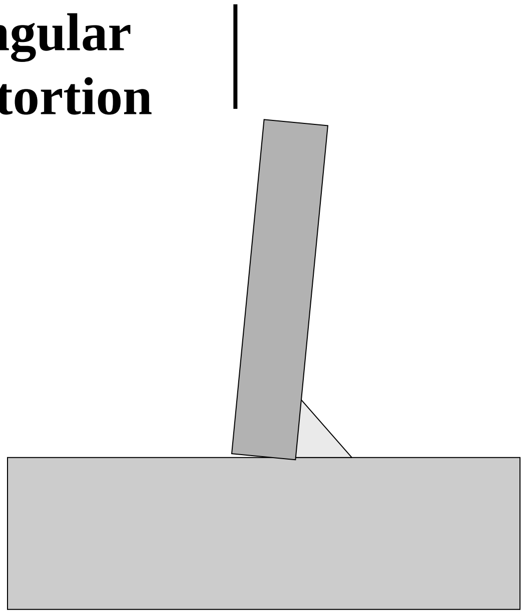
Heated Bar

Bar at room temp.

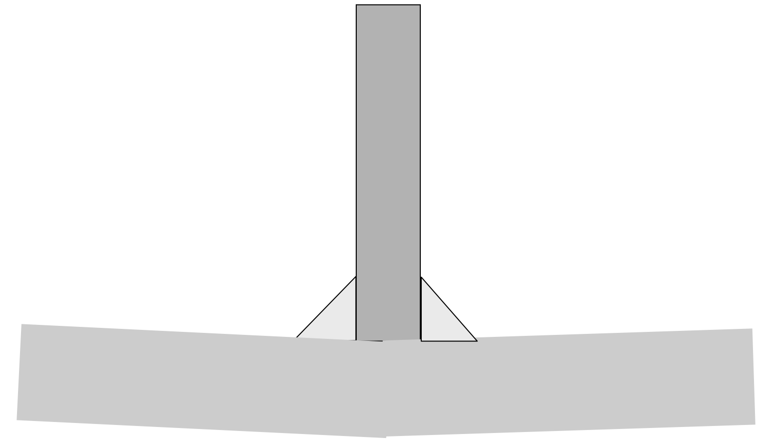
cooler base metal acts as vise

final shape

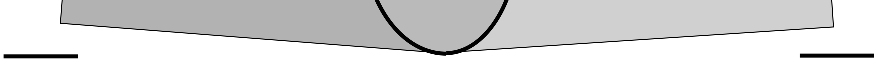
Angular Distortion



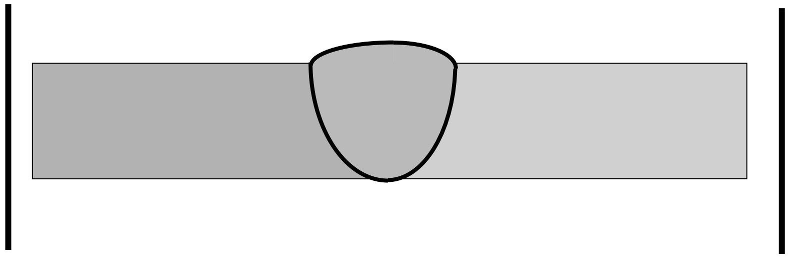
Angular Distortion



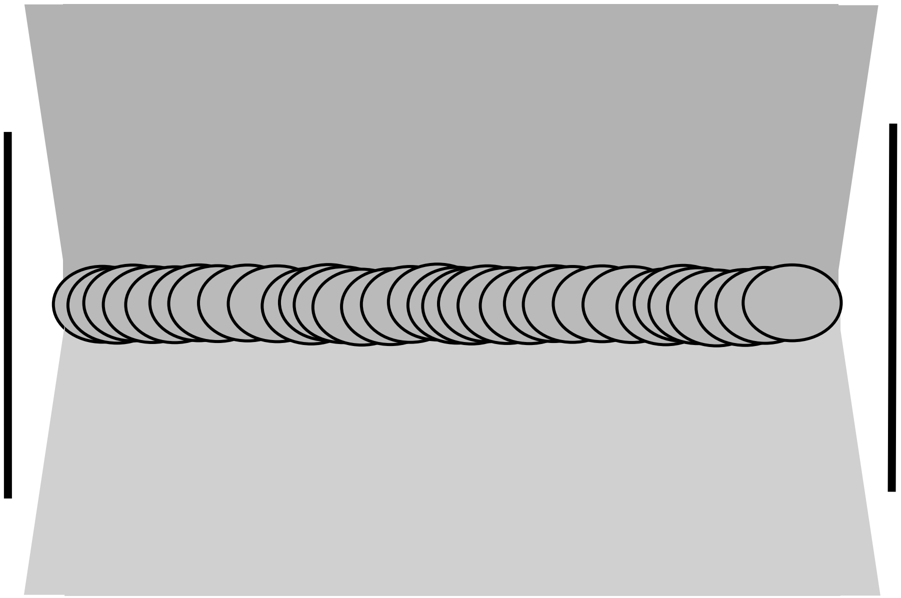
Angular Distortion

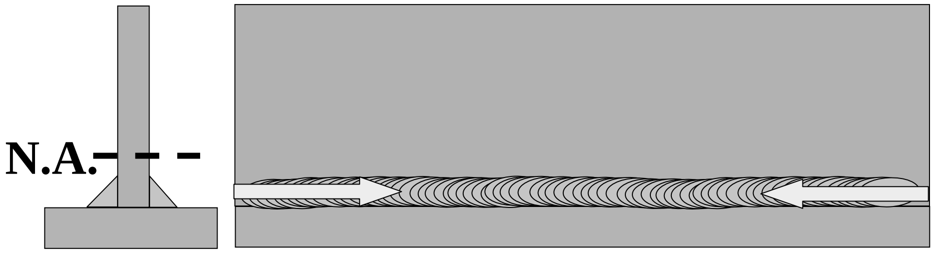


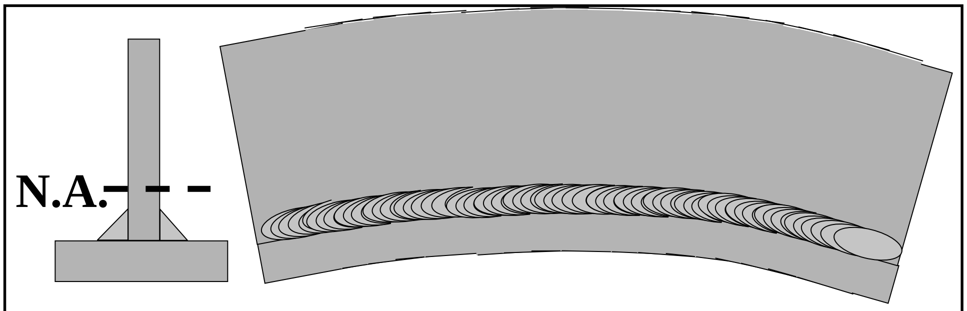
Transverse Shrinkage

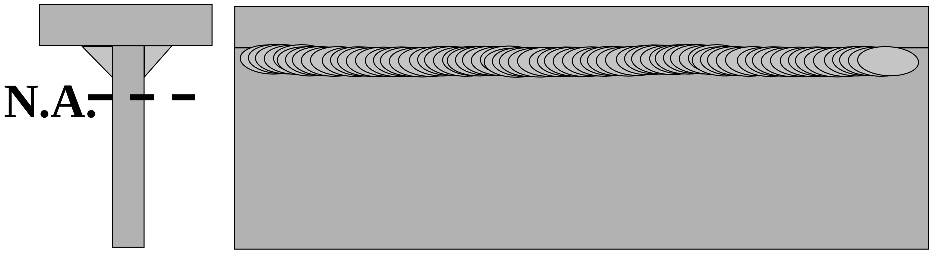


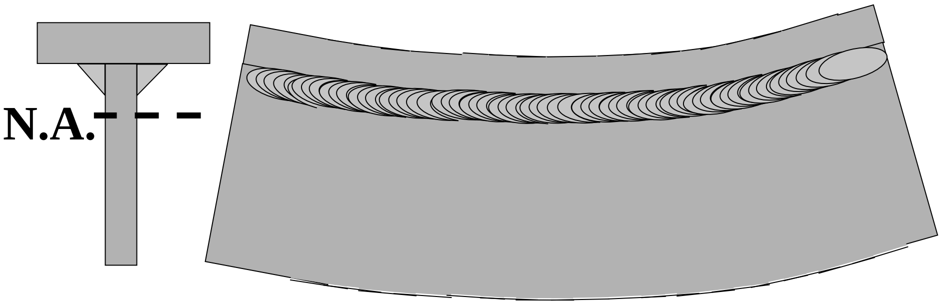
Longitudinal Shrinkage

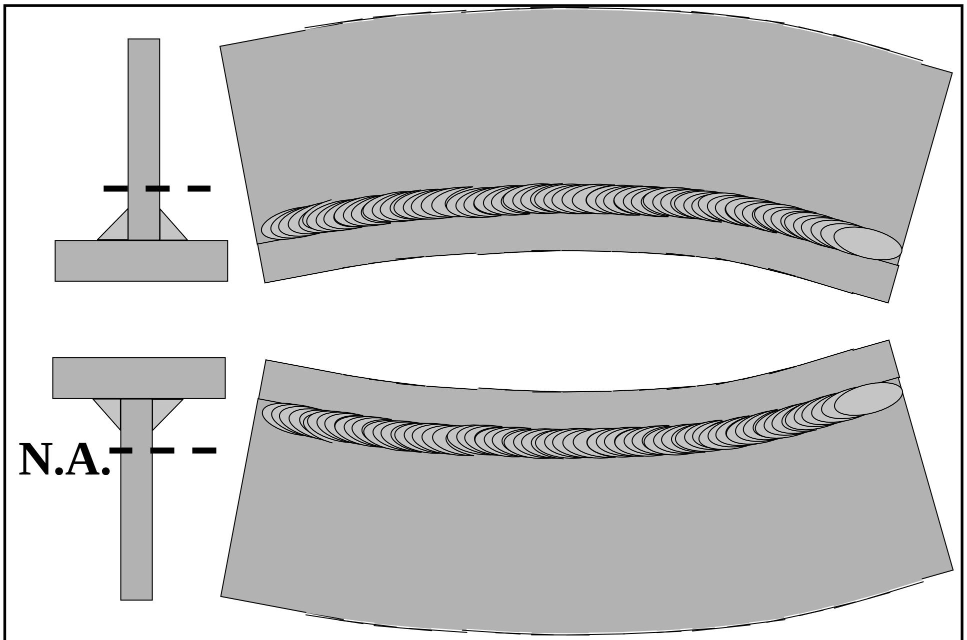



N.A.


N.A.


N.A.


N.A.

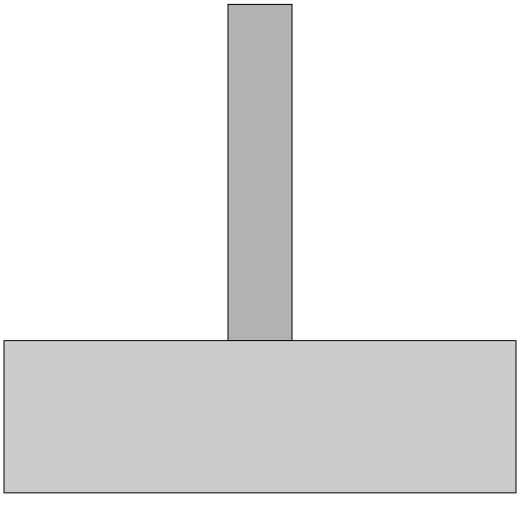


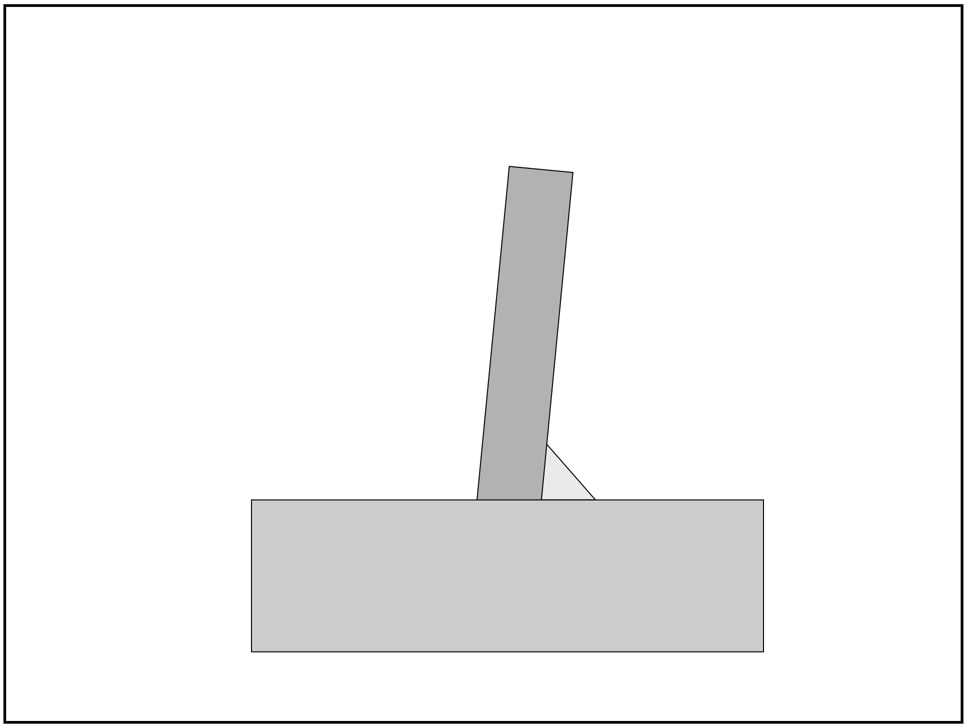
Distortion Control Principles

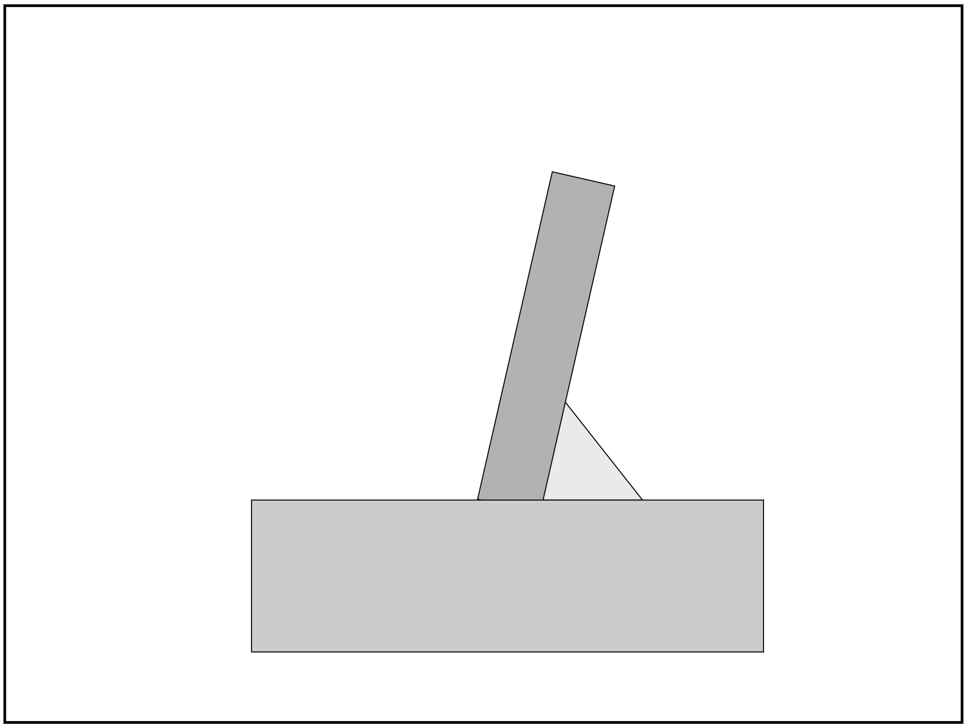
Principle #1

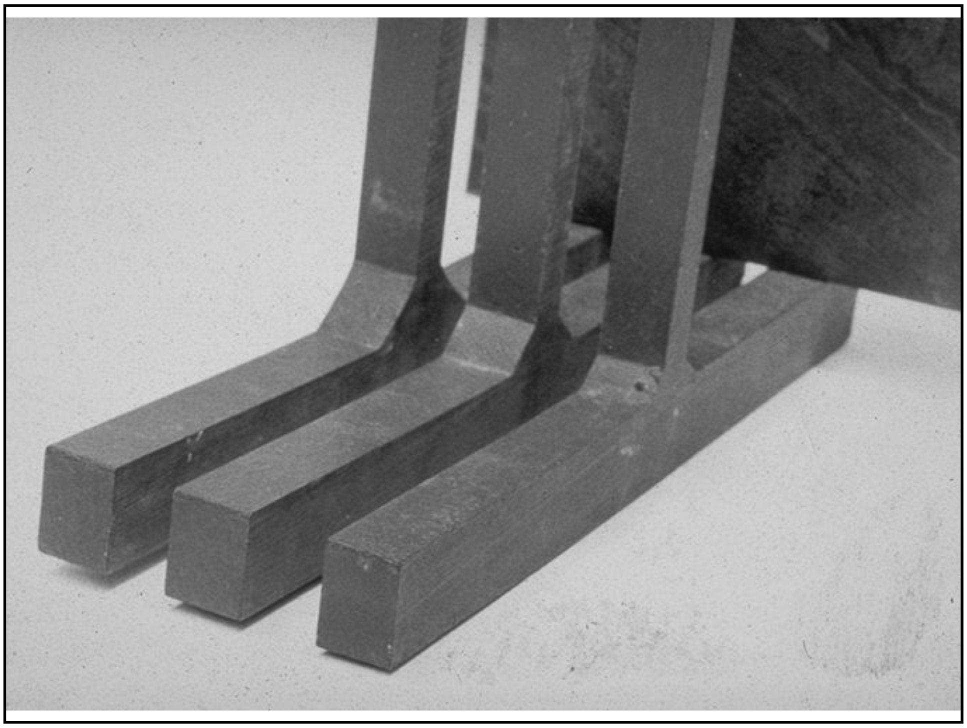
Use smallest weld size possible

Before Welding



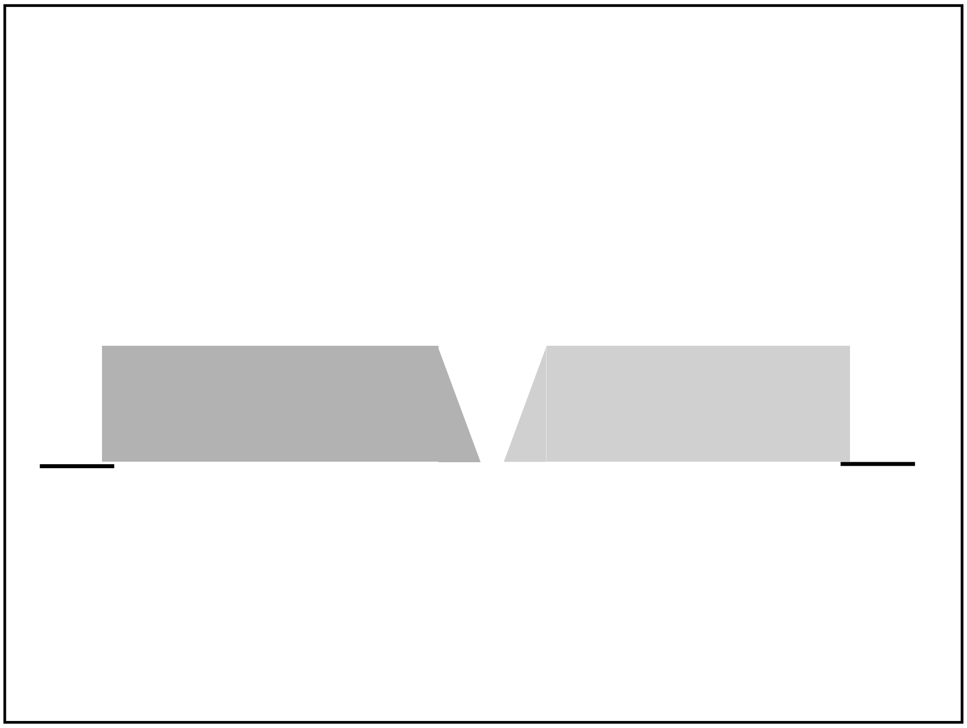


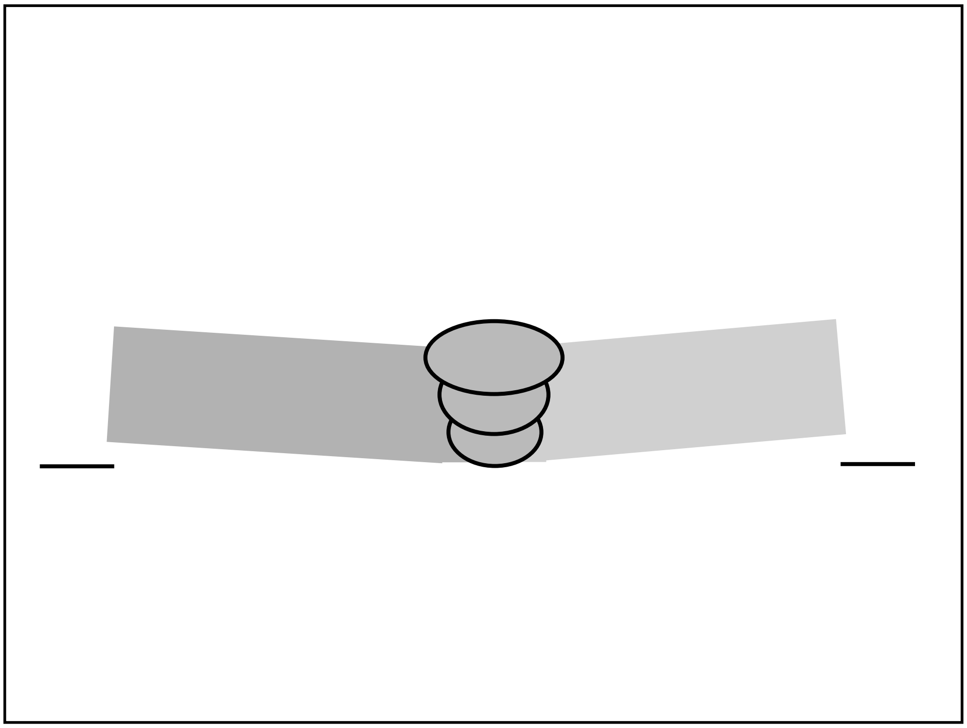


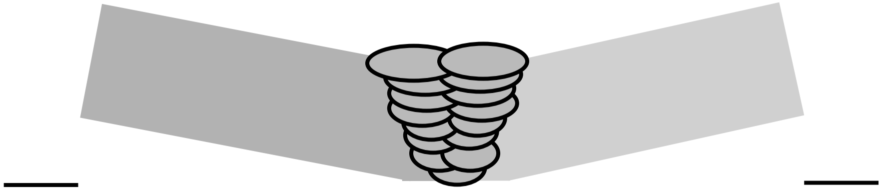


Principle #2

Use fewest number of passes





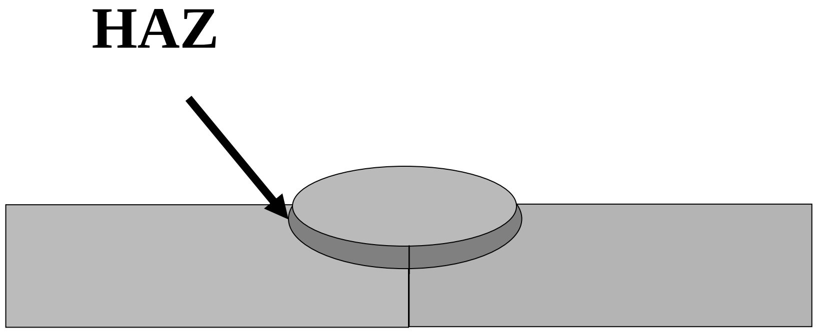


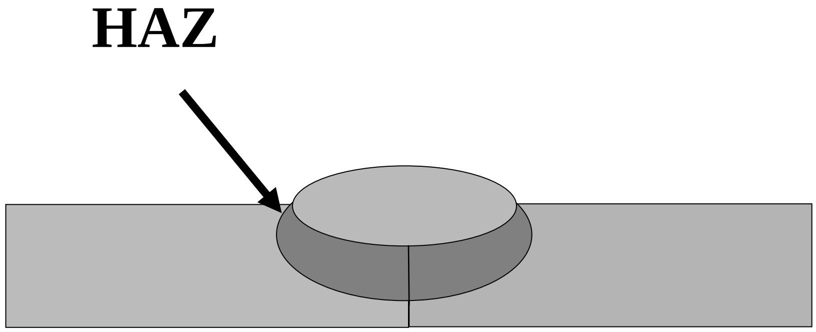

ICAL-DOWN
39 BE
VERTICAL UP
6 BEAD

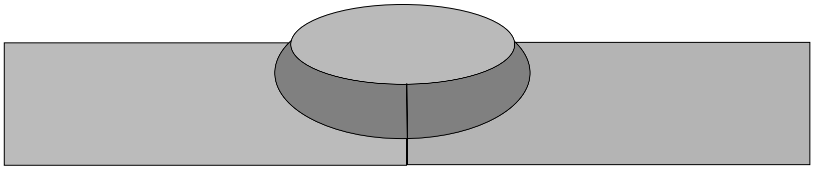
Principle #3

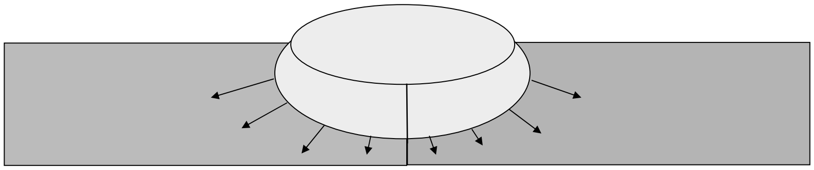
**Make the weld
with the lowest level
of heat input**

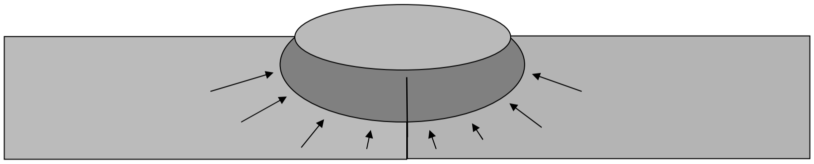
$$H = 60\ E\ I\ /\ 1000\ S$$

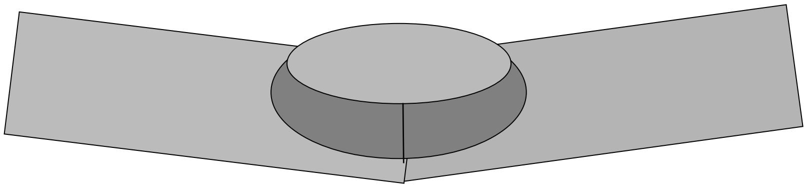

HAZ

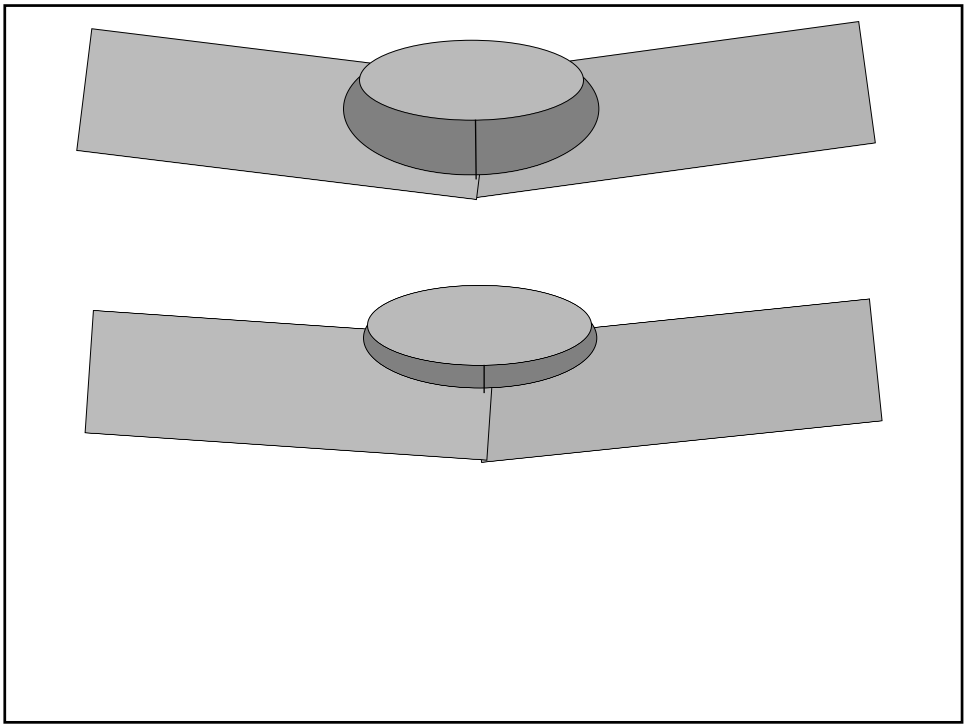

HAZ

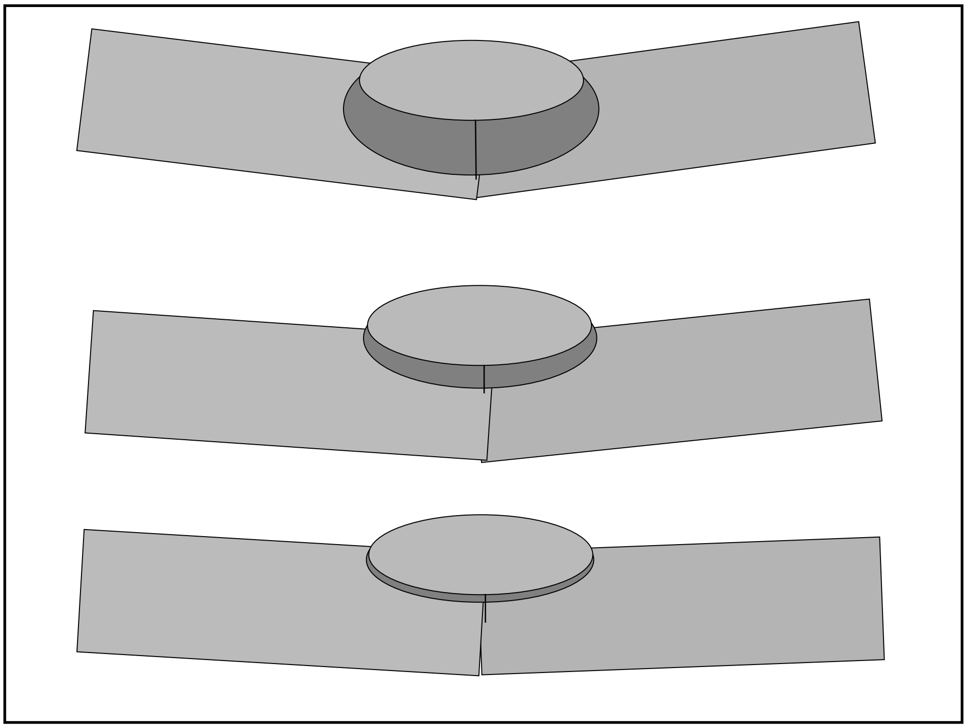






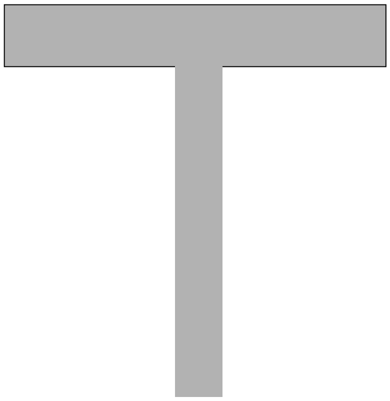


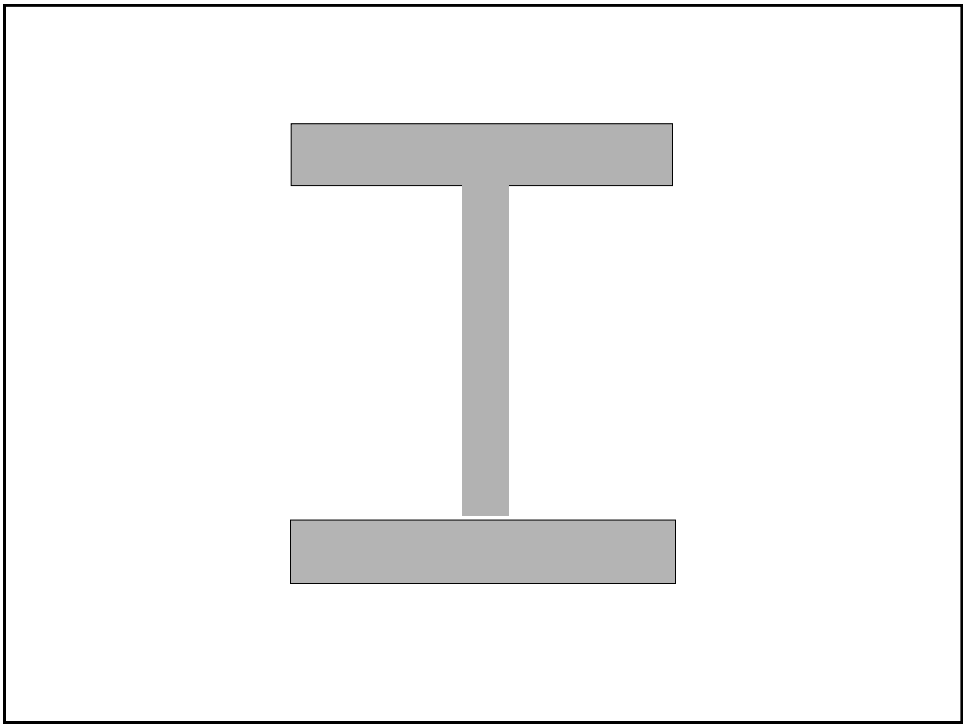


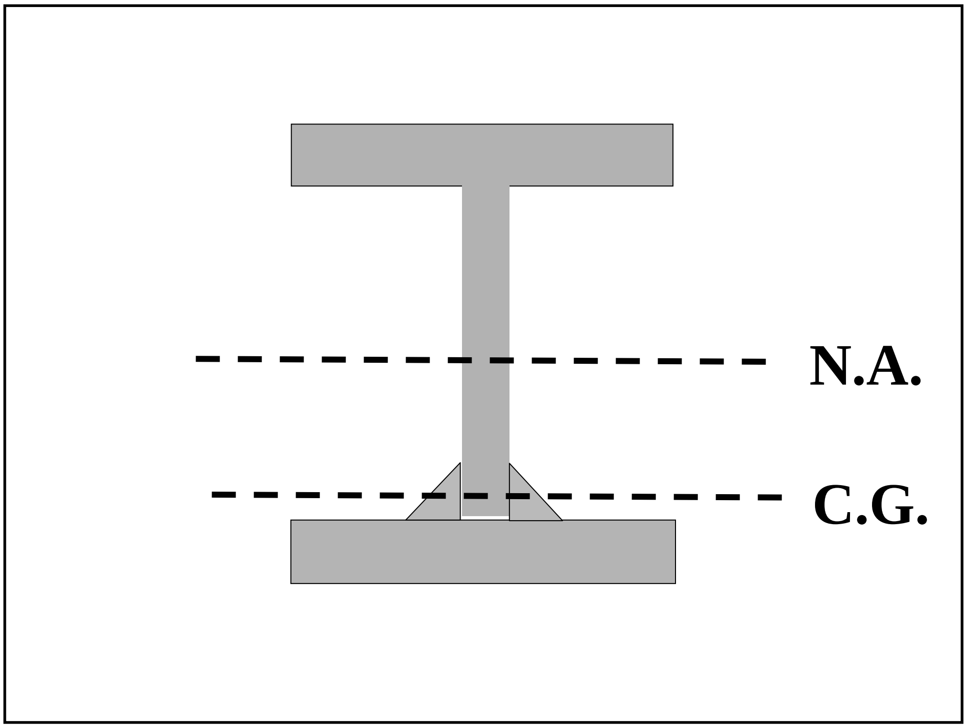


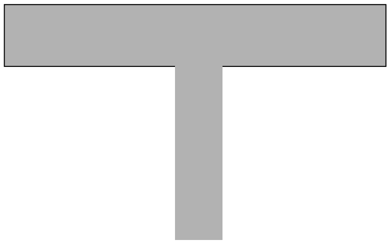
Principle #4

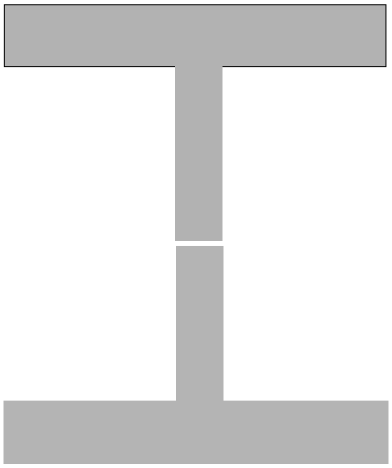
Weld on or near the neutral axis

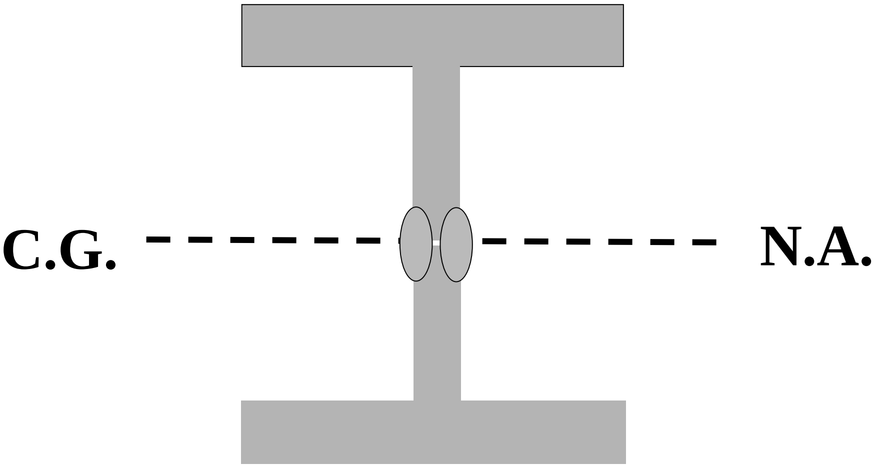


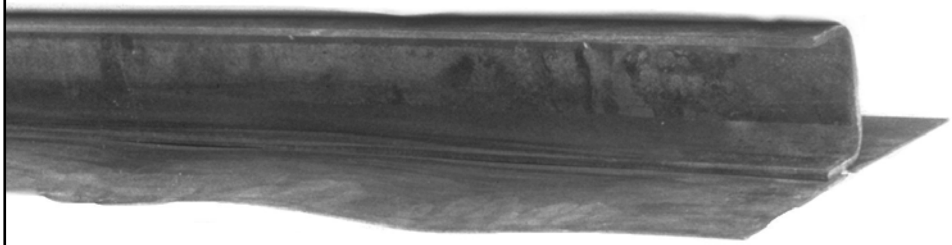


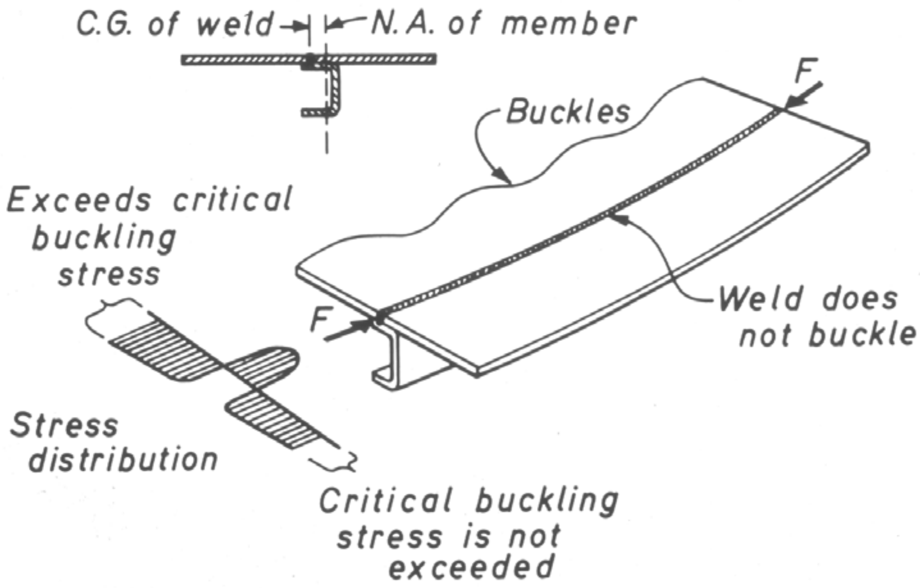

N.A.
C.G.





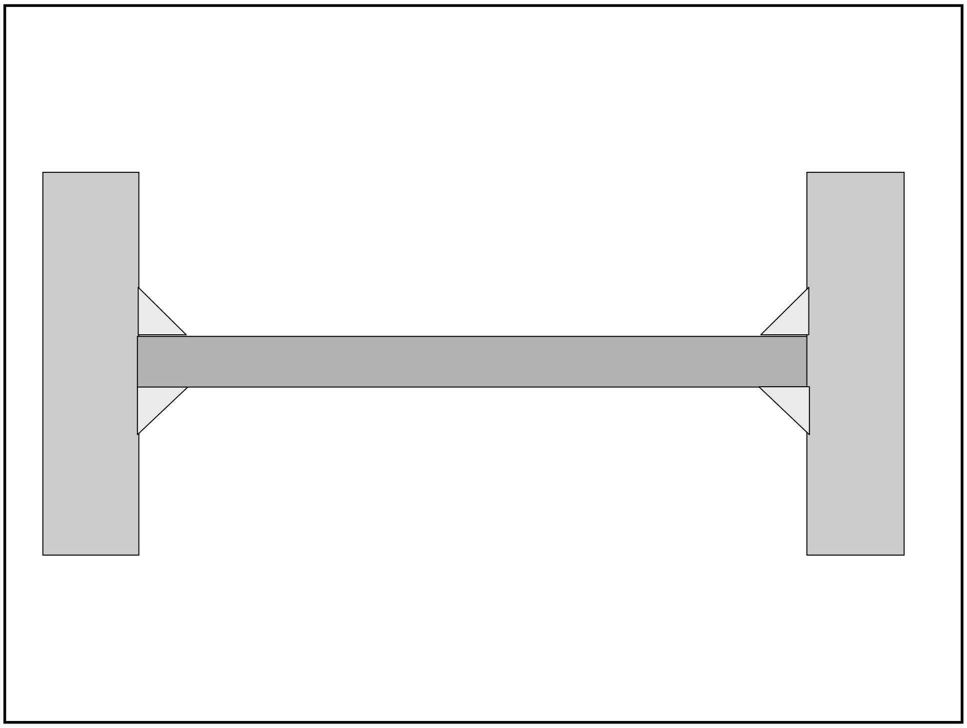

C.G.
N.A.

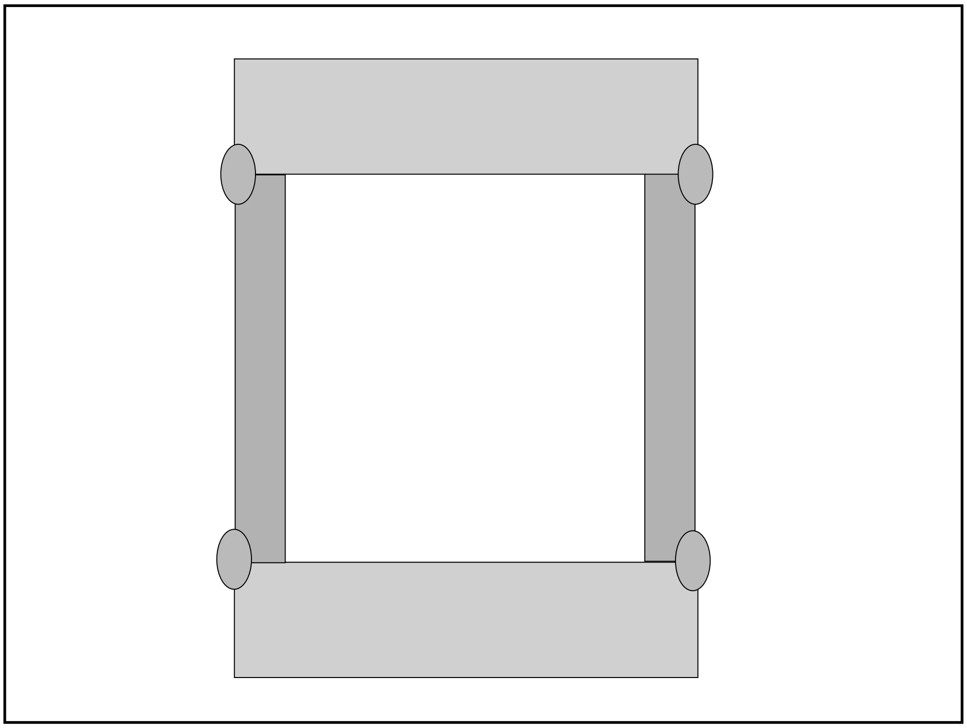




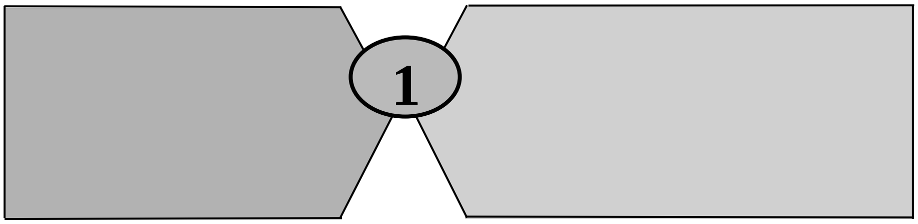
Principle #5

Balance welds about the neutral axis

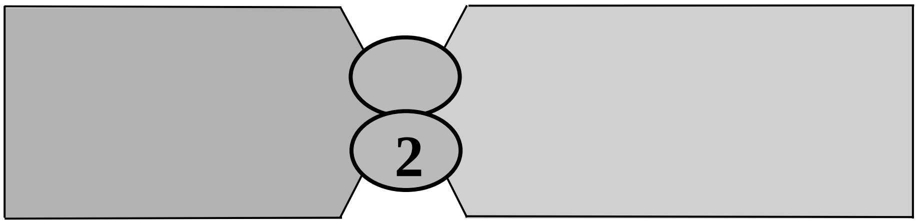




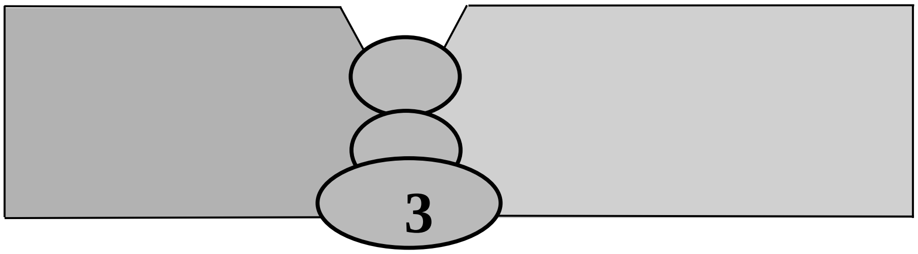
Double Groove: Control Shrinkage



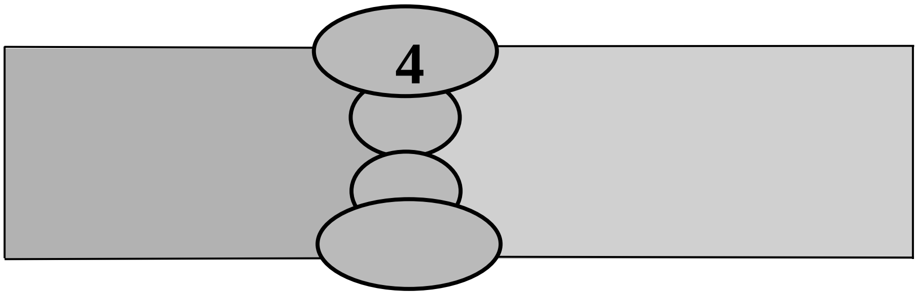
Double Groove: Control Shrinkage



Double Groove: Control Shrinkage

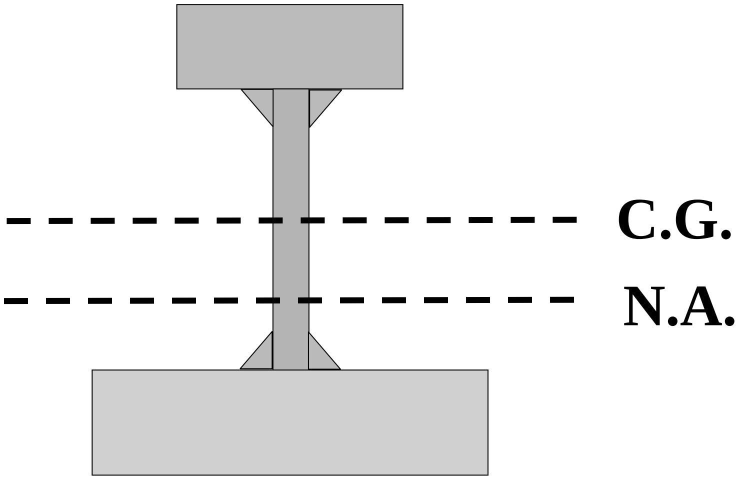


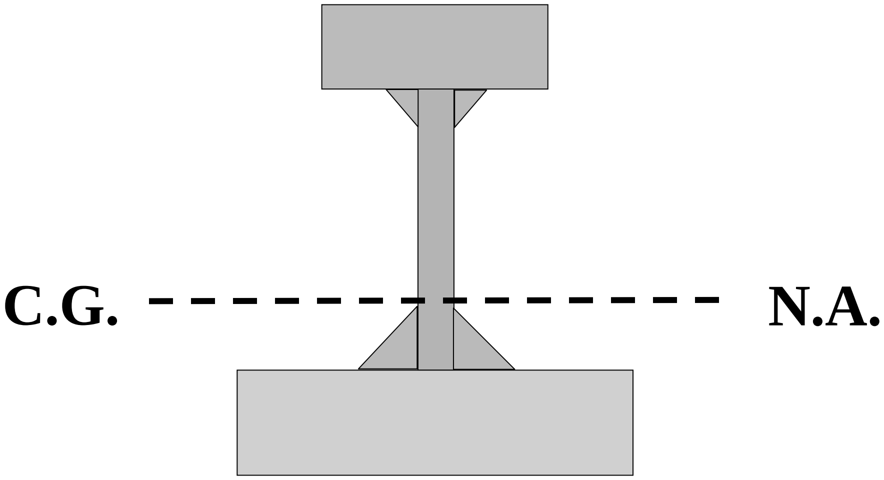
Double Groove: Control Shrinkage



Principle #6

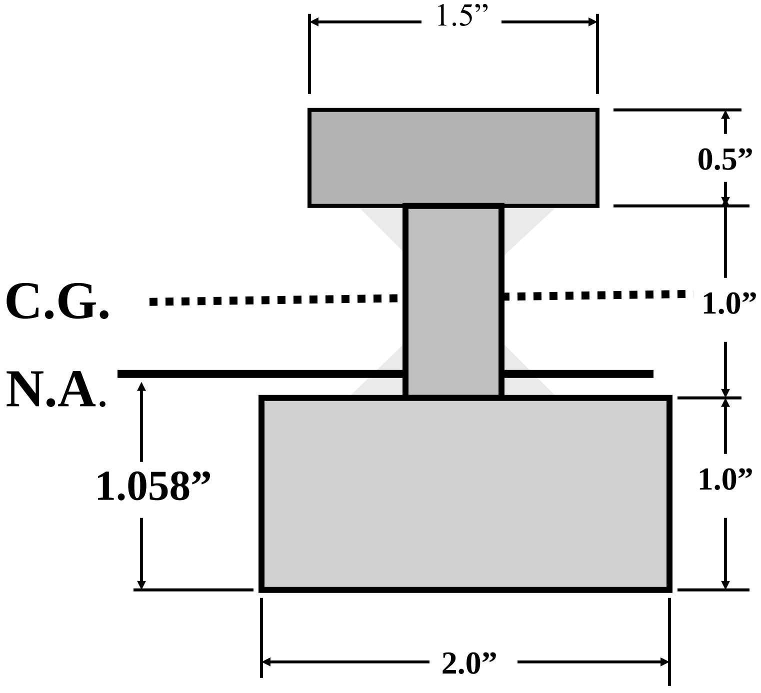
Balance weld area about the neutral axis

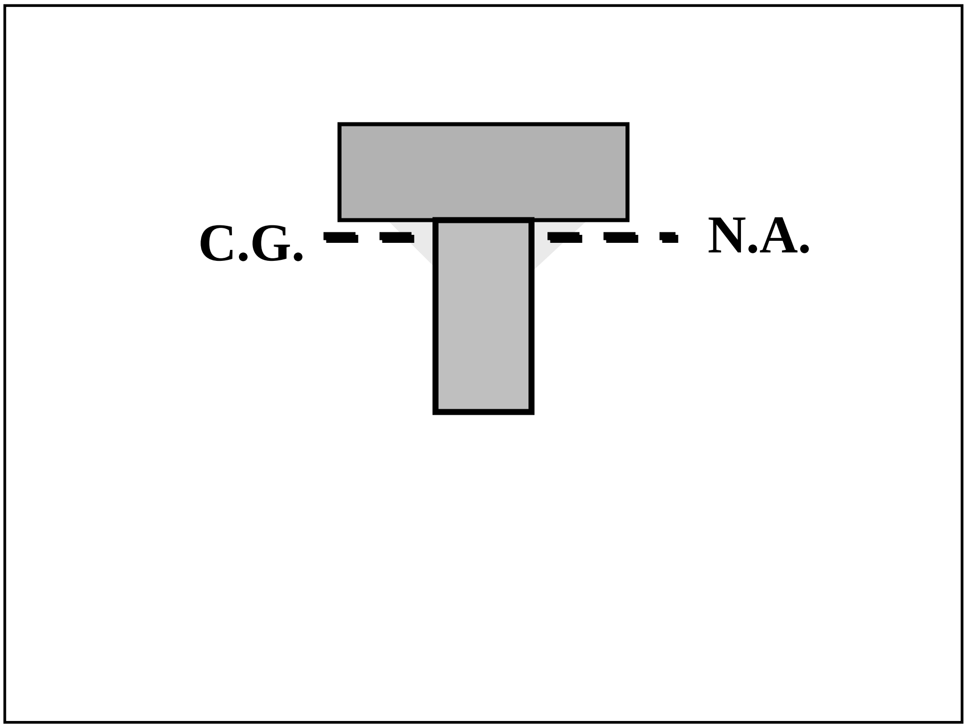

C.G.
N.A.

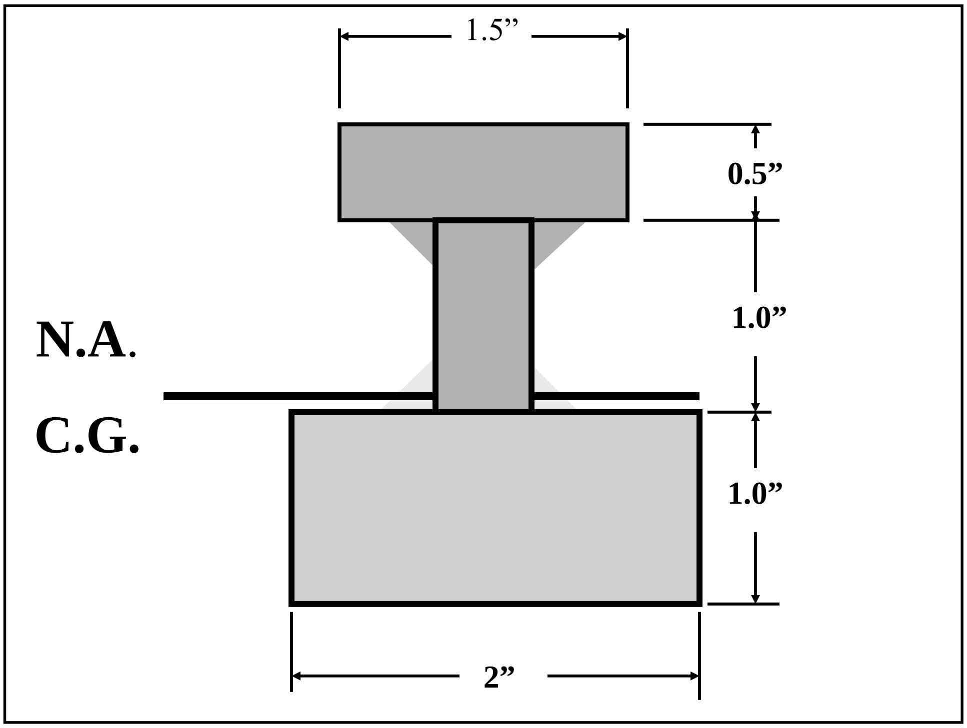

C.G.
N.A.

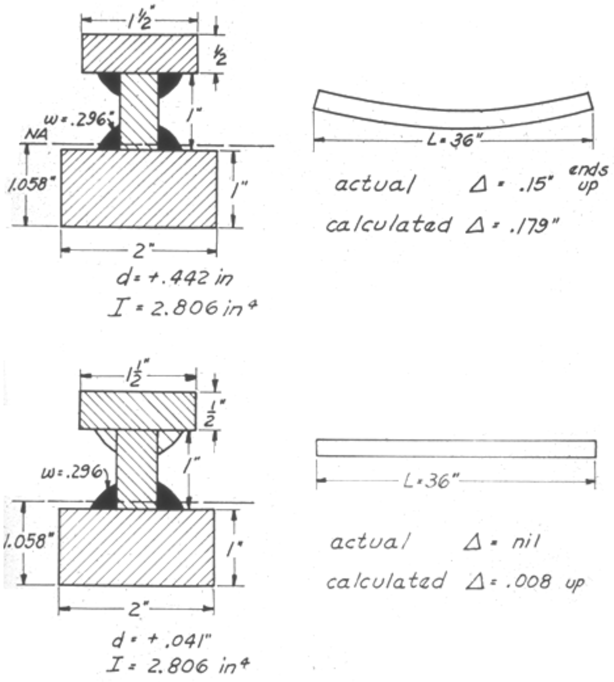
<u>Principle #7</u>

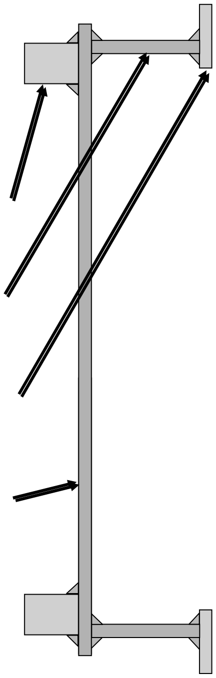
Sequence assembly to balance welds




C.G.
N.A.


1.5"
0.5"
1.0"
N.A.
C.G.
1.0"
2"



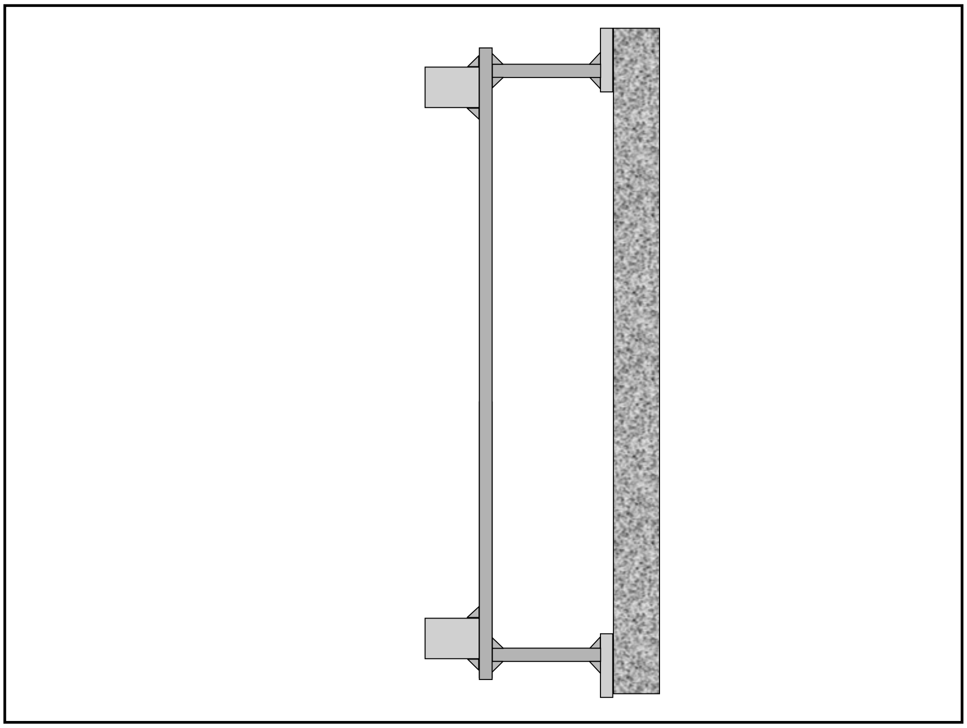


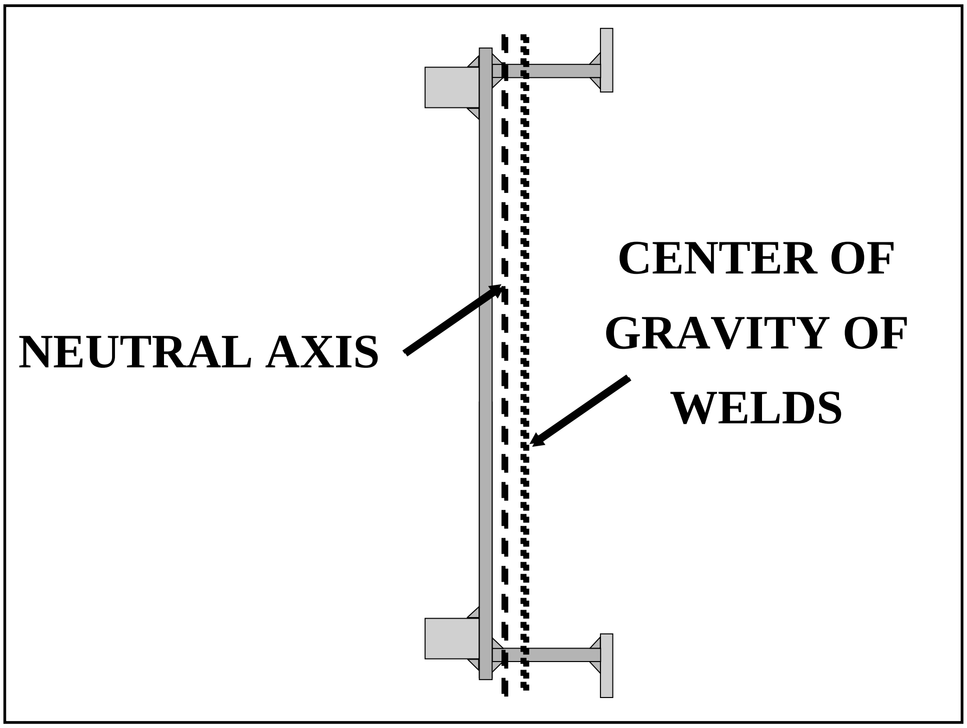
4-1/2” X 2-5/8”

3/8” X 9”

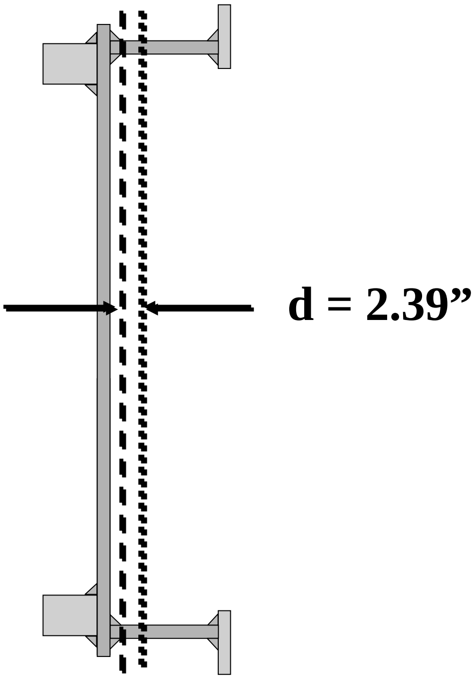
3/8” X 4-1/2”

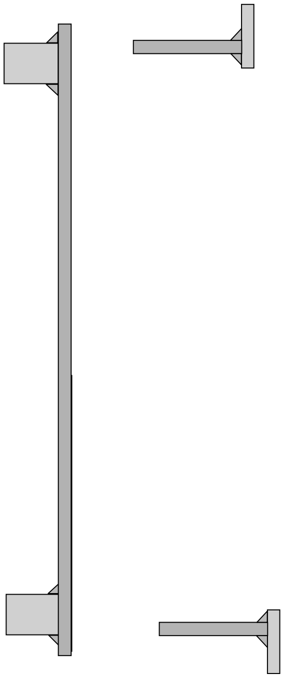
3/8” X 72”

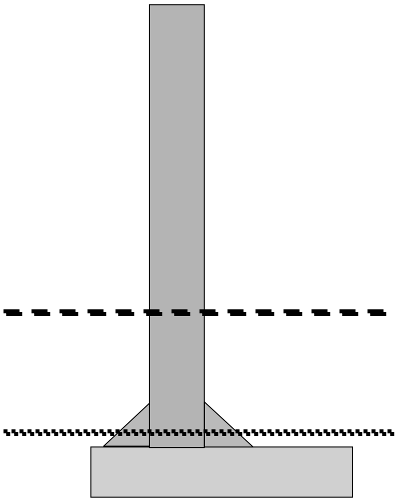




CENTER OF GRAVITY OF WELDS
NEUTRAL AXIS

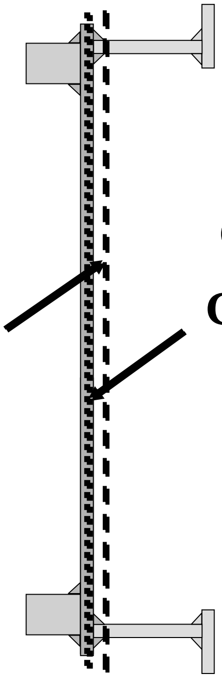

d = 2.39”





NEUTRAL AXIS

CENTER OF
GRAVITY OF WELD

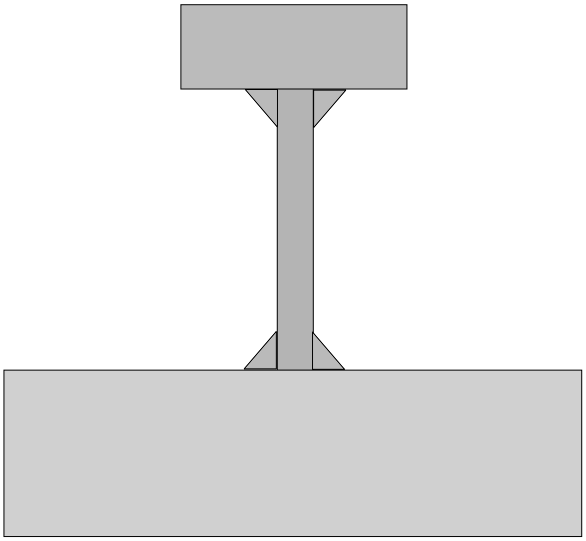


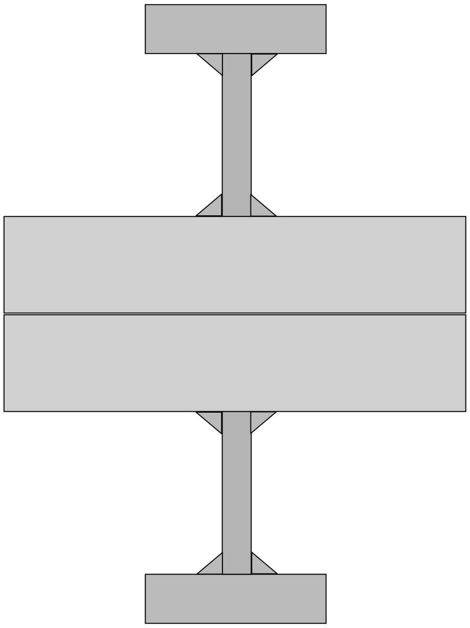
CENTER OF
GRAVITY OF
WELDS

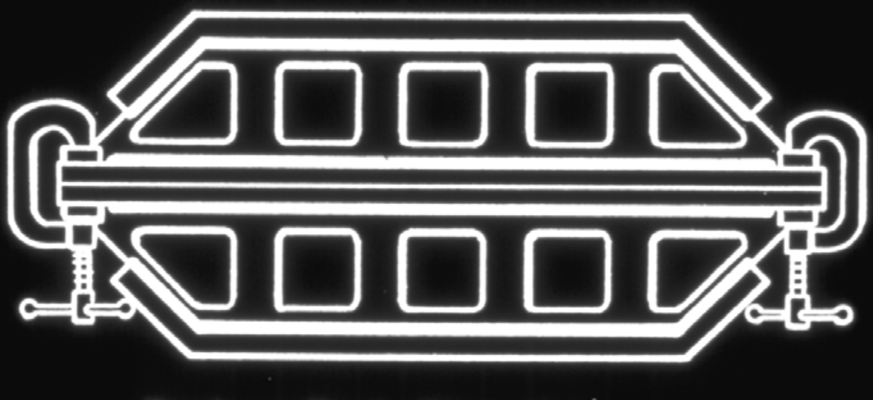
NEUTRAL AXIS

Principle #8

Mirror components



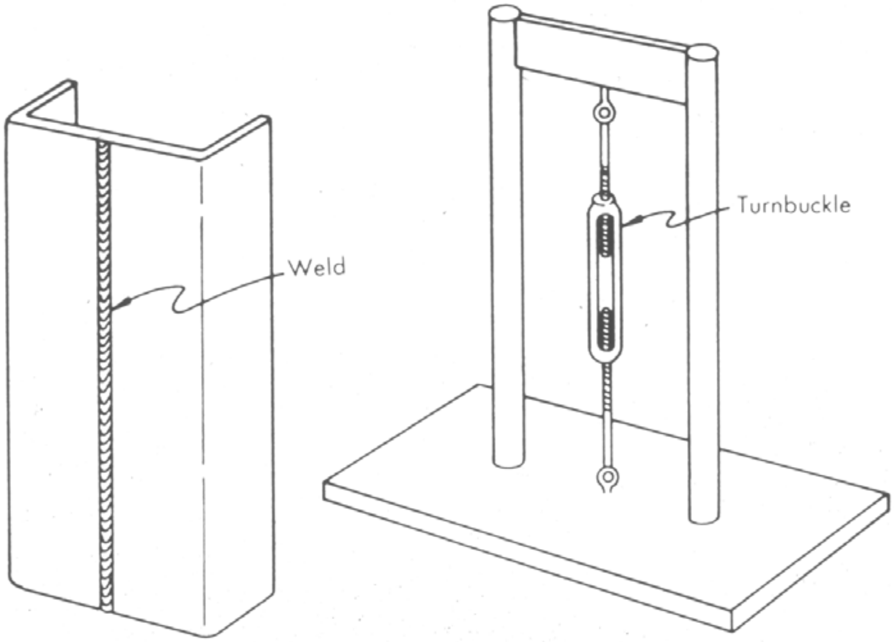


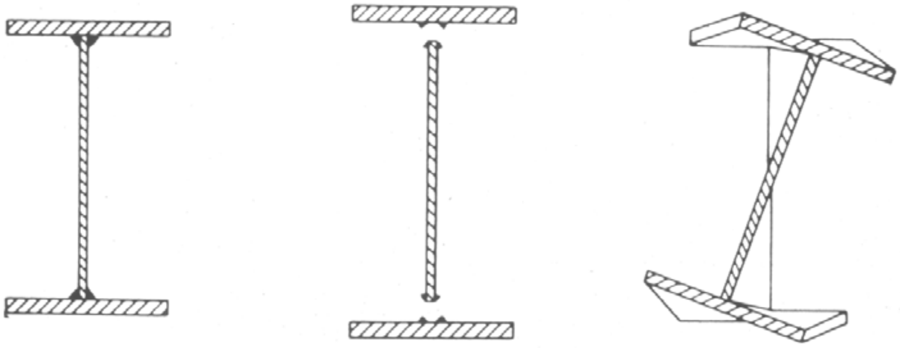


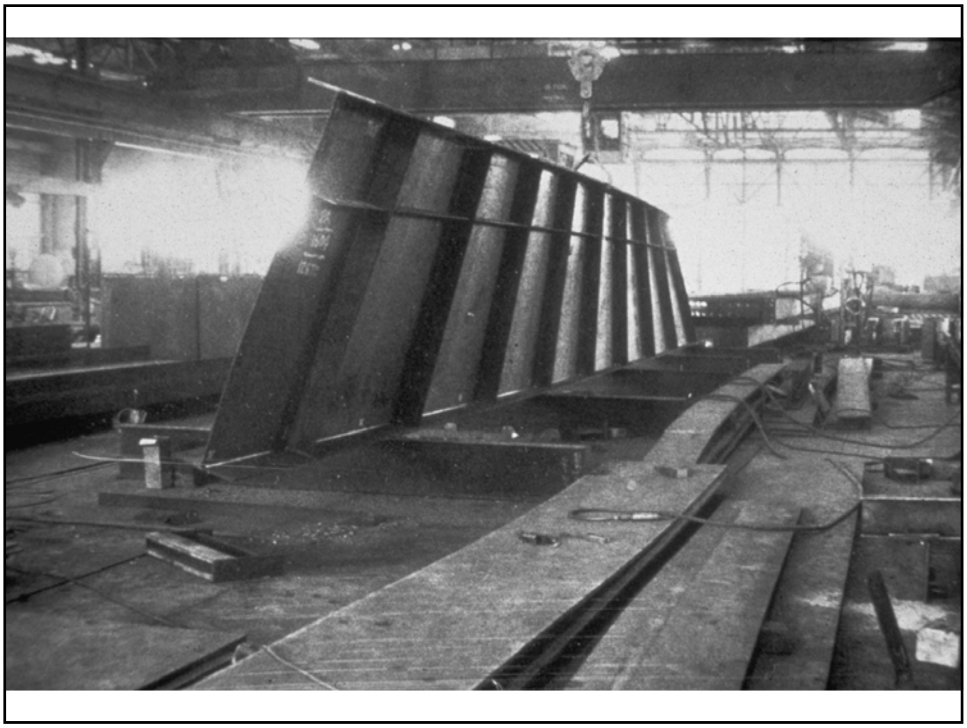
Back-to-Back Clamping

Principle #9

Increase torsional resistance

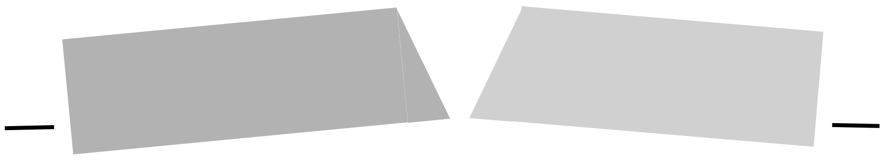


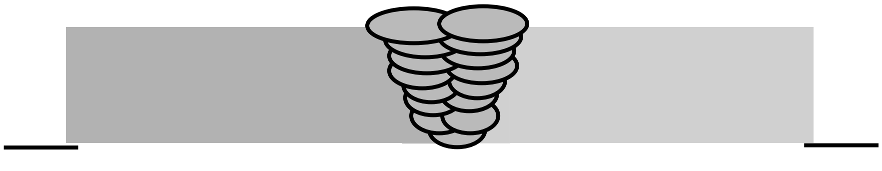


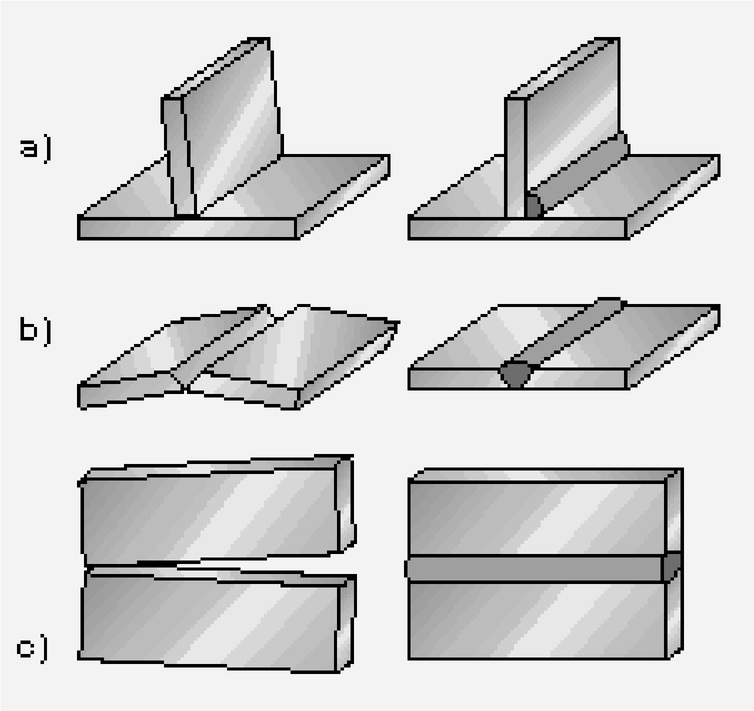


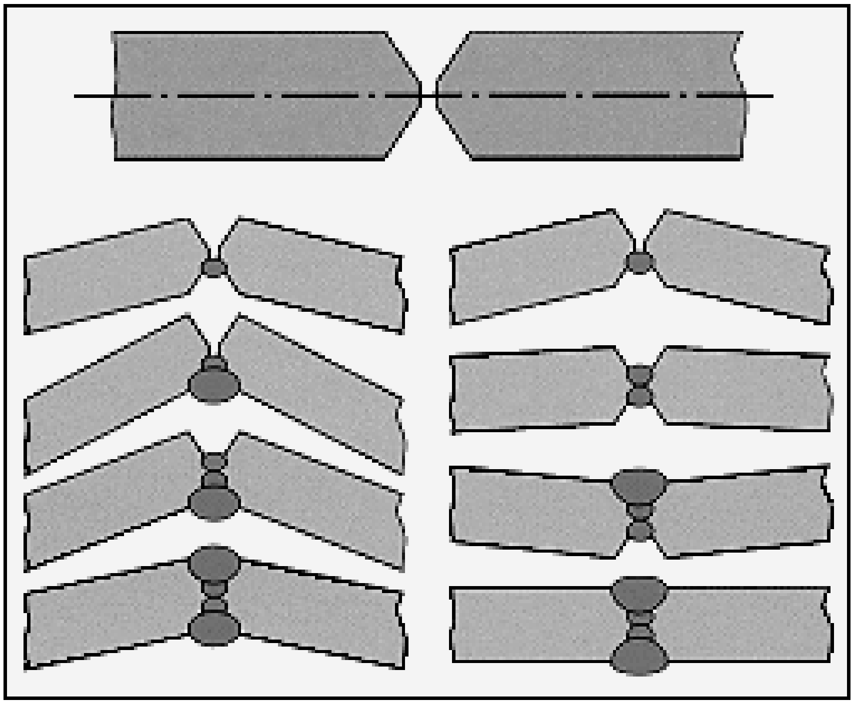
Principle #10

Consider pre-bending or pre-setting



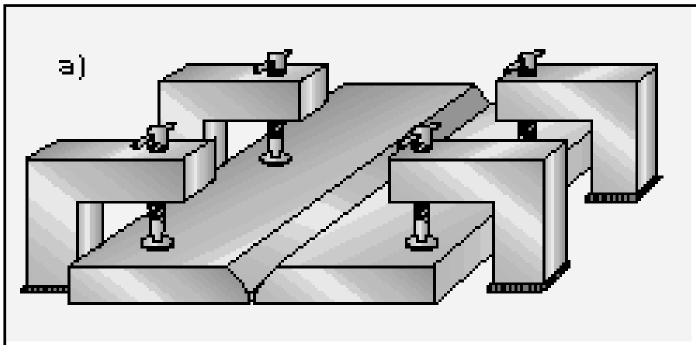


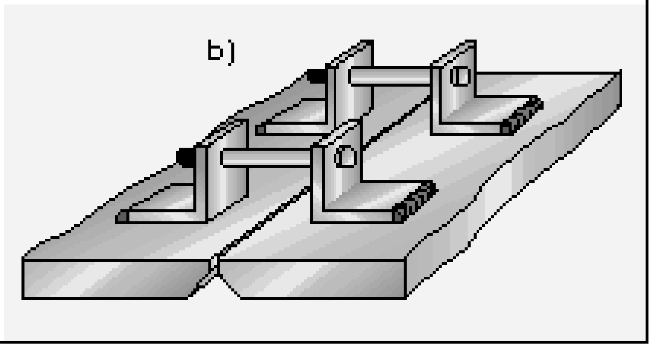

a)
b)
c)

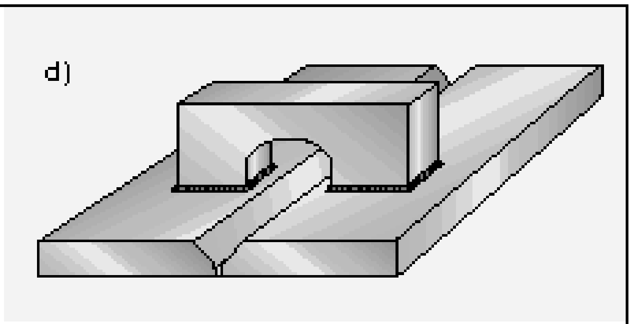


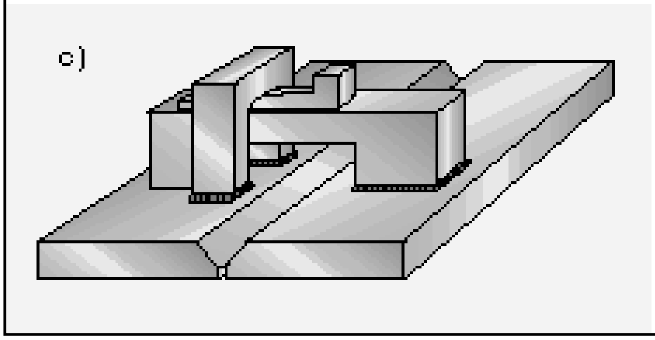
Principle #11

Clamp components


a)

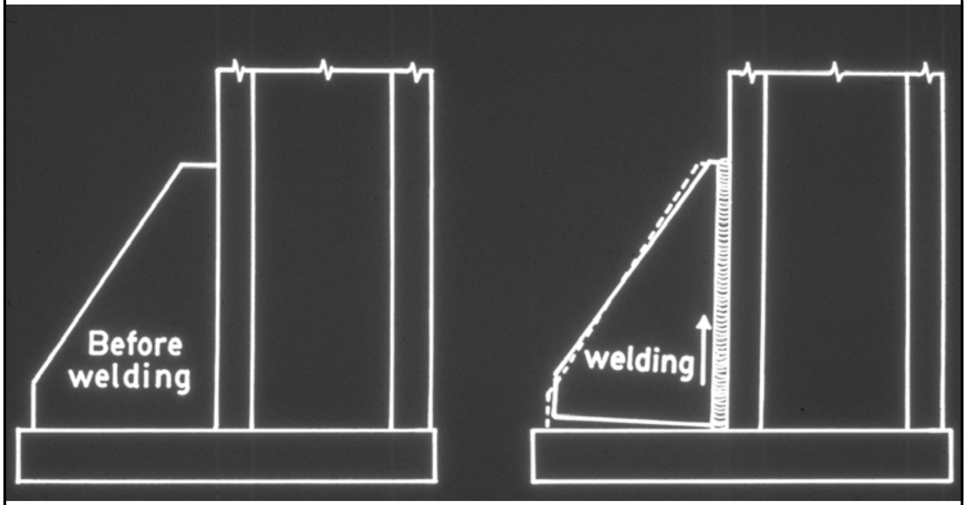

b)

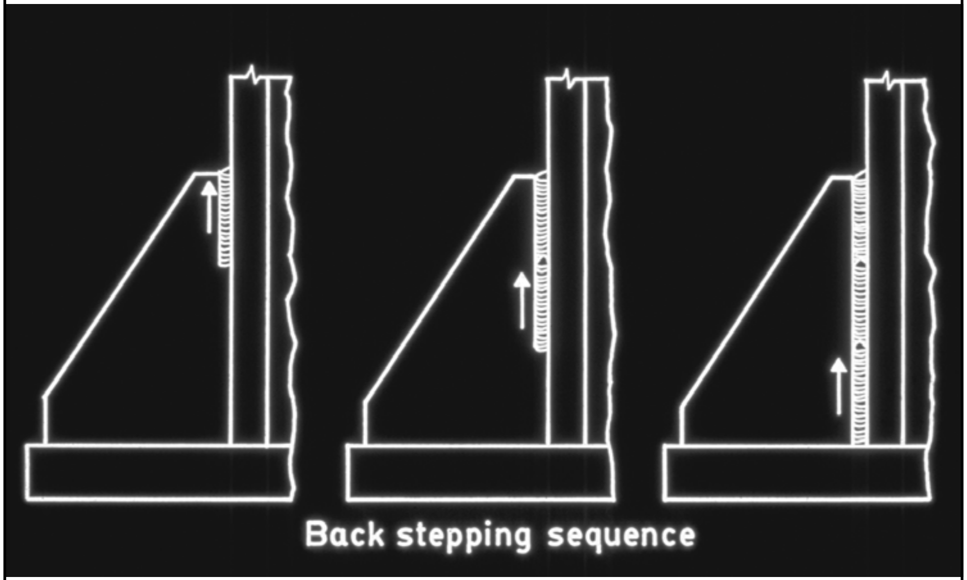

d)


c)

Principle #12

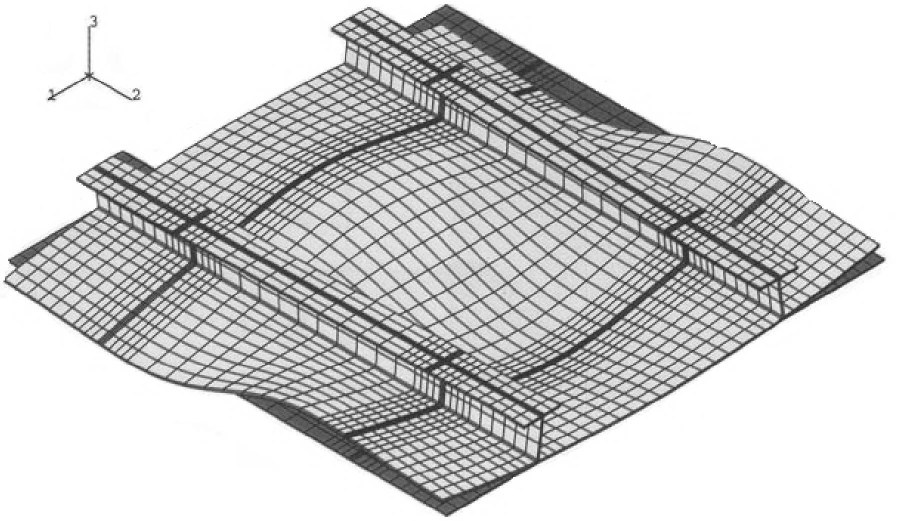
Use back-step welding technique





Back stepping sequence

Estimating Distortion



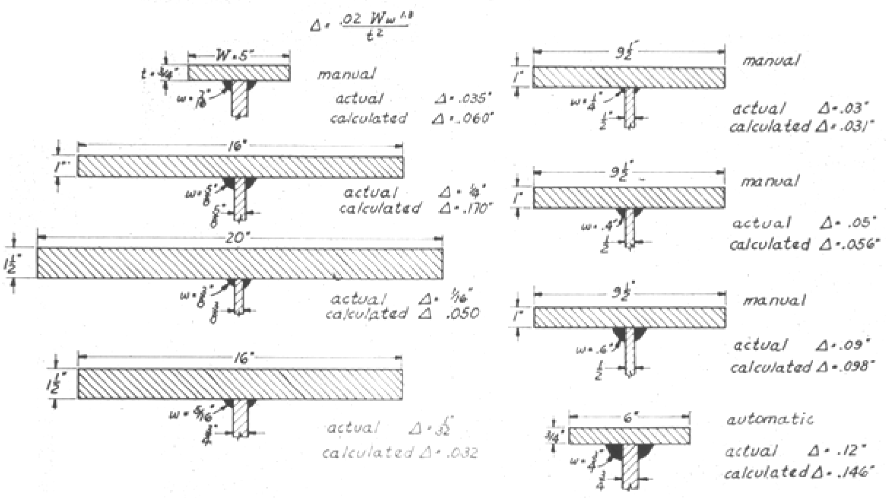
Transverse

$$\Delta_{transverse} = \frac{.10\ A_w}{t}$$

Angular

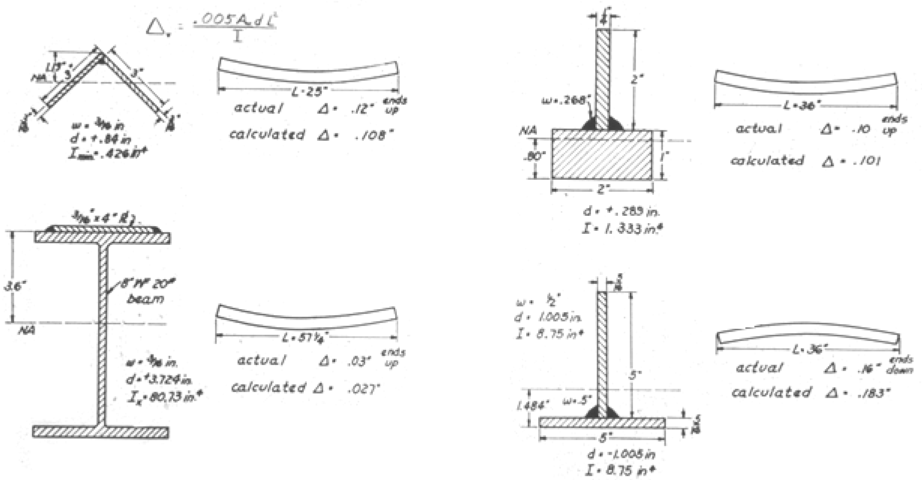
$$\Delta_{angular} = \frac{.02\ W\ \omega^{1.3}}{t^2}$$

For metric 0.02 becomes 0.19

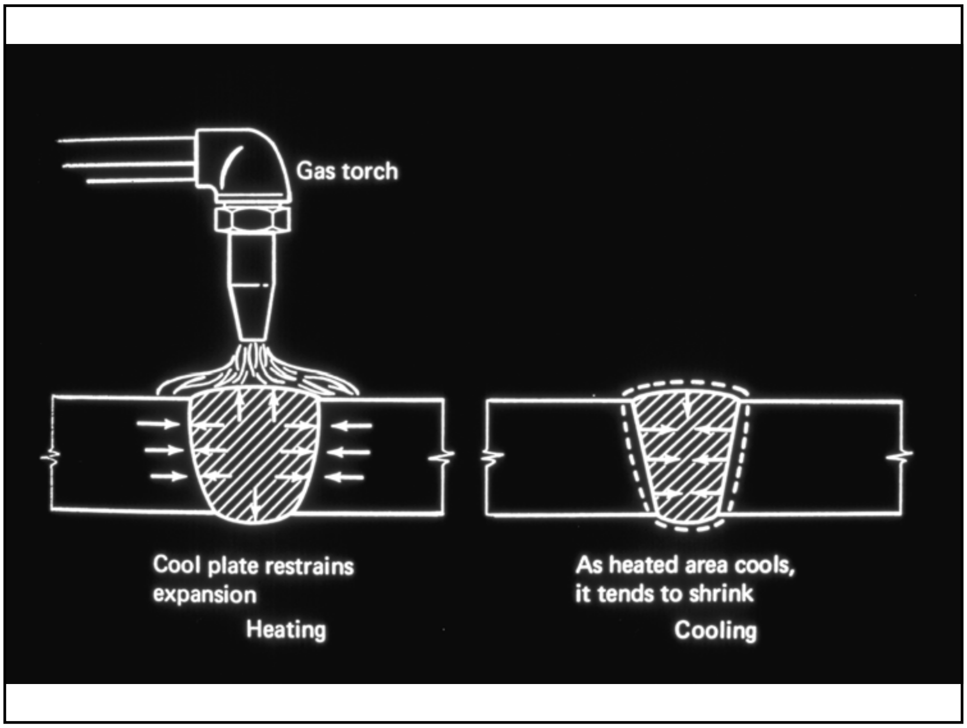


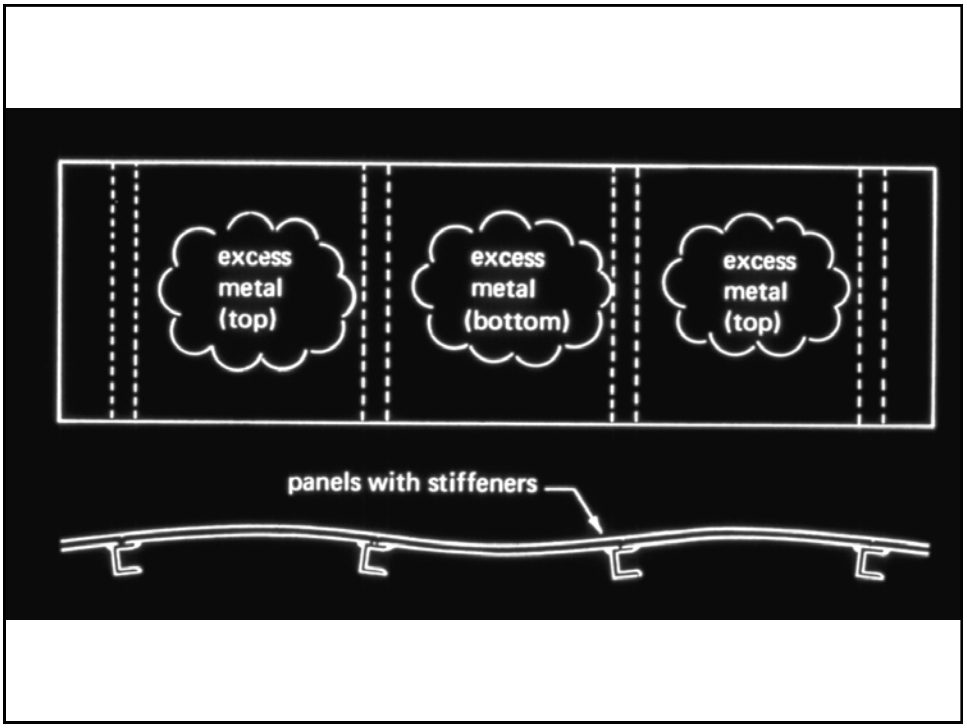
Longitudinal

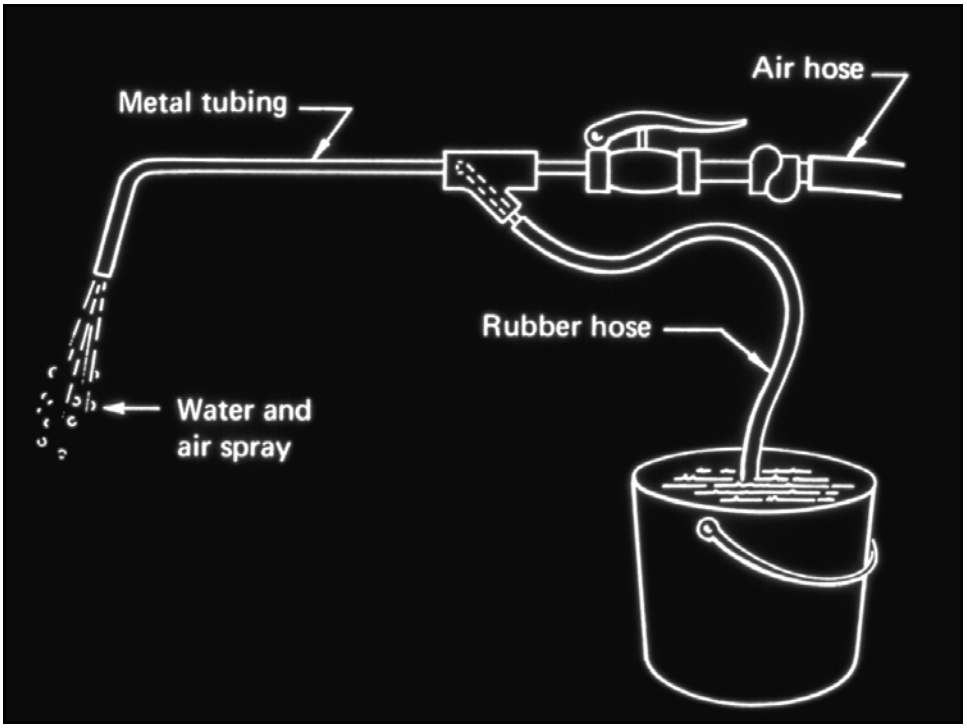
$$\Delta_{longitudinal} = \frac{.005\,A_w\;L^2\;d}{I}$$

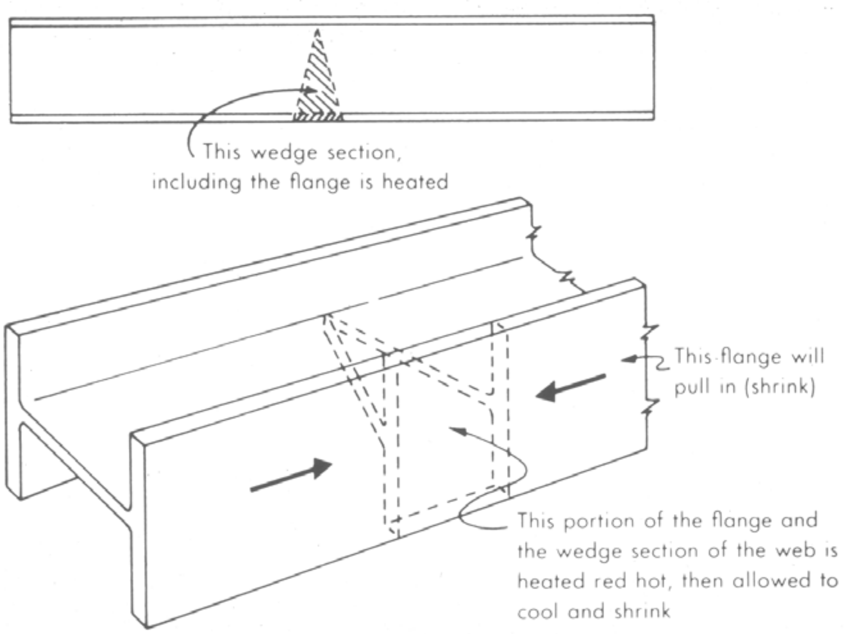


Flame Straightening and Heat Shrinking

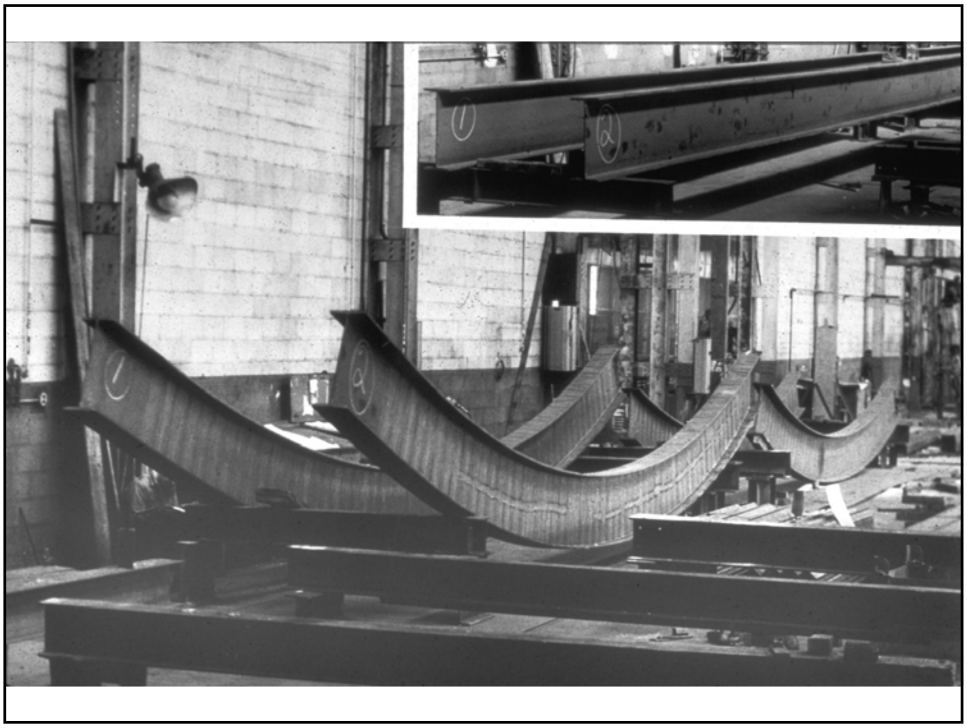



excess
metal
(top)
excess
metal
(bottom)
excess
metal
(top)
panels with stiffeners

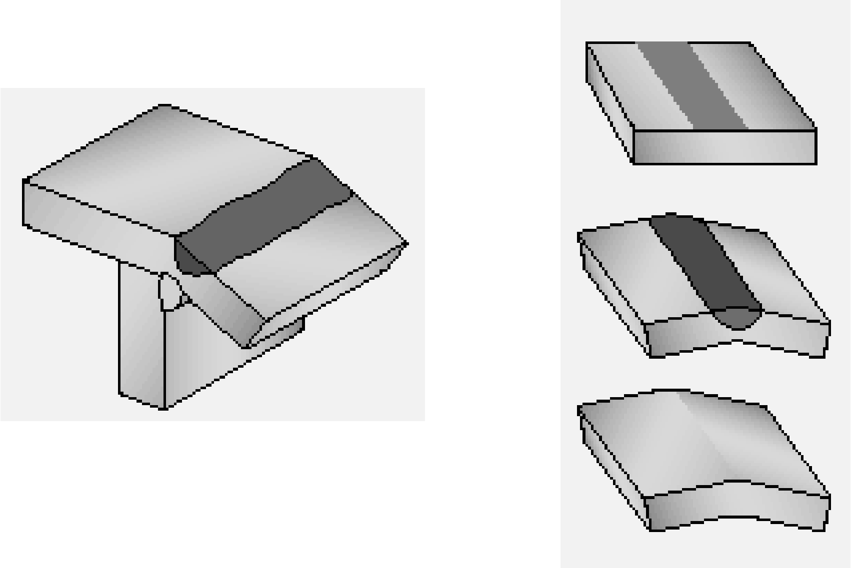

Air hose
Metal tubing
Rubber hose
Water and
air spray

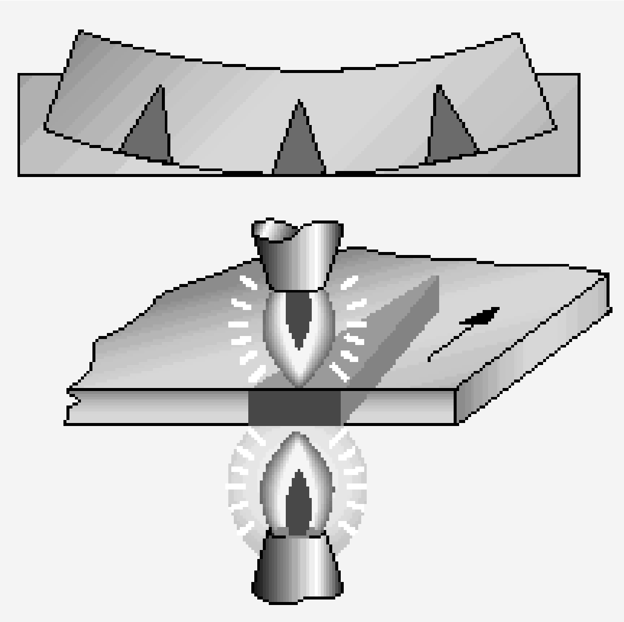

This wedge section,
including the flange is heated
This flange will
pull in (shrink)
This portion of the flange and
the wedge section of the web is
heated red hot, then allowed to
cool and shrink

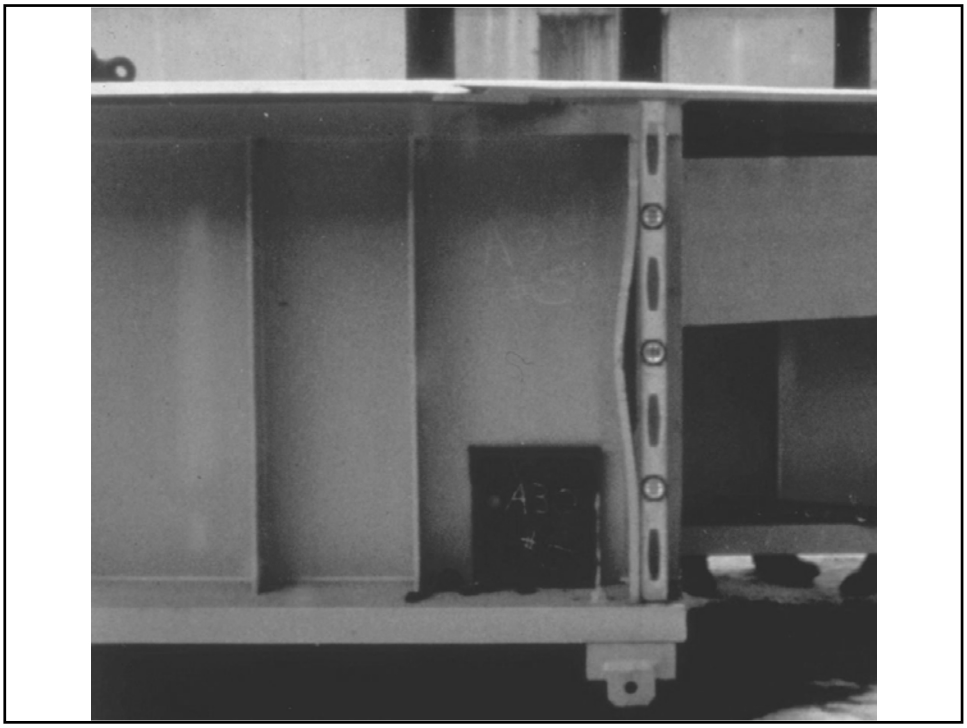

1
2

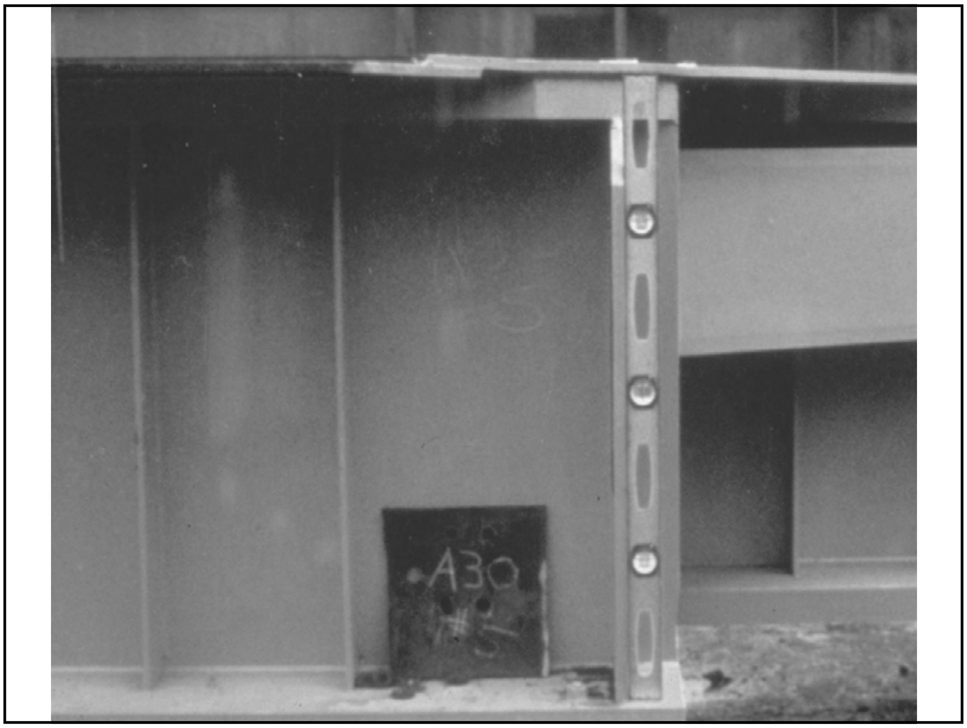

1
2

Heating Location

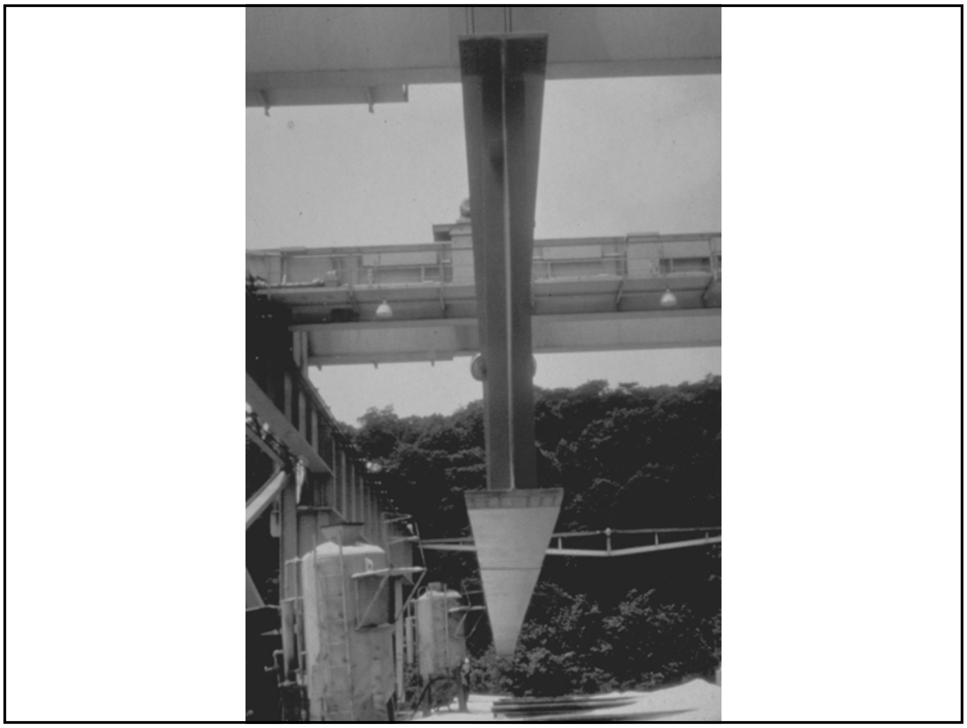


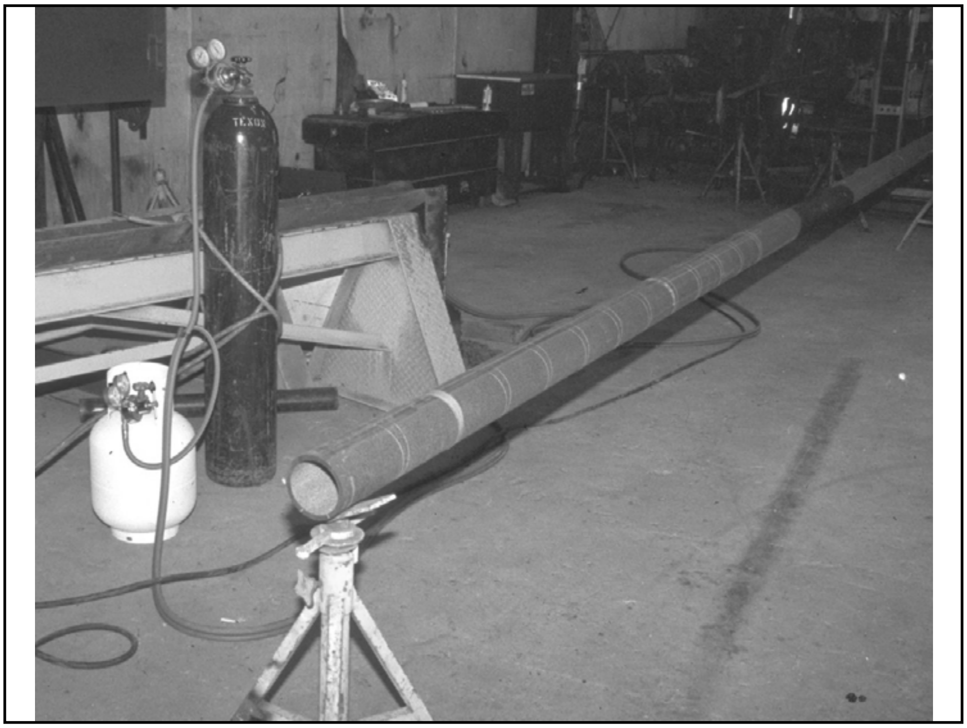


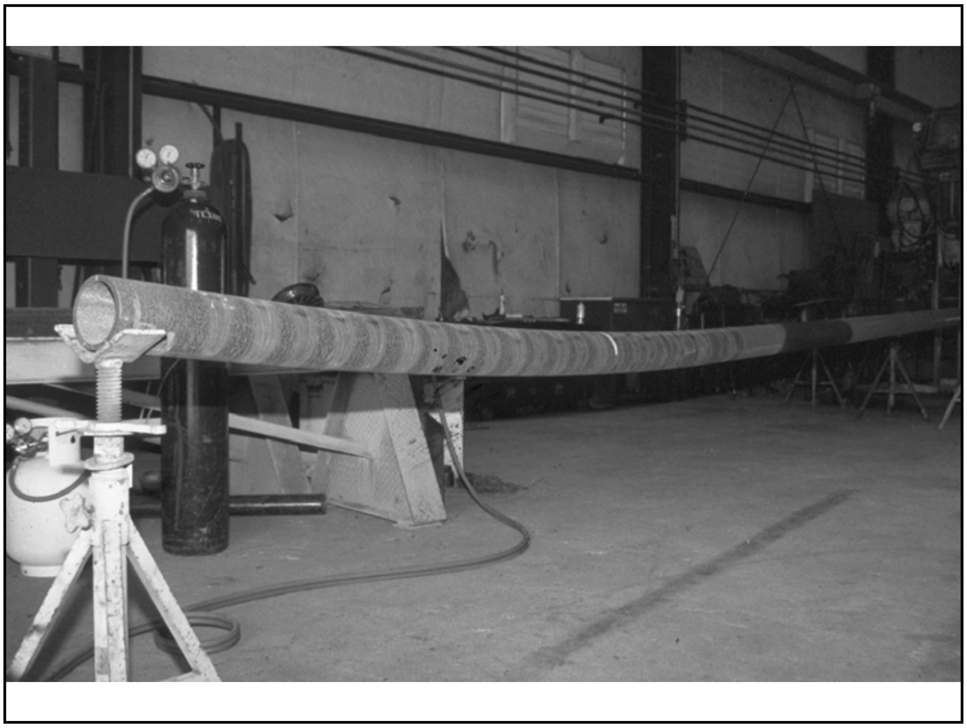

A30

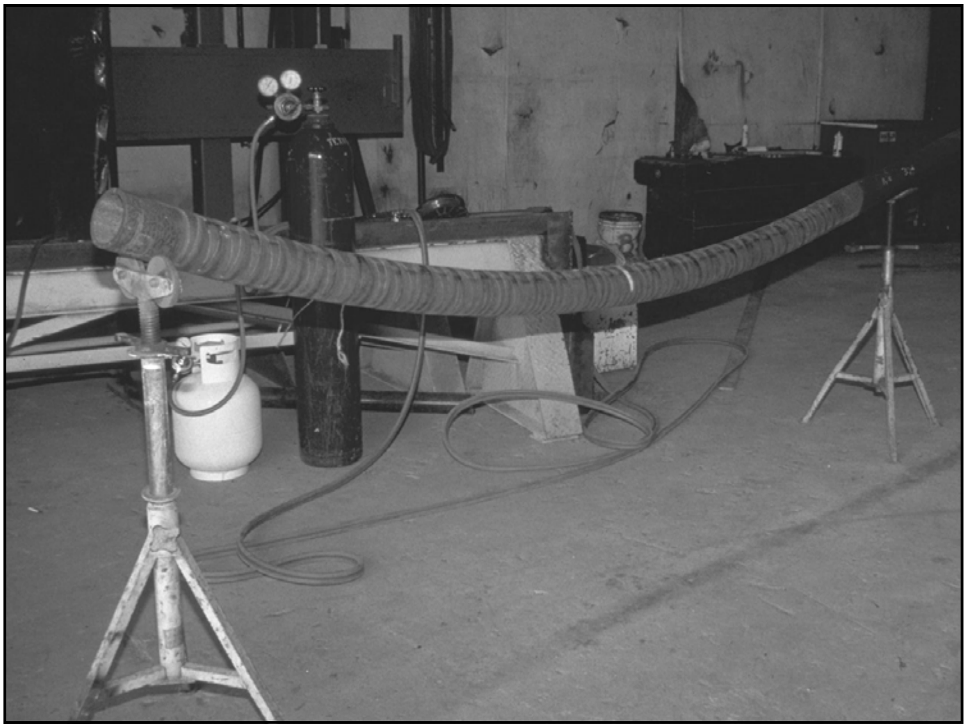

A30
#5

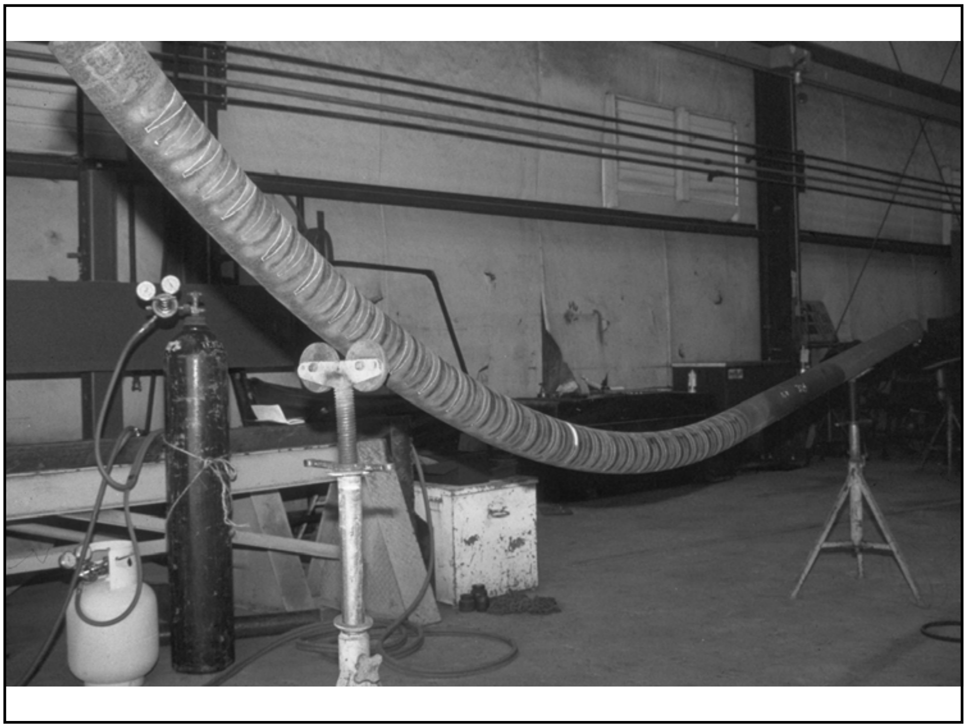

SHAW-BOX

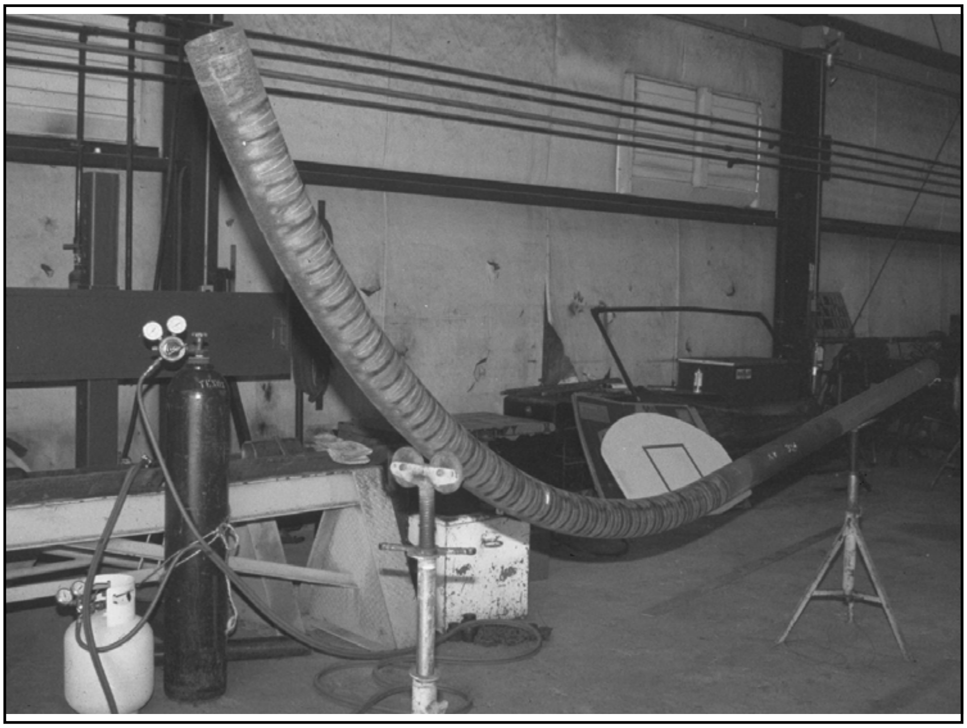








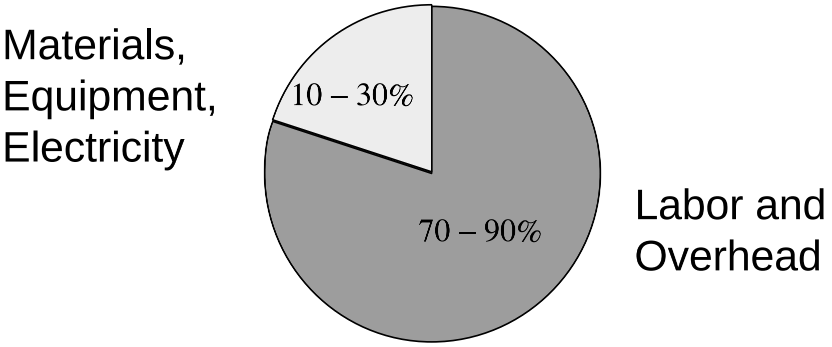




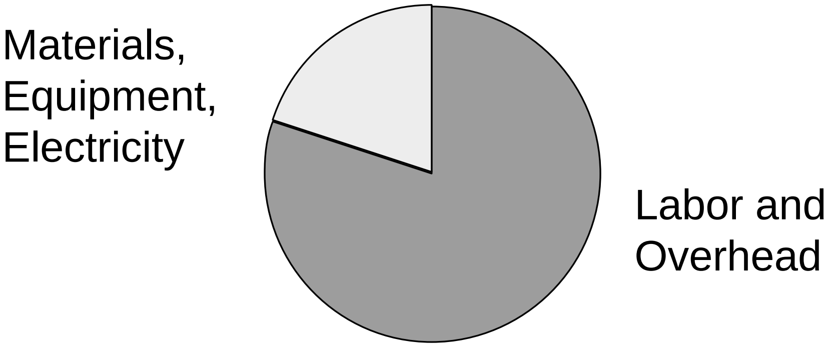
Controlling Distortion

ECONOMY IN WELDING

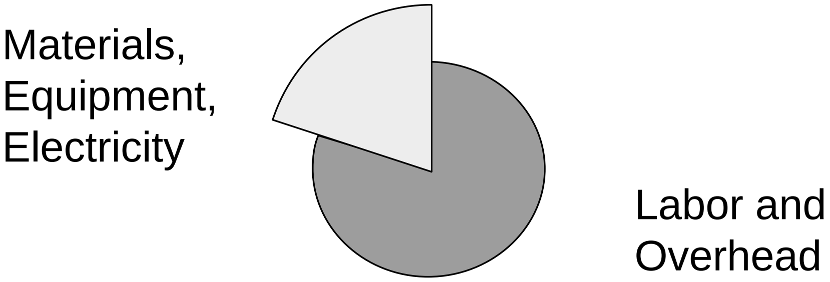
Welding Costs



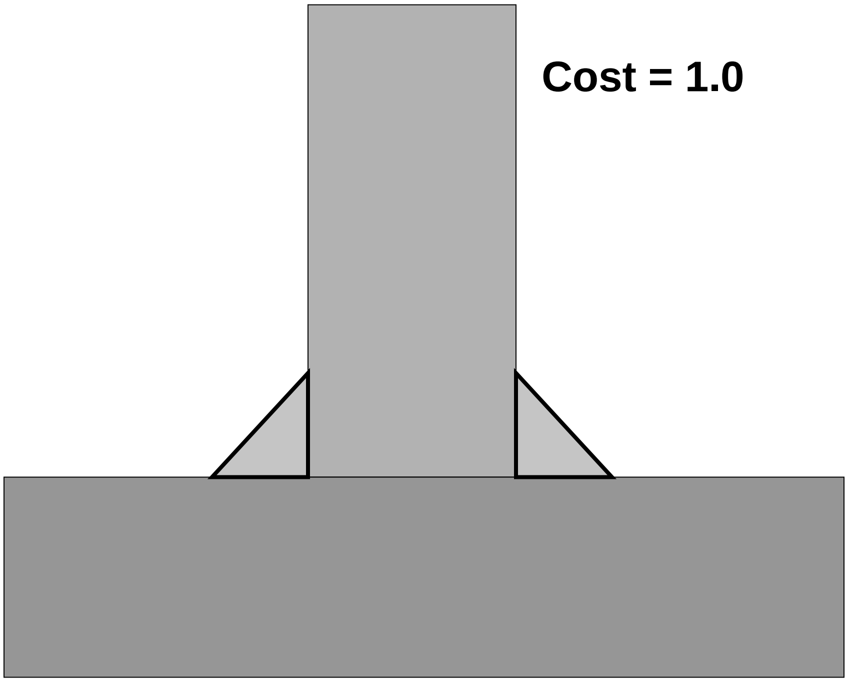
If welding speed is doubled….



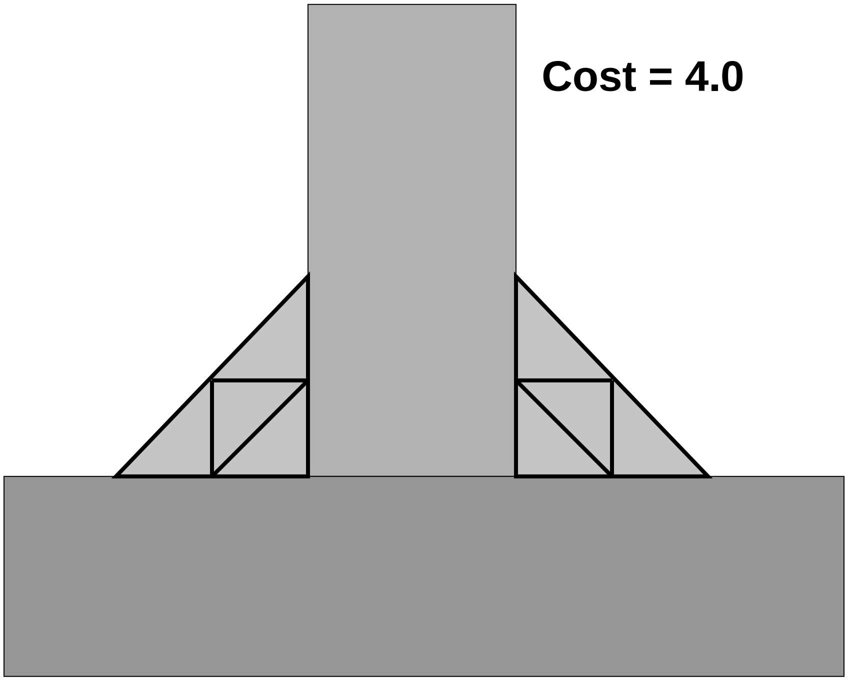
If welding speed is doubled….



Comparing costs to weld volume



Cost = 1.0



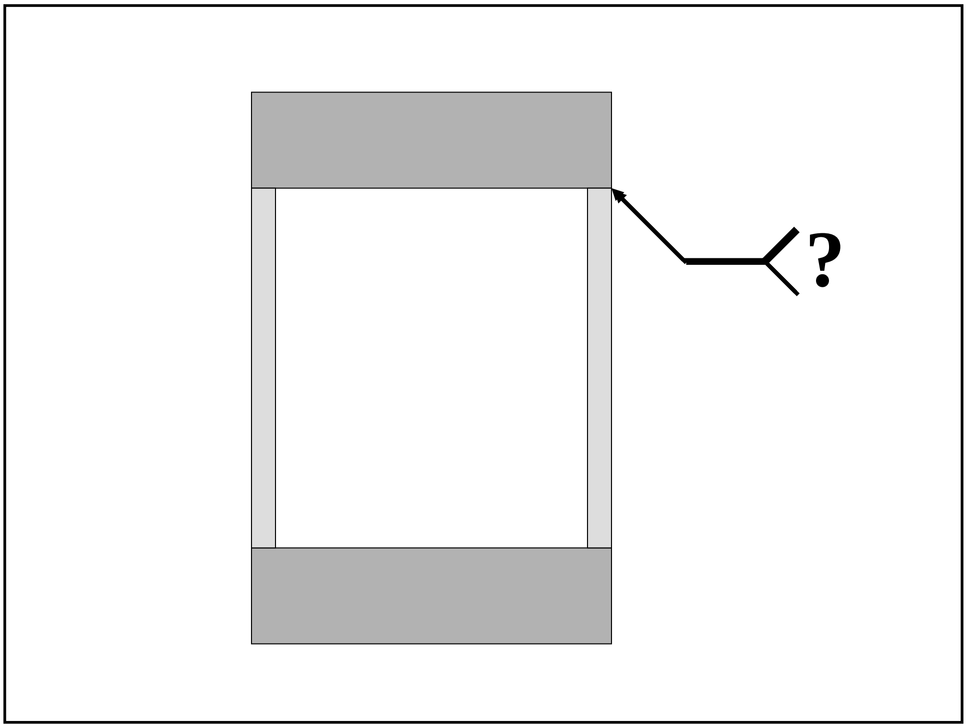
Cost = 4.0

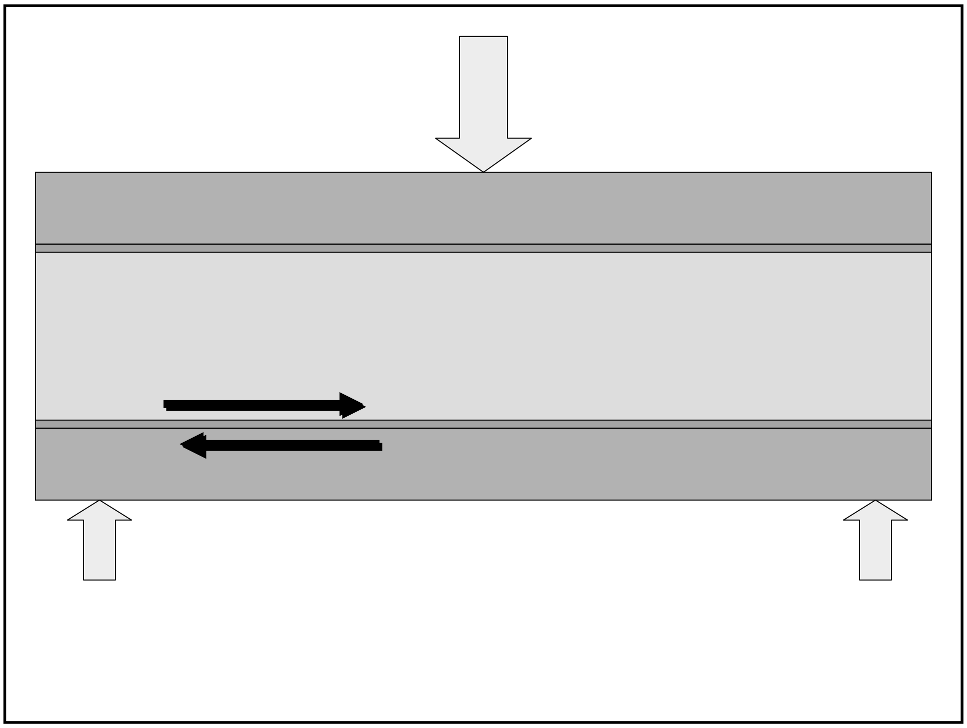
Comparing costs on weld volume

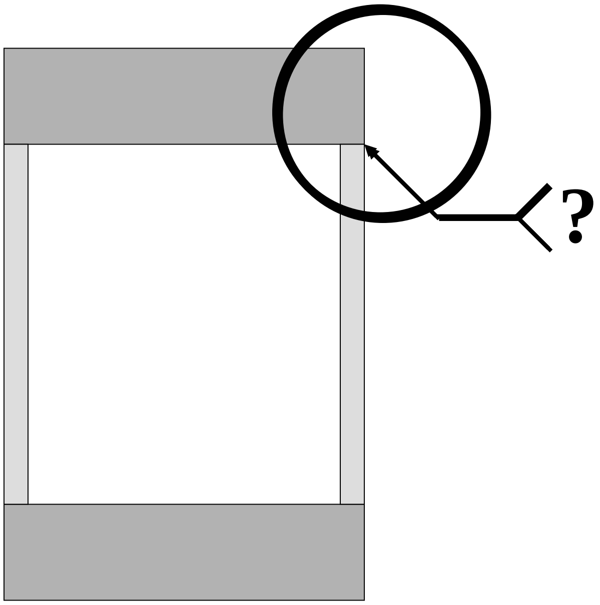
- Assumes same deposition rate
- Assumes same joint preparation cost
- Assumes same weld cleaning cost
- Assumes same labor rate, overhead factors, material costs
- Does not generate absolute cost, only relative cost
- Creates impression that material is most costly item

Economy in Welding

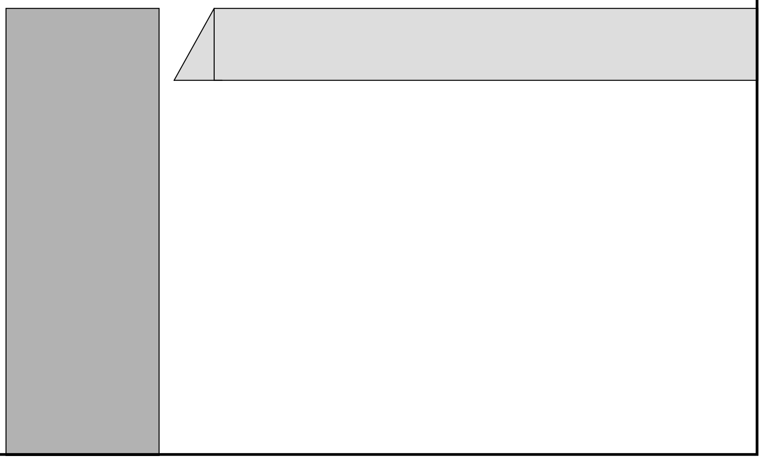
- Selection of proper weld type
  - **CJP groove welds versus alternatives**



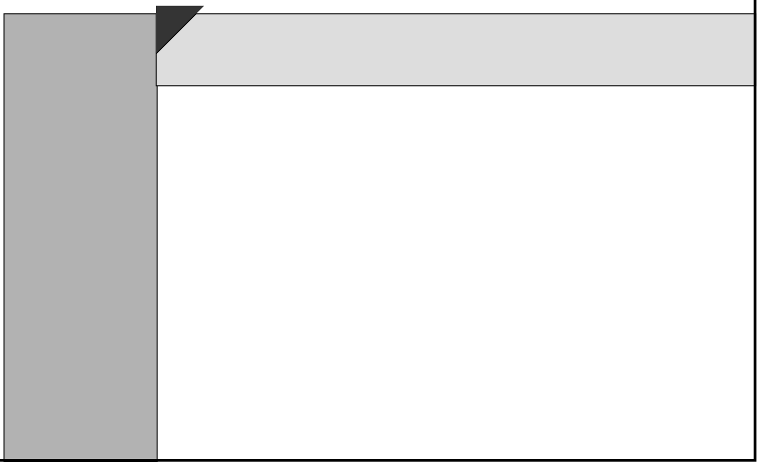




CJP



PJP



Comparison: CJP vs PJP

1.5” web

CJP: 4.41 #/ft
PJP: 1.10 #/ft

75% Less Welding

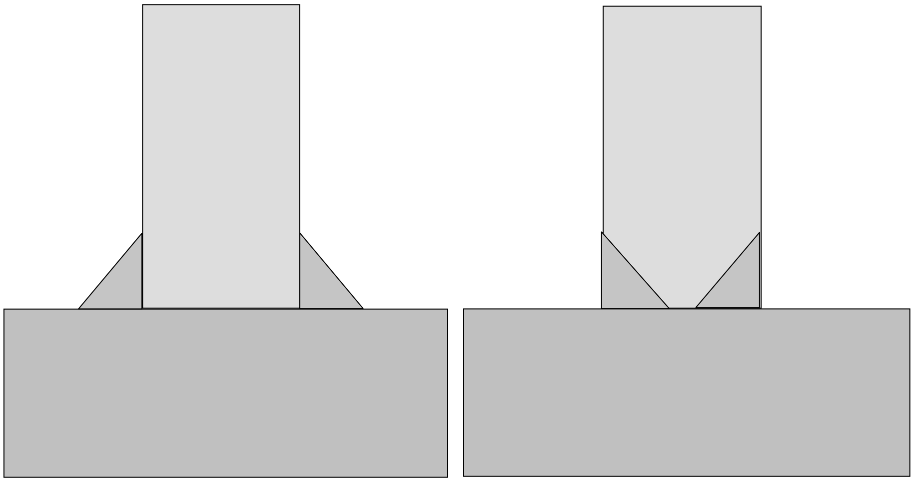
Economy in Welding

- Selection of proper weld type
  - – CJP groove welds versus alternatives
  - – **Fillet welds versus PJP groove welds**

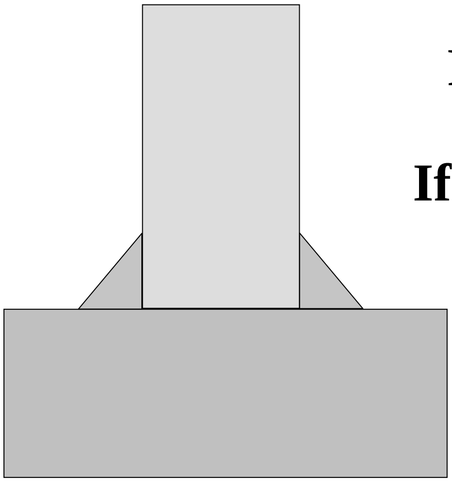
Fillet vs. PJP Groove Weld

- **Both used in corner, tee joints**
- **PJPs more "efficient" in use of weld metal**

Fillet versus PJP Groove Welds



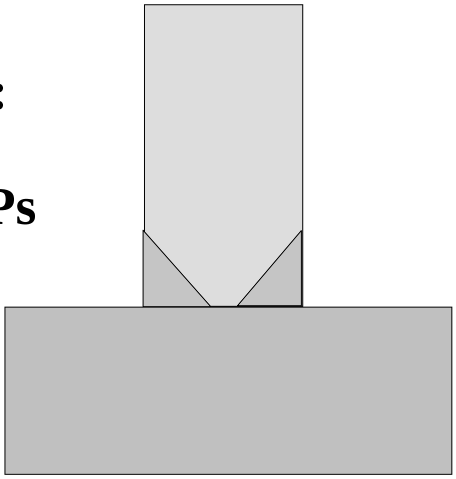
Fillet versus PJP Groove Welds



Rule of Thumb:

If t<3/4”, use fillets

Fillet versus PJP Groove Welds



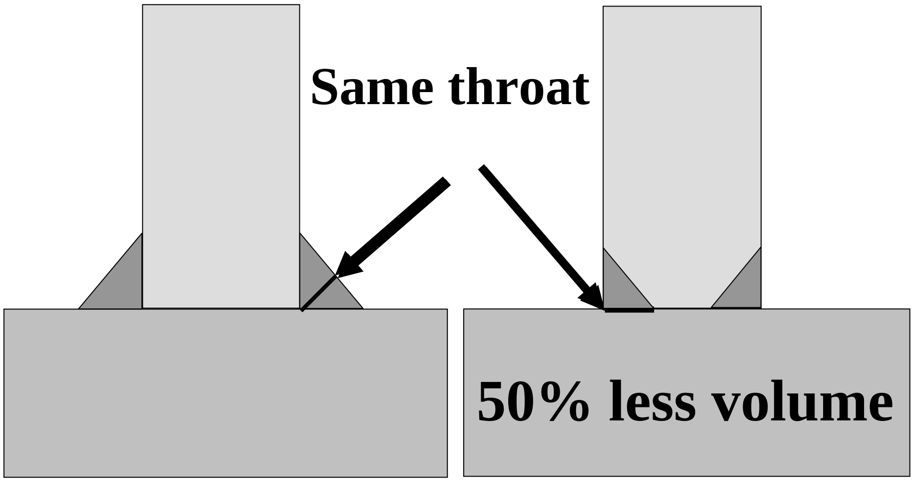
Rule of Thumb:

If t>3/4”, use PJPs

Economy in Welding

- Selection of proper weld type
  - CJP groove welds versus alternatives
  - Fillet welds versus PJP groove welds
  - **Combination fillet/PJP groove weld**

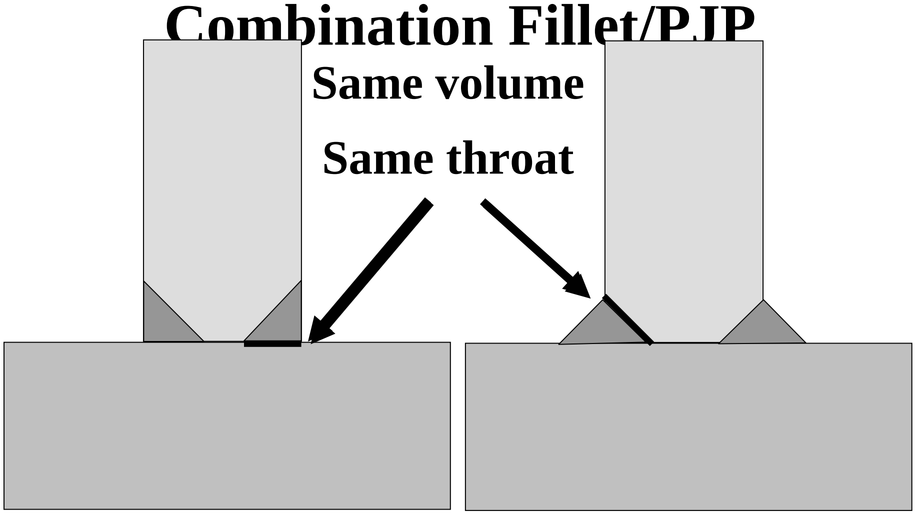
Fillet versus PJP Groove Welds



Same throat

50% less volume

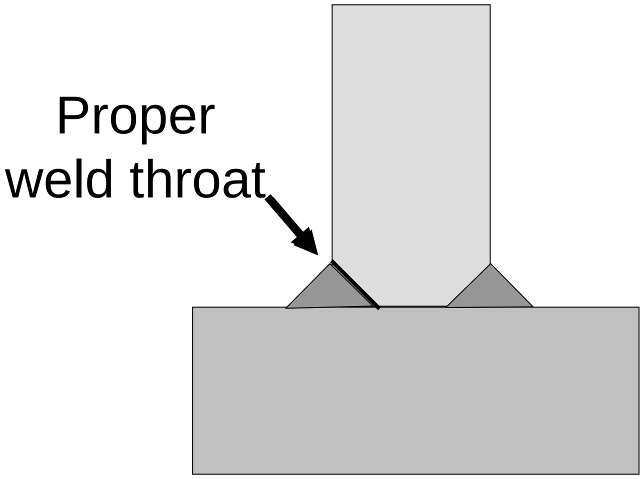
PJP Groove Weld versus Combination Fillet/PJP



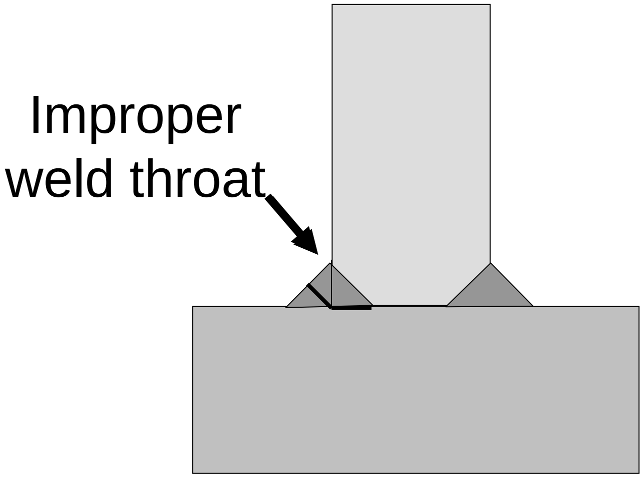
Same volume

Same throat

Combination Fillet/PJP



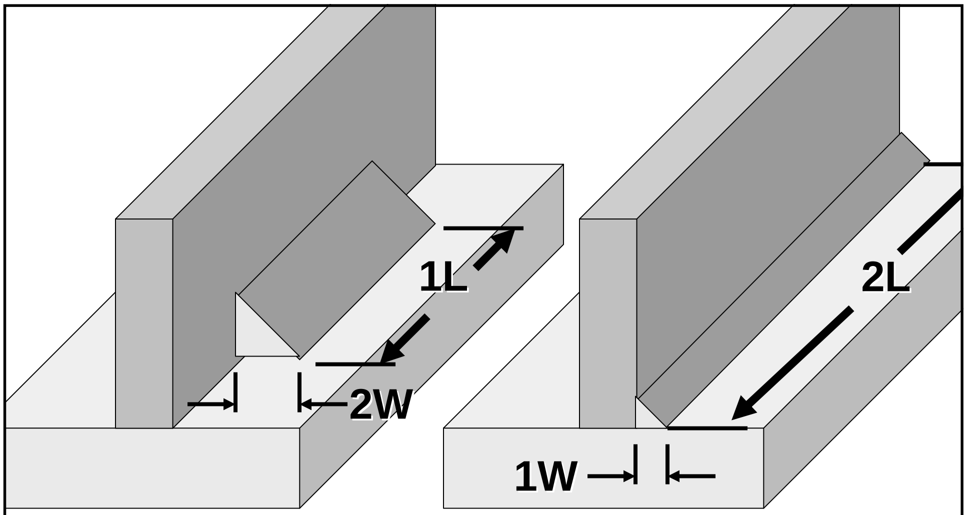
Combination Fillet/PJP



Economy in Welding

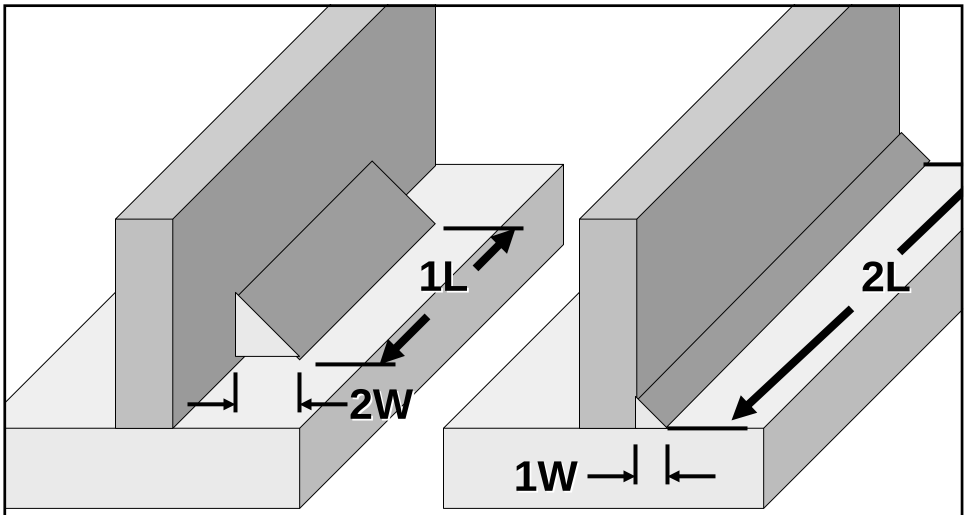
- Selection of proper weld type
  - – CJP groove welds versus alternatives
  - – Fillet welds versus PJP groove welds
  - – Combination fillet/PJP groove weld
- Proper weld detailing
  - – **Fillet welds: leg size versus length**

USE SMALLER LEG SIZE AND LONGER LENGTH FILLET WELDS



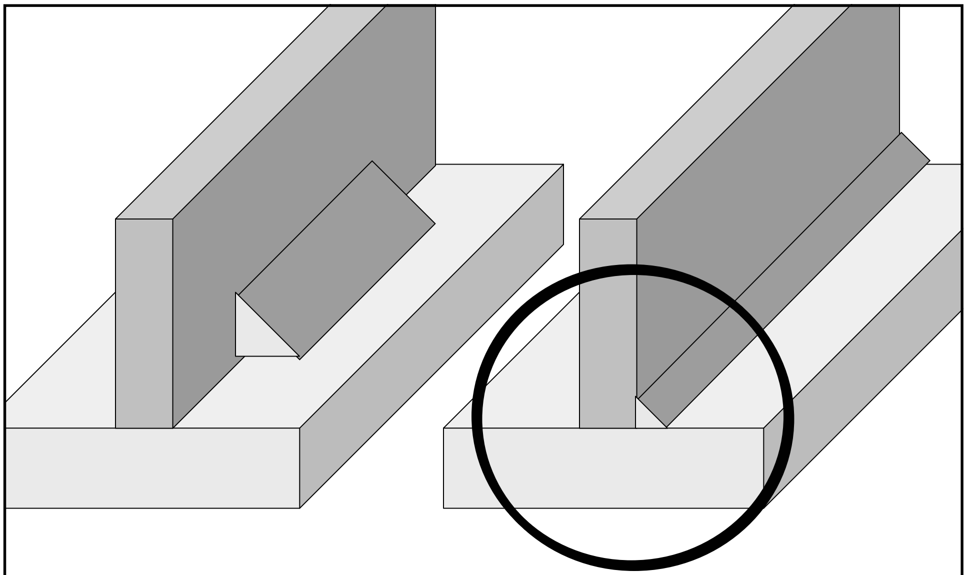
0.3EXX(0.707x2W)X1L   0.3EXX(0.707x1W)x2L

0.424 WLEXX = 0.424 WLEXX

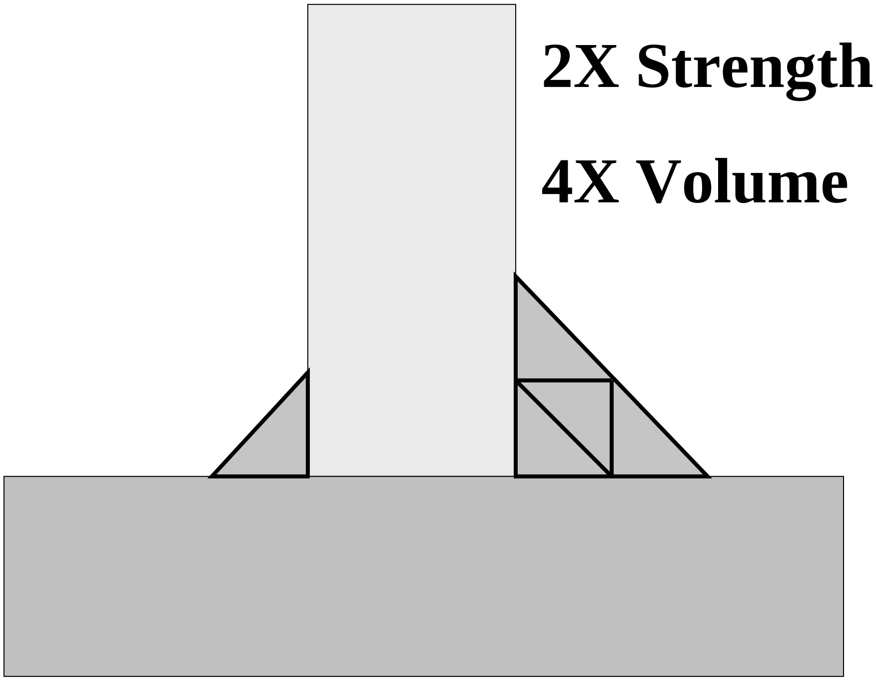


$\{(2W)^2/2\}$ X 1L   VOLUME $\{(1W)^2/2\}$ X 2L

= $2W^2L$ 2X   = $1W^2L$

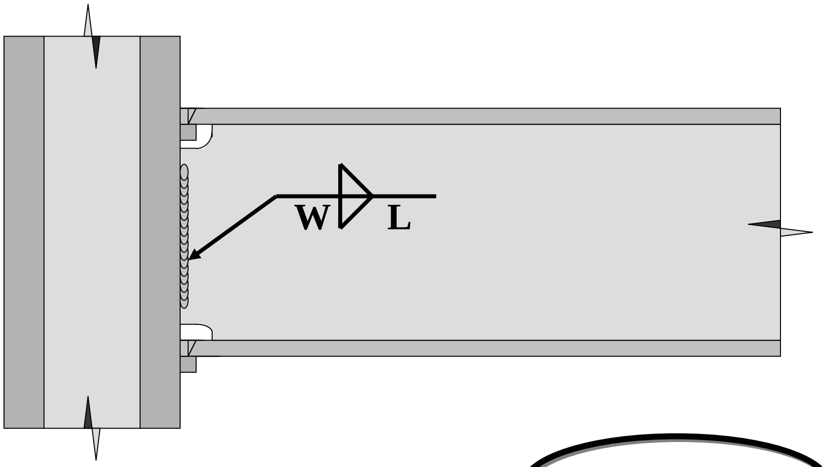


50% LESS VOLUME



2X Strength

4X Volume



5/16” – 8” long

0.087 cubic inch

1/4” – 10” long

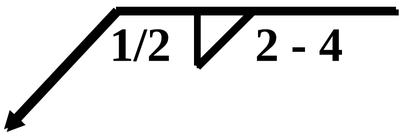
0.078 cubic inch

25% Savings

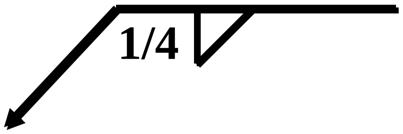
Economy in Welding

- Selection of proper weld type
  - CJP groove welds versus alternatives
  - Fillet welds versus PJP groove welds
  - Combination fillet/PJP groove weld
- Proper weld detailing
  - Fillet welds: leg size versus length
  - **Fillet weld: intermittent versus continuous**

CAPACITY

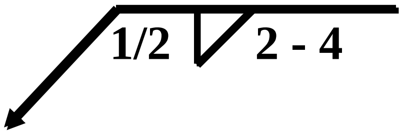


f = 0.30EXX x 0.707 x 1/2 x 2/4 = 0.053EXX

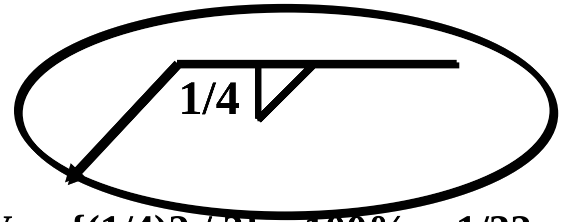


f = 0.30EXX x 0.707 x 1/4 x 1/1 = 0.053EXX

VOLUME

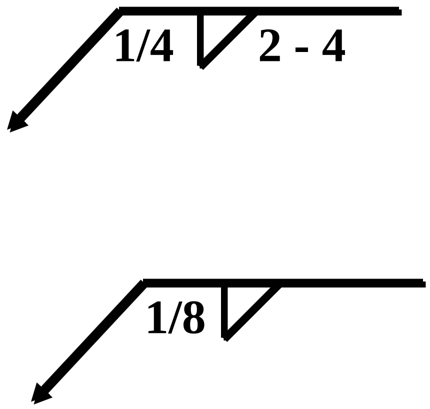


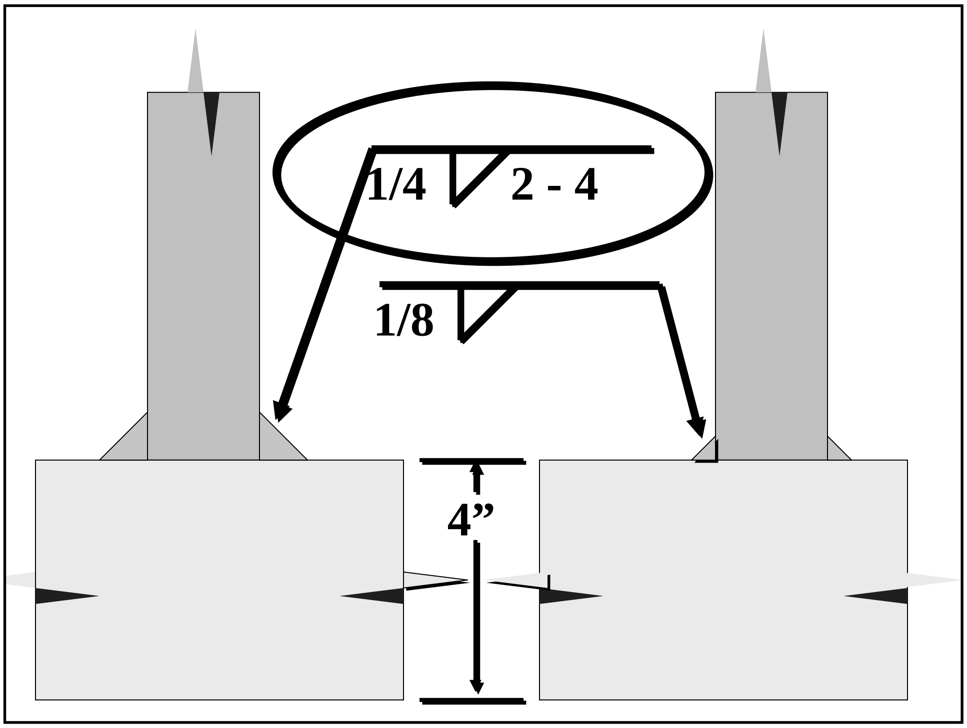
V = $\{(1/2)^2 / 2\}$ x 50% = 1/16



50% LESS

V = {(1/4)2 / 2} x 100% = 1/32


1/4
2 - 4
1/8

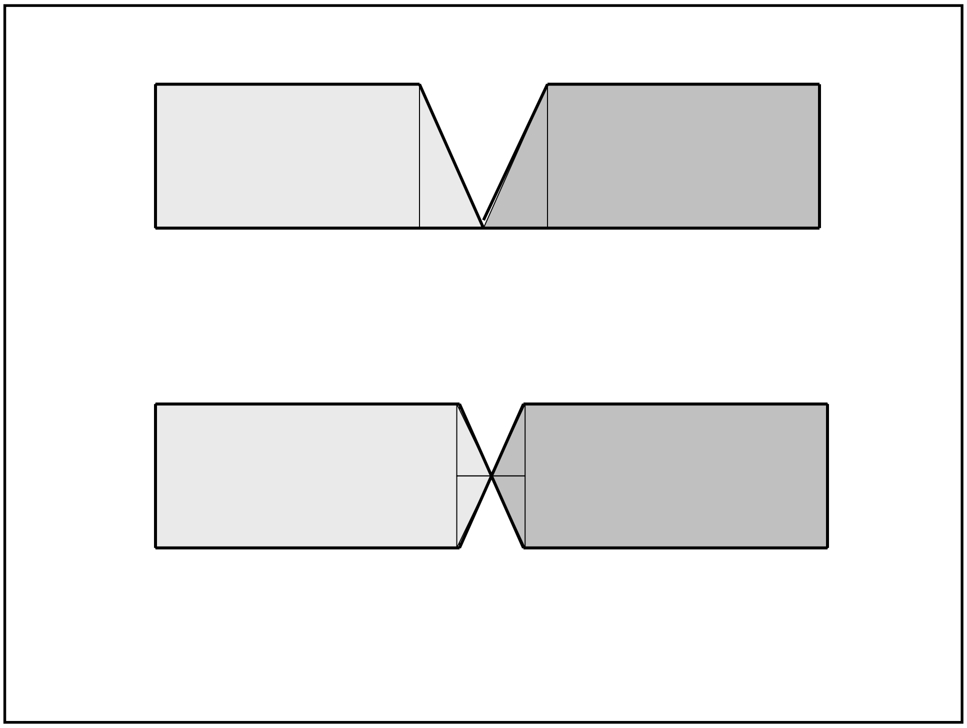

1/4
2 - 4
1/8
4”

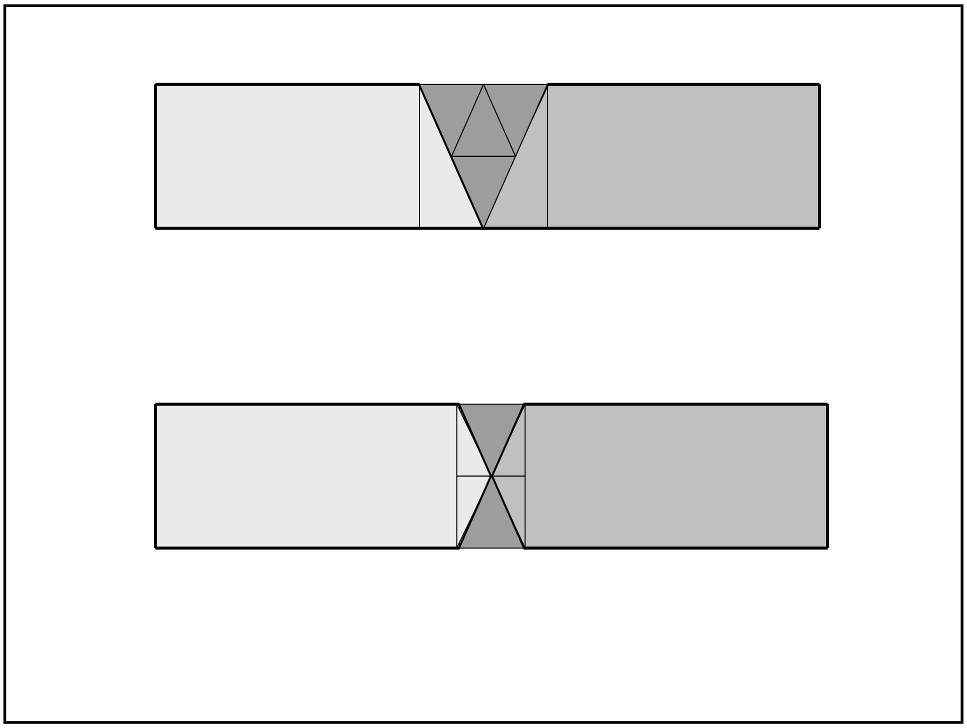
INTERMITTENT VERSUS CONTINUOUS FILLET WELDS

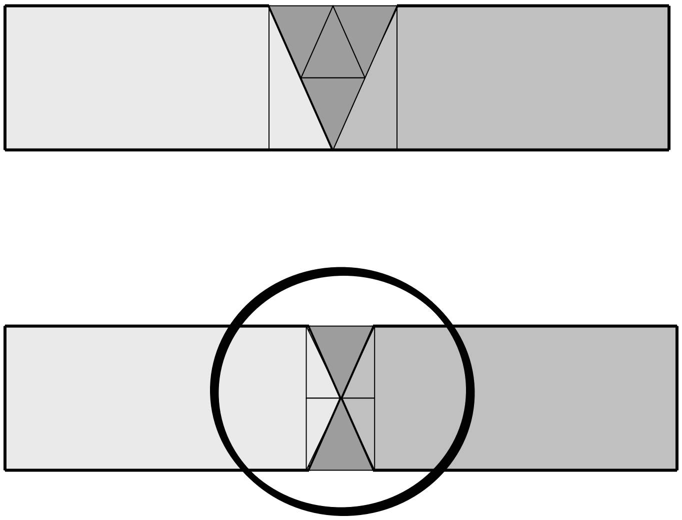
1. Start with fillet welds of the minimum size.
2. Determine required length.
3. If required length << joint length, consider intermittent fillet welds.
4. If the required length > joint length, increase fillet weld leg size.
5. If subject to cyclic loading (fatigue), consider consequences of B versus E.
6. Consider manufacturing implications of intermittent fillet welds.

Economy in Welding

- Selection of proper weld type
  - CJP groove welds versus alternatives
  - Fillet welds versus PJP groove welds
  - Combination fillet/PJP groove weld
- Proper weld detailing
  - Fillet welds: leg size versus length
  - Fillet weld: intermittent versus continuous
  - **Groove welds: single versus double sided**

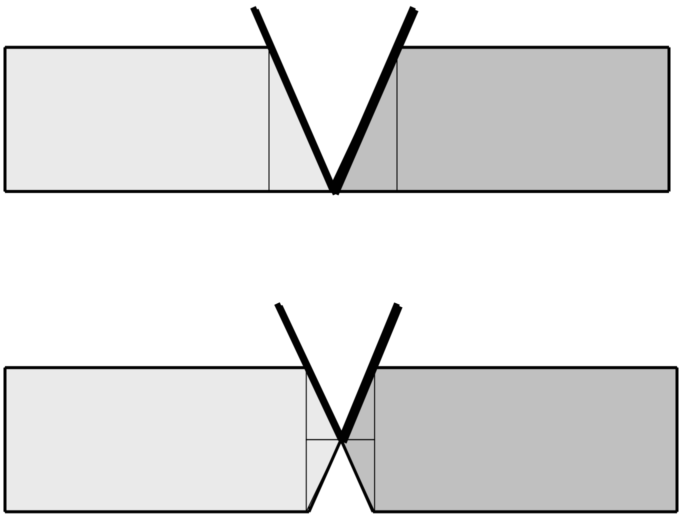




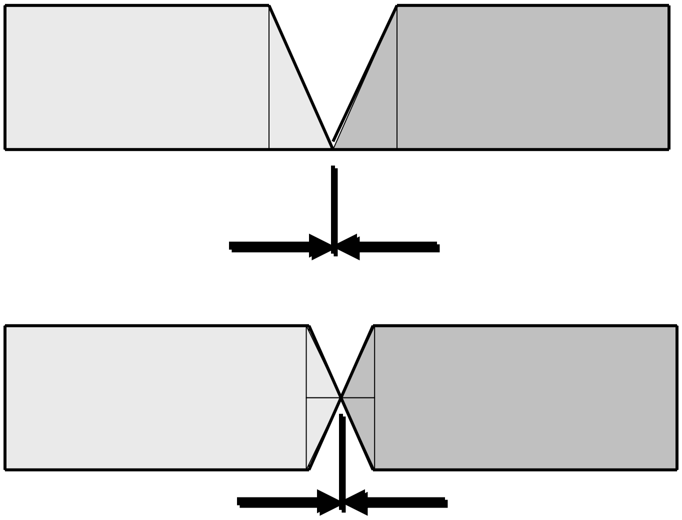


50% Less Metal **2:1 Ratio**

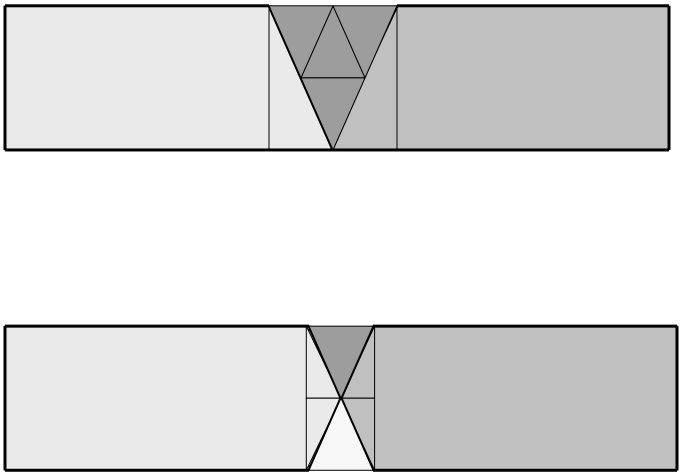
One bevel versus two



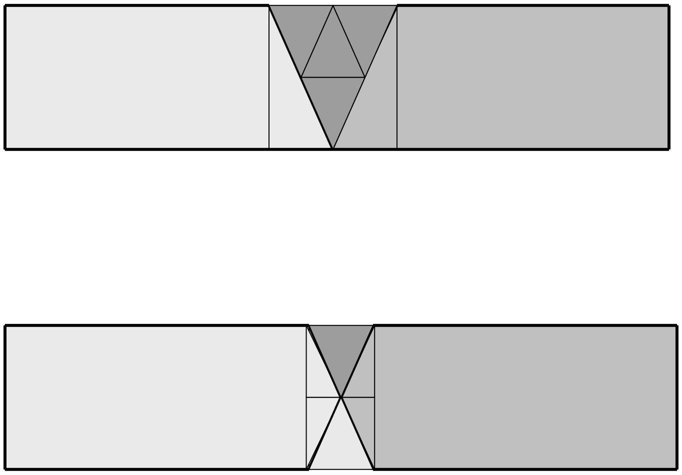
Same included angle



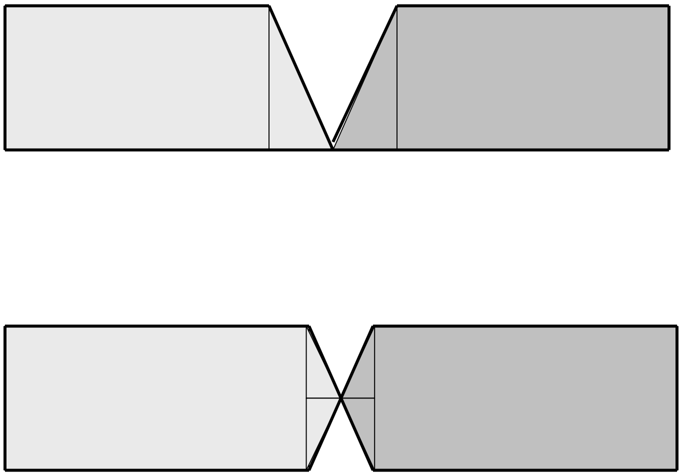
No root opening

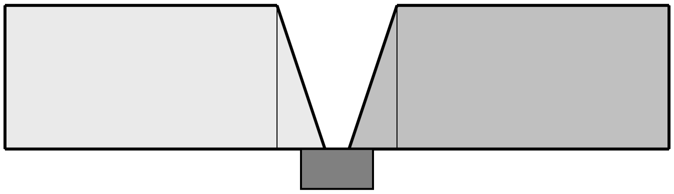


Overhead welding?

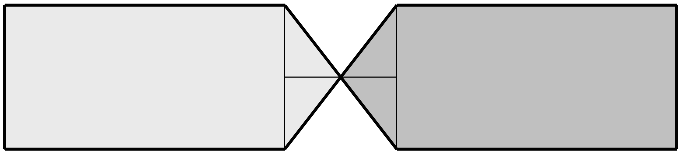


Access to both sides?





Prequalified details



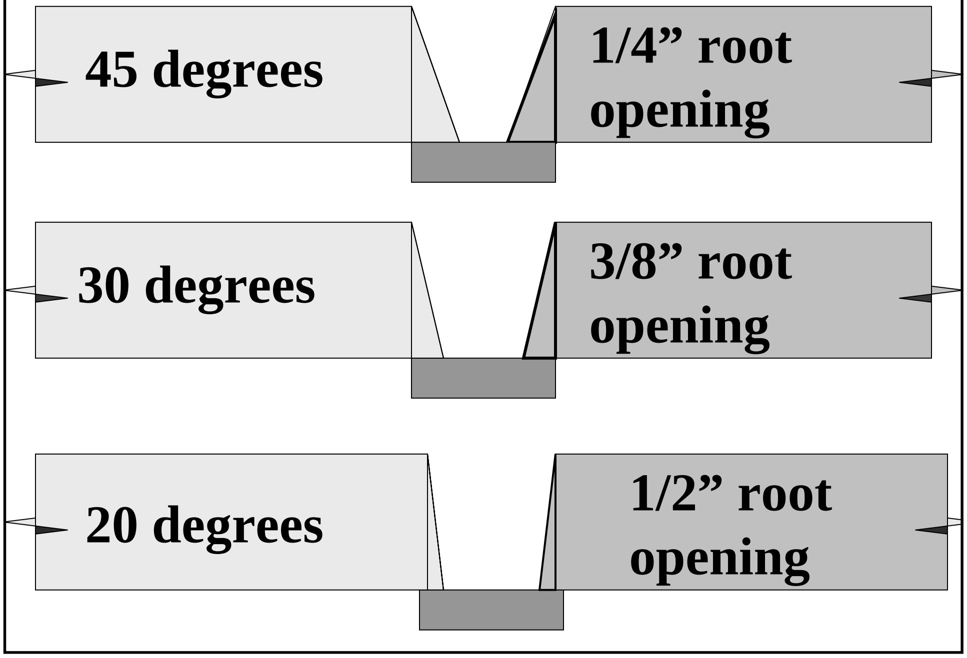
Thickness (weld throat) (in.)	Single V-groove weld, 30^{o} included angle, 3/8 in. root opening (B-U2a) (pounds/foot)	Double V-groove weld, 60^{o} included angle, 1/8 in. root opening, 0 in. root opening (B-U3b) (pounds/foot)	Ratio of Single Sided to Double Sided
½	0.99	0.60	1.50 : 1
1	2.38	1.68	1.42 : 1
2	6.54	5.37	1.22 : 1
4	20.44	18.85	1.08 : 1
6	41.72	40.42	1.03 : 1

SINGLE VERSUS DOUBLE SIDED JOINTS:

1. **Consider joint preparation time.**
2. **Consider weld volume of specific detail.**
3. **Consider one sided issues: backing, open root joint**
4. **Consider two sided issues: backgouging, access, position of second weld.**
5. **Evaluate total overall cost.**

Economy in Welding

- Selection of proper weld type
  - – CJP groove welds versus alternatives
  - – Fillet welds versus PJP groove welds
  - – Combination fillet/PJP groove weld
- Proper weld detailing
  - – Fillet welds: leg size versus length
  - – Fillet weld: intermittent versus continuous
  - – Groove welds: single versus double sided
  - – **CJP groove welds: included angle versus root opening**



45 degrees

1/4” root opening

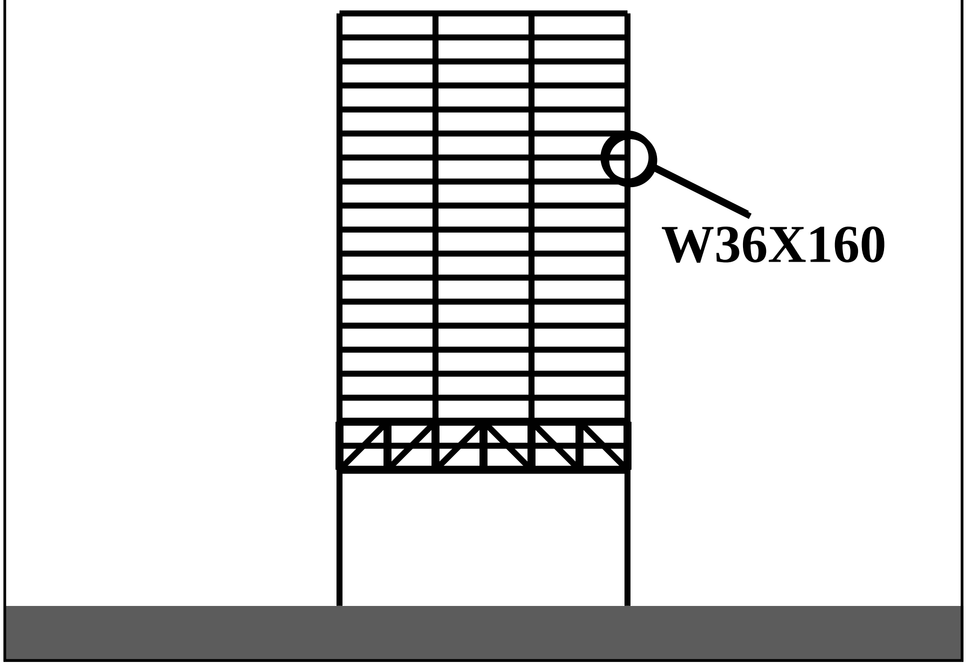
30 degrees

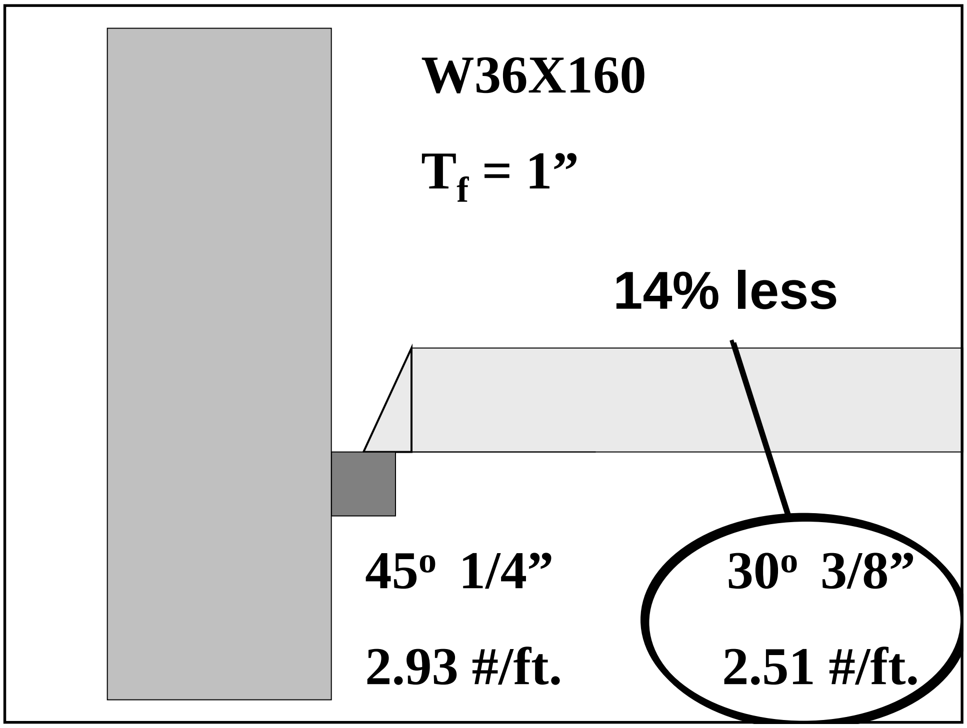
3/8” root opening

20 degrees

1/2” root opening

Thickness	1/4" 45	3/8" 30	1/2" 20
0.5	0.9	0.99	1.03
1	2.5	2.38	2.47
2	7.85	6.54	6.07
4	27.19	20.44	16.91





W36X160

T_f = 1”

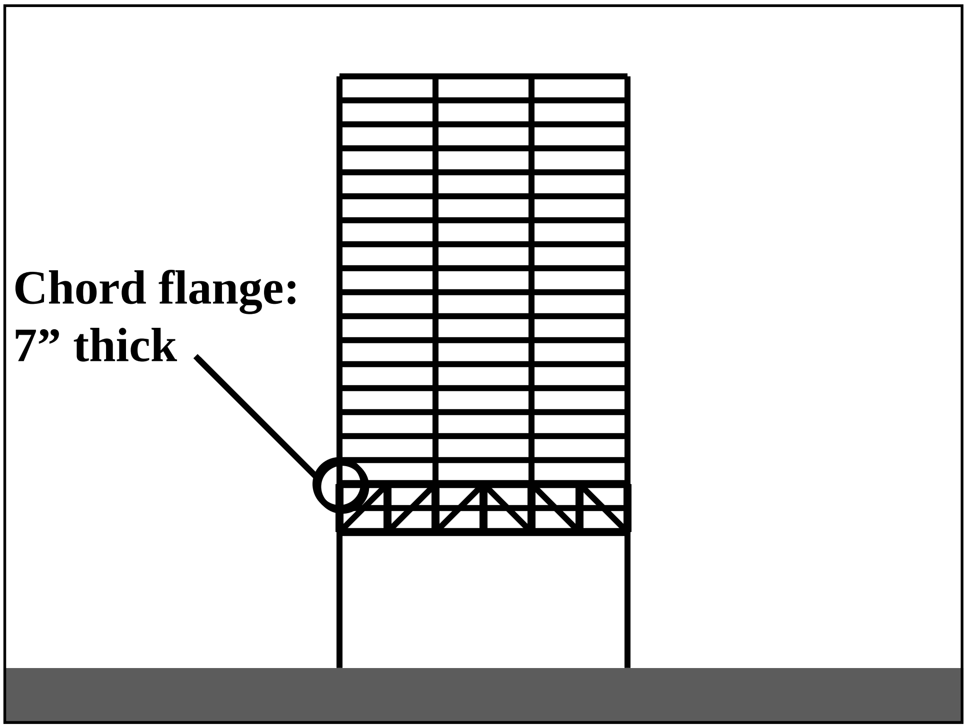
14% less

45° 1/4”

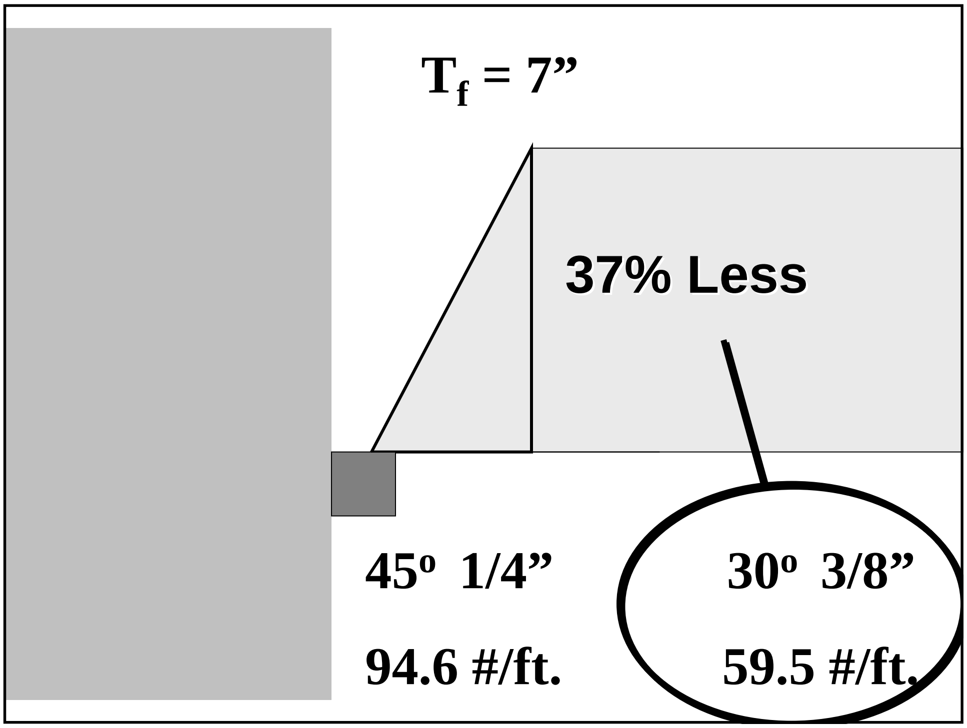
2.93 #/ft.

30° 3/8”

2.51 #/ft.



Chord flange:
7” thick



T_f = 7”

37% Less

45° 1/4”

30° 3/8”

94.6 #/ft.

59.5 #/ft.

Thickness (Weld Throat) (in.)	Single V-groove Weld (B-U2a) Weight of Weld Metal (pounds/foot)					
	Included Angle	Root Opening	Included Angle	Root Opening	Included Angle	Root Opening
	45°	1/4 in.	30°	3/8 in.	20°	1/2 in.
3/8	**0.62**		0.71		0.84	
1/2	**0.90**		0.99		1.13	
5/8	**1.23**		1.29		1.44	
3/4	**1.61**		1.62		1.76	
7/8	2.03		**1.99**		2.11	
1	2.50		**2.38**		2.47	
1 1/8	3.01		**2.80**		2.86	
1 1/4	3.56		**3.24**		3.26	
1 3/8	4.16		3.72		**3.68**	
1 1/2	4.81		4.23		**4.12**	
2	7.85		6.54		**6.07**	
3	16.08		12.57		**10.88**	
4	27.19		20.44		**16.91**	

CJP groove welds: included angle versus root opening

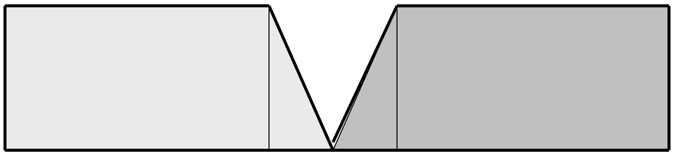
- For weld throats less than 1”, use a smaller root opening and larger included angle
- For weld throats greater than 1”, use a larger root opening and smaller included angle.

Economy in Welding

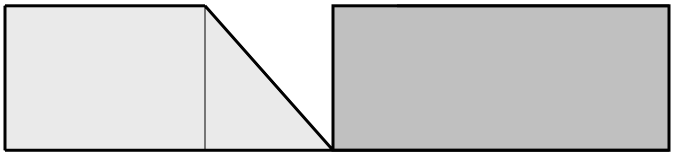
Proper weld detailing

- Fillet welds: leg size versus length
- Fillet weld: intermittent versus continuous
- Groove welds: single versus double sided
- CJP groove welds: included angle versus root opening
- **CJP groove weld: V and bevel vs. U and J**

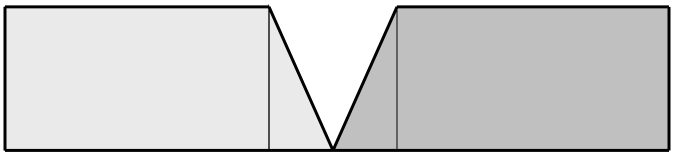
V- groove



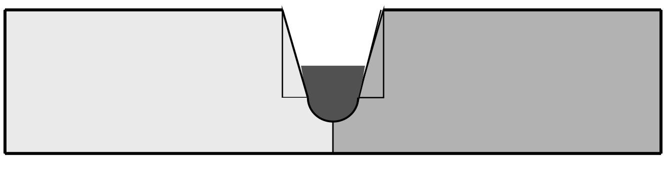
Bevel groove



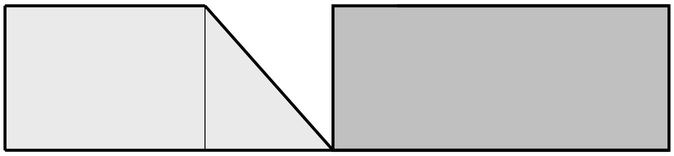
V-groove



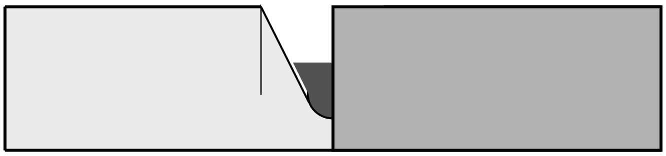
U- groove



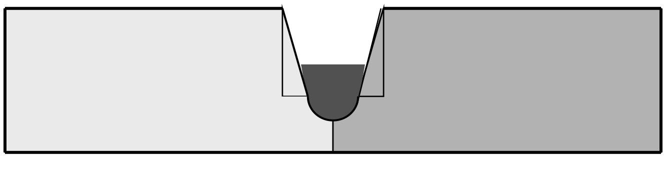
Bevel groove



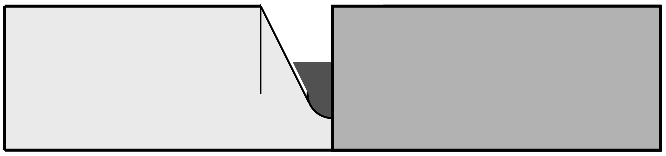
J- groove

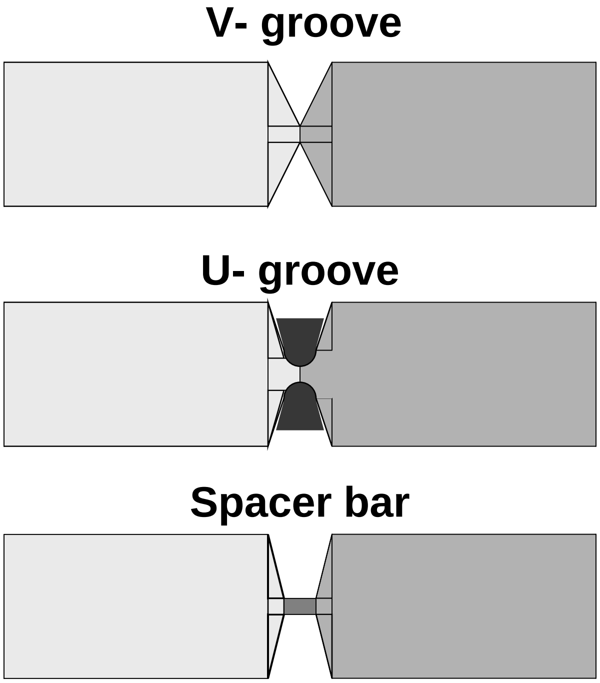


U- groove

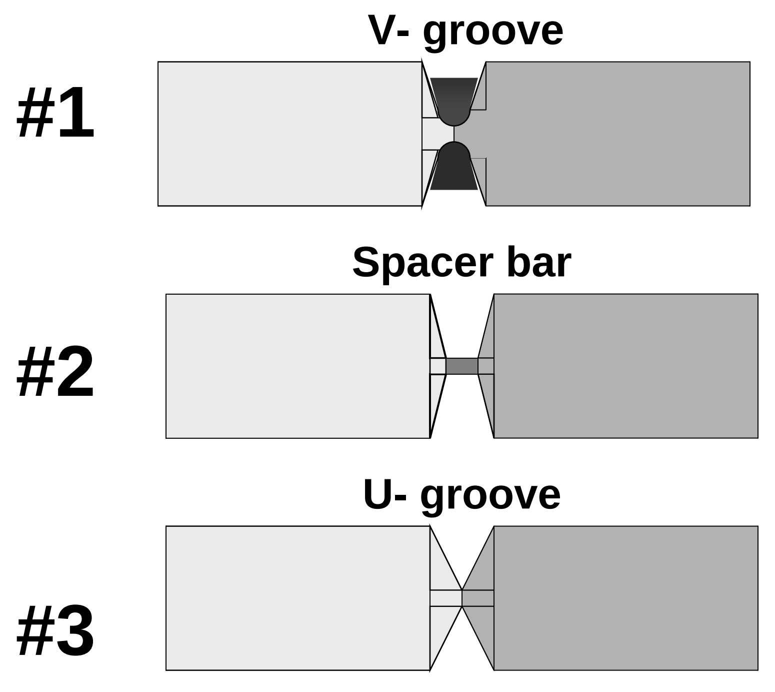


J- groove





Thickness (Weld Throat) (in)	Double Sided CJP Groove Weld Options Weight of Weld Metal (pounds/foot)					
	V Groove (B-U3c-S)		U Groove (B-U7-S)		V Groove with Spacer Bar (B-U3a)	
	α = β = 60°	f = 1/4 in.	α= β = 20°	f = 1/4 in.	α = β = 20°	f =1/4 in
	R = 0 in.	--	R = 0 in.	Bevel radius r =1/4 in.	R = 5/8 in	Spacer bar = 1/4 X 5/8 in.
2	3.79		**3.58**		5.56	
2 1/2	5.83		**4.94**		7.27	
3	8.79		**6.45**		9.13	
3 1/2	12.38		**8.11**		11.15	
4	16.04		**9.92**		13.31	
4 1/2	19.44		**11.88**		15.63	
5	26.95		**14.00**		18.10	



V- groove

#1

Spacer bar

#2

U- groove

#3

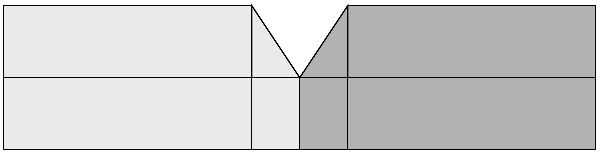
Thickness (Weld Throat) (in)	Double Sided CJP Groove Weld Options Weight of Weld Metal (pounds/foot)					
	V Groove (B-U3c-S)		U Groove (B-U7-S)		V Groove with Spacer Bar (B-U3a)	
	α = β = 60°	f = 1/4 in.	α= β = 20°	f = 1/4 in.	α = β = 20°	f =1/4 in
	R = 0 in.	--	R = 0 in.	Bevel radius r =1/4 in.	R = 5/8 in	Spacer bar = 1/4 X 5/8 in.
2	3.79		3.58		**5.56**	
2 1/2	5.83		4.94		**7.27**	
3	8.79		6.45		**9.13**	
3 1/2	12.38		8.11		**11.15**	
4	16.04		9.92		**13.31**	
4 1/2	19.44		11.88		**15.63**	
5	26.95		14.00		**18.10**	

Economy in Welding

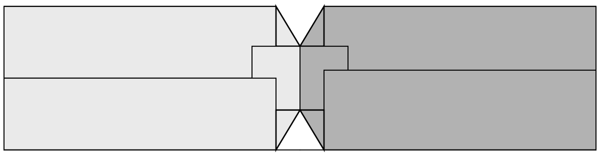
Proper weld detailing

- Fillet welds: leg size versus length
- Fillet weld: intermittent versus continuous
- Groove welds: single versus double sided
- CJP groove welds: included angle versus root opening
- CJP groove weld: V and bevel vs. U and J
- **PJP groove weld: single versus double sided**

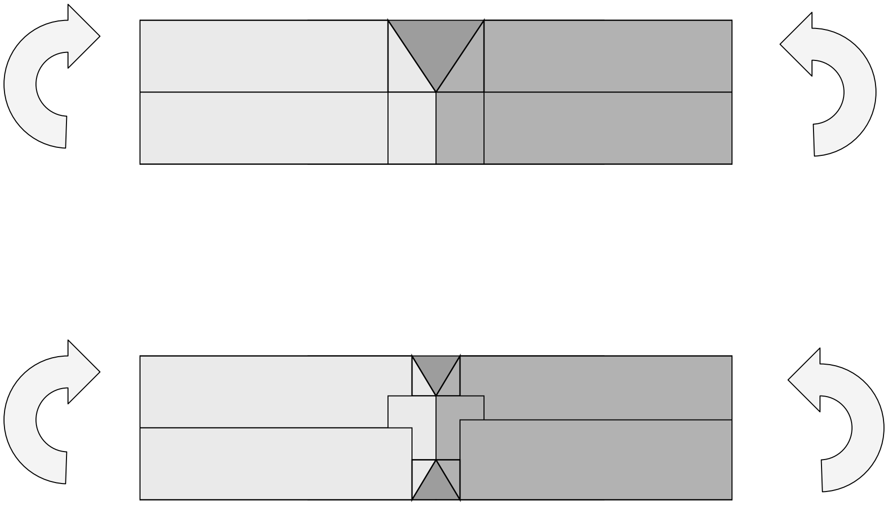
Single sided PJP V- groove



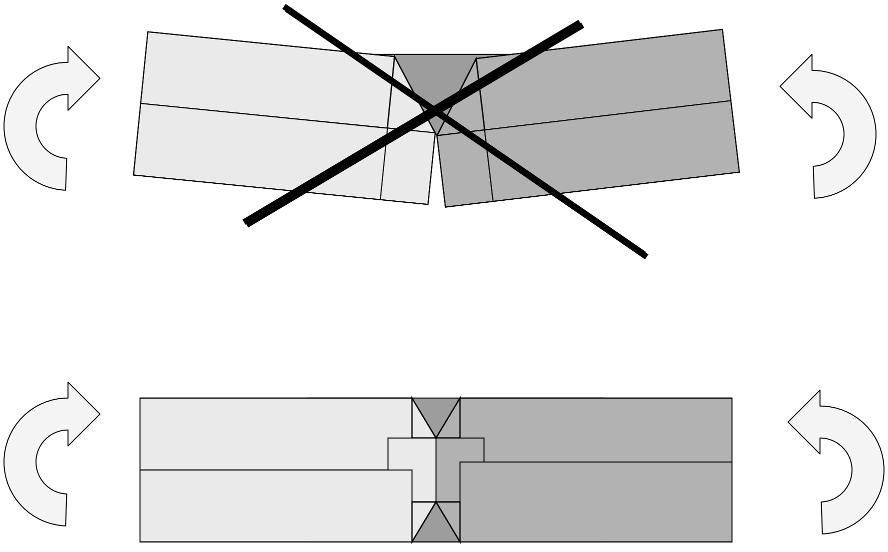
Double sided PJP V- groove



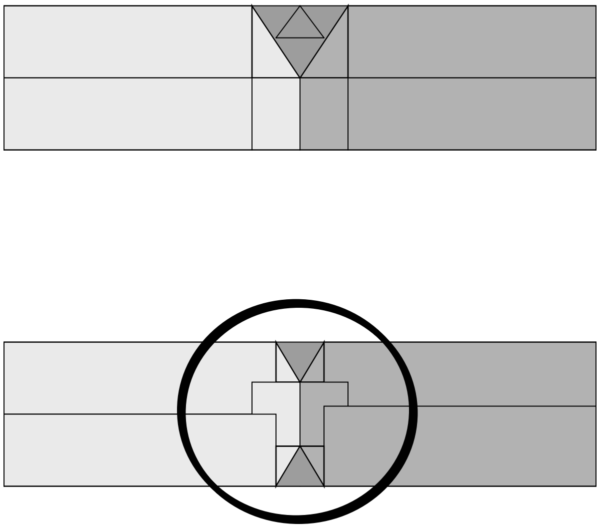
Rotation about root



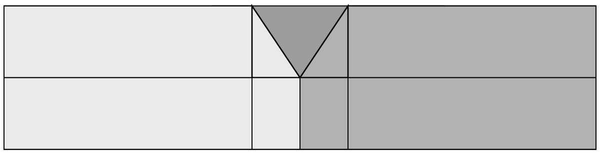
Rotation about root



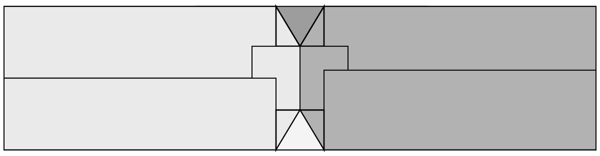
Volume—2:1 ratio



All in-position welding



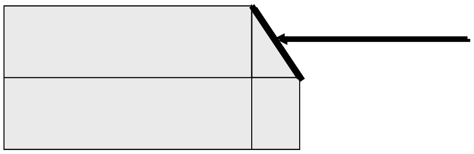
Reposition, or out-of-positon welding



One bevel cut

Two bevel cuts

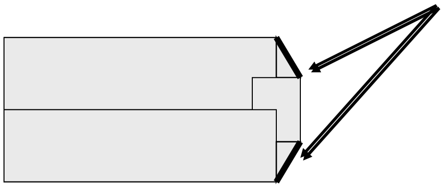
One bevel cut



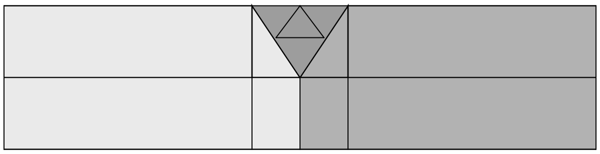
Approximately
one weld pass

Two bevel cuts

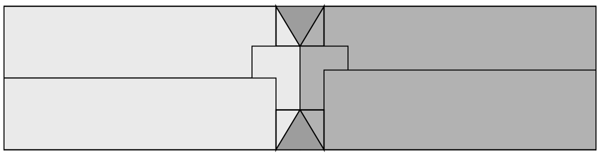
Approximately
two weld passes

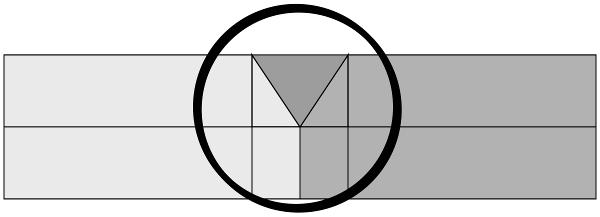


Time = 2 bevels + 4 passes = 6

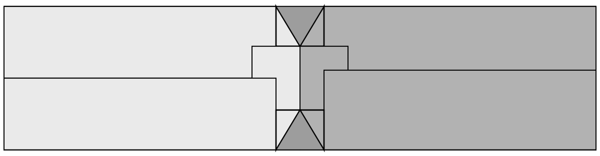


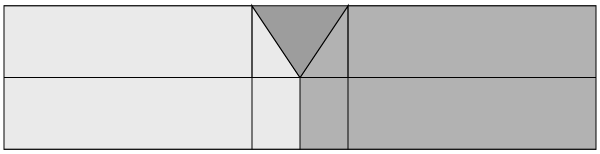
Time = 4 bevels + 2 passes = 6



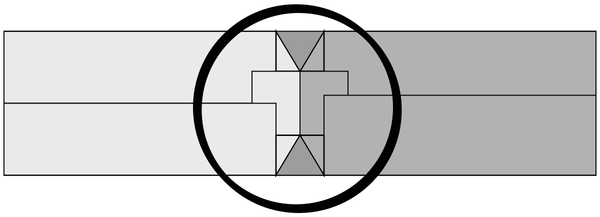


If fewer than 3 weld passes are required for single-sided PJP groove weld, use single sided detail.





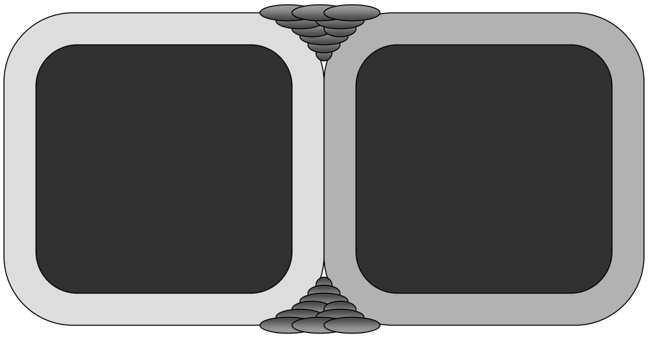
If more than 4 weld passes are required for single-sided PJP groove weld, consider double sided detail.

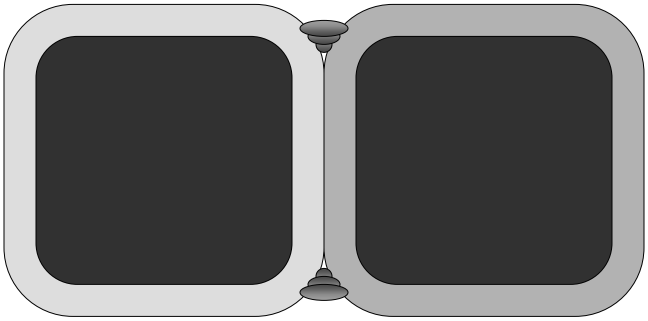


Economy in Welding

Proper weld detailing

- Fillet welds: leg size versus length
- Fillet weld: intermittent versus continuous
- Groove welds: single versus double sided
- CJP groove welds: included angle versus root opening
- CJP groove weld: V and bevel vs. U and J
- PJP groove weld: single versus double sided
- **Flare V and flare bevel groove welds**



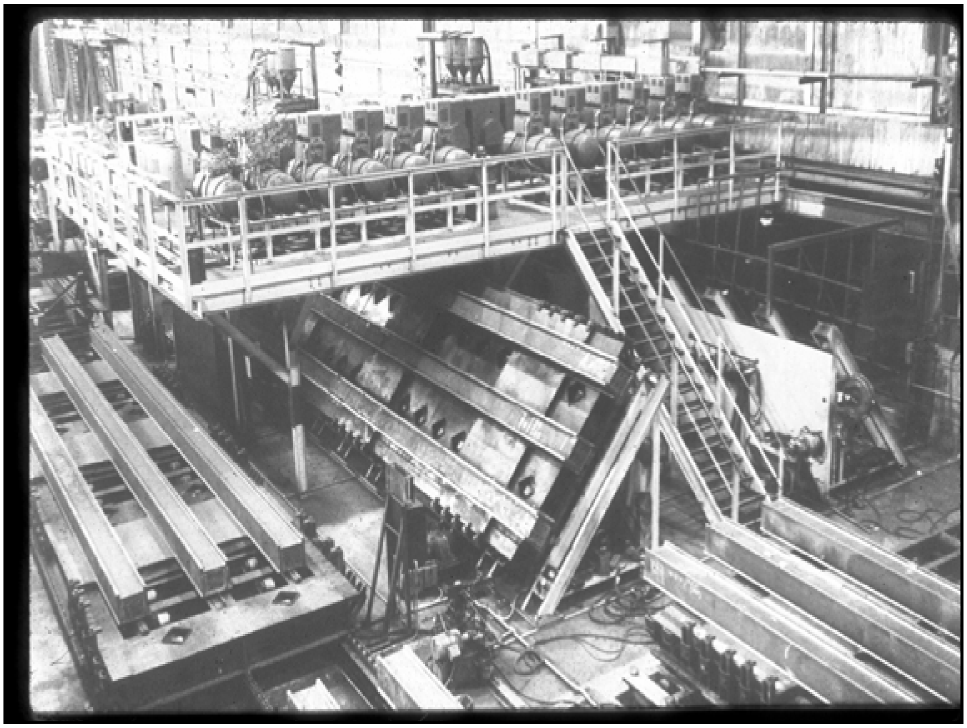


Economy in Welding

- Proper weld detailing
- **Shop versus Field Welding**

Shop versus Field Welding

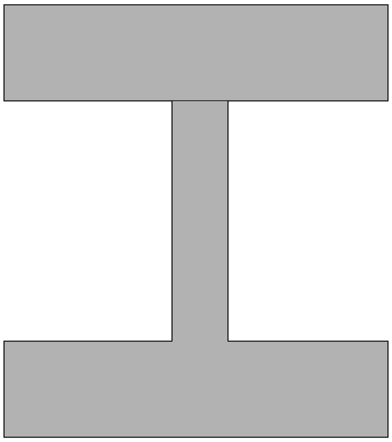
- "Everything" lower cost in shop
  - Drilling
  - Sandblasting
  - Painting
  - Bolting
  - Welding
- Cost savings opportunity: make big, complex welded connections in the shop



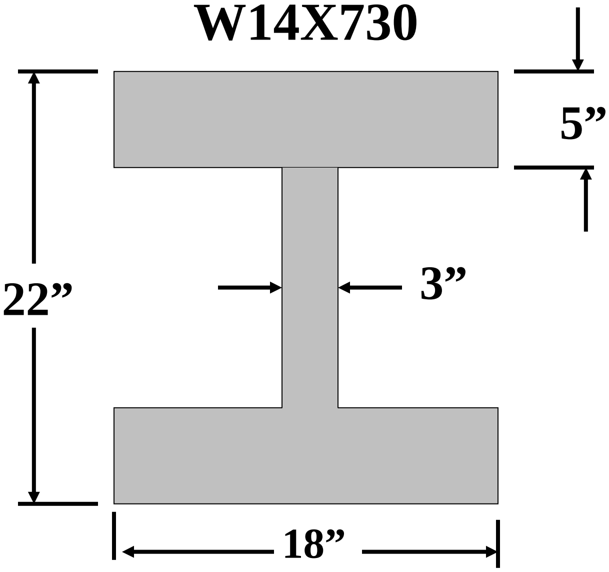
Economy in Welding

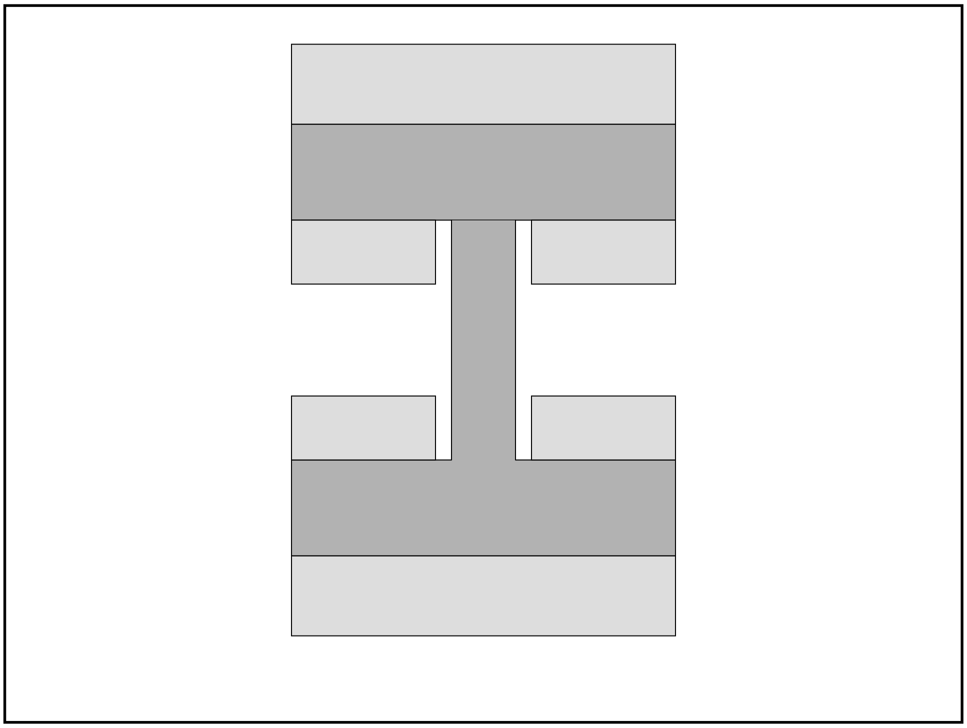
- Proper weld detailing
- Shop versus field Welding
- **Welded versus bolted connections**

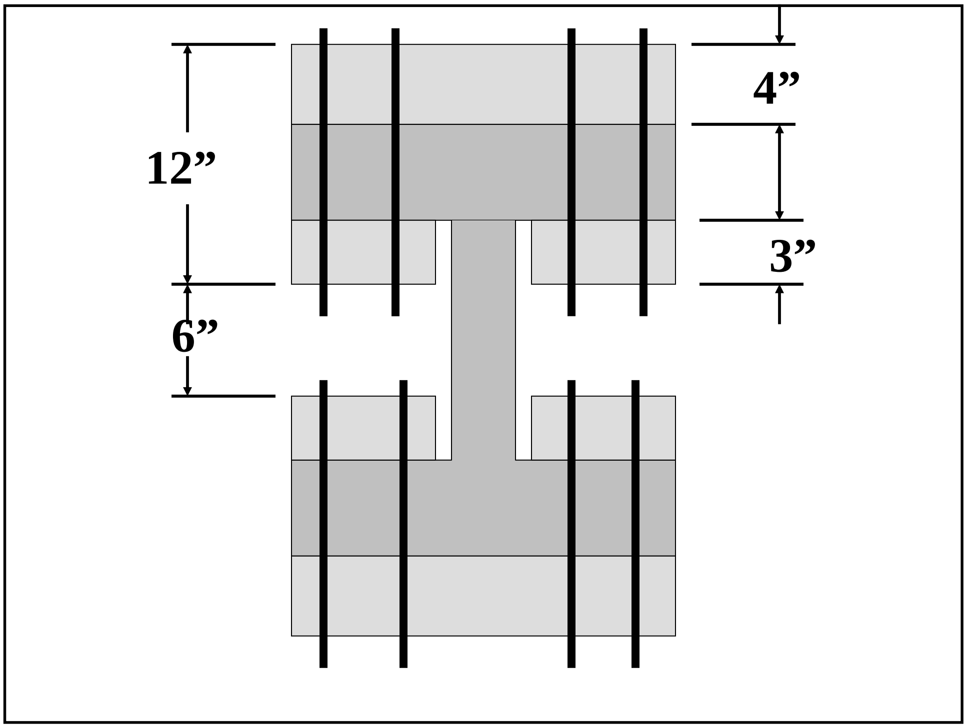
W14X730

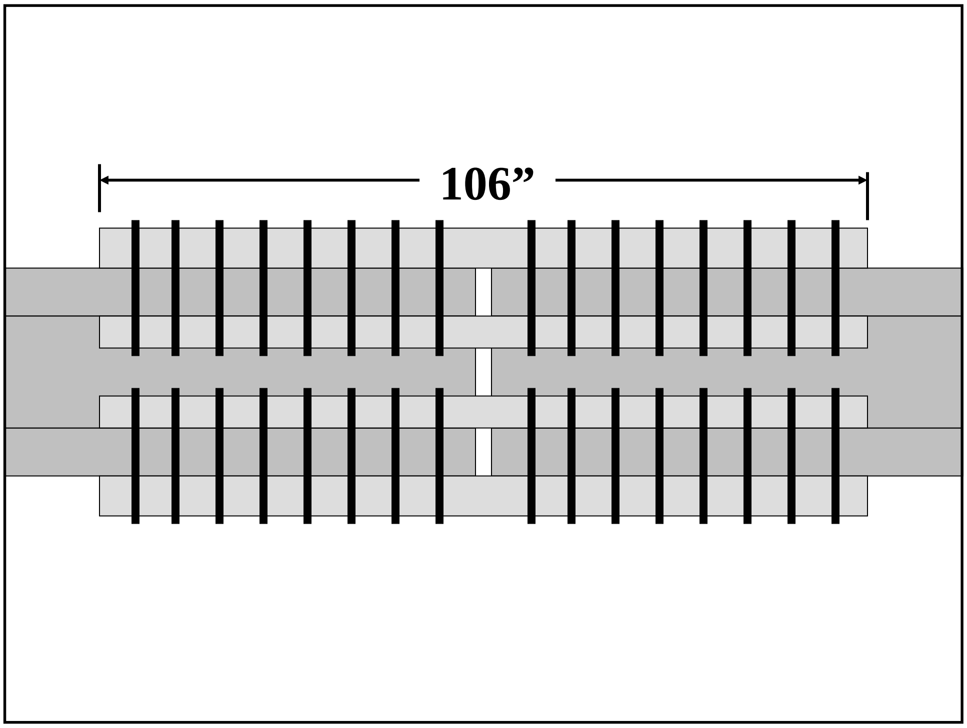


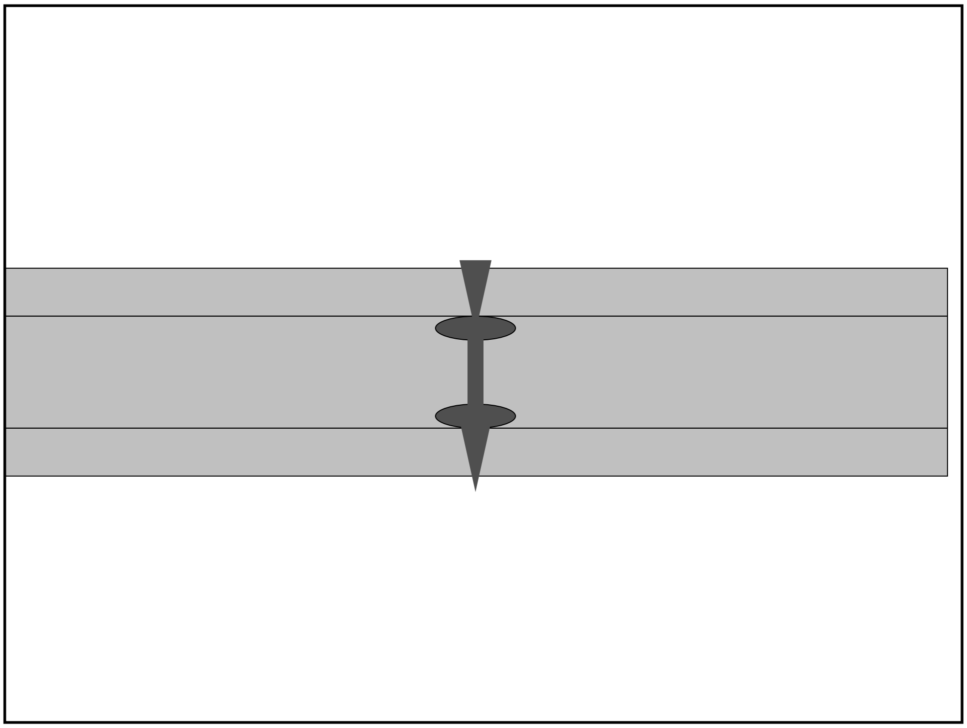
W14X730

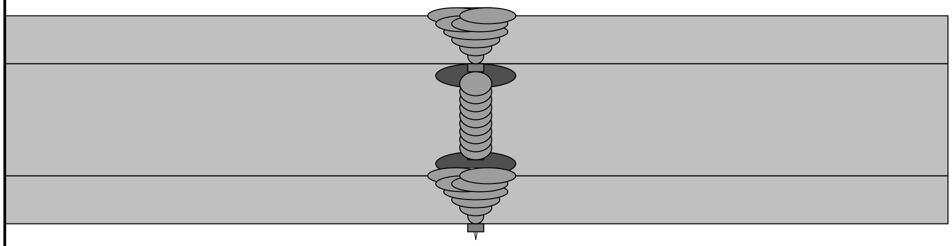





12”
6”
4”
3”


106”





Welded vs. Bolted Splice Cost Comparison

Bolted Splice

- **Labor 84.3 hrs $3,127.**
- **Materials**
  - **Steel (6900#) $1,936.**
  - **Bolts (128) $ 768.**
- **Cost per splice $5,800.**

Welded vs. Bolted
Splice Cost Comparison

Bolted Splice

- **Labor 84.3 hrs $3,127.**
- **Materials**
  - **Steel (6900#) $1,936.**
  - **Bolts (128) $ 768.**
- **Cost per splice $5,800.**

Welded Splice

- **Labor 28.6 hrs $1,072.**
- **Materials**
  - **Electrode (70 lbs)$ 42.**
  - **Flux (140 lbs.) $ 77.**
- **Cost per splice $1,200.**

Welded vs. Bolted
Splice Cost Comparison

Bolted Splice

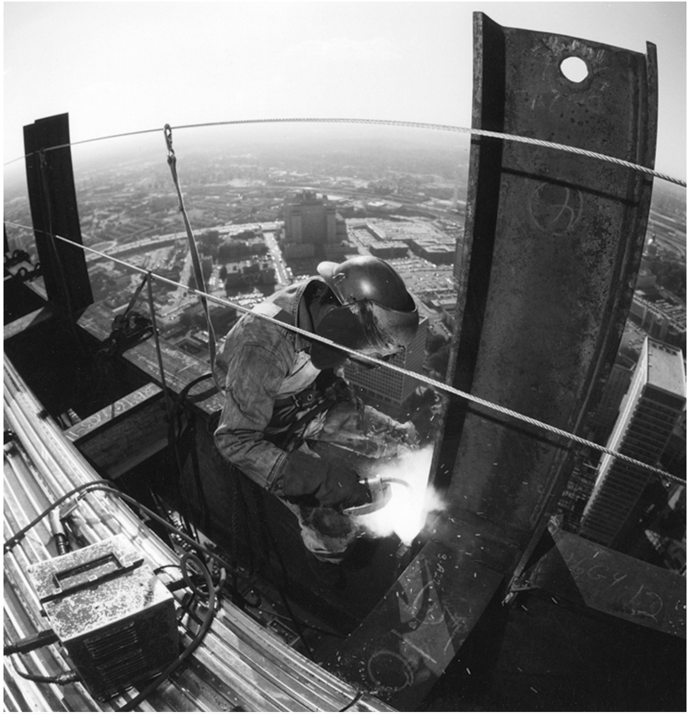
- **Labor 84.3 hrs $3,127.**
- **Materials**
  - **Steel (6900#) $1,936.**
  - **Bolts (128) $ 768.**
- **Cost per splice $5,800.**

Welded Splice

- **Labor 28.6 hrs $1,072.**
- **Materials**
  - **Electrode (70 lbs)$ 42.**
  - **Flux (140 lbs.) $ 77.**
- **Cost per splice $1,200.**

Savings per splice total $4,600 !

Shop versus Field Welding



Shop versus Field Welding

- Primarily an issue of cost
- Some environmental factors
- Position of welding
- Easier to control project in shop

American Institute of Steel Construction, Inc.

is proud to recognize

ABC Erectors, Inc.

Any City, USA

for successfully meeting the quality certification requirements for

Advanced Certified Steel Erector

Roger E. Ferch

Bobbi Marstellar

Certification valid through May 2006

Field Welded vs. Bolted Splice Cost Comparison
Field Welding Hours: 2X Shop
Field Welding Wages: 2X Shop

Bolted Splice

Labor 84.3 hrs	**$3,127.**
Materials	
– **Steel (6900#)**	**$1,936.**
– **Bolts (128)**	**$ 768.**
Cost per splice	**$5,800.**

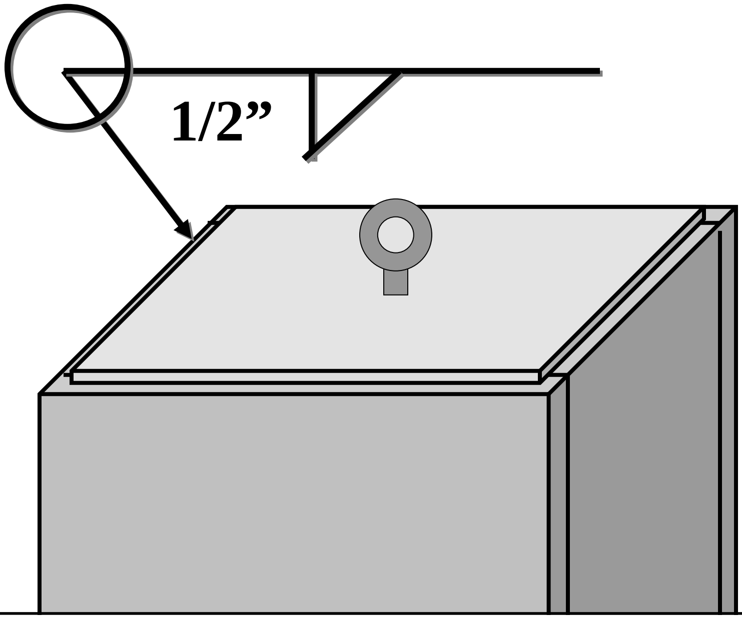
Welded Splice

Labor 57.2 hrs	**$4,288.**
Materials	
– **Electrode (70 lbs)**	**$ 42.**
– **Flux (140 lbs.)**	**$ 77.**
Cost per splice	**$4,400.**

Savings per splice total $1,400 !

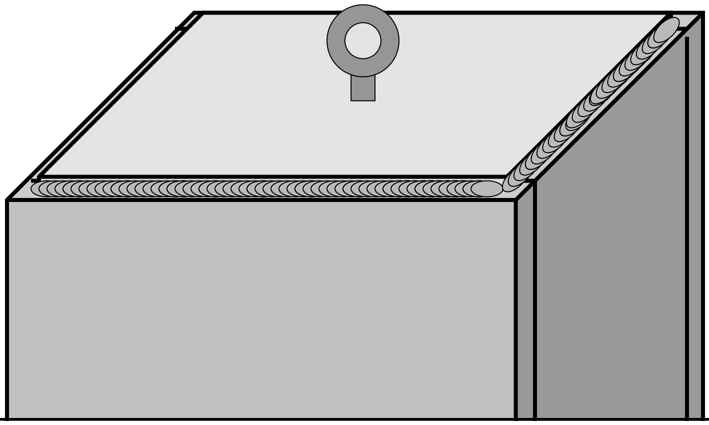
24% Savings

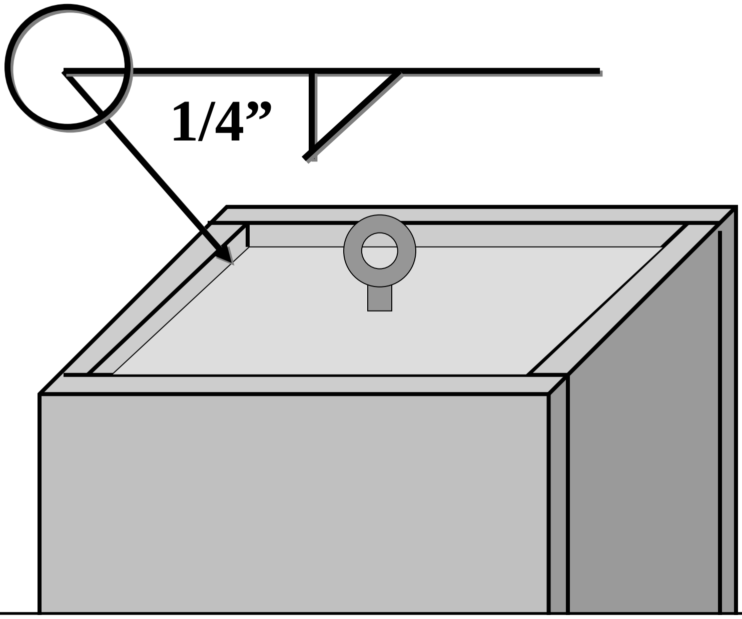
DETERMINE THE LOAD TRANSFERRED THROUGH THE CONNECTION WHEN SELECTING WELD TYPES, AND DETERMING WELD SIZES



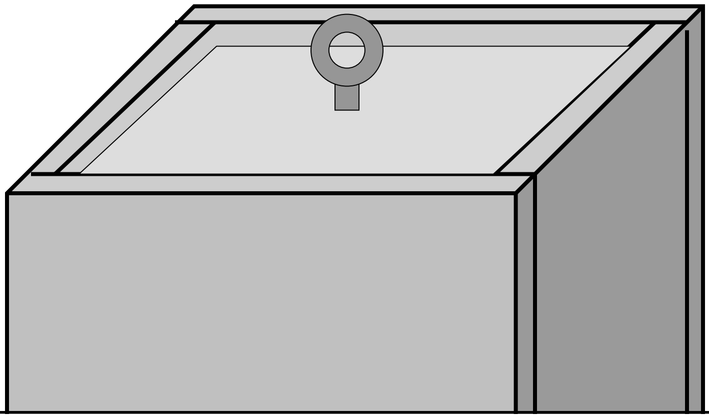
Capacity = 1/2” X 0.707 X 0.30 X E70XX X 100”

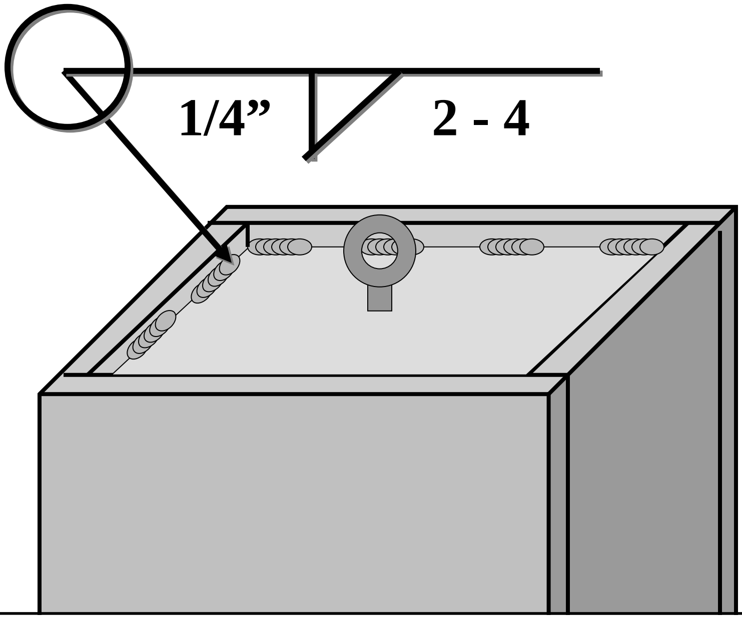
= 742 Kips





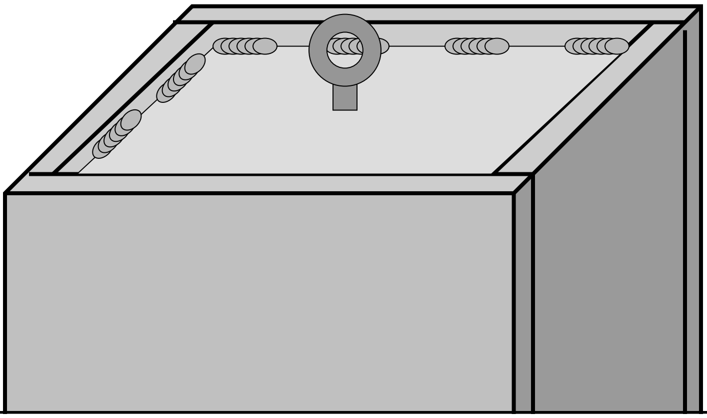
Capacity = 1/4” X 0.707 X 0.30 X E70XX X 100”
= 371 Kips





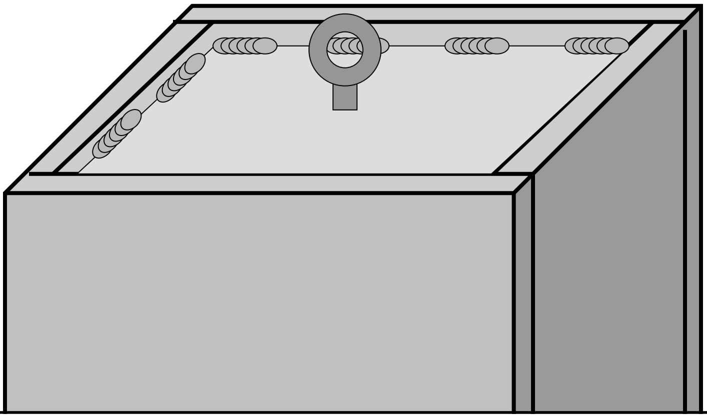
Capacity = 1 /4” X 0.707 X 0.30 X E70XX X 2/4 (100)

= 185 Kips

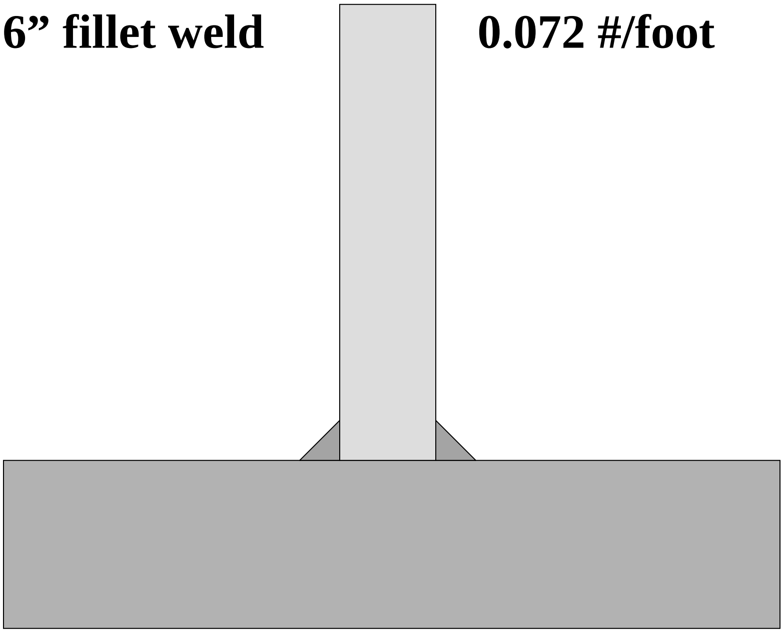


Capacity Reduced 75%

Cost Reduced 87.5%

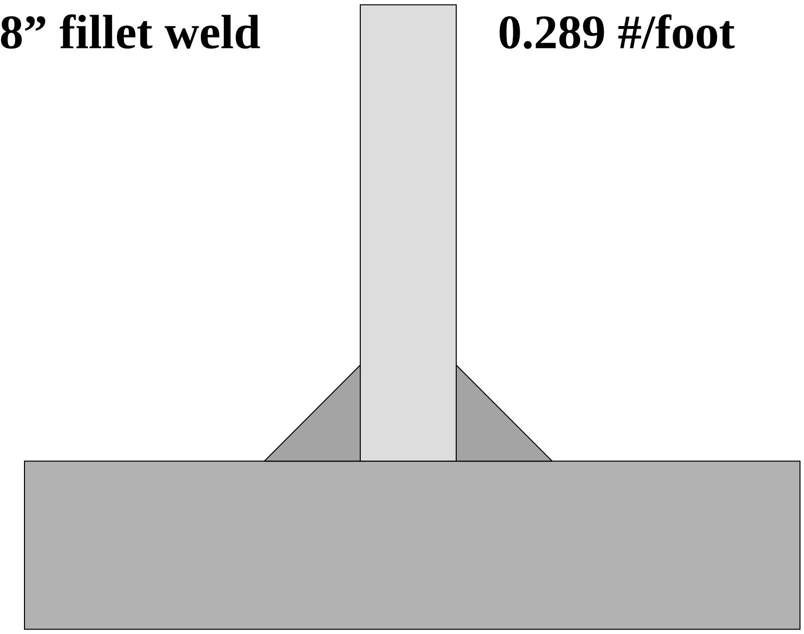


SPECIFY WELDS OF THE PROPER SIZE



3/16” fillet weld

0.072 #/foot



3/8” fillet weld

0.289 #/foot

Effect of fillet weld size

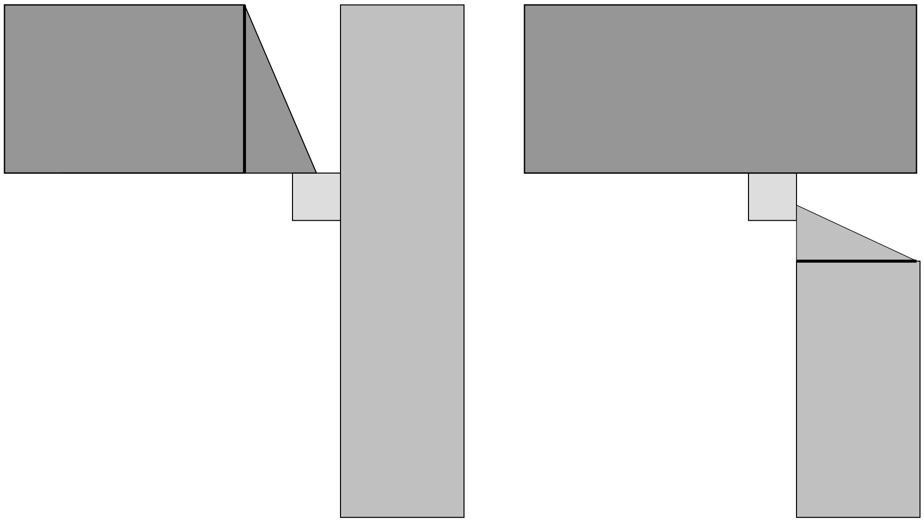
3/16” → 1/4” → + 79%

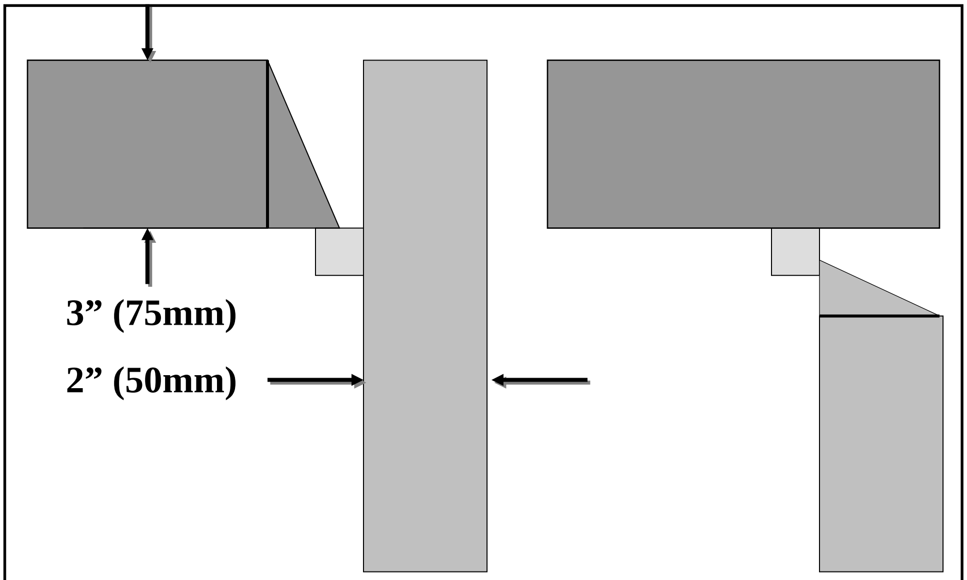
1/4” → 5/16” → + 55%

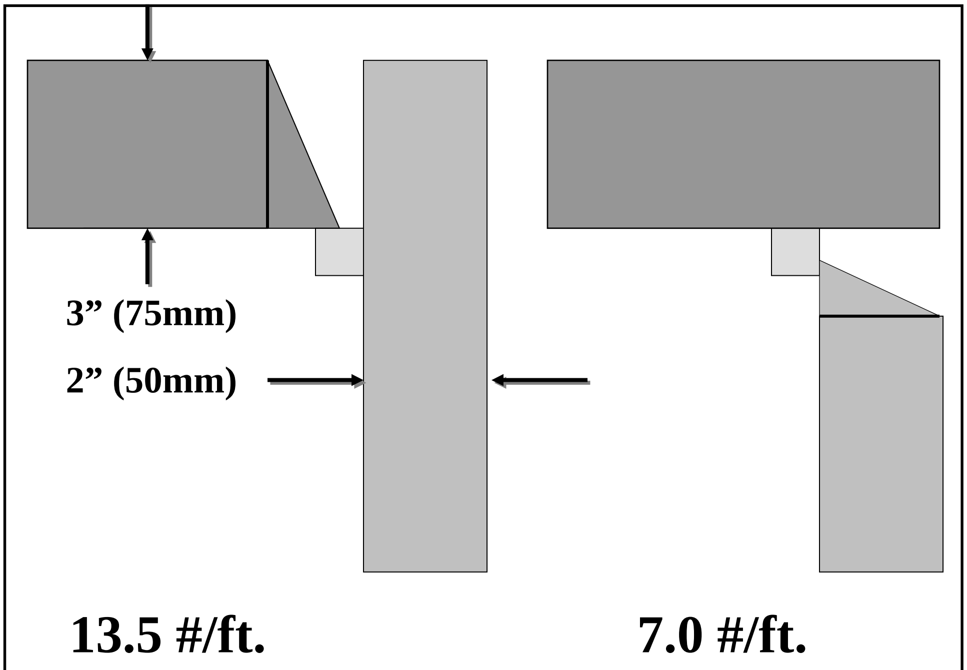
5/16” → 3/8” → + 44%

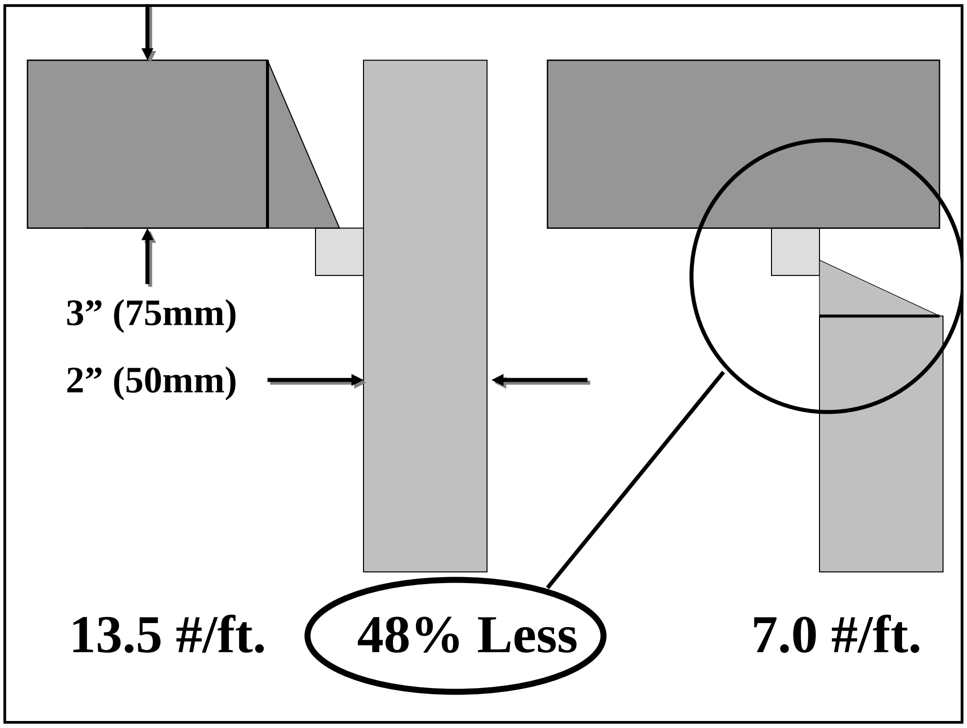
3/16” → 3/8” → +300%

PLACE THE WELD ON THE THINNER MEMBER OF CORNER JOINTS




3” (75mm)
2” (50mm)


3” (75mm)
2” (50mm)
13.5 #/ft.
7.0 #/ft.



3” (75mm)

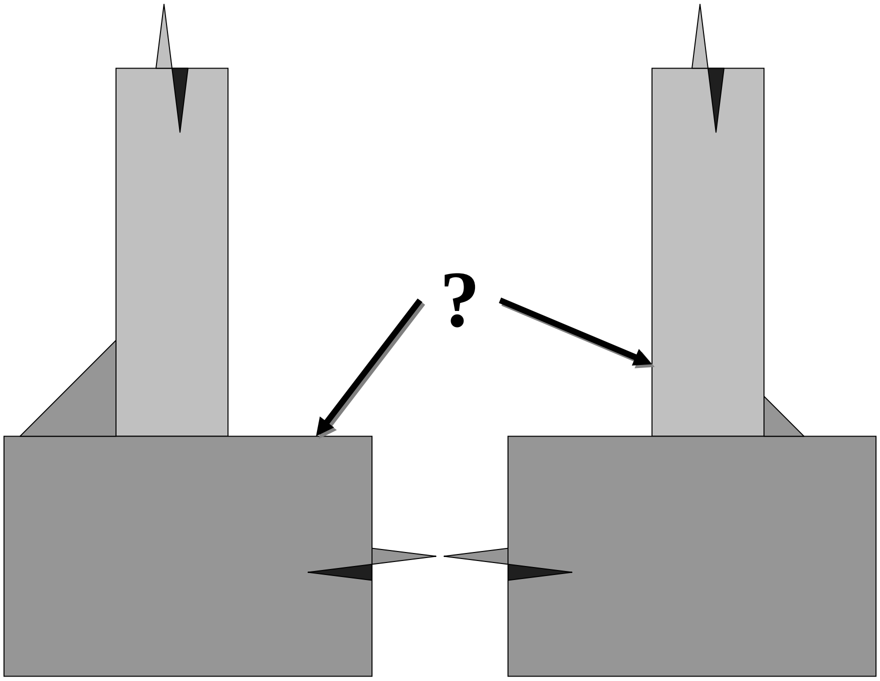
2” (50mm)

13.5 #/ft.

48% Less

7.0 #/ft.

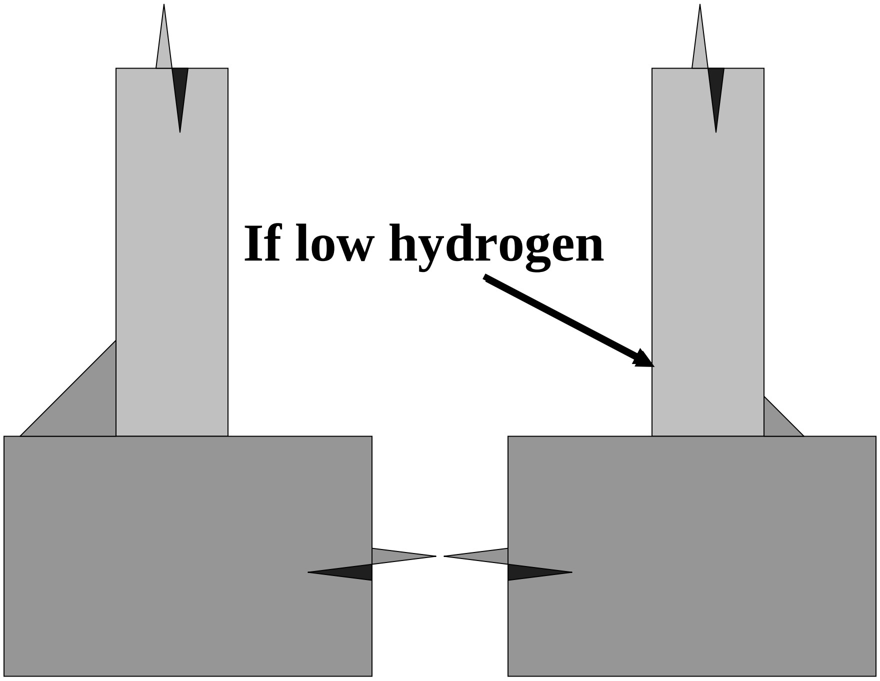
BASE THE WELD SIZE ON THE THINNER MEMBER



AWS D1.1:2004 Table 5.8

Notes:

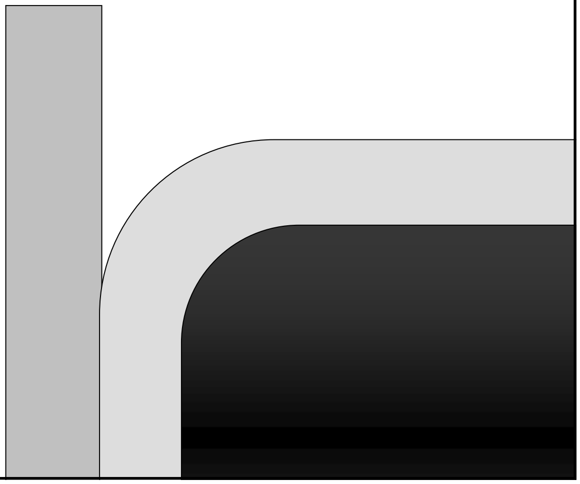
1. For non-low hydrogen processes…T = thickness of thicker part joined….for low-hydrogen processes, T = thinner part joined….



Flare V and Flare Bevel
PJP Groove Welds

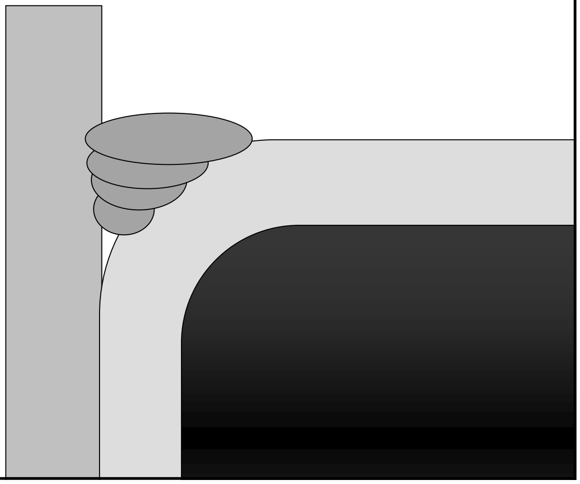
Groove Weld Types:

Flare Bevel Groove



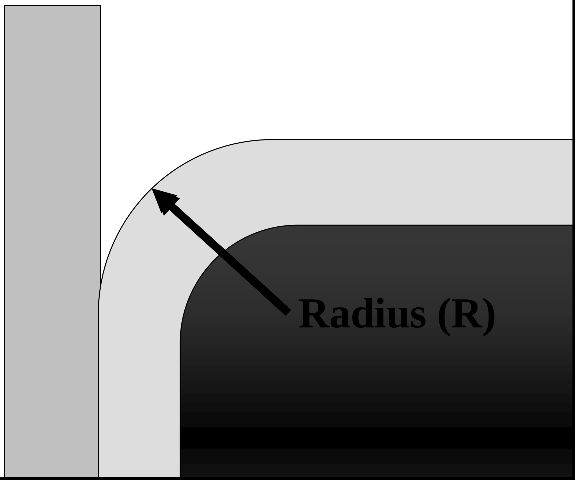
Groove Weld Types:

Flare Bevel Groove



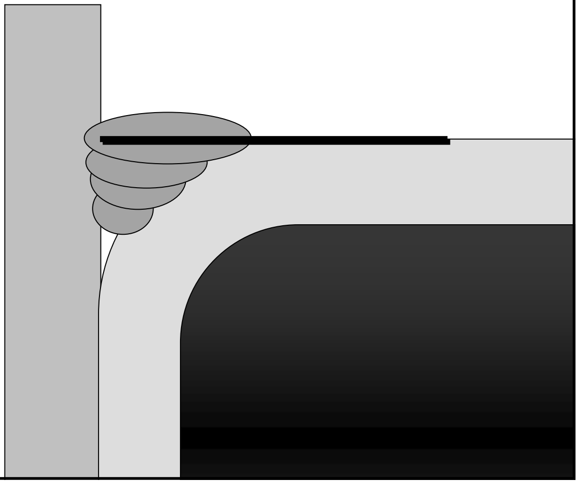
Groove Weld Types:

Flare Bevel Groove



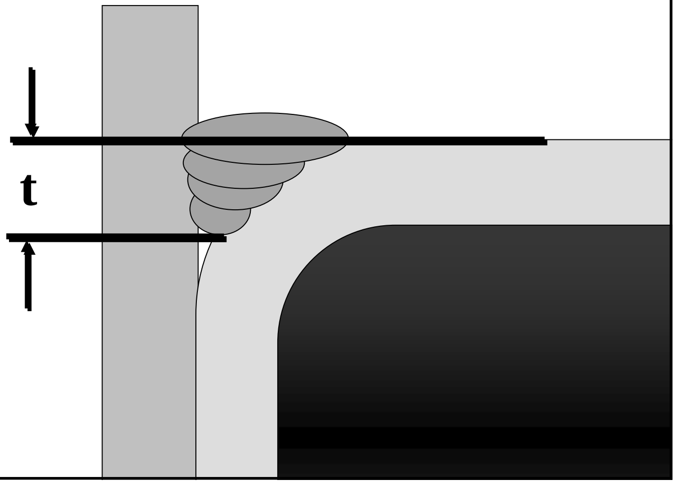
Groove Weld Types:

Flare Bevel Groove



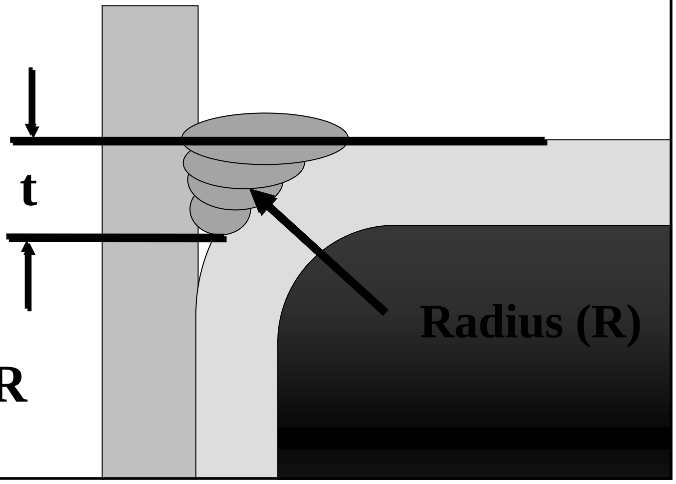
Groove Weld Types:

Flare Bevel Groove



Groove Weld Types:

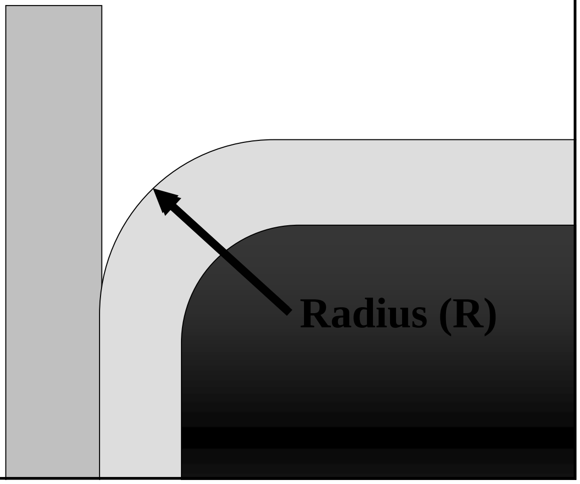
Flare Bevel Groove



t = 5/16 R

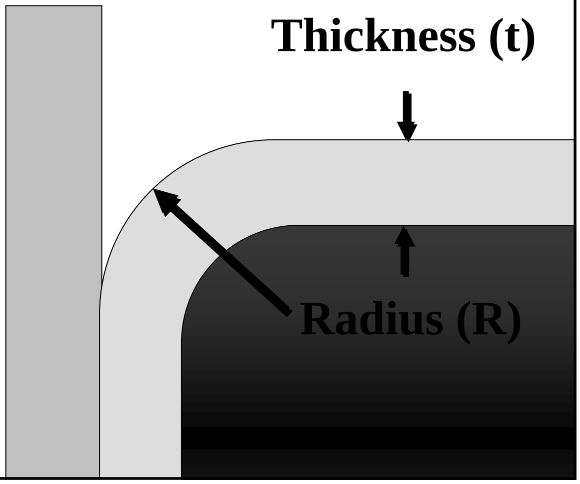
Groove Weld Types:

Flare Bevel Groove



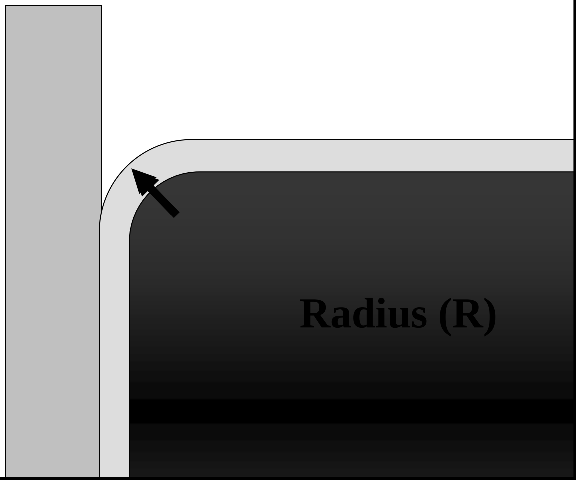
Flare Bevel Groove

$R \doteq 2t$



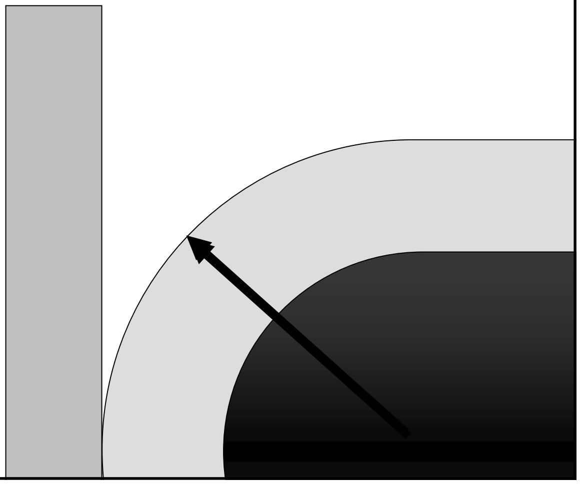
Groove Weld Types:

Flare Bevel Groove



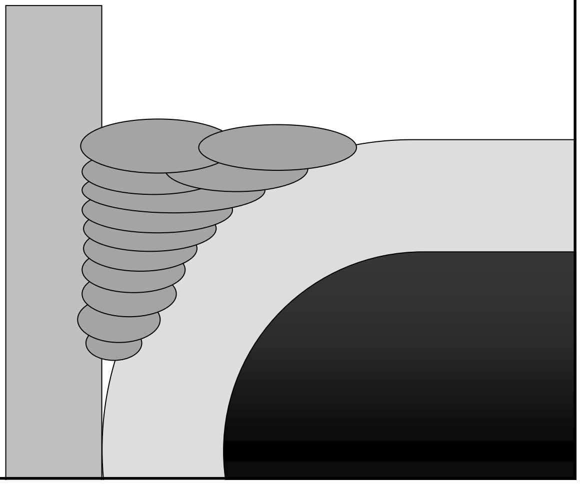
Groove Weld Types:

Flare Bevel Groove



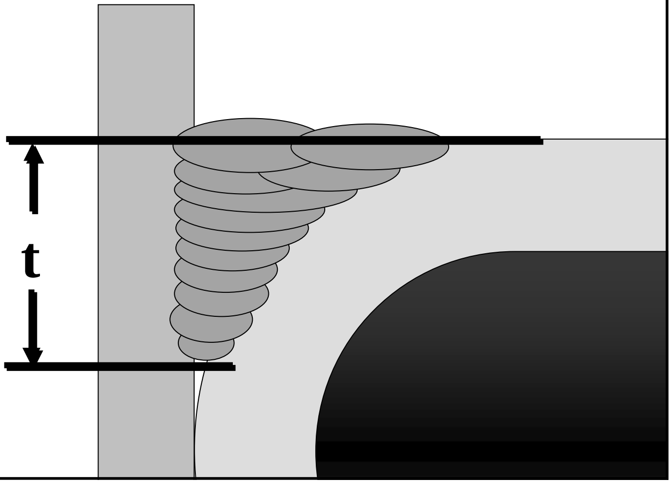
Groove Weld Types:

Flare Bevel Groove



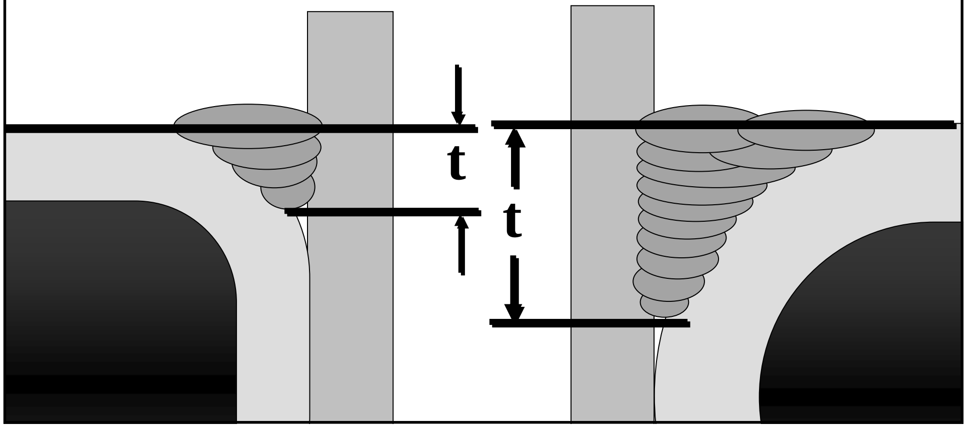
Groove Weld Types:

Flare Bevel Groove



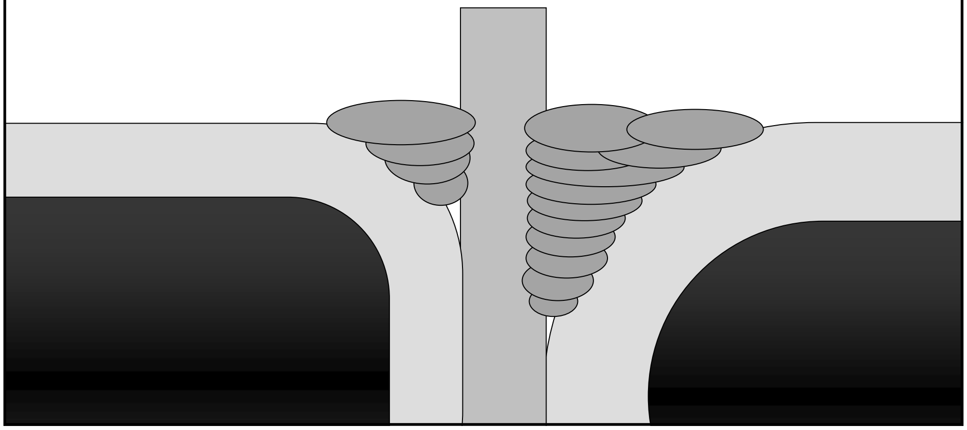
Groove Weld Types:

Flare Bevel Groove



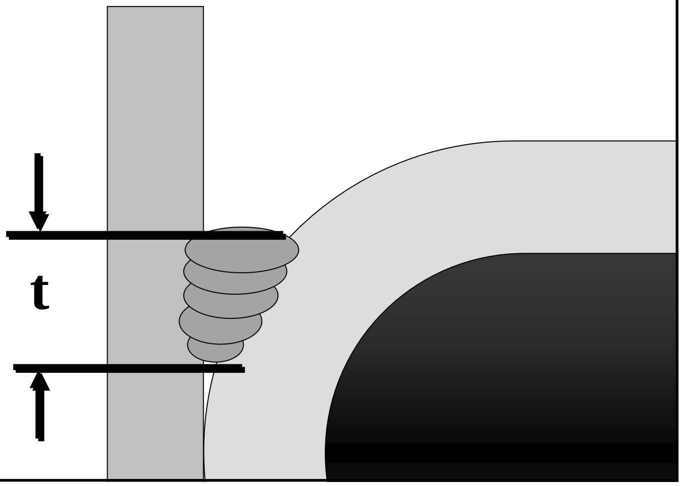
Groove Weld Types:

Flare Bevel Groove



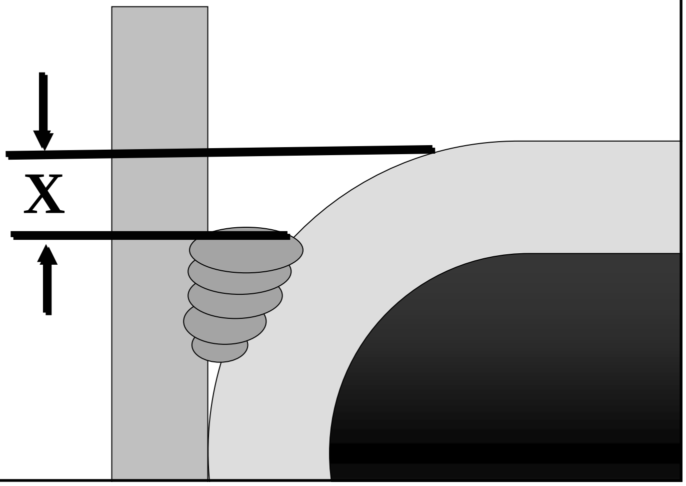
Groove Weld Types:

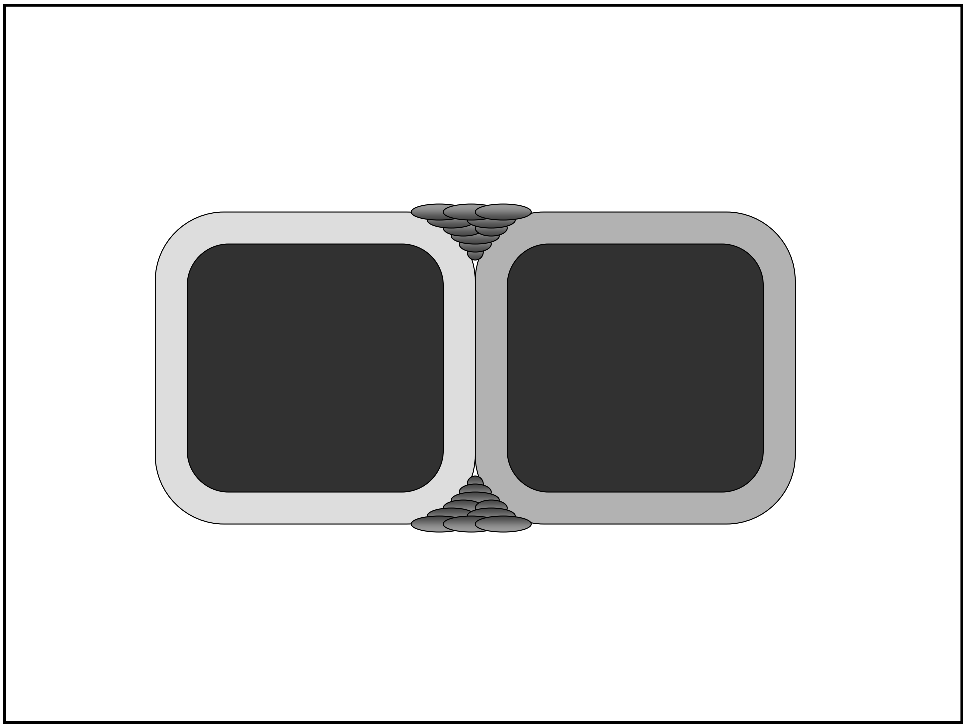
Flare Bevel Groove

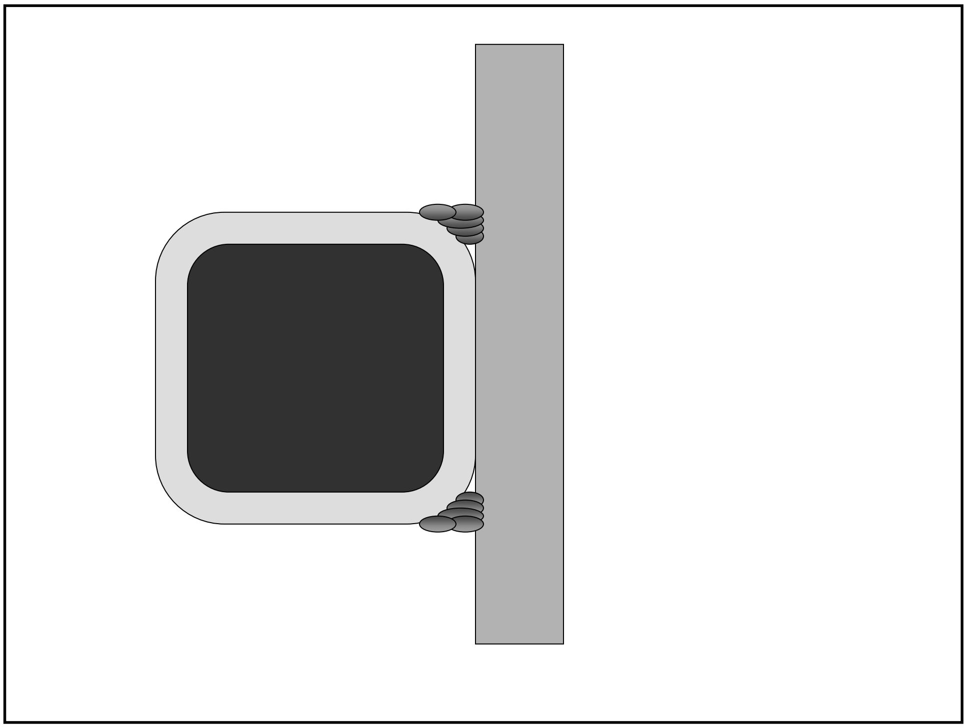


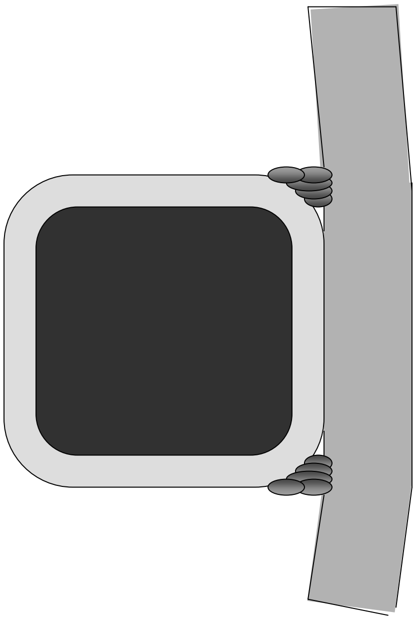
Groove Weld Types:

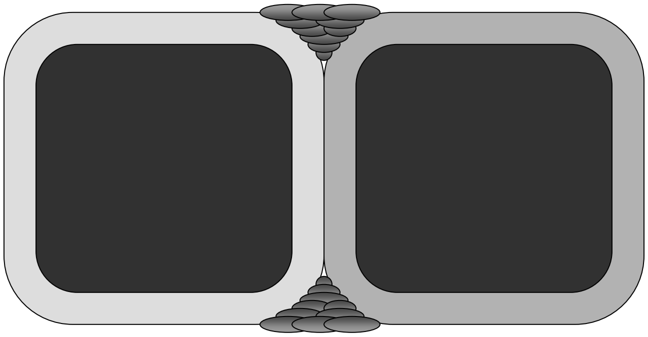
Flare Bevel Groove

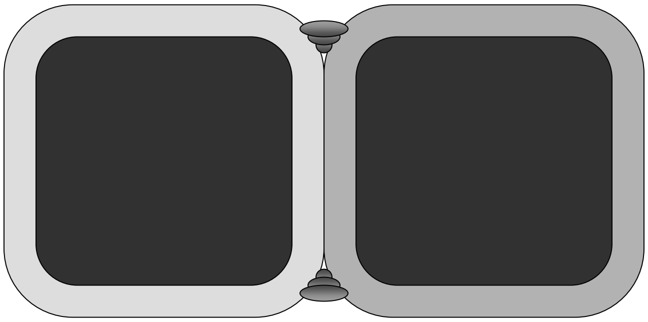












AISC LRFD Table J2.2 (old)

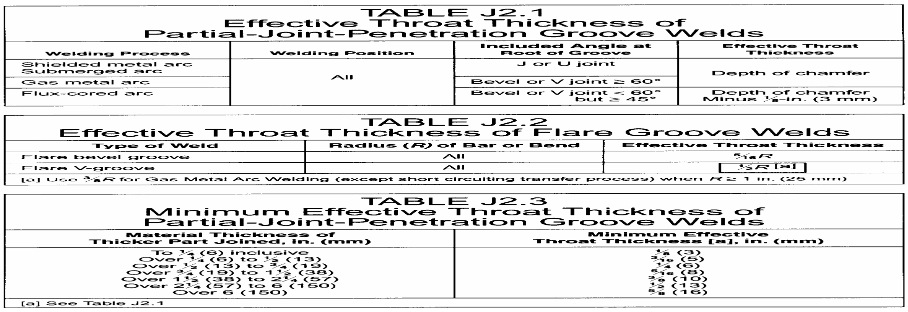


TABLE J2.1
Effective Throat Thickness of
Partial-Joint-Penetration Groove Welds

Welding Process	Welding Position	Included Angle at Root of Groove	Effective Throat Thickness
Shielded metal arc Submerged arc	All	J or U joint	Depth of chamfer
Gas metal arc		Bevel or V joint ≥ 60°	
Flux-cored arc		Bevel or V joint < 60° but ≥ 45°	Depth of chamfer Minus ⅛-in. (3 mm)

TABLE J2.2
Effective Throat Thickness of Flare Groove Welds

Type of Weld	Radius (*R*) of Bar or Bend	Effective Throat Thickness
Flare bevel groove	All	$\frac{5}{16}R$
Flare V-groove	All	$\boxed{\frac{1}{2}R\ [a]}$

[a] Use $\frac{3}{8}R$ for Gas Metal Arc Welding (except short circuiting transfer process) when $R \geq 1$ in. (25 mm)

TABLE J2.3
Minimum Effective Throat Thickness of
Partial-Joint-Penetration Groove Welds

Material Thickness of Thicker Part Joined, in. (mm)	Minimum Effective Throat Thickness [a], in. (mm)
To ¼ (6) inclusive	⅛ (3)
Over ¼ (6) to ½ (13)	3/16 (5)
Over ½ (13) to ¾ (19)	¼ (6)
Over ¾ (19) to 1½ (38)	5/16 (8)
Over 1½ (38) to 2¼ (57)	⅜ (10)
Over 2¼ (57) to 6 (150)	½ (13)
Over 6 (150)	⅝ (16)

[a] See Table J2.1

AISC Table J2.2
Effective Weld Sizes of Flare Groove Welds

Welding Process	Flare-Bevel	Flare-Vee
SMAW FCAW-S	5/16 R	5/8 R
GMAW FCAW-G	5/8 R	3/4 R
SAW	5/16 R	1/2 R

AWS D1.1:2006 Table 2.1
Effective Size of Flare-Groove Welds Filled Flush

Welding Process	Flare-Bevel	Flare-Vee
SMAW FCAW-S	5/16 R	5/8 R
GMAW FCAW-G	5/8 R	3/4 R
SAW	5/16 R	1/2 R

Since R = 2 x thickness, then the throat is as follows for flare-groove welds filled flush

Welding Process	Flare-Bevel	Flare-Vee
SMAW FCAW-S	5/8 t	5/4 t
GMAW FCAW-G	5/4 t	3/2 t
SAW	5/8 t	1/1 t

USE STEELS WITH GOOD “WELDABILITY”

AWS Standard Terms & Definitions (A3.0-94)

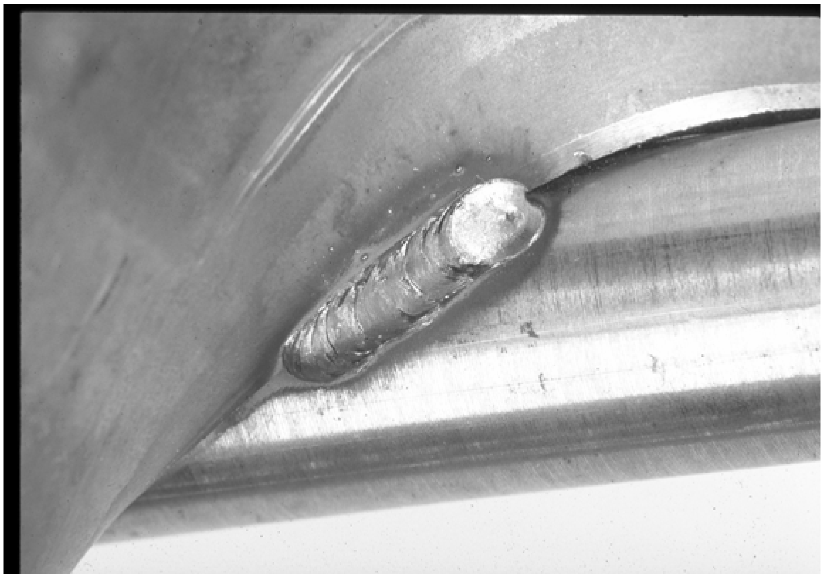
Weldability: The capacity of a material to be welded under the imposed fabrication conditions into a specific, suitably designed structure, and to perform satisfactorily in the intended service.

ASTM A6/A6M, Section X3

Weldability: A term that usually refers to the relative ease with which a metal can be welded using conventional practice.

Preferred analysis of Carbon Steel for Good Weldability

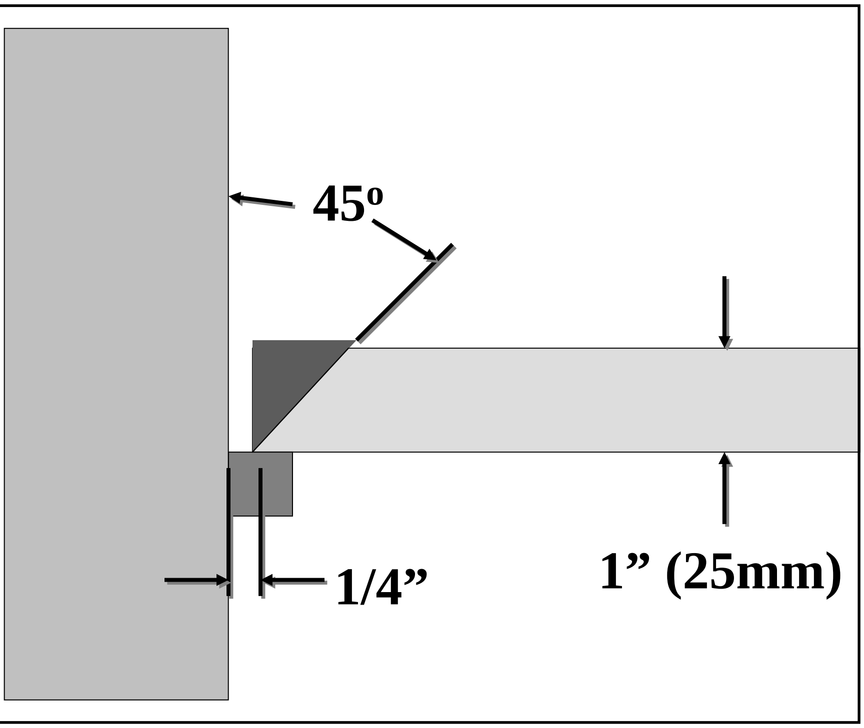
Element	Normal Range	Extra Care
Carbon (C)	0.06-0.20%	0.35%
Manganese (Mn)	0.35-0.80%	1.40%
Silicon (Si)	0.10% max.	0.30%
Phosphorus (P)	0.035% max.	0.050%
Copper (Cu)	0.15% max.	0.20%

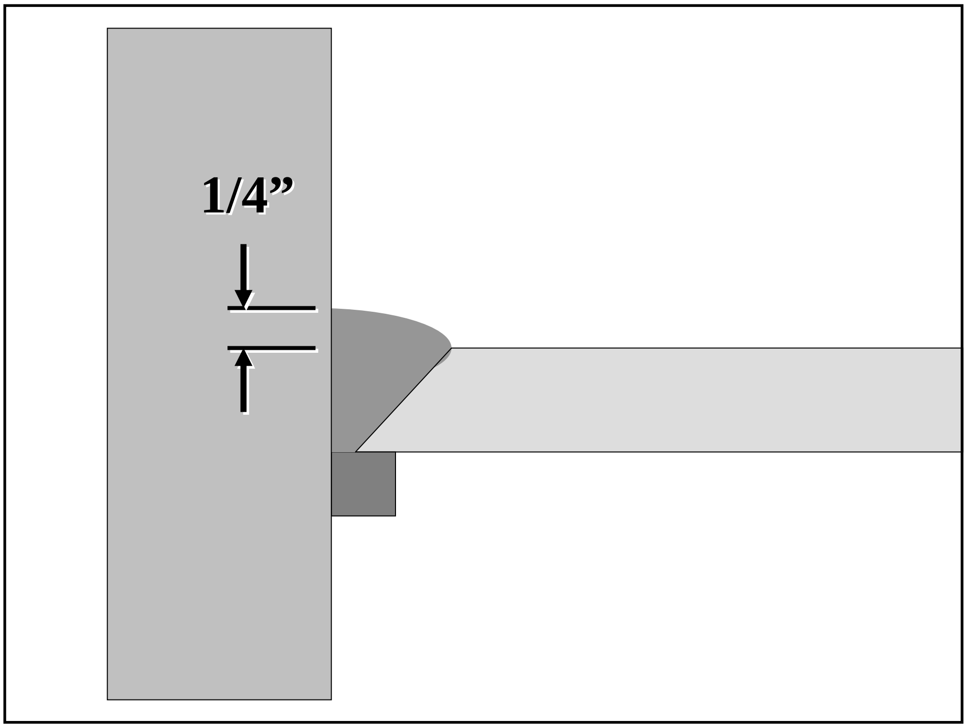


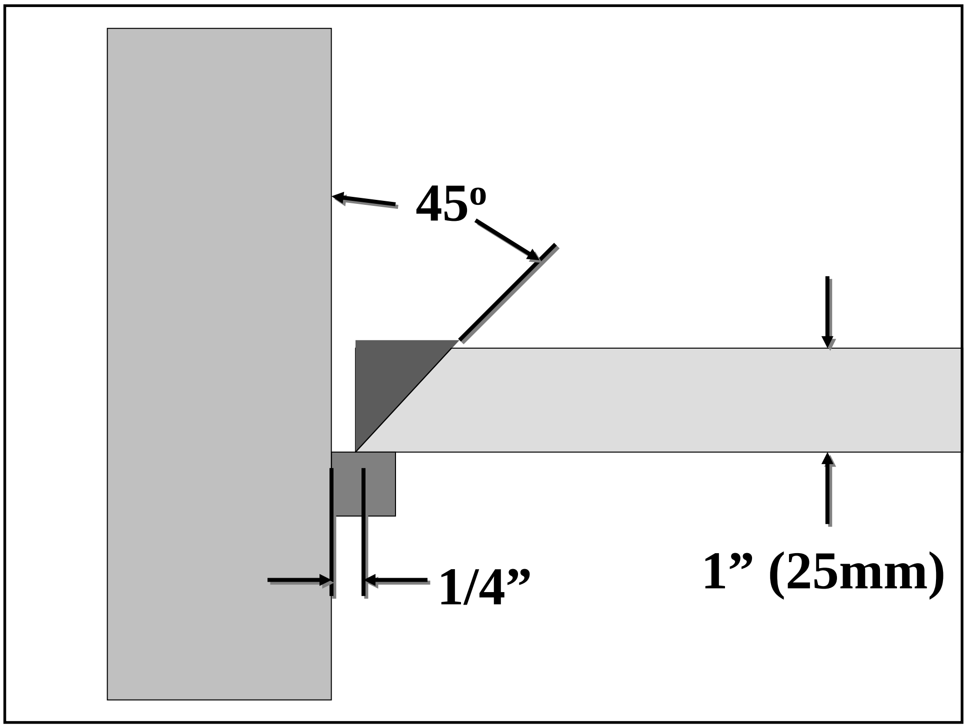

END OF
RHTER
N WELD

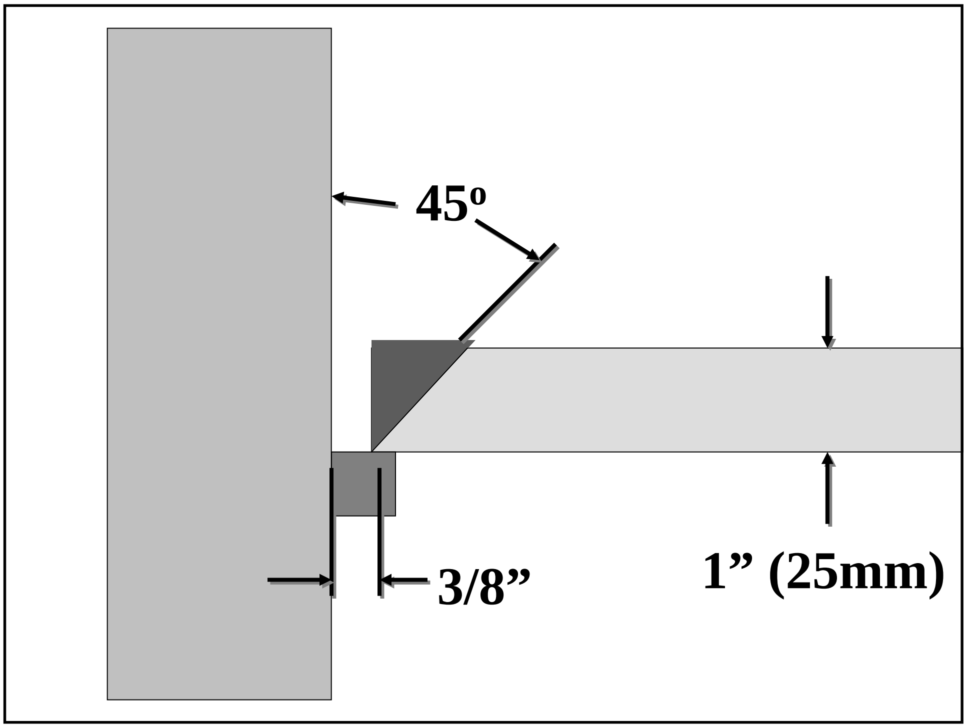
AWS D1.1:2004:

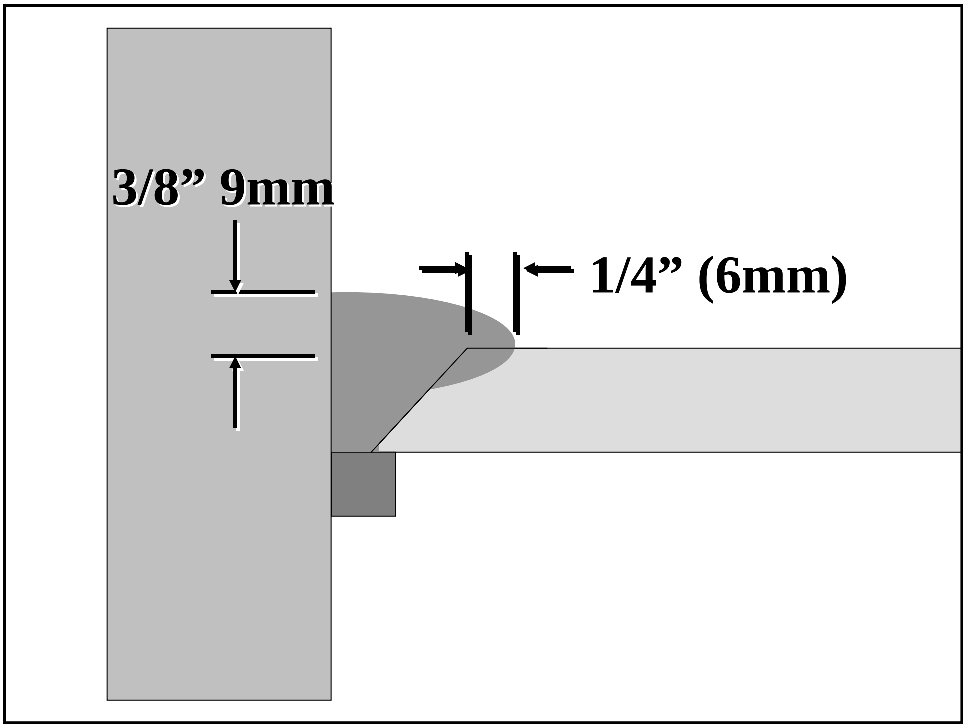
Table 3.1
Annex M

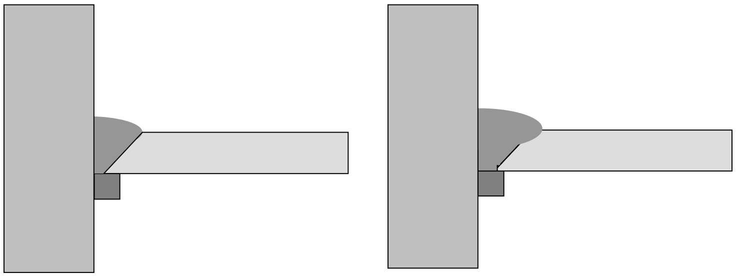



1/4”

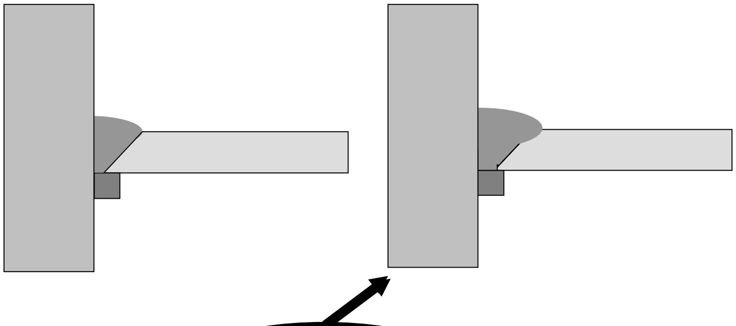

45º
1/4”
1” (25mm)


45º
3/8”
1” (25mm)


3/8” 9mm
1/4” (6mm)



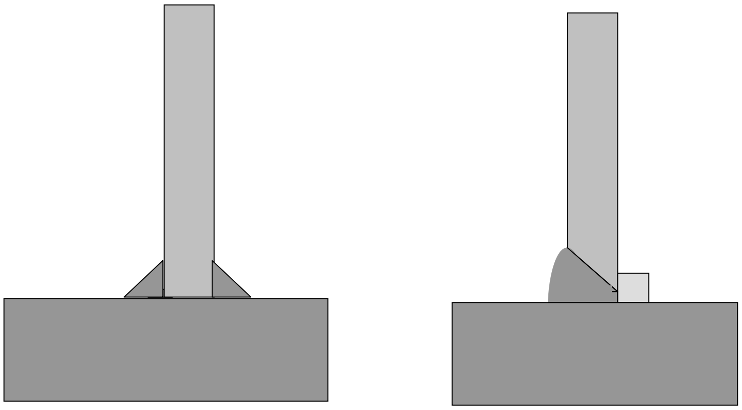
3.26 #/ft. **4.00#/ft.**



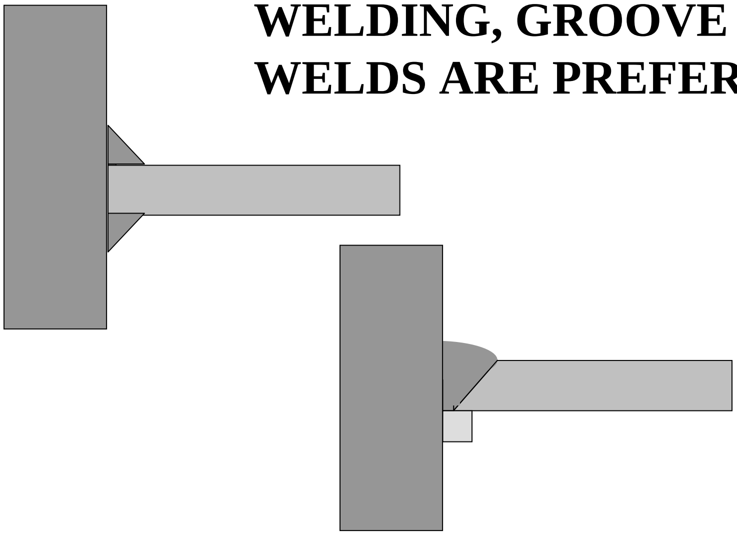
3.26 #/ft. **23% More** **4.00#/ft.**

CONSIDER THE POSITION OF WELDING WHEN SELECTING WELD DETAILS

FILLET WELDS GENERALLY PREFERRED OVER GROOVE WELDS, BUT…



IF FILLET WELDS REQUIRE OVERHEAD WELDING, GROOVE WELDS ARE PREFERRED



---

welded

There’s always a solution in steel!

Bolting & Welding

Part 2: Fundamentals of High-Strength Bolting

Geoffrey L. Kulak, Ph.D.
University of Alberta
Edmonton, AB
Canada

Structural Bolts

- Fundamentals and Behavior
- AISC Specification Requirements

©

Overview of the seminar..

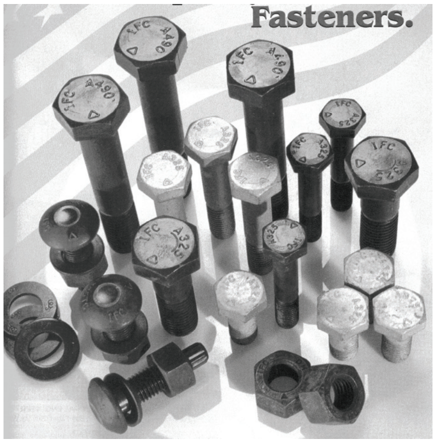
- Goal is to develop an understanding of:
  - how individual fasteners behave
  - how fasteners work in joints
  - the Specification rules that reflect these issues

Role of the Structural Engineer…

- Selection of suitable bolt types and grades
- Design of the fasteners
- Responsibility for installation
- Responsibility for inspection

Mechanical Fasteners

- Rivets
  - evaluation of existing structures
- Bolts
  - Common (ordinary) bolts: ASTM A307
  - High-strength bolts: ASTM A325 & A490
  - Other H/S bolts



Common (ordinary) bolts

- ASTM A307
  - Three grades: A, B, and C
    - Grade A: general applications
    - Grade B: for piping systems
    - Grade C: non-headed anchor bolts or studs
  - A307 Grade A
    - minimum tensile strength 60 ksi

ASTM A307 Bolts

- often a good choice when loads are static
- strength level inferior to high-strength bolts
- pretension indeterminate

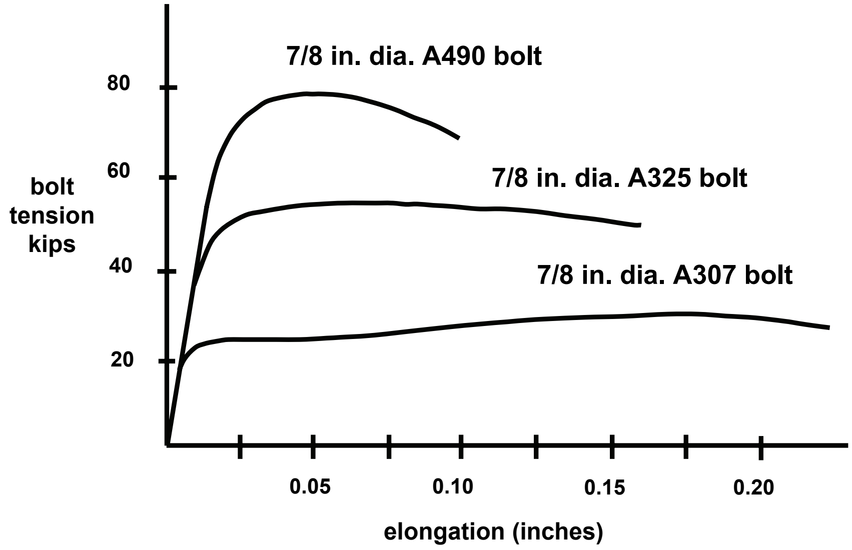
ASTM A325 Bolts

- Type 1 or Type 3 (weathering steel)
- ASTM Spec. ←■→ RCSC Spec.
- Minimum tensile strength: 120 ksi
  (or 105 ksi for diameters > 1 in.)
- Pretension can be induced if desired

ASTM A490 Bolts

- Types 1 or Type 3 (weathering steel)
- Minimum tensile strength: 150 ksi,
  (maximum 170 ksi)
- ASTM Spec. ←■→ RCSC Spec.
- Pretension can be induced if desired

Comparison of Bolts: Direct Tension



Comments…

- Note that we quote the ultimate tensile strength of the bolt
  - this is the benchmark for strength statements (e.g. shear strength is some fraction of ultimate tensile strength)
- What about yield strength?
- What is “proof load”

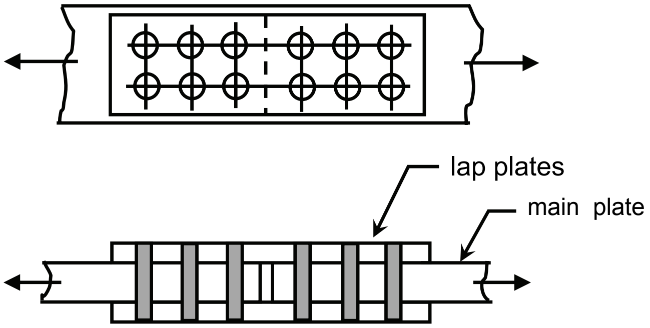
…comments cont'd

- Nuts: ASTM A563
- Washers: if needed, ASTM F436
- Bolt – nut – washer sets implied so far, but other configurations available

Loading of Bolts

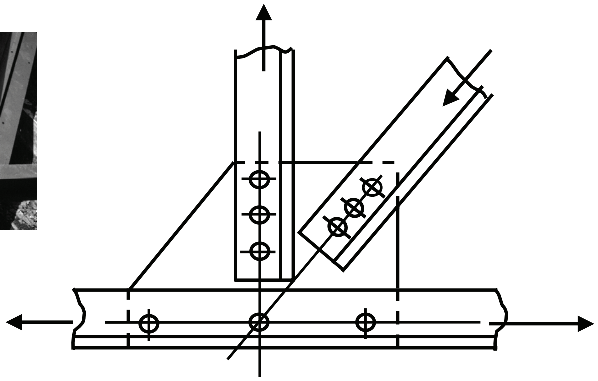
- Shear
  - load transfer by shear in bolt and bearing in connected material OR
  - load transfer by friction (followed by shear and bearing)
- Tension
- Combined Tension and Shear

Shear Loading of Bolts



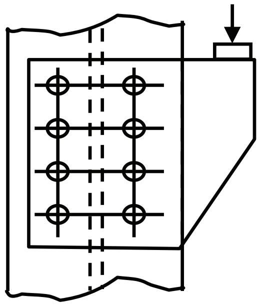
Shear Splice

Shear Loading cont'd



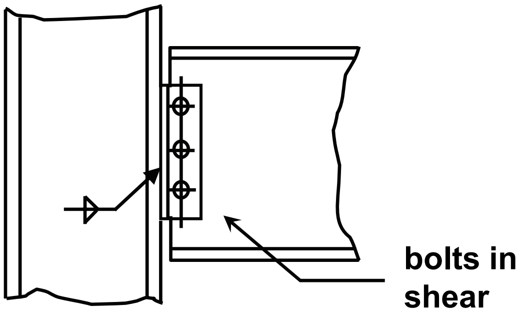
Truss Joint

Shear Loading cont’d



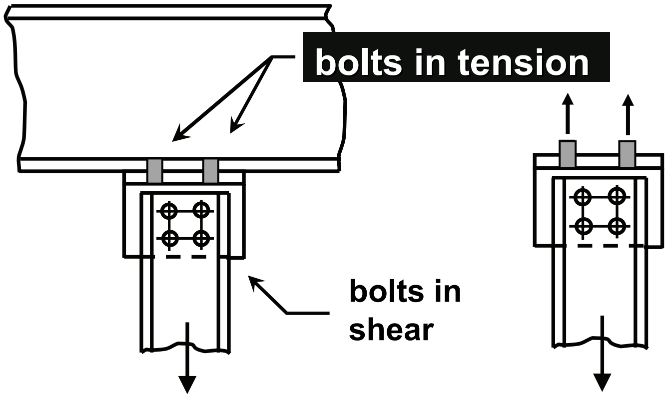
Eccentric Connection

Shear Loading cont’d



Standard Beam Connection

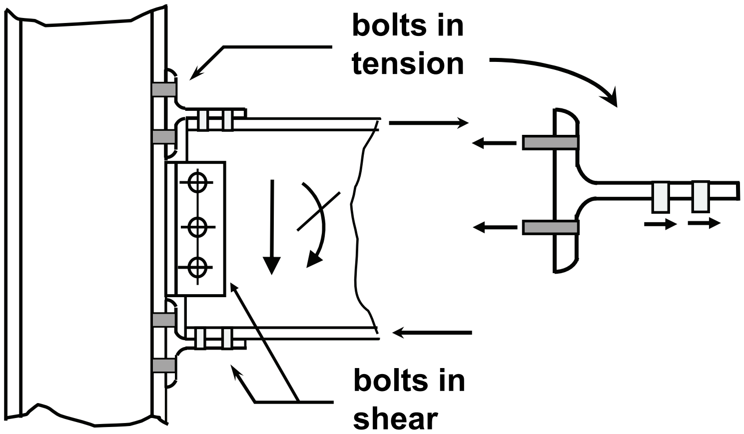
Bolts Loaded in Tension



bolts in tension

bolts in shear

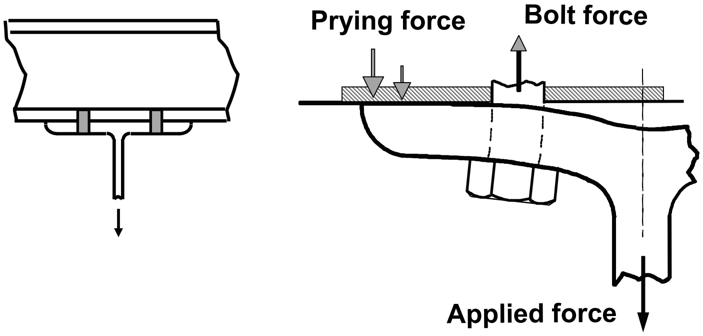
Bolts Loaded in Tension



bolts in tension

bolts in shear

Bolts in Tension – prying



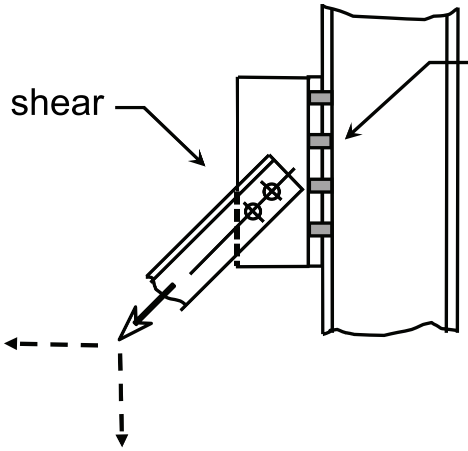
Prying force

Bolt force

Applied force

High-strength bolts in tension can be a source of problems!

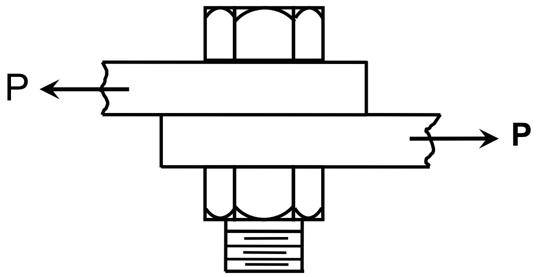
Bolts in combined tension and shear

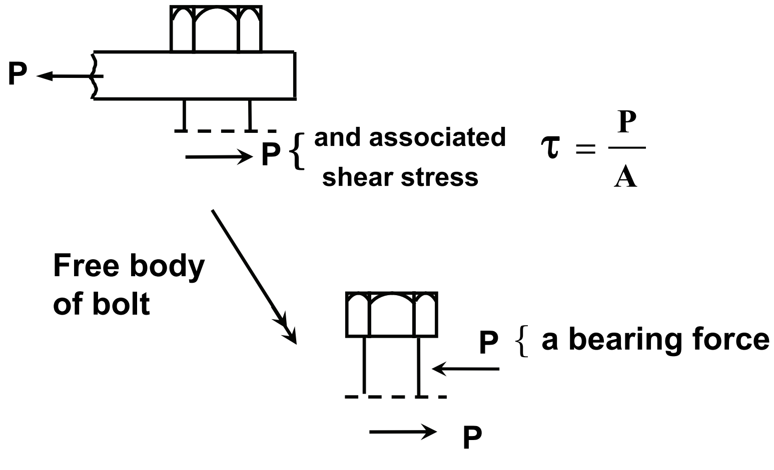


bolts in shear

bolts in combined shear and tension

Consider a simple joint —





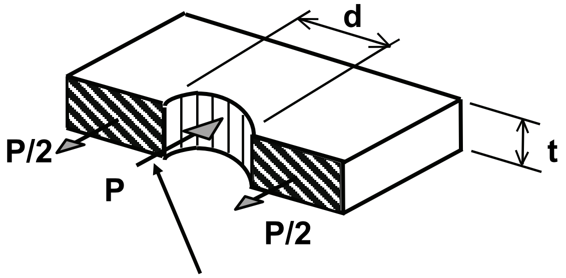
P { and associated shear stress

$\tau = \frac{P}{A}$

Free body of bolt

P { a bearing force

Finally...



note that this force is equal and opposite to the bearing force shown previously

In the example, we identified…

- the force in the bolt (a shear force)
- the force that the bolt imposed on the plate (a bearing force)
- the force in the plate itself (a tensile force)
- (force transfer could also be by friction: not included in this illustration)

Design Specifications

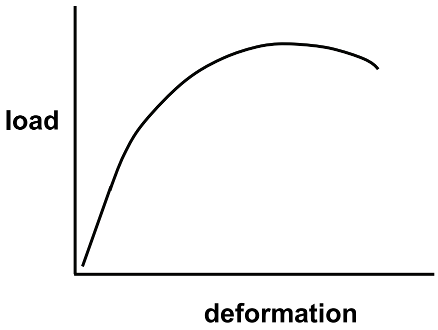
- **Limit States Design (*LRFD*) <u>or</u>**
  Allowable Stress Design (*ASD*)
- **Historically:**
  - **allowable stress design: apply a factor of safety to yield strength**
  - **limit states design: use maximum capacity of element as basis**

? ↕

Comment…

Connection design historically has been done on basis of ultimate strength, regardless of framework used.

bolt in shear



AISC Standard 2005

- Parallel LRFD and ASD rules
- LRFD uses a resistance factor, Ø
- ASD uses a safety factor, Ω
- Loads as appropriate:
  - factored loads for LRFD
  - non-factored loads for ASD

AISC Standard cont’d

LRFD: req’d strength LRFD $\leq \phi \enclose{circle}{R_n}$

ASD: req’d strength ASD $\leq \enclose{circle}{R_n} / \Omega$

(Better to write it as resistance ≥ req’d strength?)

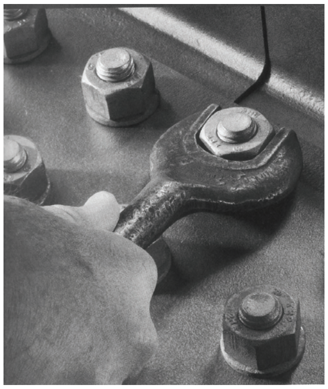
i.e. $\phi R_n \geq$ req’d strength

…and another comment

AISC Specification says—

The use of high-strength bolts shall conform to the *RCSC Specification for Structural Joints Using ASTM A325 or A490 Bolts*

Installation —



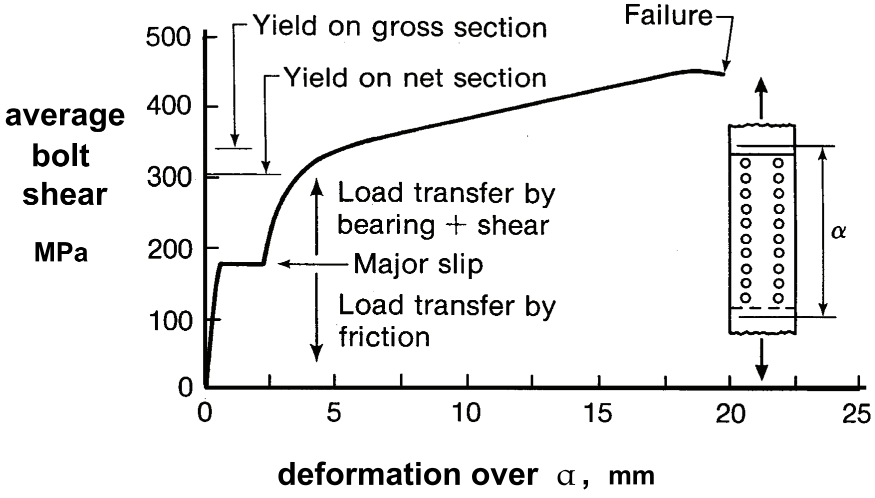
- **Snug-tight only**
- **Pretensioned**
  - **– Calibrated wrench**
  - **– Turn-of-nut**
  - **– Other means:**
    - **Tension control bolts**
    - **Load-indicator washers**

As a result of the installation…

- **Bolts are either not pretensioned (i.e. snug-tight) OR —**
- **Bolts have a pretension**
  - **When do we need pretension?**

We will deal with these issues later.

Behavior of a large joint (shear splice) —



Bolts in Shear: Issues

- Shear strength of bolt (single shear or double shear, threads in shear plane?)
- Bearing capacity of bolt (never governs)
- Bearing capacity of plate
- Tensile capacity of plate

Bolts in shear: pretensioned bolts

- Bolts are in holes 1/16 in. larger than the bolt diameter. (Oversize holes and slotted holes can also be used.)
- Amount of slip possible is two hole clearances (i.e. 1/8 in.) (See comment next image)
- If slip is a problem (e.g., fatigue) — use pretensioned bolts in a slip-critical connection. More about this later.

Slip in bolted joints…

- Can be as much as two hole clearances
- In a joint with a reasonable number of bolts, some will already be in bearing at start of loading
- Both laboratory tests and field measurements indicate that slip is more like 1/2 hole clearance

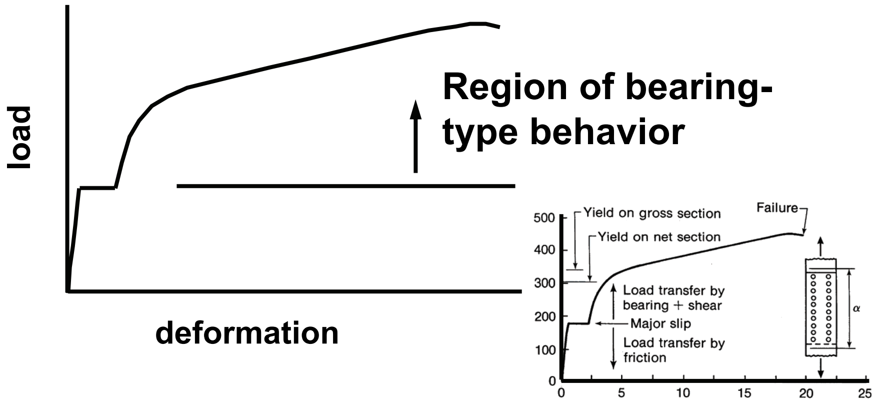
Bolts in shear-type connection:

- Common type of joint
- Specifications distinguish between:
  - bearing type connections
  - slip-critical connections
  - Note: a slip-critical joint (service loads) must also be checked as a bearing joint (factored loads)

Bearing-type connections:

- **Issues**
  - – **bolt shear strength**
  - – **bearing capacity connected material**
  - – **member strength**
- **Shear strength of bolts is <u>not dependent</u> on presence or absence of pretension. (How come?)**

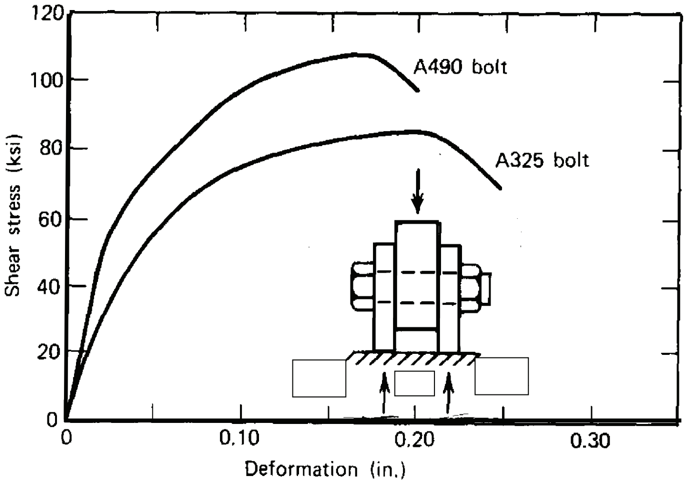
Bolts in bearing-type connections…



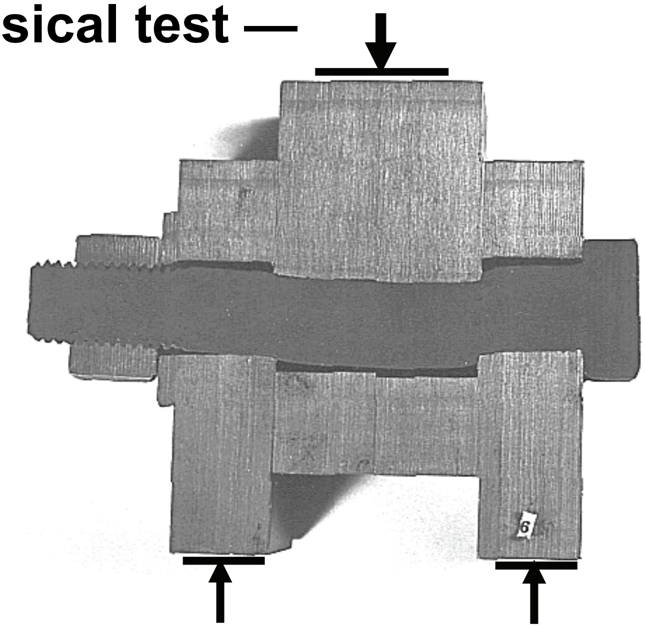
Bolt Shear Strength

- Bolt shear strength ≈ 62% of bolt ultimate tensile strength (tests)
  - Design rule takes 80% of this value
  - Threads in shear plane?
  - Long joint effect: another discount applied.

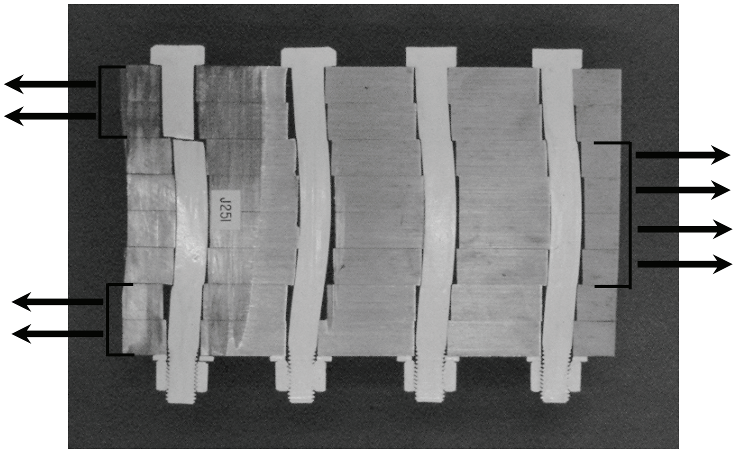
Individual bolt in shear



Physical test —

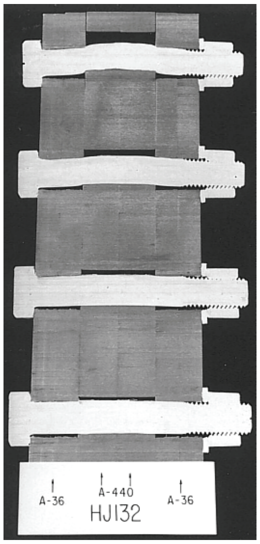


Long Joint Effect —

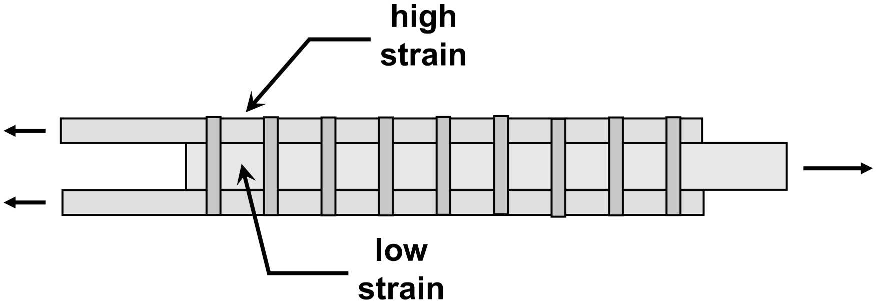


Uneven loading of bolts –

(End four bolts of 13)



Bolts are loaded (in shear) as a consequence of the differential strains between the plates…

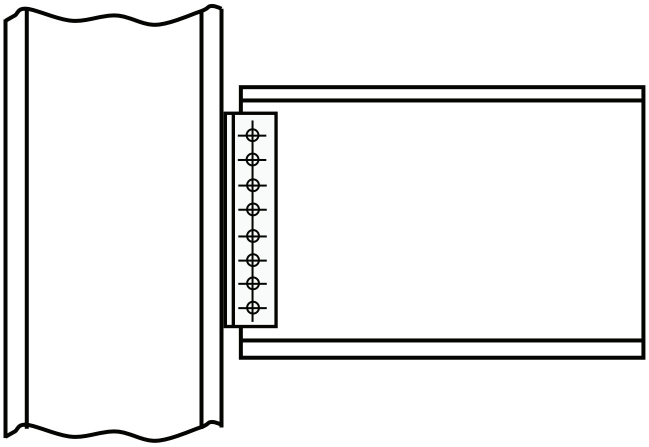


high strain

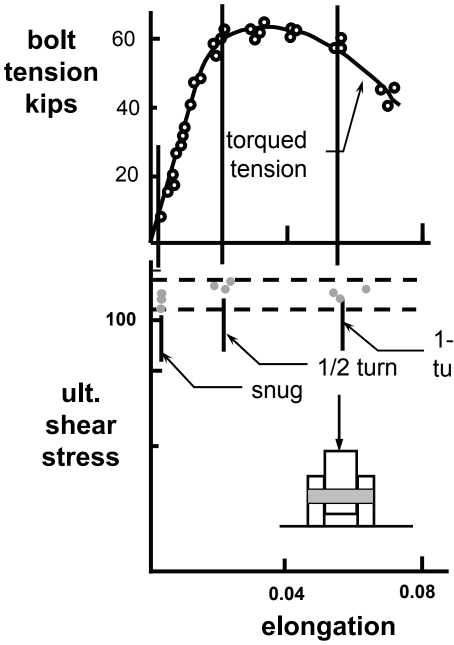
low strain

= high differential strain

Long joint effect for this case?



Effect of bolt pretension on bolt shear strength



ultimate shear stress – independent of bolt pretension (why?)

Further Comment: Bolt Capacity in Shear

- We recognize that shear strength of a bolt is not dependent on the pretension in the bolt.
- Looking ahead: If the bolt shear strength is not dependent on bolt pretension, why do we need to inspect the bolt for pretension?

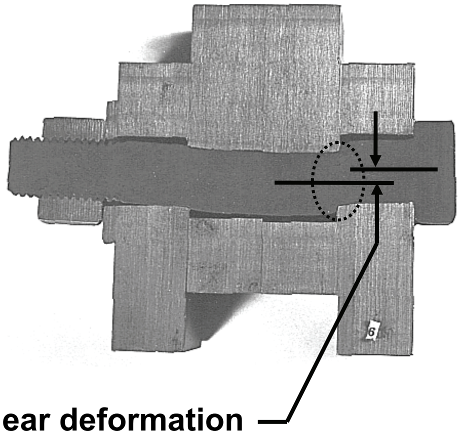
Bolt Pretension v. Shear

- The bolt pretension is attained as a result of small axial elongations introduced as nut is turned on
- These small elongations are relieved as shear deformations and shear yielding take place
- Confirmed by both bolt tension measurements and shear strength tests

Back to bolt in shear —

Shear strength of single bolt (tests) —

$$\tau = 0.62\,\sigma_{u\ bolt}$$



Shear deformation

Bolts in Shear — AISC

$$\phi\,R_n = \phi\ F_v\ A_b$$

$\phi\,R_n$ = design shear strength

F_v = nominal shear strength, ksi

nominal shear strength …

$$\phi = 0.75$$

$$F_v = 80\% \, (0.62 \times F_u) = 0.50 \; F_u$$

Thus…

$$\text{A325 bolts}: \; F_v = 0.50 \times 120 \text{ ksi} = 60 \text{ ksi}$$

$$\text{A490 bolts}: F_v = 0.50 \times 150 \text{ ksi} = 75 \text{ ksi}$$

— these are the values tabulated in Table J3.2 of the Specification for the thread <u>excluded</u> case. For threads <u>included</u>, the tabulated values are 80% of the above.

Comments…

- If threads in shear plane, another reduction, already indicated
- The discount for length (use of 80%) is conservative
- If joint length > 50 in., a further 20% reduction
- The ø – value used for this case (0.75) is also conservative.

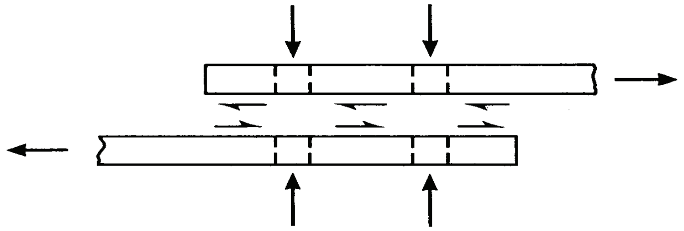
Threads in shear plane?

- Use 0.80 reduction factor in order to account for reduced area through threads.
- Distinguish between threads in one or both shear planes?

Let's return now to slip-critical connections…

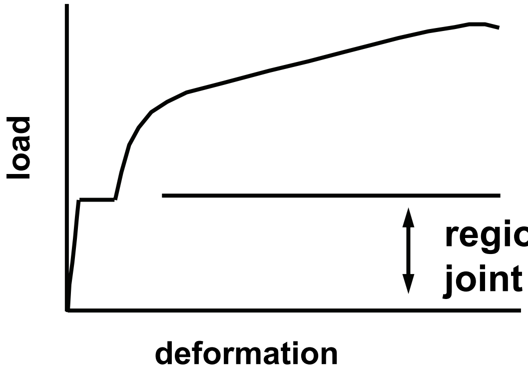
Slip-Critical Connection

Clamping force from bolts (bolt pretension)

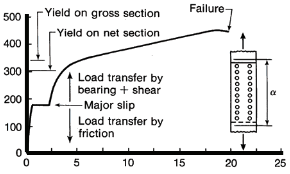


Load at which slip takes place will be a function of …?

Bolts in slip-critical connections…

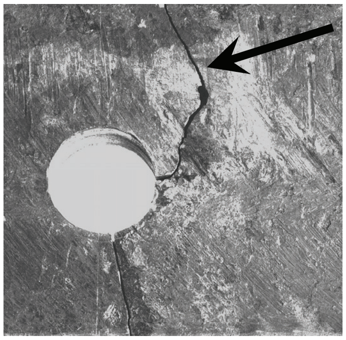


region of slip-critical joint behavior



Slip-critical joints specified when…

- **Load is repetitive and changes from tension to compression. (Fatigue by fretting could occur.)**
- **Change in geometry of structure would affect its performance.**
- **Certain other cases.**
- **Comment: for buildings, slip-critical joints should be the exception, not the rule.**



Slip-critical criteria:

- **Choice:**
  - **a serviceability limit state (no slip under the service loads) OR**
  - **a strength limit state (no slip under the factored loads)**

Which one do we use?

- No slip at service loads: e.g. fatigue loading
- No slip at factored loads: e.g. long-span flat roof truss (ponding could result as factored loads attained)

and don't forget….

After you have designed the joint as slip-critical, you must still check shear and bearing (factored load)

First principles, slip resistance is —

$$P = k_s \; n \; \Sigma T_i$$

k_s = slip coefficient (μ)

n = number of slip planes (usually 1 or 2)

T_i = clamping force (i.e., bolt pretension)

Design slip resistance, AISC

$$\phi R_n = \mu D_u \; h_{sc} \; T_b \; N_s$$

no. slip planes

clamping force

slip coefficient

The terms ϕ and D_u need to be defined

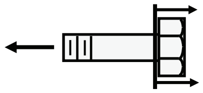
and the modifiers …

h_{sc} = modifier re hole condition
e.g., oversize hole, slotted hole etc.

$D_u = 1.13$, the ratio of installed bolt tension to specified minimum bolt tension

ϕ = resistance factor
$= 1.0$ no slip at service loads $(\beta = 1.4)$
$= 0.85$ no slip at factored loads $(\beta = 1.5)$

Bolts in Tension

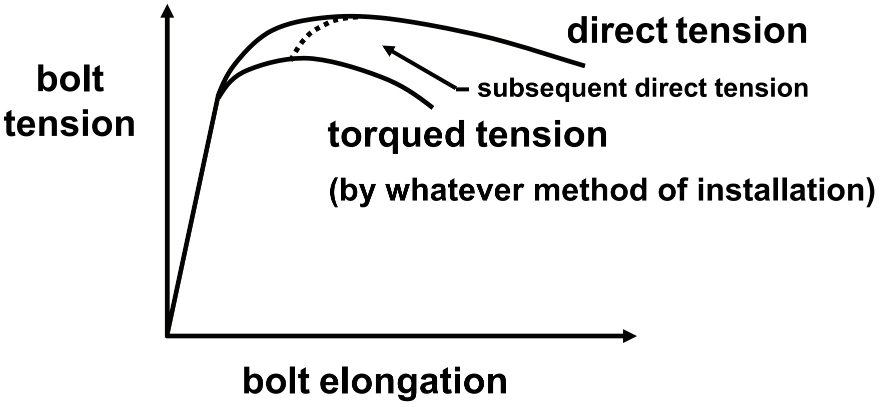


- <u>Capacity</u> of a bolt in tension: product of the ultimate tensile strength of the bolt and the tensile stress area of the bolt (i.e. F_u A_{st})
- Specifications directly reflect this calculated capacity (…to come)
- <u>Force</u> in bolt must reflect any prying action affect

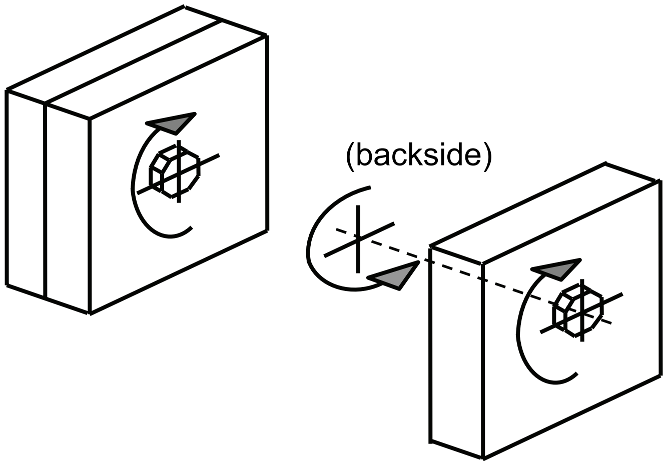
Bolts in Tension – some comments

- Preference: avoid joints that put bolts into tension, especially if fatigue is an issue
- Use A325 bolts rather than A490 bolts
- Minimize the prying action

Direct tension v. torqued tension



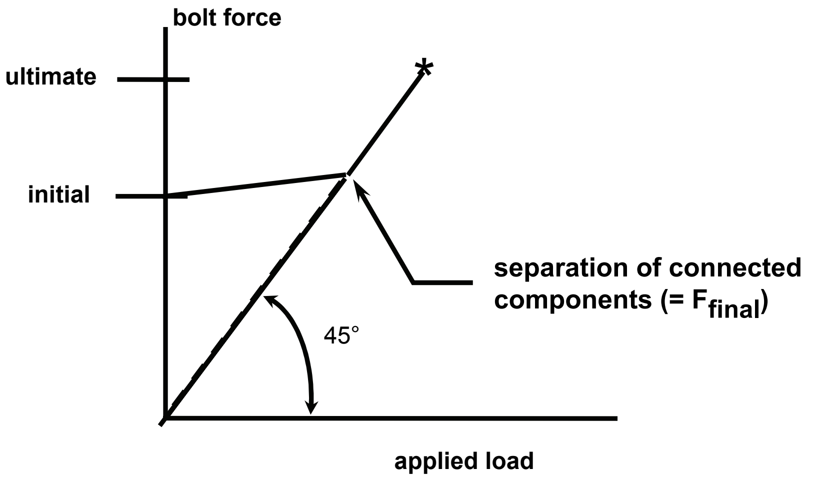
How is the torsion resisted?



Question…

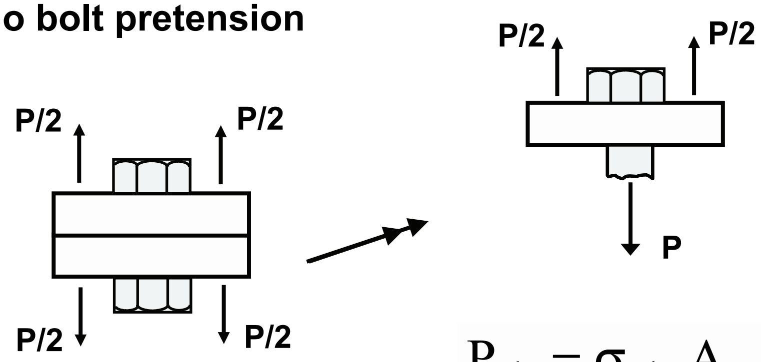
- pretensioned bolt in a connection
- apply external tension force to the connection
- do the bolt pretension and the external tension add?

Bolt pretension + external tensile load ?



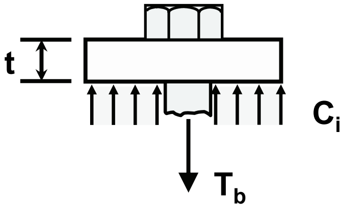
Explore this bolt tension issue…

1. No bolt pretension

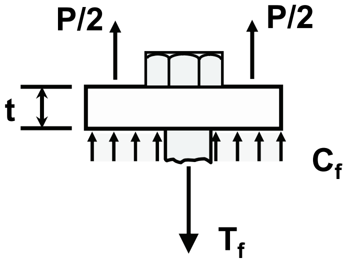


$$P_{ult} = \sigma_{ult}\ A_{st}$$

2. Bolt pretension present



No external load:
$C_i = T_b$ (1)



External load applied:
$T_f = C_f + P$ (2)

Elongation of bolt and elongation of plate must be identical during this process….

$$\delta_b = \frac{(T_f - T_b)}{A_b\ E}\ t \qquad \delta_t = \frac{(C_i - C_f)}{A_p\ E}\ t$$

Equating these two expressions for the change in length gives the relationship…

$$\frac{(T_f - T_b)}{A_b} = \frac{(C_i - C_f)}{A_p}$$

Using this and Eq. 1 and 2, the final bolt force can be obtained as…..

$$T_f = T_b + \frac{P}{1 + \frac{A_p}{A_b}}$$

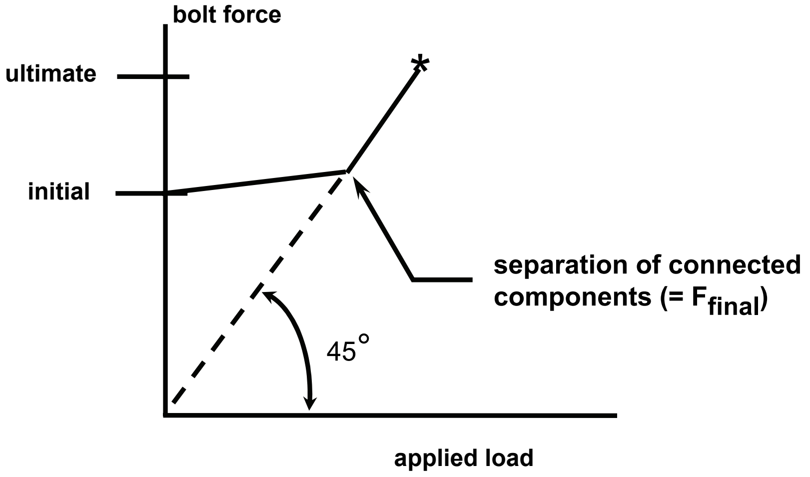
$$T_f = T_b + \frac{P}{1 + \frac{A_p}{A_b}}$$

Final bolt force = initial bolt pretension (T_b) + a portion of the applied external load.

The final bolt pretension reflects the bolt area (which we know) and the contributory plate area (which we don't know).

A reasonable estimate for the ratio is 9, and this results in a bolt force increase of about 10%

as already seen, the result is…



AISC rule, bolts in tension—

$$\phi R_n = \phi \ F_{nt} \ A_b$$

bolt area for nominal diameter

nominal tensile strength

$$\phi R_n = \text{design tensile strength}$$

What is nominal tensile strength, F_{nt} ?

$$P_{ult} = F_u \ A_{st} = F_u \ (0.75 A_b)$$

Adjusted area

$$\text{or,} \quad P_{ult} = \underbrace{0.75 \, F_u}_{} \ A_b$$

Call this F_{nt} ←

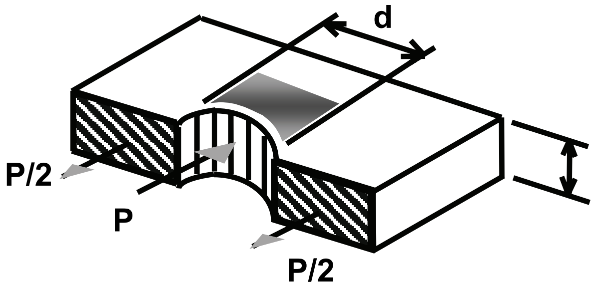
So, the AISC rule for bolts in tension…

$$\phi R_n = \phi \ F_{nt} \ A_b$$

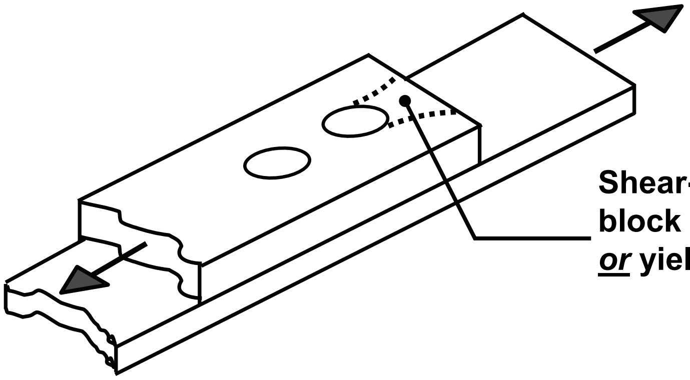
where F_{nt} = 0.75 F_u as tabulated in the Specification

As we now know, the 0.75 really has nothing to do with F_u

Returning to shear splice joints, we still have to deal with the bearing capacity of the connected material.

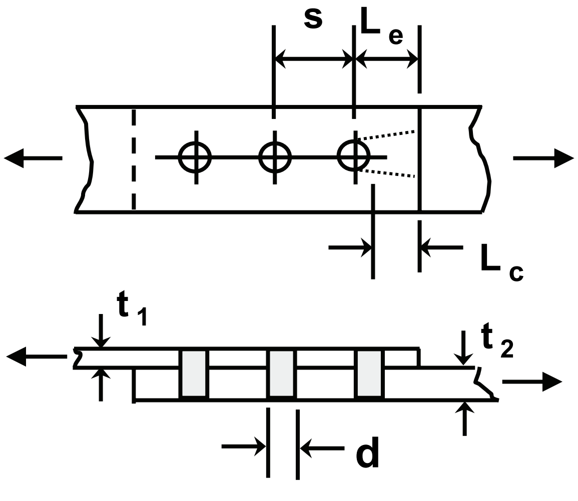


Bearing capacity (of connected material)



Shear-out of a block of material *or* yielding

Bearing stresses at bolt holes…



Needed:

1. shear-out rule
2. yield rule (deformation)

Plate bearing stresses…

$$\text{Shear - out is } \; 2\,(\tau_{ult} \times L_c \times t)$$

$$\text{or, } \; R_n = 2\,(\,0.75\,\sigma_u \times L_c \times t) \;\longleftarrow$$

$$\swarrow$$

and AISC rule is: $R_n = 1.5\, F_u\, L_c\, t$

Plate bearing…

from tests: $$\frac{\sigma_b}{\sigma_u^{pl}} = \frac{L_e}{d}$$

$$\text{or, } \; \sigma_b = \sigma_u^{pl}\left(\frac{L_e}{d}\right)$$

$$\text{and, } R_n = \boxed{\sigma_b\; d\; t} = \sigma_u^{pl}\left(\frac{L_e}{d}\right) d\; t$$

$$\text{found valid for } L_e \geq 3\, d$$

Plate bearing…

Making the substitution and using ..

$$F_u \equiv \sigma_u^{pl}$$

$$R_n = \sigma_b \; d \; t = \sigma_u^{pl} \left(\frac{L_e}{d} \right) d \; t$$

$$R_n = 3 \; d \; t \; F_u \qquad \longleftarrow$$

Finally, the AISC rule for plate bearing capacity is …

$$R_n = 1.5 \, F_u \, L_c t \quad \leq \; 3.0 \, d \; t \; F_u$$

(with a ϕ-value still to be inserted)

Further note re bearing…

$$R_n = 1.5\,F_u\,L_c t \quad \leq 3.0\,d\,t\,F_u$$

But, Specification says that when deformation a consideration, use

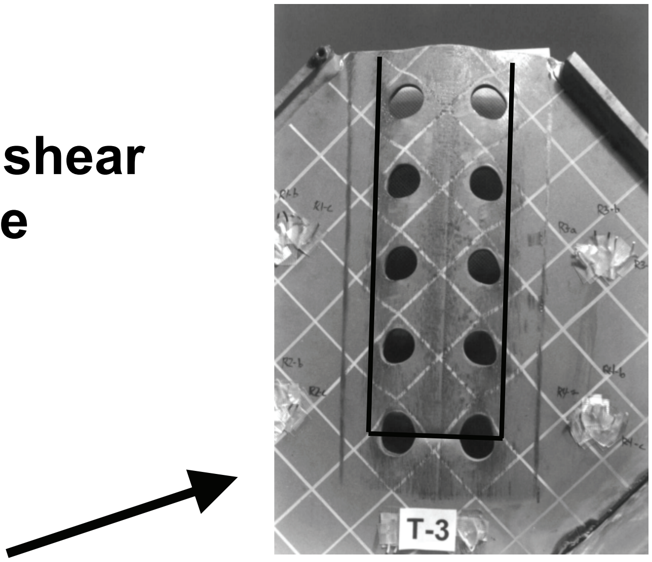
$$R_n = 1.2\,F_u\,L_c t \quad \leq 2.4\,d\,t\,F_u$$

Why this difference, and when do we use the latter?

Plate bearing limit based on limiting deformations…

- **Rule was developed on basis that most of the ultimate force is developed at about 0.25 in. deformation.**
- **The deflections in question are at ultimate load.**
- **Question test conditions**
- **Second-order effects (e.g. tall bldg.) are still small with deformations of this magnitude.**

Block shear rupture

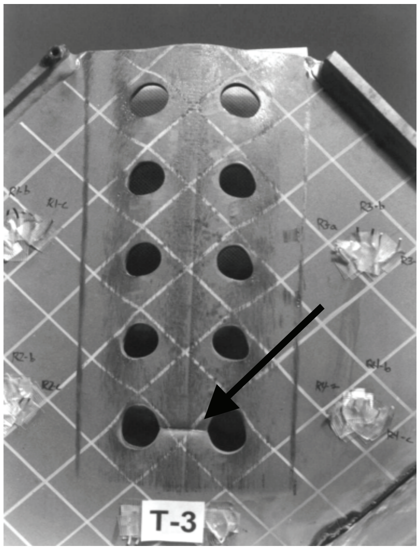


An aside: this is what we're usually shown…

Failure (ult. load) is always by tensile fracture, at location shown, regardless of geometric proportions.

Shear yield along vertical planes.

Failure is controlled by *ductility* – not strength.



Basics…

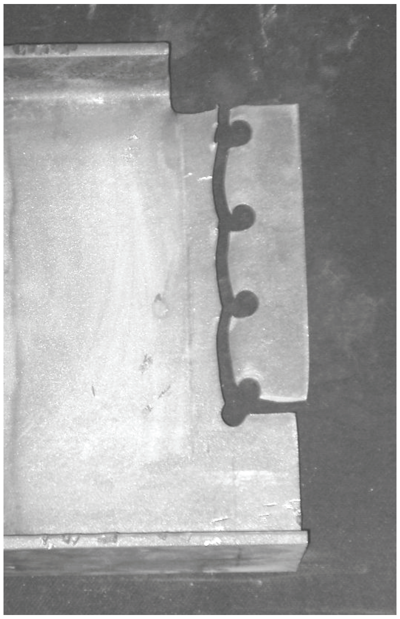
$$T_r + V_r = \underbrace{\phi\, A_{nt}\, F_u}_{\text{tension fracture}} + \underbrace{0.60\, \phi\, A_{gv}\, F_y}_{\text{shear yield}}$$

where A_{nt} = net area in tension

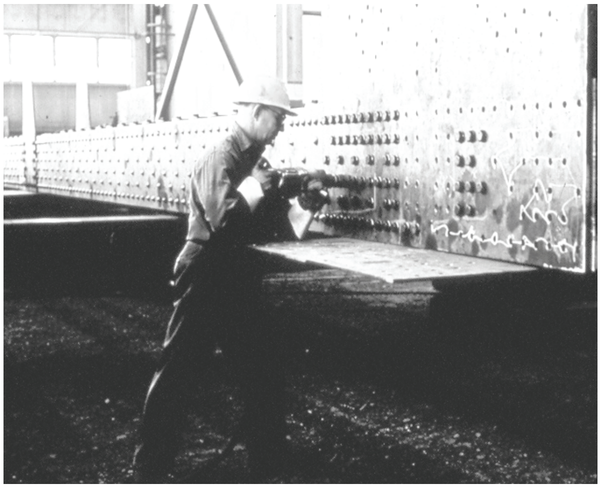
and A_{gv} = gross area in shear

(There are some other requirements, including specific case of coped beams.

An example of shear + tension failure in a coped beam…



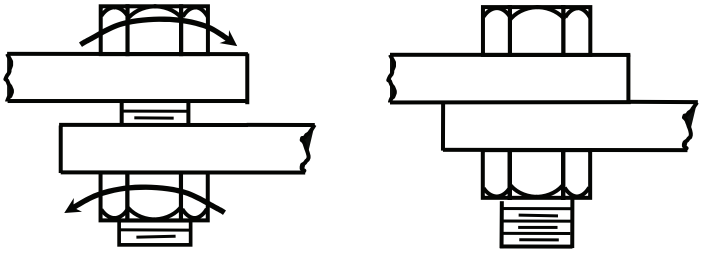
Back to installation…



Bearing-Type Connections—Installation of Bolts

- Bolts can be installed to “snug-tight condition — ordinary effort of worker using a spud wrench. (Pretension unknown, but usually small)

Installation —

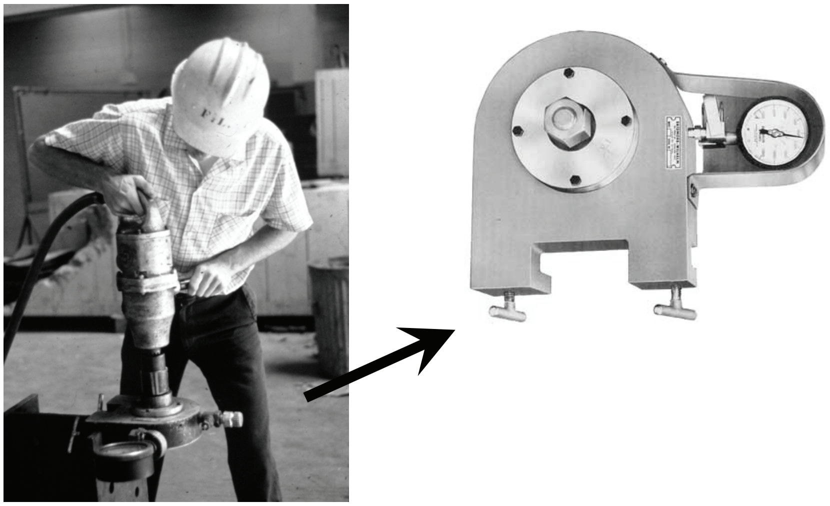


– bring parts together, continue turning nut, bolt elongates, tension develops in bolt, and clamped parts compress

Calibrated Wrench Installation

- **Reliable relationship between torque and resultant bolt tension?**
  NO ! (and is forbidden by RCSC)
- **Establish relationship by <u>calibration</u> of the installing wrench.**

Hydraulic calibrator –



Calibrated wrench, cont'd

- Adjust wrench to stall or cut out at desired level of bolt pretension
- Target value of pretension (RCSC) is 1.05 times specified min. value
- Calibrate using at least three bolts
- Calibration is unique to bolt lot, length, diameter, grade of bolt
- Washers must be used

Turn-of-Nut Installation

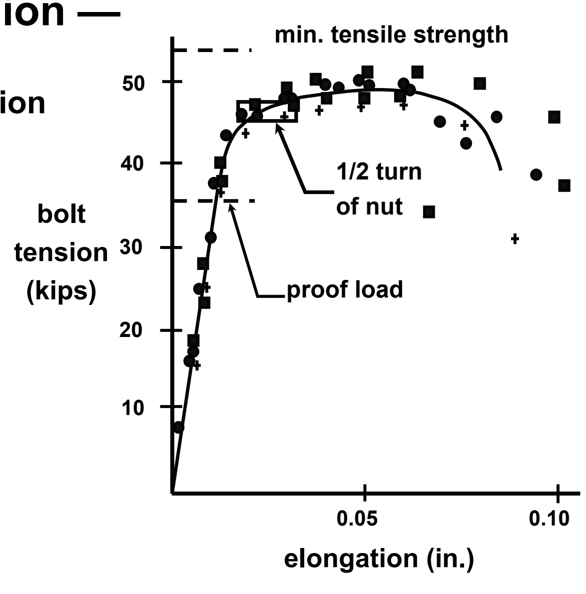
- Run nut down, bring parts into close contact
- Work from stiffer regions to edges
- Establish "snug-tight" condition (first impact of impact wrench or full effort of worker using a spud wrench)
- Apply additional one-half turn nut (or other value, depending on bolt size)

Does this definition of snug-tight seem a little vague?

How influential is “snug-tight?”

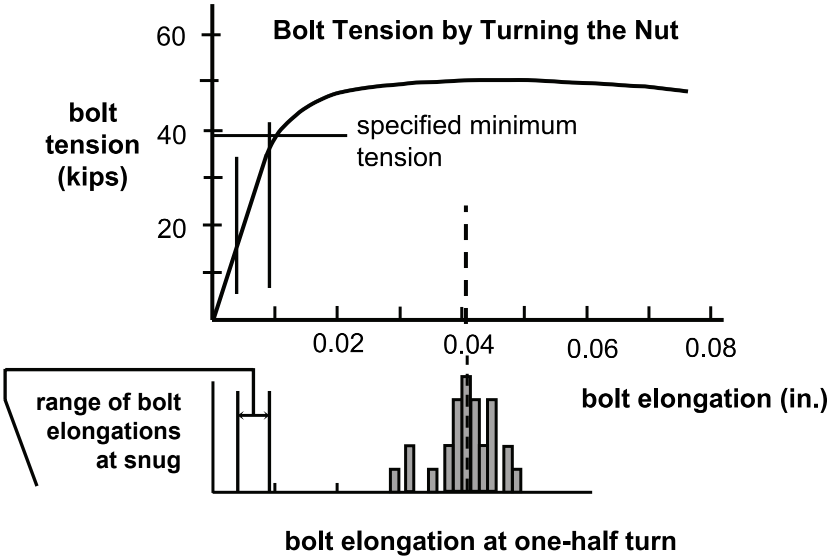
Bolt pretension —

Load vs. Elongation Relationship, Torqued Tension

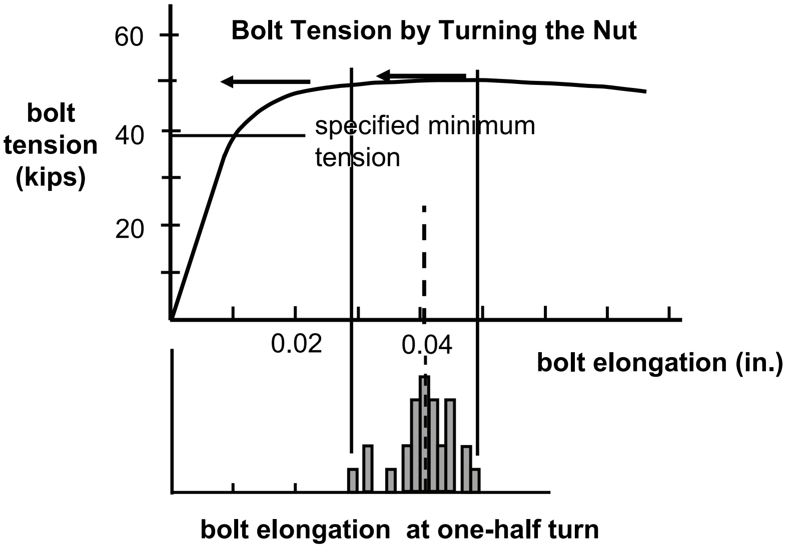


**7/8 in. dia.
A325 bolt**

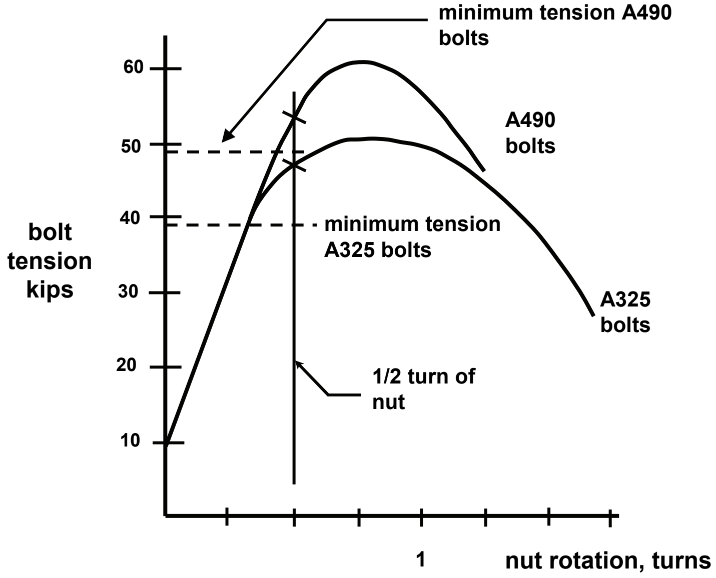
Bolt Tension by Turning the Nut



Bolt Tension by Turning the Nut



Tension vs. Rotation



Inspection of Installation

- Principles:
  - – Determination of the bolt pretension after installation is <u>not practical</u>
  - – Understand the requirements e.g., are pretensioned bolts required?
  - – Monitor the installation on the site
  - – Proper storage of bolts is required

Inspection of Installation

- Is bolt tension required? — if not, why inspect for it !
- Know what calibration process is required and monitor it on the job site
- Observe the work in progress on a regular basis

Inspection of installation:

Consider the following AISC cases —

1. Bolts need be snug-tight only
2. Bolts are pretensioned (but not a slip-critical joint)
3. Slip-critical joint

Snug tight only….

- Bearing-type connections
- Bolts in tension (A325 only)
  - only when no fatigue or vibration (bolt could loosen)

Inspection – snug tight

- Establish that the bolts, nuts, and washers (if any) meet the requirements of the specifications
- Hole types (e.g., slotted, oversize) meet specified requirements
- Contact surfaces are reasonably clean
- Parts are in close contact after bolts snugged

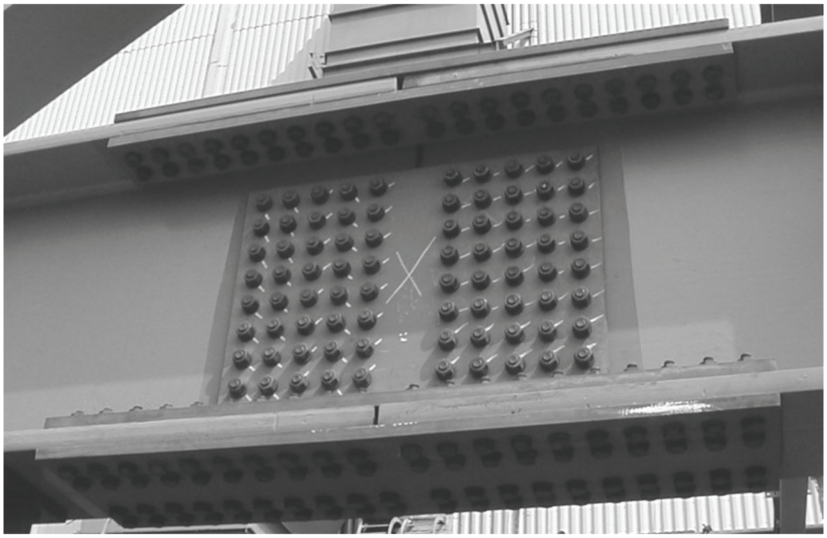
Inspection: if pretensioned bolts required…

- All of requirements for snug-tight case
- Observe the pre-installation verification process
  - turn of nut, or;
  - calibrated wrench, or;
  - other (direct tension washers, tension-control bolts)
- Calibration process done minimum once per day
- Calibration process done any time conditions change

Inspection: for slip-critical joints

- All of the above, plus
- Condition of faying surfaces, holes, etc.
- In addition to observing the calibration process, the inspection must ensure that the same process is applied to the field joints

An inspected joint (turn-of-nut)



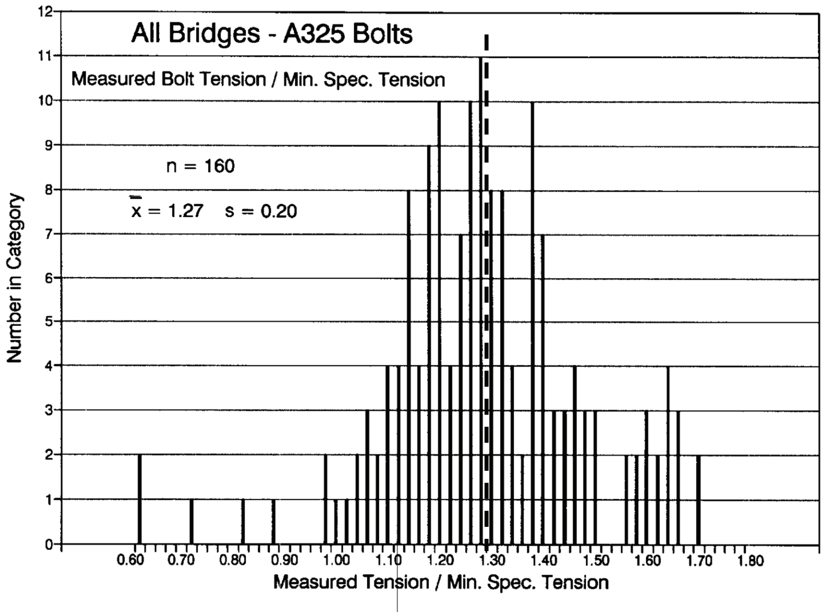
and some other comments…

- Pretension values <u>greater</u> than those specified are not cause for rejection.
- <u>Rotation</u> tests are useful for short-grip bolts or coated fasteners (requirement is in ASTM A325 spec. and is for galvanized bolts)

What happens in the field?

Pretensions have been measured in installed bolts, both in buildings and in bridges

An example of the results….



Actual pretensions, cont’d

- For A325 bolts, turn-of-nut:
  - Average tensile strength exceeds spec. min. tensile by about 1.18
  - Average pretension force is 80% of actual tensile
  - Result is that actual bolt tension is about 35% greater than specified bolt tension

Actual pretensions, cont’d

- A325, ½ turn-of-nut: 35% increase
- A490, ½ turn-of-nut: 26% increase
- A325 and A490, calibrated wrench: 13% increase
- etc. for other cases

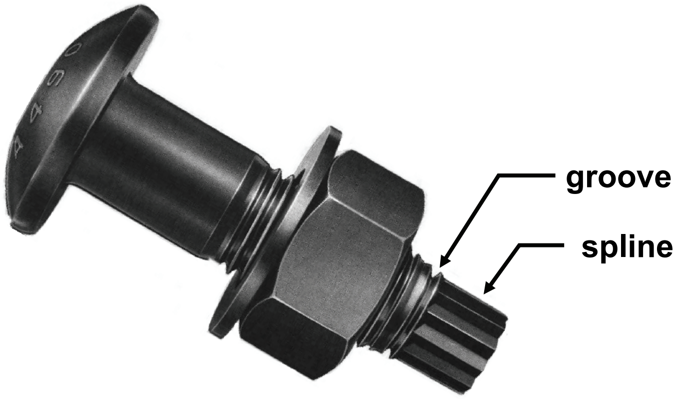
Note: these increased pretensions are embodied in the specification rules

Some other options for bolts —

Other bolts / fastening methods—

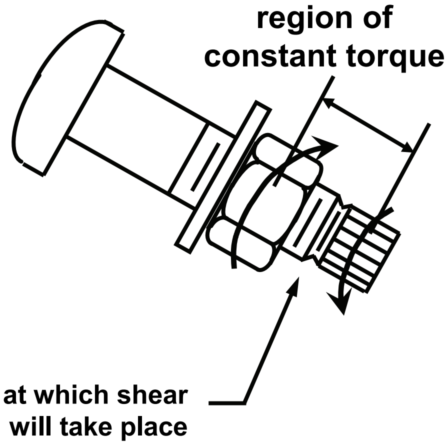
- Tension-control bolts (ASTM F1852)
- Load-indicating washers (ASTM F959)
- Alternative designs, e.g. Huck bolts

Tension control bolts…

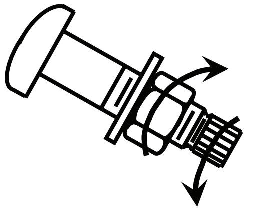


Tension Control Bolts

ASTM F1852



Tension Control Bolts



- Wrench has coaxial chucks
- Nut is turned in one direction
- Splined end is turned in other direction
- Splined end will shear off at groove
- If properly calibrated, shear will take place when pretension is attained

---

Tension control bolt pretension…

- material strength of bolt
- diameter of annular groove
- thread friction conditions
- friction at nut–washer interface

Tension control bolt pretension…

- Manufacturer provides the lubricant (on bolts, nuts, washers)
- User must calibrate (as per calibrated wrench)

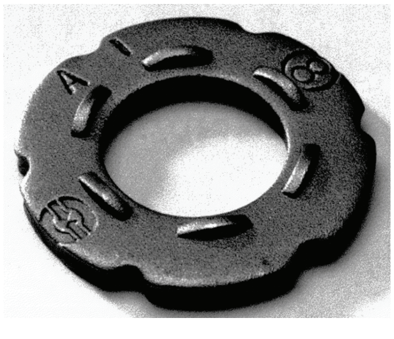
Tension control bolts….

- NOTE: evidence that tips have sheared off <u>is not</u> in itself evidence that desired pretension is present
- Consider limits:
  - Friction conditions are very high…
  - Friction conditions are very low…
- Hence, calibration is essential!

Tension-Control Bolts

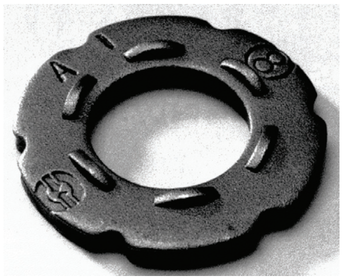
- **Advantages**
  - **Installation is from one side**
  - **Electric wrench is used**
  - **Installation is quiet**
- **Disadvantages**
  - **More expensive**
  - **Pre-installation calibration required**

Direct tension indicators—



Direct Tension Indicators

- Protrusions formed in special washer
- Protrusions compress as force in bolt is developed
- Use feeler gage to measure gap (or refusal)
- User must verify the process (like calibrated wrench)



ASTM 959

Reliability of these bolts..

- Calibration required
- Reliability should be same as calibrated wrench installations
- Tension-control bolt is torque-dependent
- Load-indicating washer is elongation-dependent
- Calibration is to specified pretension +5%

Some references —

Load and Resistance Factor Design Specification for Structural Joints Using ASTM A325 or A490 Bolts, Research Council on Structural Connections, 2004

(free download available)

References, cont'd.

- **G.L. Kulak, J.W. Fisher, and J.A.H. Struik, *Guide to Design Criteria for Bolted and Riveted Joints*, Second Edition, John Wiley, New York, 1987 (free download at RCSC website)**
- **Bickford, John H., "An Introduction to the Design and Behavior of Bolted Joints," Second Edition, Marcel Dekker Inc., New York, 1990**
- **G.L. Kulak, *A Bolting Primer for Structural Engineers*, AISC Design Guide 17, Chicago, 2002**

….and some web sites

- aisc.org
- boltcouncil.org (RCSC Spec., *Guide,* education bulletins, etc.)
- steelstructures.com
- steelstuff.com

Some additional topics …

- Details, other topics
  - washers
  - slotted or oversize holes
  - joints with both bolts and welds
  - shear lag
  - seismic design
- Design example

Washers

- Standard hardened washer required under turned element when torque-based installation used (calibrated wrench, tension-control bolt)
- Washers req'd when direct tension indicators used
- Washers not req'd
  - when snug-tightened joints used
  - for pretensioned joints, turn-of-nut
  - for slip-critical, turn-of-nut

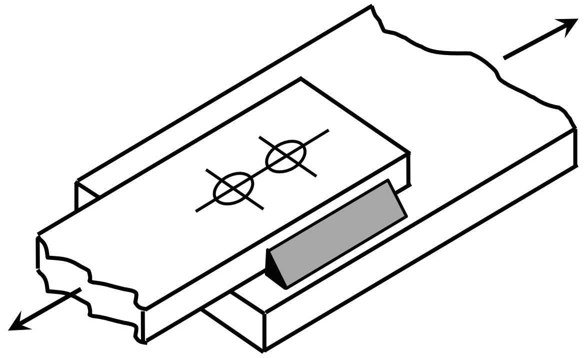
Washers cont'd

- But, washers required for
  - sloping surfaces present
  - A490 bolts used when material $F_y < 40$ ksi
  - many cases of slotted or oversize holes, regardless of type of joint or method of installation

Slotted or oversize holes

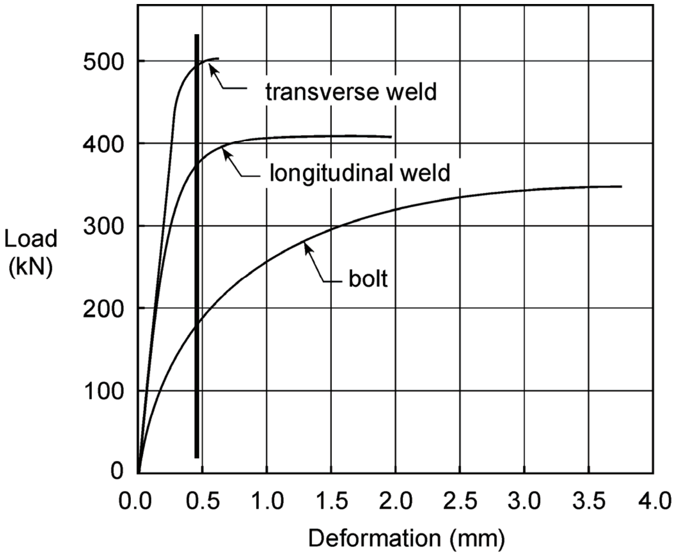
- Advantageous for erection
- Effect of oversize or slot taken into account directly in the member design
- Oversize or slotted hole can affect the pretension induced, regardless of the type of installation
- Washers or hardened bars required for many of these situations

Joints with bolts + welds



…existing bolted joint, add weld to increase capacity

Deformation v load characteristics differ…



Bolts + welds…

- Transverse welds are basically ineffective (they fracture early)
- AISC rules for bolts + longitudinal welds OK
- Upgrading existing structures: See AISC Engr. Jrn. Article (2003)

Recent work indicates…

$$R_{\text{ult}} = R_{\text{friction}} + R_{\text{bolts}} + R_{\text{long. weld}}$$

$$R_{\text{friction}} = 0.25 \times P_{\text{slip}}$$

$$R_{\text{long. weld}} = R_{\text{ult long. weld}}$$

$$R_{\text{bolt}} = 0.50 \times R_{\text{ult shear bolt}}$$

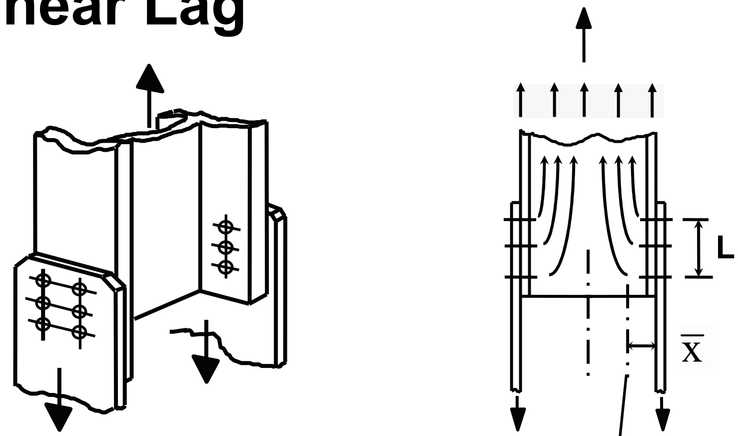
U of A work…

…and check the ultimate capacity of the individual components.

e.g., 100% of the bolts alone could be > 50% of bolt shear strength + weld strength, meaning it wasn’t useful to add the welds.

Shear lag…an illustration…

Shear Lag



centroid of area tributary
to gusset plate

Shear lag…

AISC rules largely based on physical tests

$$P_u = \left[1 - \frac{\overline{x}}{L}\right] A_n F_u$$

with some simplifications provided for the most common cases ("*U* – values")

AISC rules work pretty well

Shear lag…

So, for example,

W–shape, flange width not < 2/3 depth of section, bolts, only flanges connected, at least 3 lines of bolts…

$$A_{ne} = 0.90 A_n$$

and so on for other cases

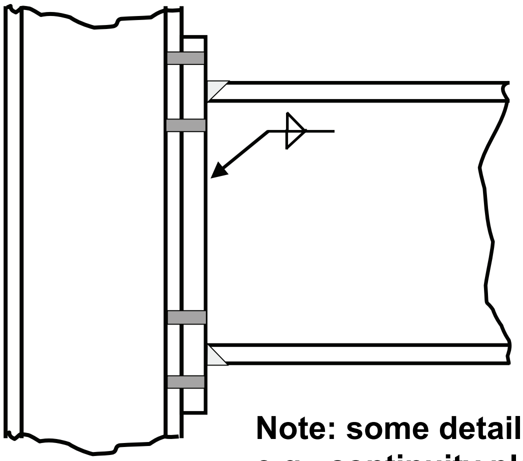
Connection design: seismic conditions

- Frames classified as (simplified list):
  - Ordinary moment frame (OMF)
  - Intermediate moment frame (IMF)
  - Special moment frame (SPM)
- Basis of design:
  - Rotation angle at beam to column junction OR
  - Drift per story (0.01, 0.02, and 0.04 radians respectively)

Seismic cont’d

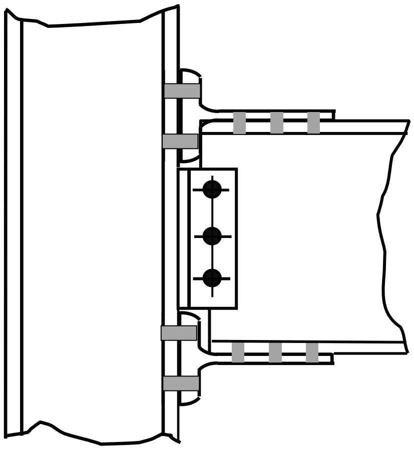
- Analyze structure in order to compute the forces
  - Use FEMA 350 and/or AISC Seismic Design Spec.
- With forces now known, design connectors
- Advisable to use pre-qualified configurations

Pre-qualified bolted connections



Note: some details not shown, e.g., continuity plates

…another pre-qualified seismic connection

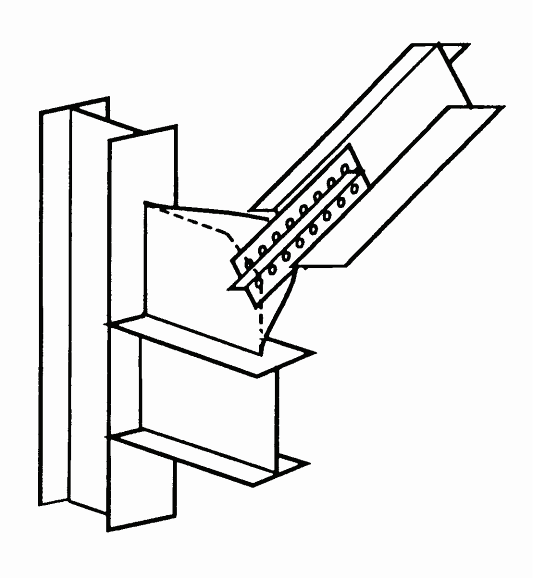


Note: some details not shown, e.g., continuity plates. Bolts in std. holes, sized for bearing, pretensioned.

…bolted joints, seismic design

- All bolts pretensioned
- Faying surfaces as per slip-critical
- Use bearing values for bolts
  - moderate quakes: No slip
  - major quakes: Slip will occur and bolts go into bearing
- Normal holes or short slotted only (perpendicular)
- No bolts + welds in same faying surface

Design example: gusset plate connection



Determine ultimate load for this gusset plate (which is one that was tested)

F_y = 39.9 ksi

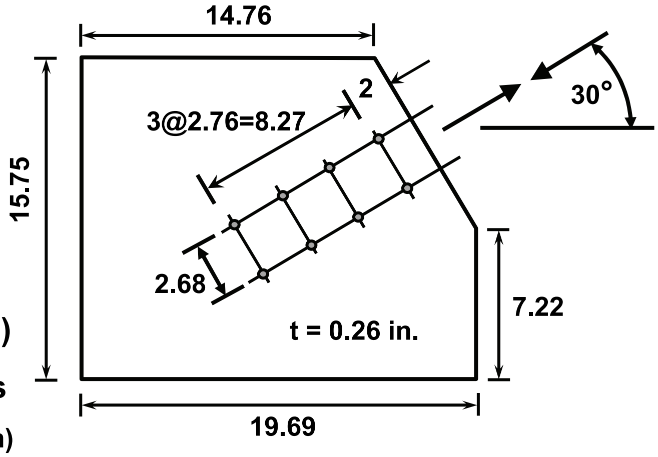
F_u = 69.0 ksi

7/8 A325 bolts

(holes 15/16 in.)

$P_{u\ test}$ =164 kips

(compression)



Set out the issues…

- Brace force in tension–
  - slip load of bolts (no slip at service load)
  - shear load of bolts
  - bearing capacity of plate
  - block shear

Continuing…

- **Brace force in compression**
  - **slip capacity of bolts (already checked for load in tension)**
  - **shear capacity of bolts (already checked for load in tension)**
  - **bearing capacity of plate (already checked)**
  - **block shear (doesn't apply)**
  - **capacity of gusset plate in compression (New)**

Slip load (calculate at factored load level)

$$R_n = \mu\, D_u\, h_{sc}\, T_m\, N_s \quad \text{(per bolt)}$$

$\mu = 0.35$ (clean mill scale) $h_{sc} = 1.0$ (std. holes)

$A_b = \pi\, d^2 / 4 = 0.60\text{ in.}^2$ (7/8 in.dia.)

$F_u = 120$ ksi (A325 bolts)

$n = 8$ bolts $N_s = 2$ slip planes $\phi = 1.0$

$$T_m = \text{spec. min. bolt pretension} = (0.75 \times A_b)(F_u)70\%$$

$$= 0.75 \times 0.60\text{ in.}^2 \times 120\text{ ksi} \times 70\% = 37.88\text{ kips}$$

Slip load calculation cont'd.

$$R_n = \mu D_u h_{sc} T_m N_s \text{ (per bolt)}$$

$$= 0.35 \times 1.13 \times 1.0 \times 37.88 \text{ kip} \times 2 \text{ slip planes}$$

$$= 29.96 \text{ kips / bolt}$$

or, for 8 bolts, 240 kips

Finally, $\phi R_n = 1.0 \times 240 \text{ kips} = 240 \text{ kips}$

Shear resistance of bolts

$$\phi R_n = \phi F_v A_b$$

Use ø =1.0 so that we can compare this load with the test load, assume threads in shear plane, no joint length effect

$$F_v = 80\% [0.62 \times 120 \text{ ksi}] = 60 \text{ ksi}$$

$$\phi R_n = 1.0 \times 60 \text{ ksi} \times 0.60 \text{ in.}^2 = 36.0 \text{ kips (per bolt)}$$

or, for 8 bolts, 2 shear planes, threads in shear plane

$$= (36.0 \times 8 \times 2) \text{kips} \times 0.80 = 461 \text{ kips}$$

Bearing resistance (use $\phi = 1.0$)

$$R_n = 1.5\ F_u\ L_c t \quad \leq 3.0\ d\ t\ F_u$$

$$3\ d\ t\ F_u =$$
$$3 \times 7/8\ \text{in.} \times 0.26\ \text{in.} \times 69.0\ \text{ksi} = 47.1\ \text{k/bolt}$$

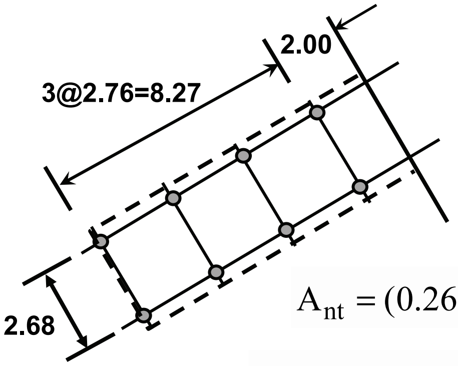
$$1.5\ L_c\ t\ F_u =$$
$$1.5 \times 1.53\ \text{in.} \times 0.26\ \text{in.} \times 69.0\ \text{ksi} = \boxed{41.2\ \text{k}}$$

Bearing resistance…

…the governing value is 41.2 kips/bolt and, for 8 bolts—

Bearing resistance is 330 kips

Block shear



$$A_{nt} = (0.26)(2.68 - 15/16) = 0.45 \text{ in.}^2$$

$$A_{gv} = (8.27 + 2.00)2 \times 0.26 = 5.34 \text{ in.}^2$$

$$T_r + V_r = \phi\, A_{nt}\, F_u + 0.60\, \phi\, A_{gv}\, F_y$$

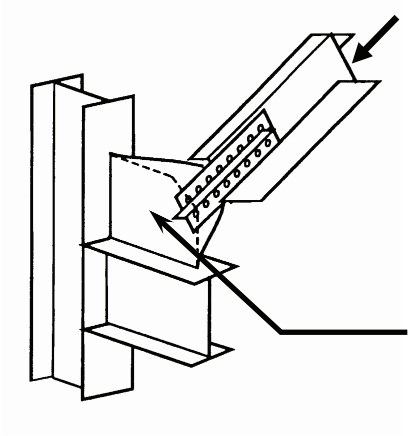
Block shear, cont'd

$$T_r = 0.45 \text{ in.}^2 \times 69.0 \text{ ksi} = 31.0 \text{ kips}$$

$$V_r = 0.60 \times 5.34 \text{ in.}^2 \times 39.9 \text{ ksi} = 127.8 \text{ kips}$$

and the total block shear resistance (unfactored) is 158.8 kips

Brace force in compression:



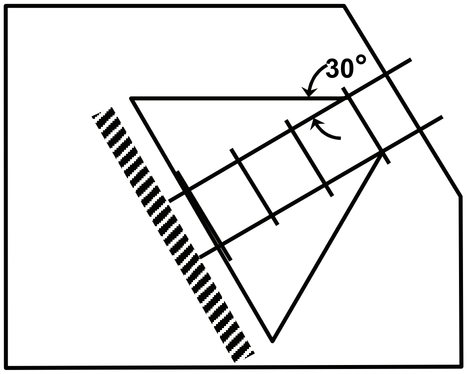
issue is sway buckling in this region

Checking the buckling…

- Whitmore method (checks yield)
- Thornton method (checks buckling)
- Modified Thornton method (checks buckling)

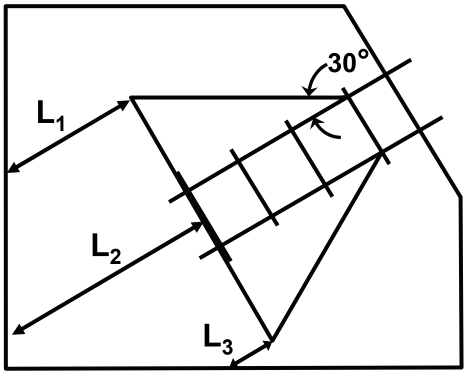
Whitmore method….

- Use beam formulae to check perceived critical sections
- Use 30^o , as shown to check yielding at location shown.
- Does not predict ultimate capacity very well, usually conservative but sometimes non-conservative



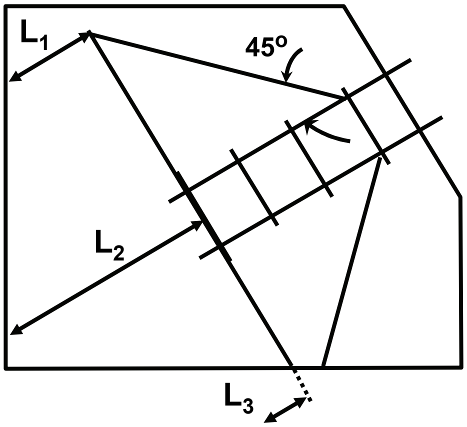
Thornton method…

- Use longest (or average) of L_1, L_2, L_3 to compute a buckling load on a unit width column, then apply this to the total width.
- Use k = 0.65 in the column formulae



Thornton method, modified

As per Thornton method but spread load out at 45°

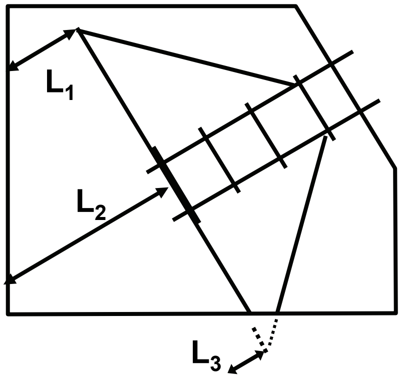


Yam & Cheng gusset plate tests (U of A, 13 tests)

	$\frac{P_u}{P_W}$	$\frac{P_u}{P_T}$	$\frac{P_u}{P_{T'}}$
mean	1.33	1.67	1.06
std. dev.	0.26	0.12	0.08

we'll use this method ↑

Calculations for buckling capacity:



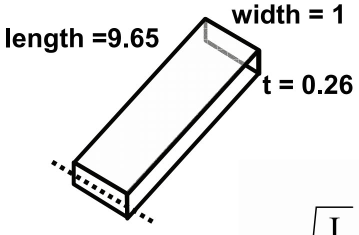
Using scale dwg.
L_2 = 9.65 in.

Width of the 45^o base is 19.2 in.

$$\phi_c\ P_n = \phi_c\ A_g\ F_{cr} \quad (\text{use}\ \phi_c = 1.0)$$

$$F_{cr} = (0.658^{\ F_y / F_e})\ F_y \qquad \text{use}\ k = 0.65$$

Consider a 1 in. wide strip that is 9.65 in. long



$$r = \sqrt{\frac{I}{A}} = \sqrt{\frac{\frac{1}{12}\times 1\times 0.26^3}{0.26\times 1}} = 0.0751\ \text{in.}$$

and then completing the calculations,
P_n = 6.91 kips (on a 1 in. wide strip)

And applying this to the total width…

P_u = (6.91 k/in.) (19.2 in.) = 132 kips

and the test ultimate load on this particular specimen was 164 kips

so, $P_u / P_{T'}$ = 1.23

(The corresponding ratios for Whitmore and Thornton for this specimen were 1.31 and 1.80)

Summary of our calculations

Brace Force	slip load	bolt shear	plate bearing	block shear	buckling	test load
Tension	226	461	330	159	—	—
Compress.	—	—	—	—	132	164

It all started with rivets….

There's always a solution in steel.

American Institute of Steel Construction, Inc.
One East Wacker Drive, Suite 700
Chicago, IL 60601-1802

312.670.2400 www.aisc.org