CONNECTIONS USED IN STEEL STRUCTURES

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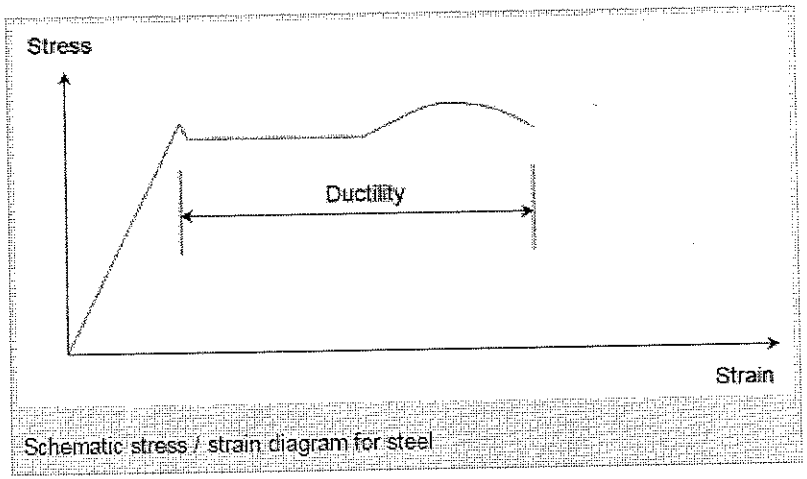
Mechanical properties of steel

Modulus of elasticity,	$E = 210{,}000\ N/mm^2$
Shear modulus,	$G = E/[2(1 + \nu)]\ N/mm^2$, often taken as $81{,}000\ N/mm^2$
Poisson's ratio,	$\nu = 0.3$
Coefficient of thermal expansion,	$\alpha = 12 \times 10^{-6}/°C$ (in the ambient temperature range).

Material properties required for design
The properties that need to be considered by designers when specifying steel construction products are:

1. Strength
2. Toughness
3. Ductility
4. Weldability
5. Durability



Schematic stress / strain diagram for steel

http://www.steelconstruction.info/Steel_material_properties

Steel design methods

1. Allowable Stres Design – ASD (**Emniyet Gerilmeleri Yöntemi)**
2. Plastic Design **(Plastik Tasarım)**
3. Load and Resistance Factor Design - LRFD (**Yük ve Mukavemet Faktörü İlkesi**)

Loads in steel structures

1. Main loads : self weight, live loads, snow load, crane self load,
2. Superimposed (secondary loads) wind load, earthquake load, crane brake loads

Loads combinations according to ASD in steel structures

1. LC1 : main loads (EY in Turkish design code)
2. LC2 : main loads+ superimposed loads (EIY in Turkish design code)

Çelik Cinsi	Akma Sınırı σ_F (kN/cm²)	Emniyet Gerilmesi σ_{em}		Kayma Emniyet Gerilmesi τ_{em}	
		EY (H)	EİY (HZ)	EY (H)	EİY (HZ)
St 37	24	14	16	9	10,5
St 52	36	21	24	13,5	15,5

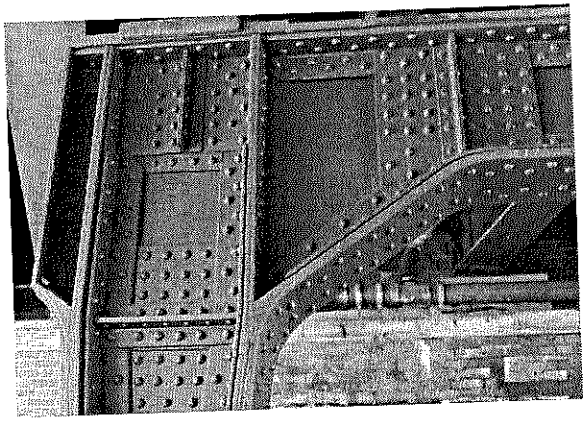
Fasteners and Welds for Structural Connections

There are three common ways to connect structural steel members

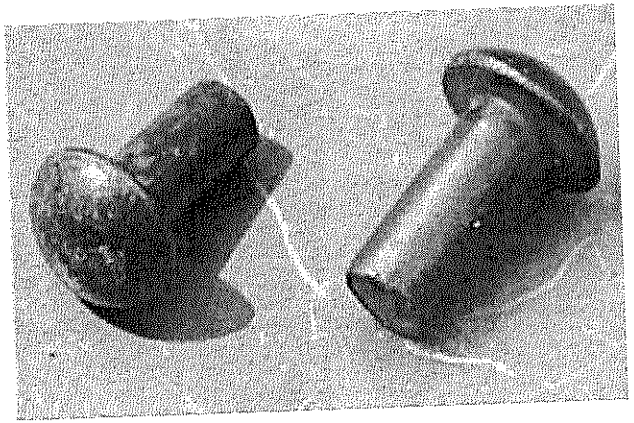
1. Rivet (not currently used for new structures) Aircrafts, Ships, Machines
2. Bolt (easy to disassamble)
3. Weld (fixed)
4. Pins

- Rivets are permanent mechanical fasteners.
- Rivets are no longer a practical method of forming structural connections.
- Rivets used to be a very common method of forming steelwork connections, but they are almost never used now.
- Before fitting, rivets are rather like unthreaded bolts. They are installed hot in pre-drilled holes, and then the portion of shank protruding from the hole is hammered down to form a second 'head' to the rivet.

(http://www.tatasteelconstruction.com/en/reference/teaching-resources/architectural-teaching-resource/elements/connections/bolting-and-riveting)

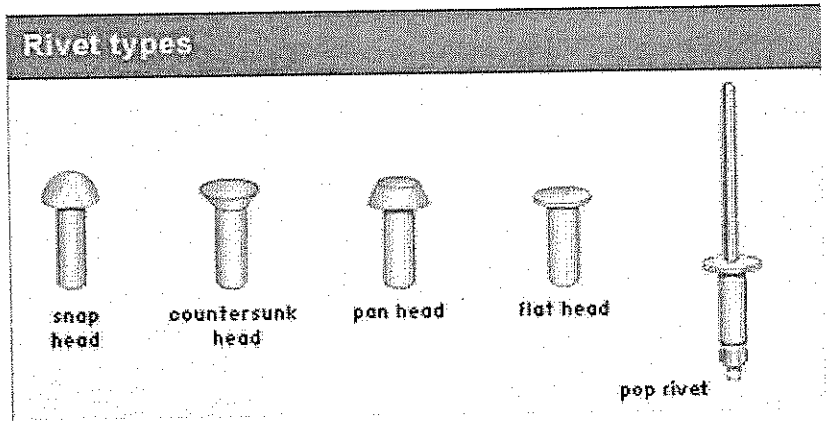


https://en.wikipedia.org/wiki/Rivet

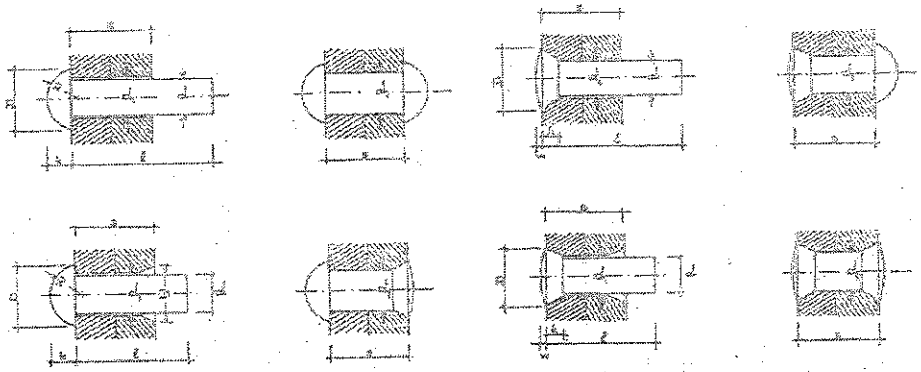


https://en.wikipedia.org/wiki/Rivet

http://www.instartupland.com/?photos_keywords=rivets



http://www.bbc.co.uk/schools/gcsebitesize/design/resistantmaterials/jointsrev4.shtml



http://web.itu.edu.tr/~ustundai/course/celiksunum.pdf

- Rivet heated before driving are called hot-driven rivets.
- As it cools, shrinks in length.
- Shrinking in length is largely prevented by the plates, thus producing tension in the shank of the rivet and compression between plates which sets up frictional resistance to sliding.
- To make the use of rivet easy in practice, the diameters of the rivets are standardized in the market.

Disadvantages of rivets

1. Ordinary bolts are economical for small static loads and for secondary elements (purlins, girts, bracing, etc.).
2. Bolting of steel structures is very rapid field erection process and requires less skilled labour than riveting and welding.
3. For bolted connections it is possible to alter or disassemble the structures and changes in connections are quite simple.
4. High-strength bolts and welds are used for fatigue loading.
5. Bolting is satisfactory for fieldwork.
6. To use welds for very thick members requires extra care, and bolted connections may be used instead.

http://www.insaat.anadolu.edu.tr/kivanct/%C4%B0N%C5%9E%20324/icerik/INS324%20II-Bolted%20Con.%20(ASD)_ENGLISH.pdf

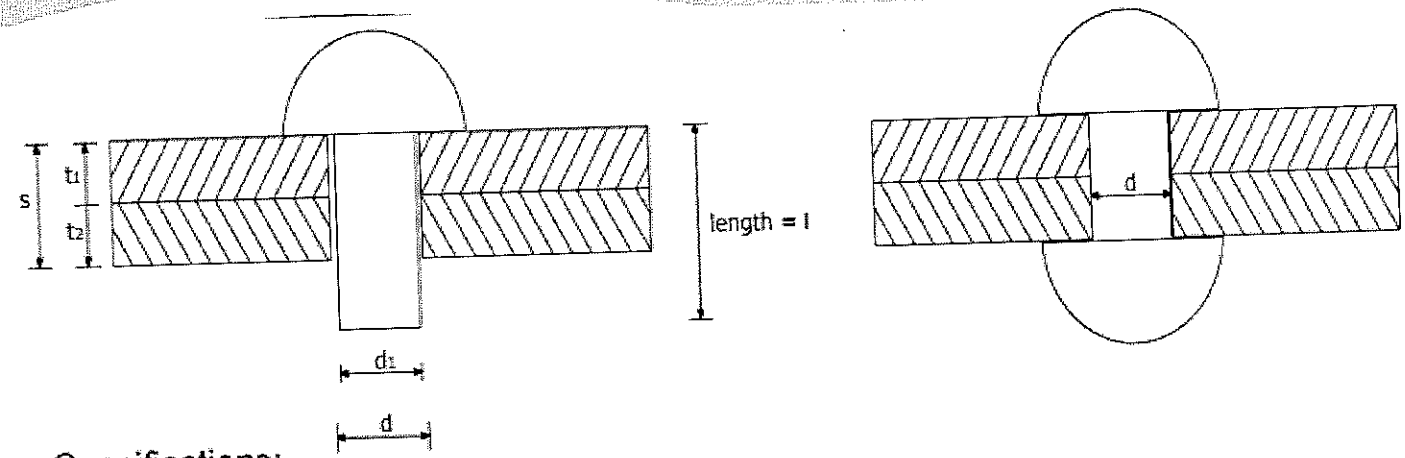
Hot riveting

https://www.youtube.com/watch?v=P30hhK15SCs

https://www.youtube.com/watch?v=I9Q5OHYDbvo

Removal of a rivet

https://www.youtube.com/watch?v=qD9eWgcAtLg



Specifications:

$d_1 = d\text{-}1^{mm}$

$l = s + (4/3)d$ for filling the hole

The diameter of the rivet and hole should be selected considering the minimum thickness of the plate

$d \leq (5t_{min})^{1/2}\text{-}0.1^{cm}$ hole diameter

$d_1 \leq (5t_{min})^{1/2}\text{-}0.2^{cm}$ rivet diameter

t_{min} (cm)

d (cm)

d_1 (cm)

t_{min} (cm) = t_1, t_2 } min

s< 6.5d (Countersunk rivets) Gömme başlı

s< 4.5d (Round head) Yuvarlak başlı

Table shows the suitable rivet diameters with respect to the thickness of the members, which are connected to each other.

t (mm)	4~5	4~7	5~10	6~13	8~17	11~20	14~24
d_1 (mm)	11	13	17	21	23	25	28

- In the steel design project, rivets are denoted as Φ.
- Recommended rivet diameters for various plate thickness are Φ13, Φ17, Φ21, and Φ25.

The following table demonstrates the allowable stresses for the rivet;

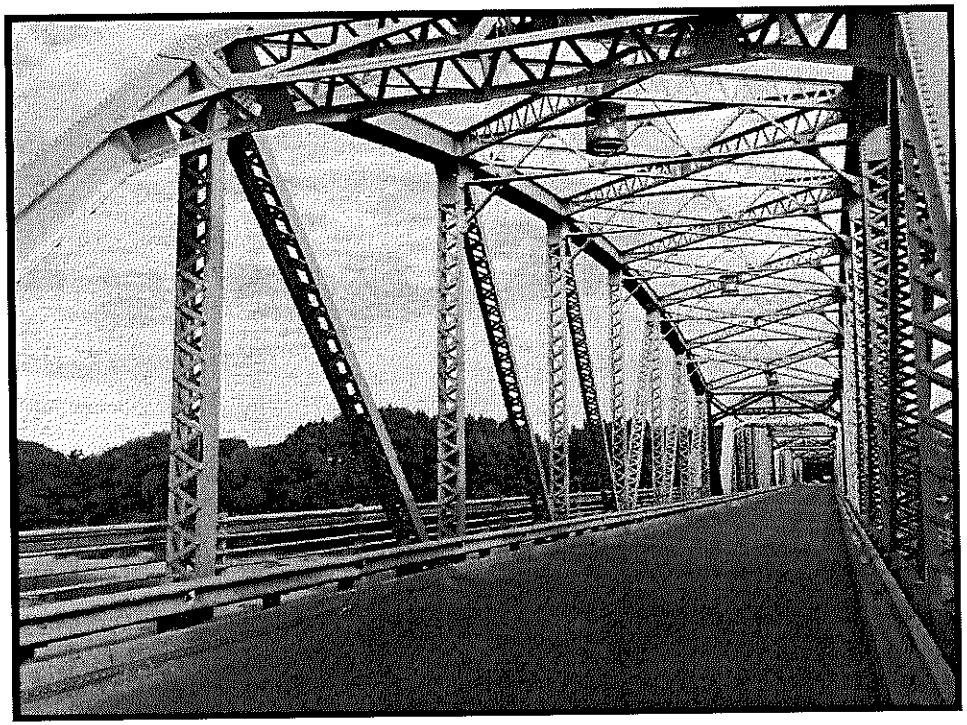
Allowable stresses for the rivet

Main Material	τ_{all}		$\sigma_{b,all}$ (t/cm^2)		$\sigma_{z,all}$ (t/cm^2)	
	LC1	LC2	LC1	LC2	LC1	LC2
St 37	1.40	1.60	2.80	3.20	0.48	0.54
St 52	2.10	2.40	4.20	4.80	0.72	0.81

- Steels used for rivets have to be very ductile.

- Although the tensile strength of rivet steel are less than those of the main materal, heating and driving together with air cooling increase the strength of the rivets.

- For St37 steel, St34 rivets are used.
- For St52 steel, St44 rivets are used.



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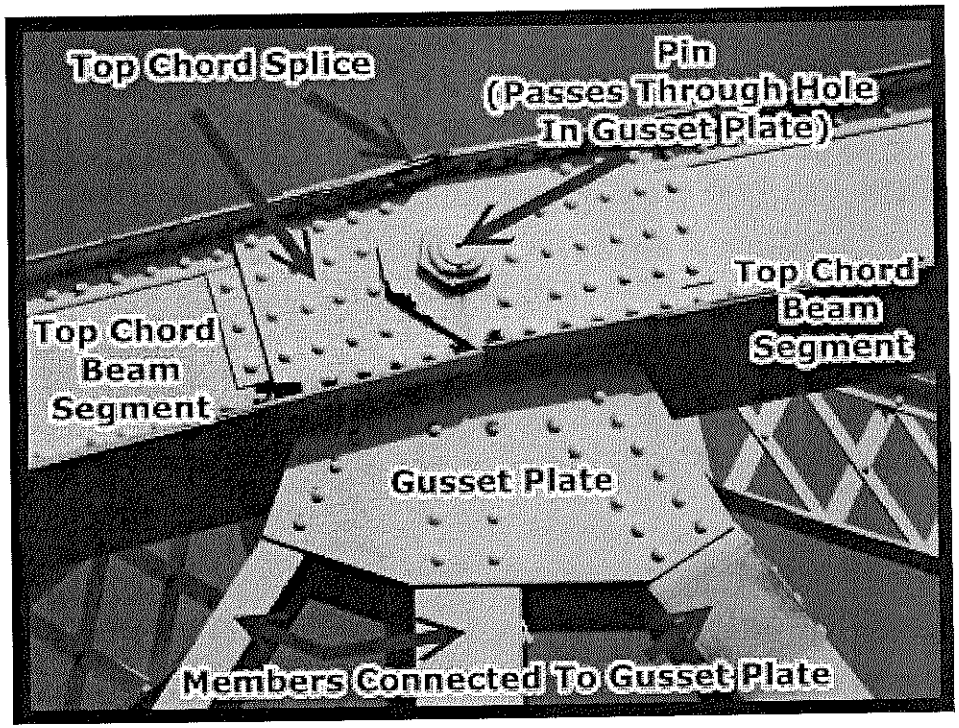
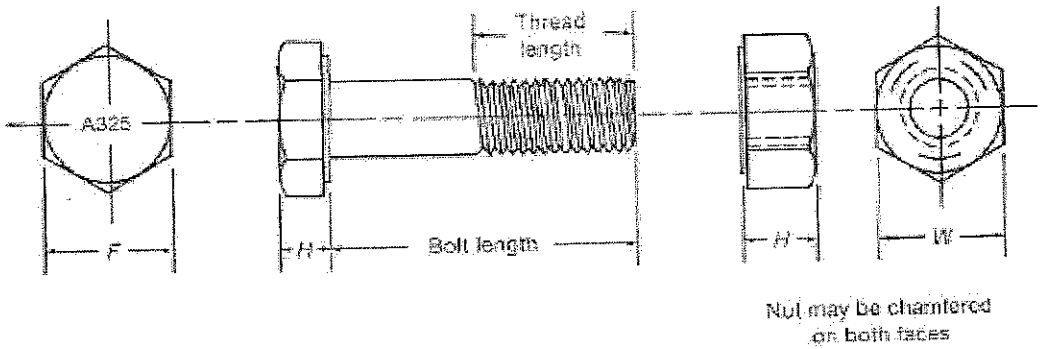


http://historicbridges.org/bridges/browser/?bridgebrowser=pennsylvania/nanticoke/

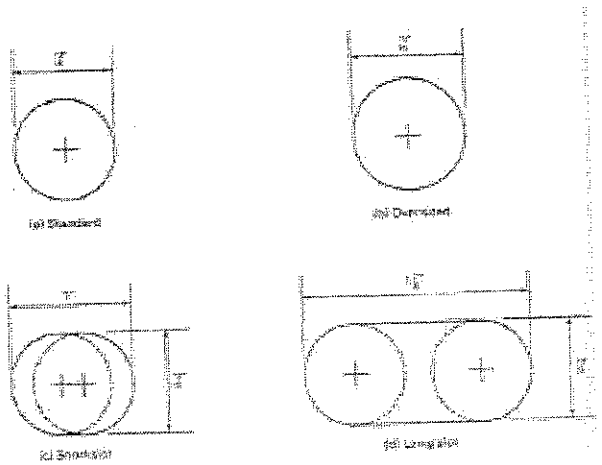
Bolts

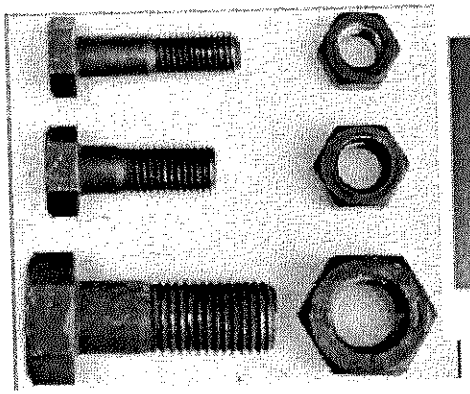
Bolts are pieces of round steel bars with generally hexagonal head at one end, and a threaded portion at the other.

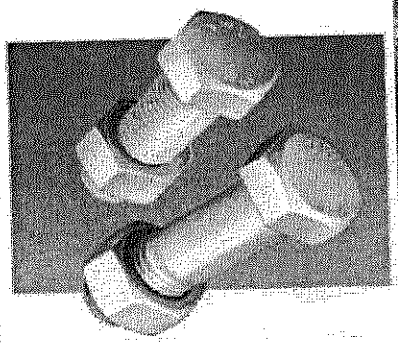


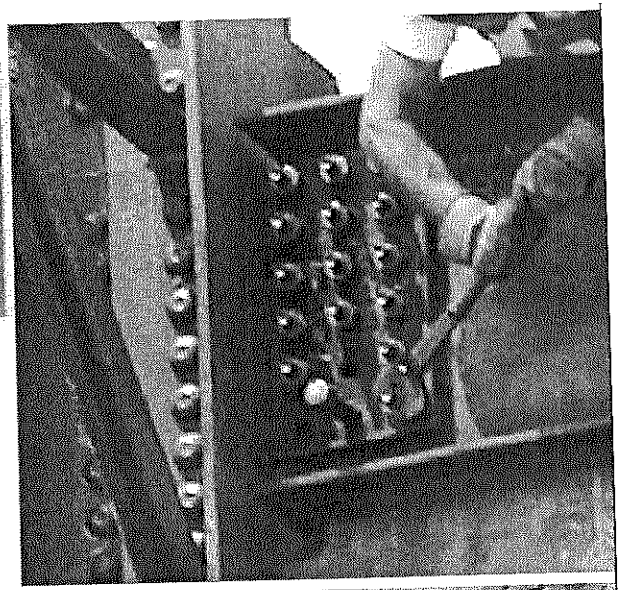
Nuts are for securing bolts in place and keeping threaded parts outside the grip

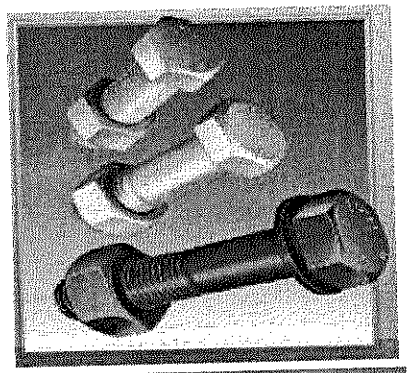
Washers are used between the nut and the plate

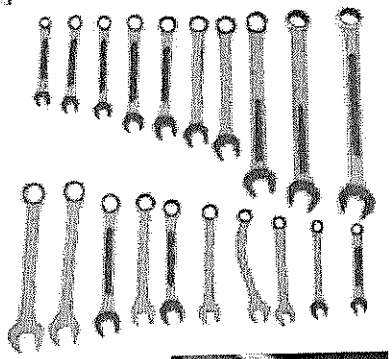


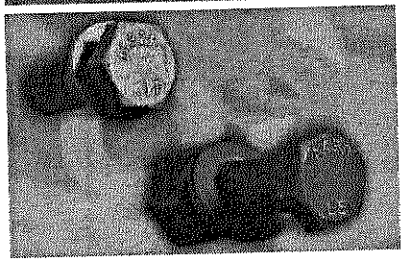


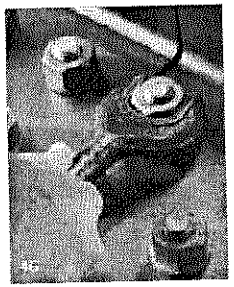


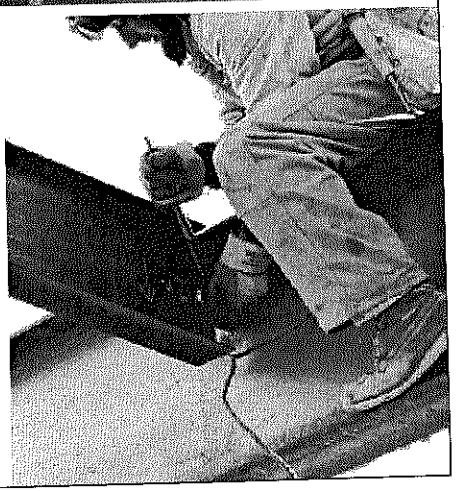


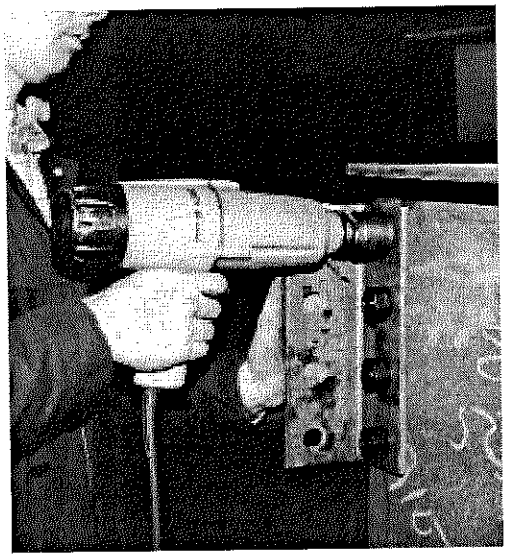


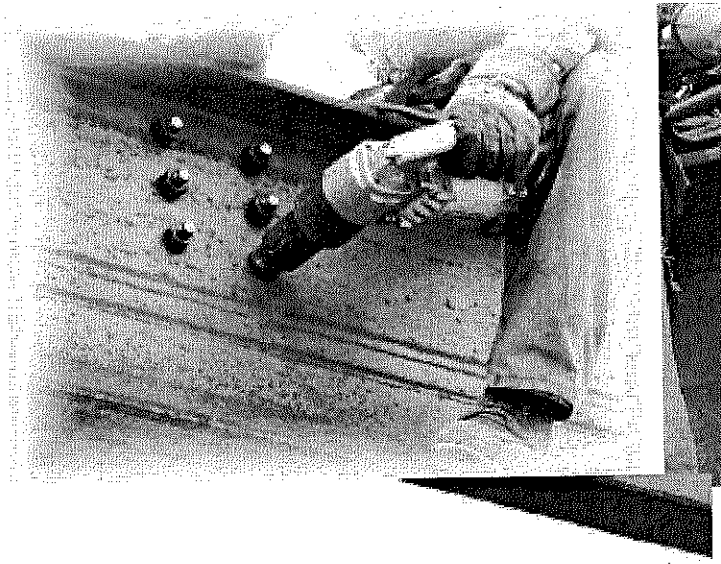


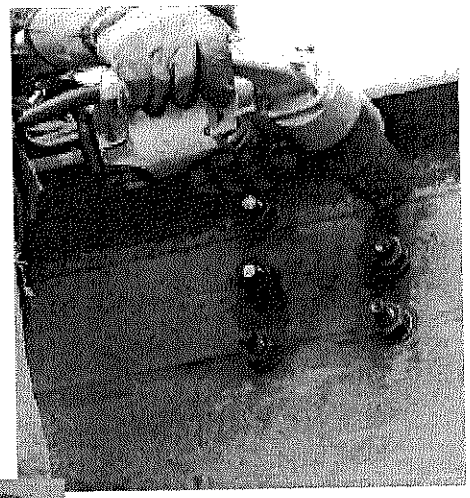


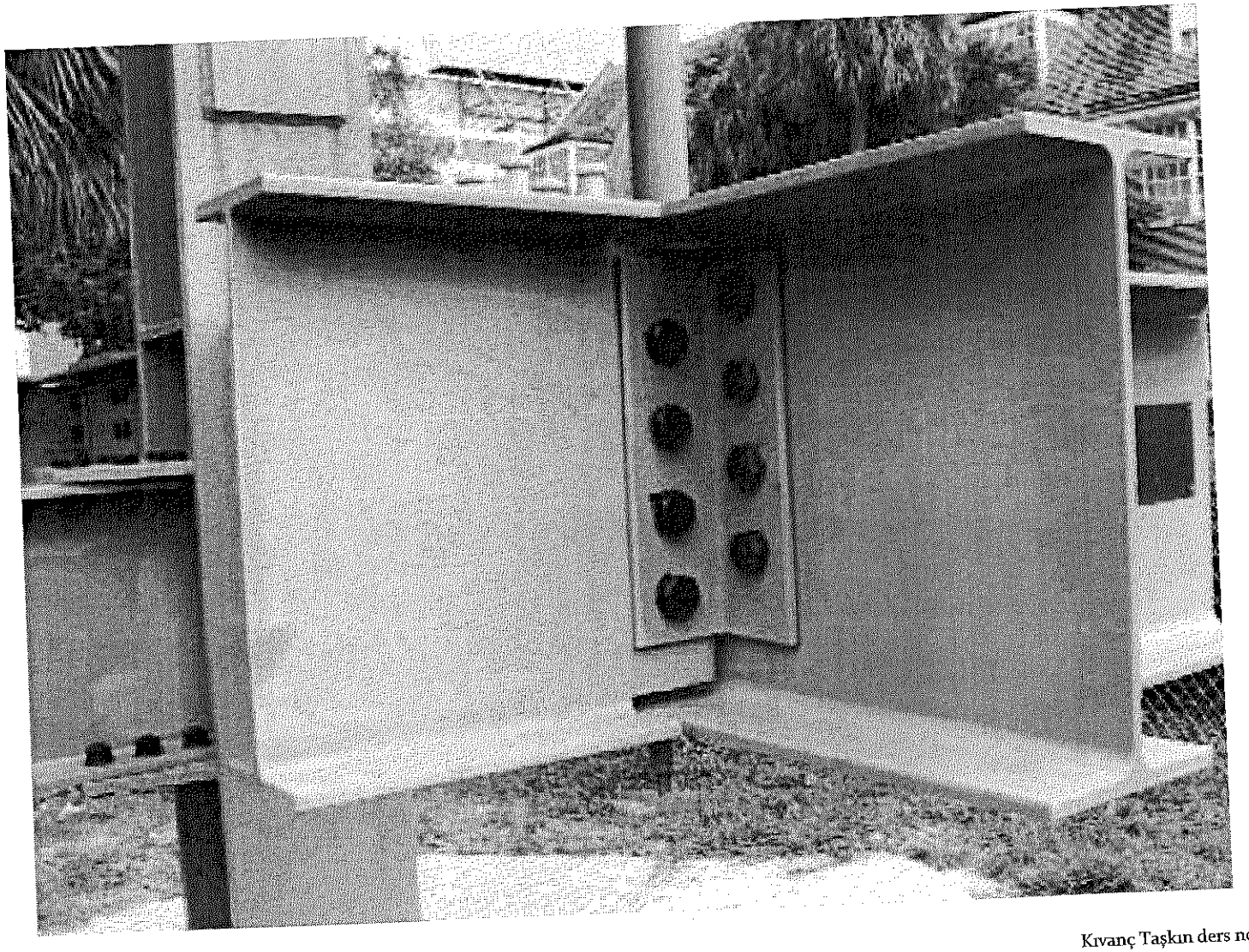


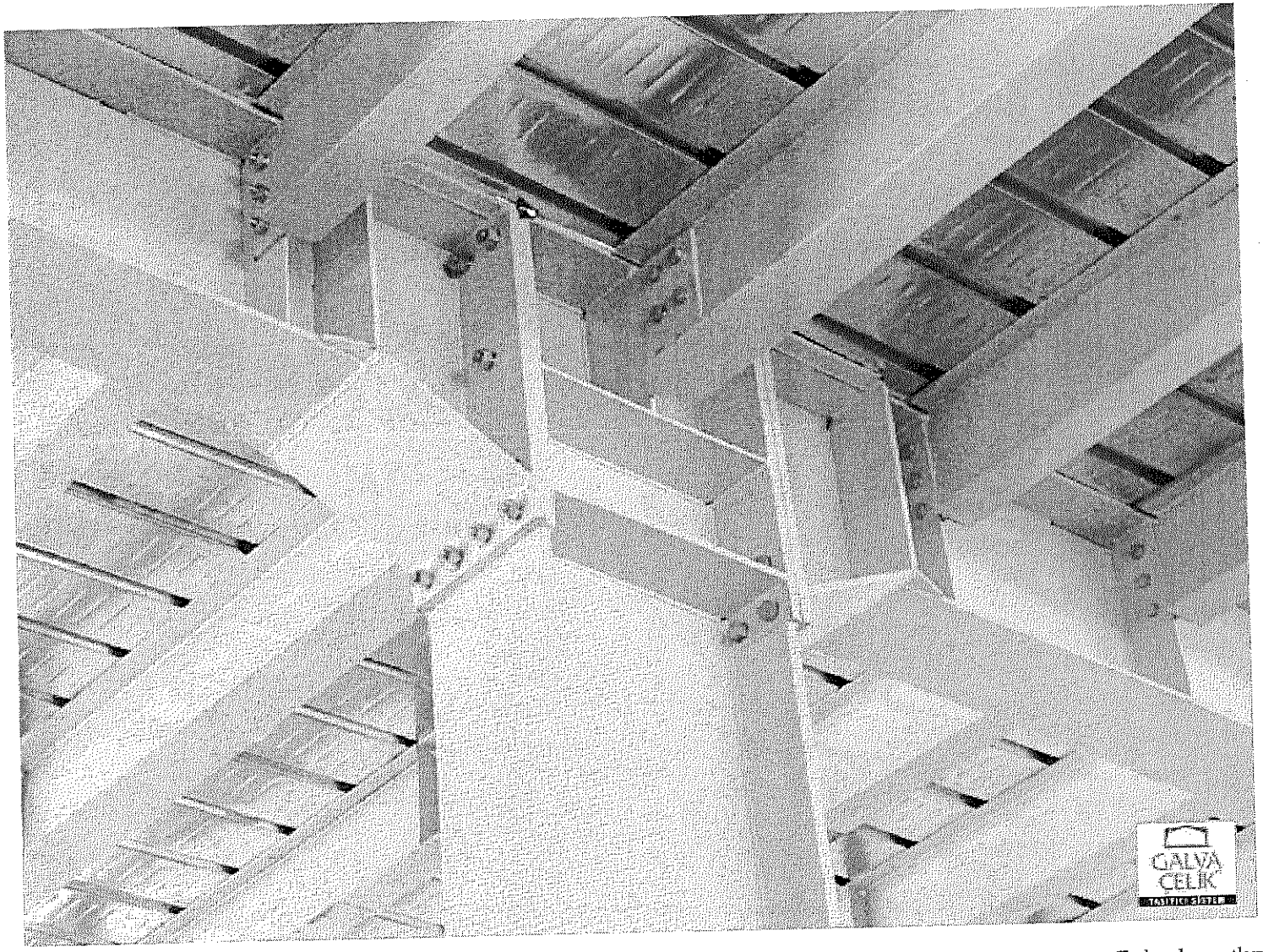








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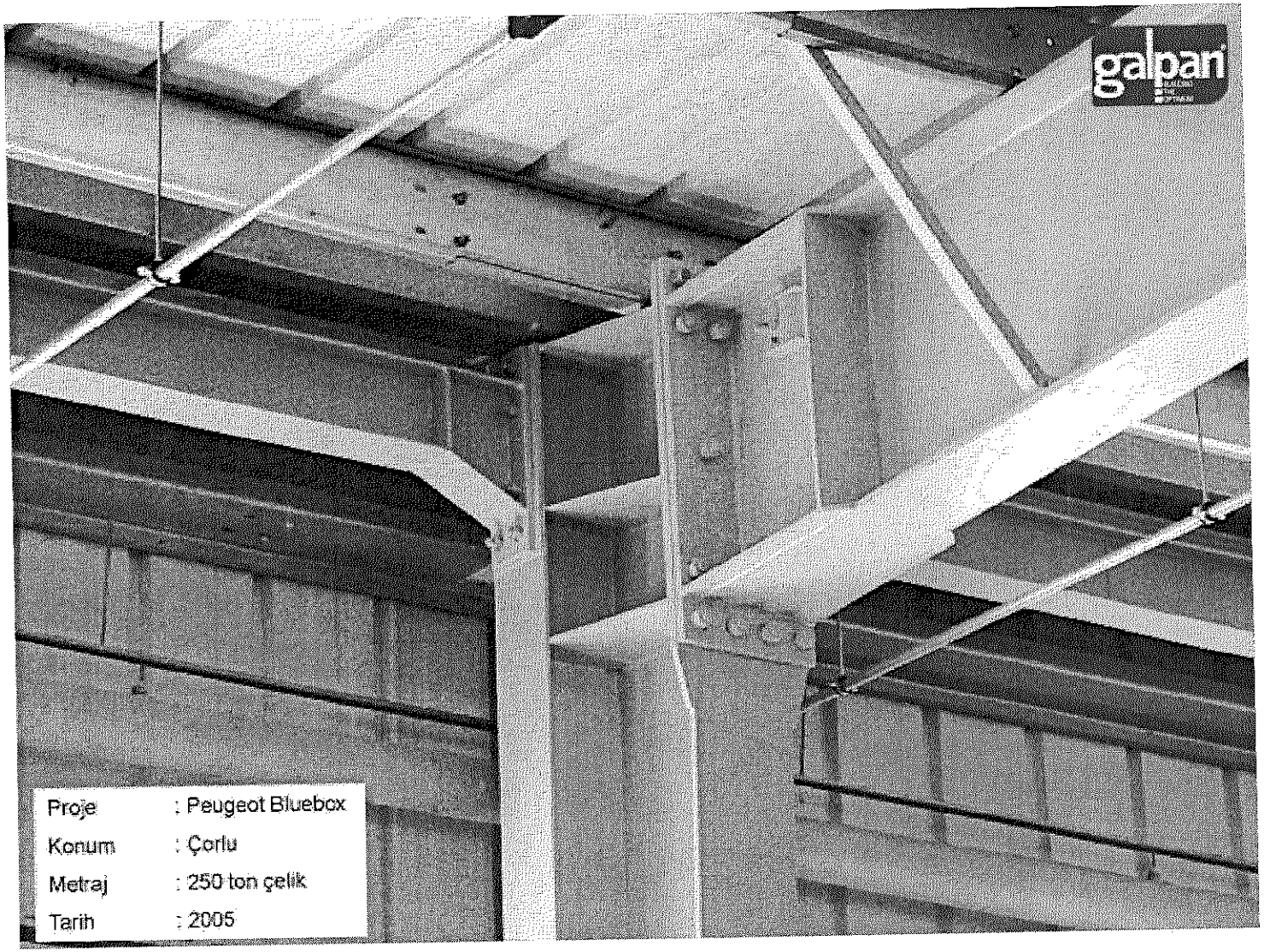
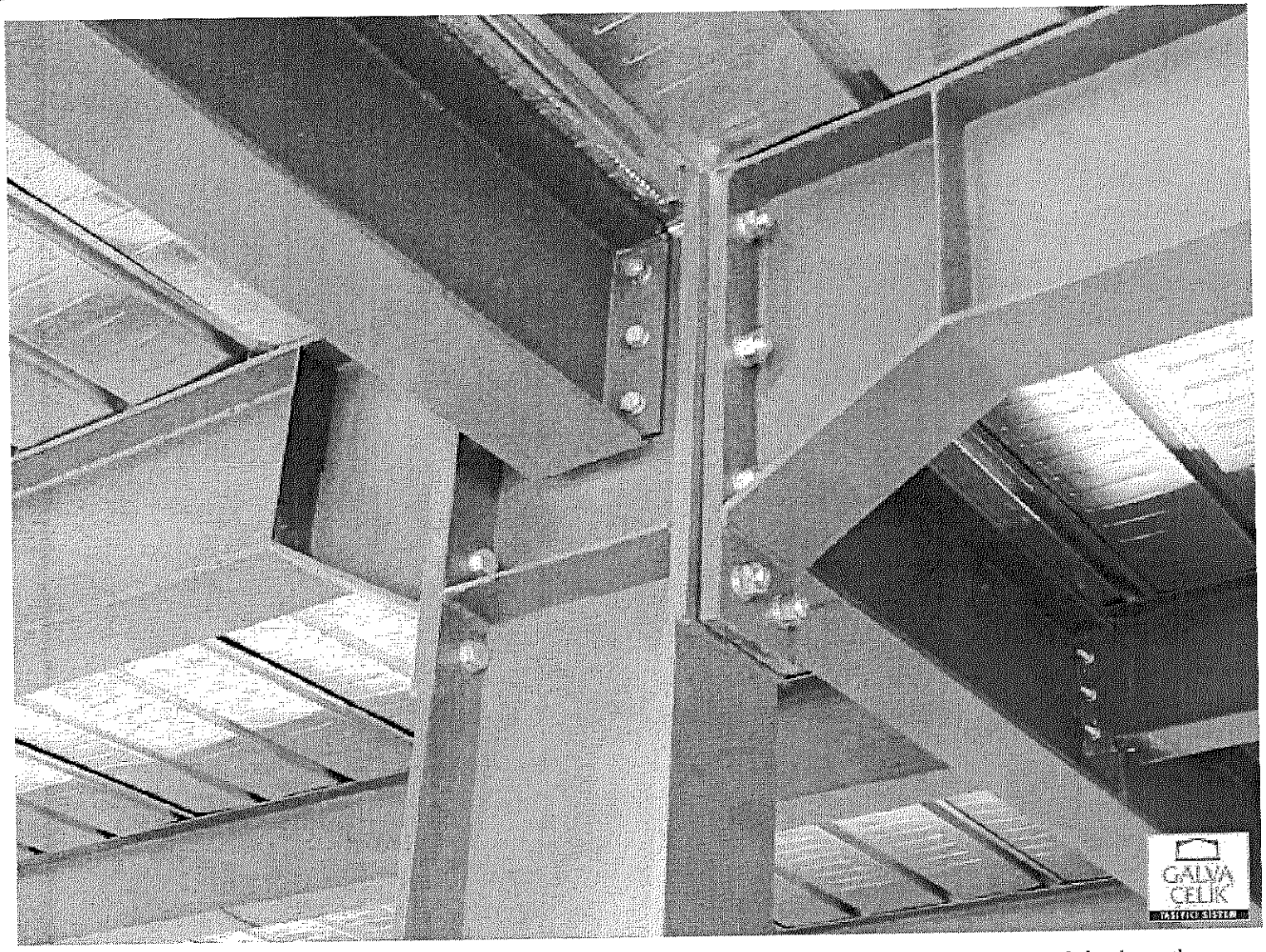


Kıvanç Taşkın ders notları



Kıvanç Taşkın ders notları

Types of bolts:

1. Common (ordinary) Bolts; widely used in steel structures (4.6, 5.6, 6.8)

   a) Unfinished (rough)
   b) Finished (precision)

Easy to turn and need less turning space. Used in structures subjected to static loads and for secondary members. (Machine bolts and unfinished bolts.)

2. High strength Bolts (HV) (8.8, 10.9, 12.9)

   a) SL ($d_1-d \leq 1$) hareketsiz yük , SLP bolts ($d_1-d \leq 0,3$) hareketli yük (transmits shear and bearing)

   b) GV ($d1-d \leq 1$) (transmits only friction force) and GVP bolts ($d_1-d \leq 0,3$) (transmits shear, bearing, friction) (with bolt pre-tension) (Friction) Pv : pretension force (Slip critical connection)

Tensile strength is two or more times greater than ordinary bolts. Used for all types of structures. (Pre-tension and high strength bolts.)

- **Slip-critical joint**, from structural engineering, is a type of bolted structural steel connection which relies on friction between the two connected elements rather than bolt shear or bolt bearing to join two structural elements.

Shear (and tension) loads can be transferred between two structural elements by either a bearing-type connection or a slip-critical connection.

In a slip-critical connection, loads are transferred from one element to another through friction forces developed between the faying surfaces of the connection. These friction forces are generated by the extreme tightness of the structural bolts holding the connection together. These bolts, usually tension control bolts or compressible washer tension indicating type bolts, are tensioned to a minimum required amount to generate large enough friction forces between the faying surfaces such that the shear (or tension) load is transferred by the structural members and not by the bolts(in shear) and the connection plates(in bearing). The "turn of the nut" method is also widely used to achieve that state of friction.

If slip-critical connections fail (by slipping), they revert to bearing-type connections, with structural forces now transferred through bolt shear and connection plate bearing. Thus a slippage failure of a slip-critical connection is not necessarily a catastrophic failure. However, slippage of a slip-critical connection in a columns may lead to column instability. Slippage of a slip critical joint in a roof truss could result in unintended ponding effects.

The faying surfaces of slip-critical connections must be properly prepared in order to maximize friction forces between the surfaces joined. Usually this requires cleaning, descaling, roughening, and/or blasting of the faying surfaces. Painting the faying surfaces with a class B primer also allows to be in accordance with most of the design that ask for *Slip-critical joint*.

https://en.wikipedia.org/wiki/Slip-critical_joint

- Common bolts : 4.6; 5.6; 6.8
- High strength bolts : 8.8; 10.9

Bolts M12, M16, M20, M24, M30, M36

Standard hole diameters: d: Bolt diameter h: Hole diameter

M12~M14	: d=(12~14) mm	h=d+1	mm
M16~M24	: d=(16~24) mm	h=d+2	mm
M and >27	: d=27 mm	h=d+3	mm

Kıvanç Taşkın ders notları

Tensile properties of bolts in steel construction

	Grade/Classification	Properties		
		Yield Stress f_y MPa (min)	Ultimate Tensile Stress f_{ub} MPa (min)	Elongation Percentage (min)
Specification IS 1367 (part 3) (ISO 898) Specifications of fasteners threaded steel for technical supply conditions	3.6	180	330	25
	4.6	240	400	22
	4.8	320	420	14
	5.6	300	500	20
	5.8	400	520	10
	6.8	480	600	8
	8.8: (d < 16 mm)	640	800	12
	(d > 16 mm)	660	830	12
	9.8	720	900	10
	10.9	940	1040	9
	12.9	1100	1220	8

https://en.wikipedia.org/wiki/Slip-critical_joint

BULON		M12	M16	M20	M24	M27	M30	M36
Delik çapı (D) (mm)		13	17	21	25	28	31	37
Delik çapı (d) (mm)	Kaba bulonda	12	16	20	24	27	30	36
	Uygun bulonda	12	17	21	25	28	31	37

Birleşim araçlarında emniyet gerilmeleri (kg/cm²)

Birleşim aracı türü		Ana malzeme St 37						Ana malzeme St 52					
		σ_{basm}		τ_{kes}		$\sigma_{çek}$		σ_{basm}		τ_{kes}		$\sigma_{çek}$	
		H	HZ	H	HZ	H	HZ	H	HZ	H	HZ	H	HZ
Perçin		1400	1600	2800	3200	980	840	2100	2400	4200	4800	1260	840
Bulon	Kuba	1120	1280	2240	2560	1120	1120	—	—	—	—	—	—
	Uygun	1400	1600	2800	3200	1120	1120	2100	2400	4200	4800	1500	1500
	Ankraj	—	—	—	—	1120	1120	—	—	—	—	1500	1500

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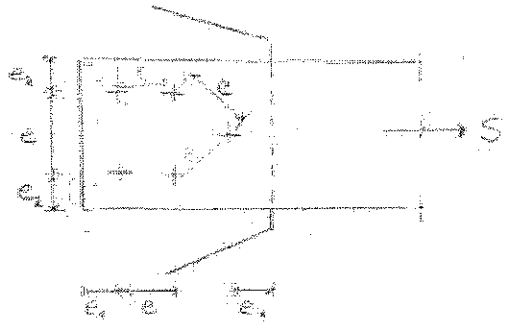
Birleşim araç aralıkları ve kenara uzaklıklar



e : Birleşim araçları arasındaki uzaklık

e_1 : Kuvvet doğrultusuna dik kenara olan uzaklık

e_2 : Kuvvet doğrultusuna paralel kenara olan uzaklık

Uzaklık		Binalar için		Köprüler için	
		min.	max.	min.	max.
e	Perçinde	3d	8d, 15t	3d	6d, 12t
	Bulonda	3,5d	8d, 15t	3,5d	6d, 12t
e_1		2d	3d, 6t	2d	3d, 6t
e_2		1,5d	3d, 6t	1,5d	3d, 6t

d = Birleşim aracı çapı
t = Birleşimdeki en ince kalınlık

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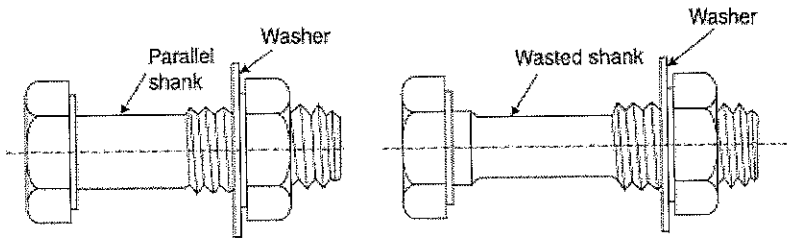
When should bolted connections be specified as slip-critical?

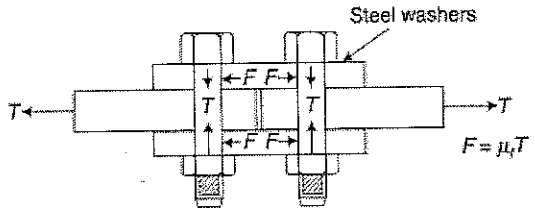
In some cases, slip resistance is required. The AISC and RCSC Specifications list cases where connections must be designated by the Structural Engineer of Record as slip-critical:

- Connections with oversized holes
- Connections with slotted holes when the direction of the slot is not perpendicular to the direction of the load, unless slip is the intended function of the joint.
- Connections subject to fatigue or significant load reversal.
- Connections in which welds and bolts share in transmitting shear loads at a common faying surface

https://www.aisc.org/DynamicTaxonomyFAQs.aspx?id=1766

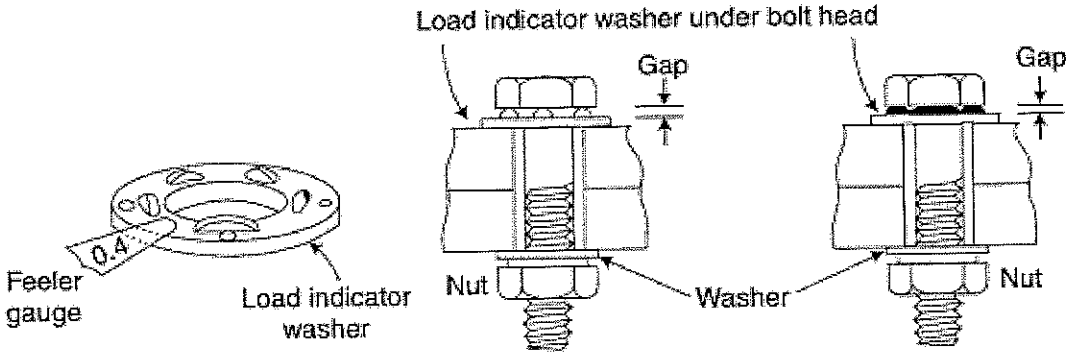


(a) Types of high-strength bolts



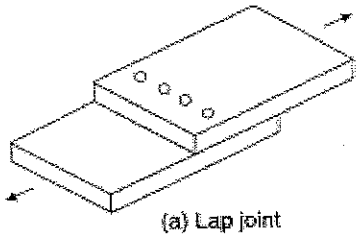
(b) Slip resistance

High-strength bolted connection

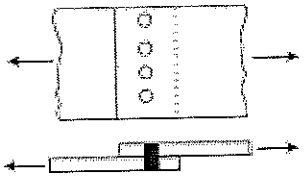


(a) Load indicator washer (b) Before tightening (b) After tightening

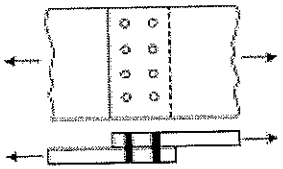
Bolt installation with load indicating washers



(a) Lap joint

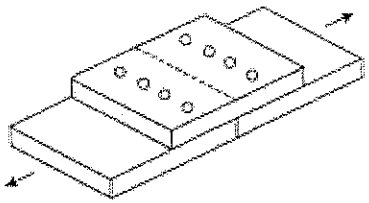


(b) Single bolted lap joint

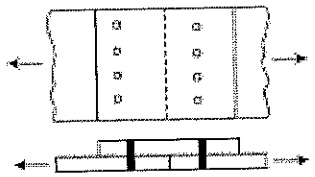


(c) Double bolted lap joint

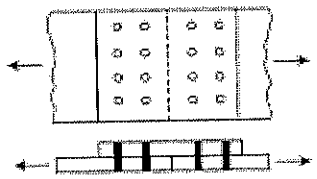
(d) Eccentricity in lap joint



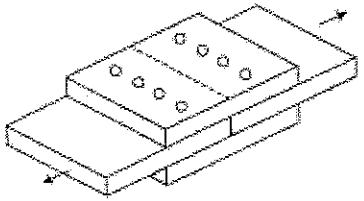
(e) Single-cover butt joint



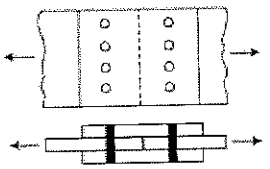
(f) Single-cover single bolted butt joint



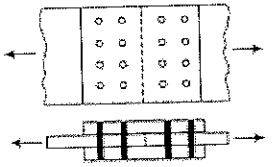
(g) Single-cover double bolted butt joint



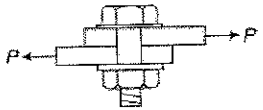
(h) Double-cover single bolted butt joint

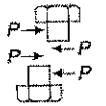


(i) Double-cover single bolted butt joint

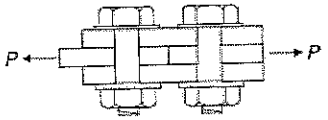


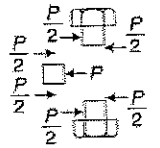
(j) Double-cover double bolted butt joint





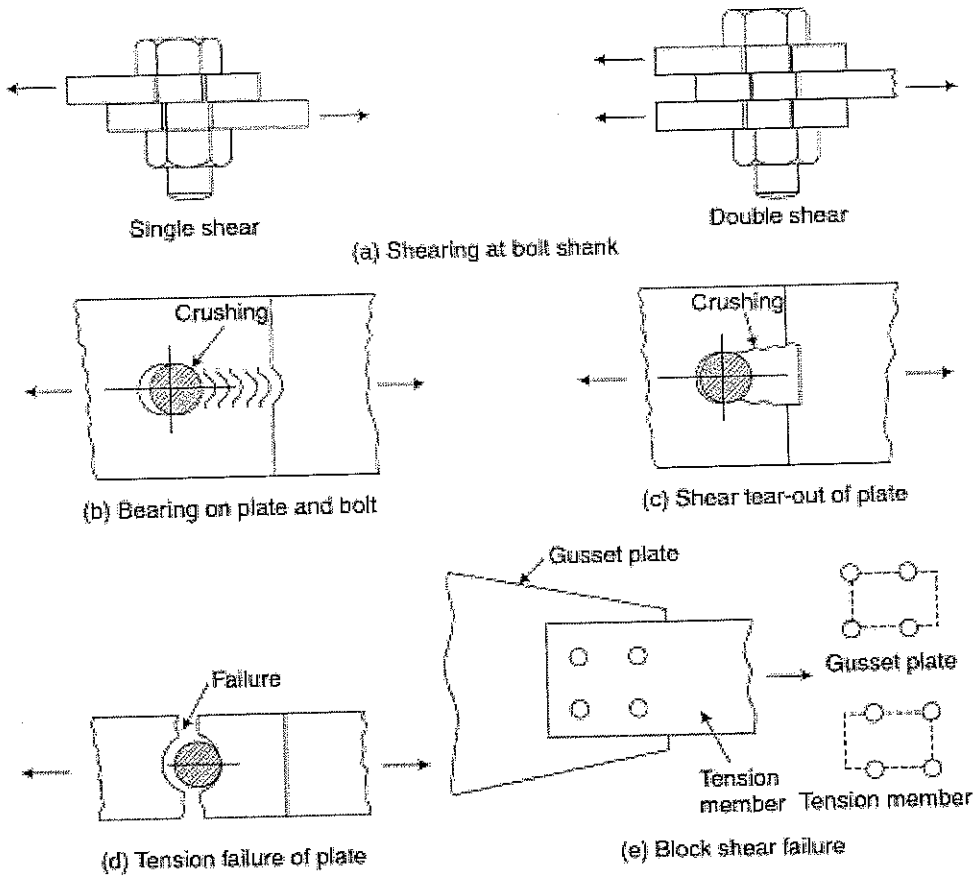
(k) Lap joint, bolt in single shear





(l) Butt joint, bolt in double shear

Types of bolted joints



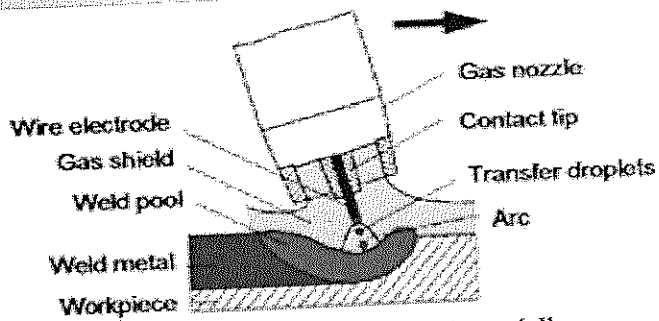
Failure modes of bolted joints

A short film demonstrating the types of steel connection that could be used within a structure

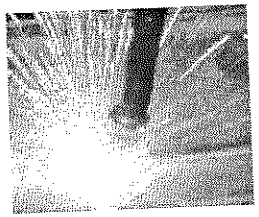
https://www.youtube.com/watch?v=zX8HNbHmToM

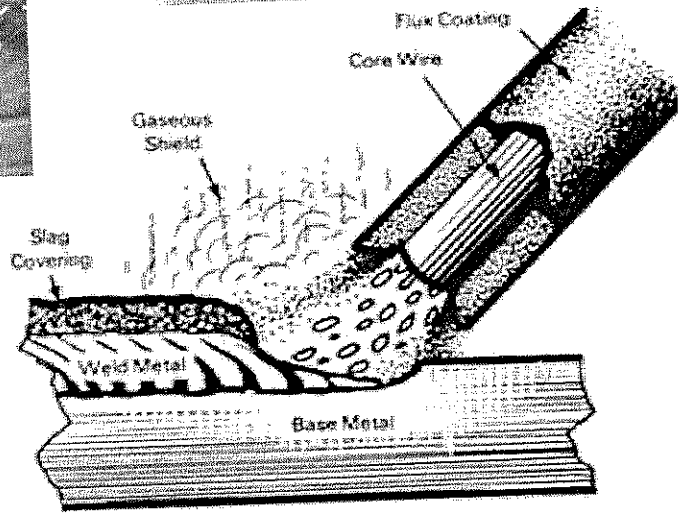
https://www.aisc.org/DynamicTaxonomyFAQs.aspx?id=1766

Welds

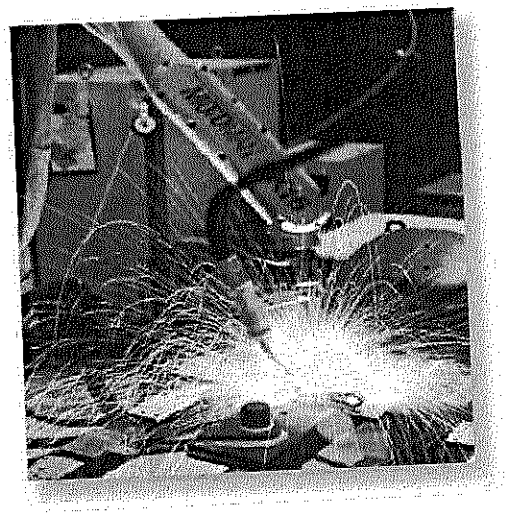


MIG (Metal Inert Gas) welding

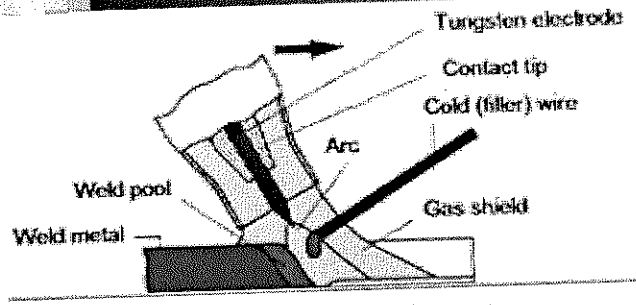




Flux core welding

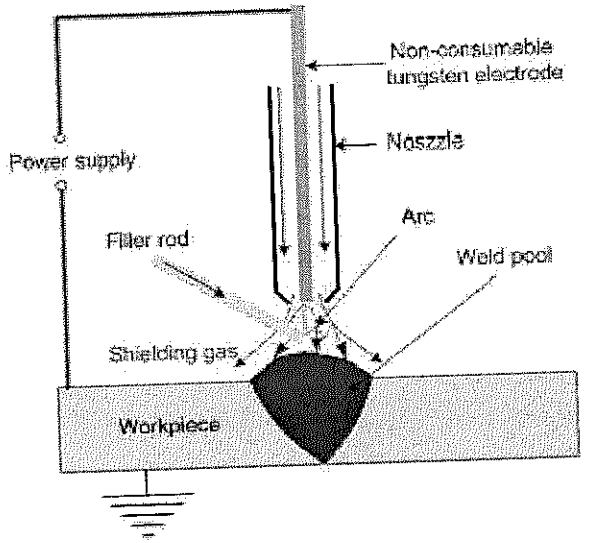


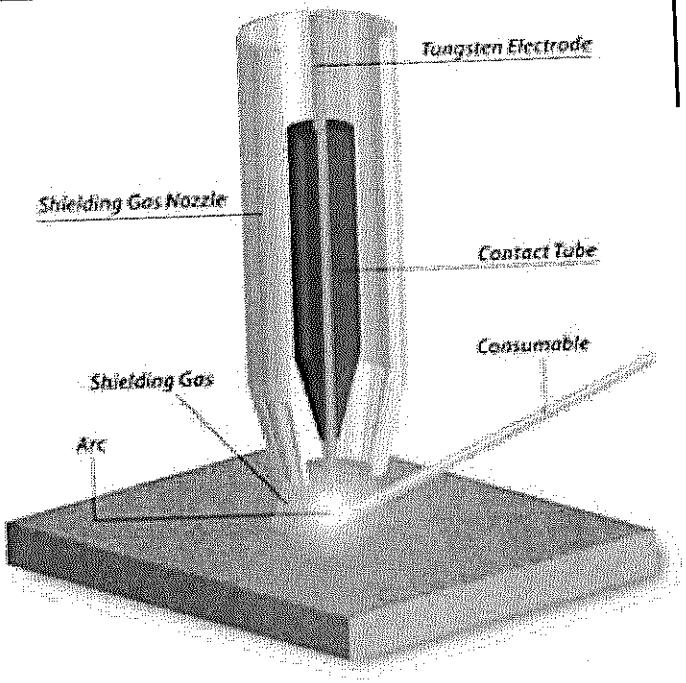
1. Shielded metal arc welding (SMAW): Shielded metal arc welding, which is also known as stick welding, is the most widely used process.
2. Gas metal arc welding (GMAW): This process is also referred to as metal inert-gas (MIG) welding uses an uncoated continuous
3. Gas tungsten arc welding (GTAW): Also known as tungsten inert-gas (TIG), the process uses a non-consumable electrode.
4. Flux-cored arc welding (FCAW): The shielding gases and slag are provided by the decomposing flux that is contained within the electrode.



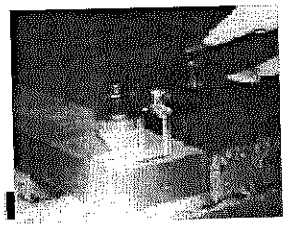
Tungsten inert gas arc welding

(TIG, GTAW)

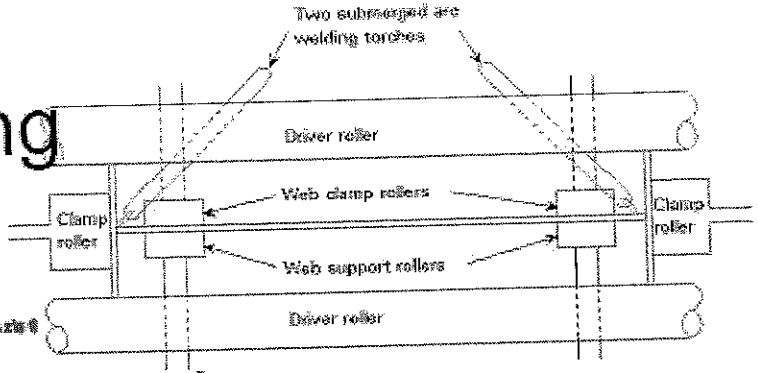


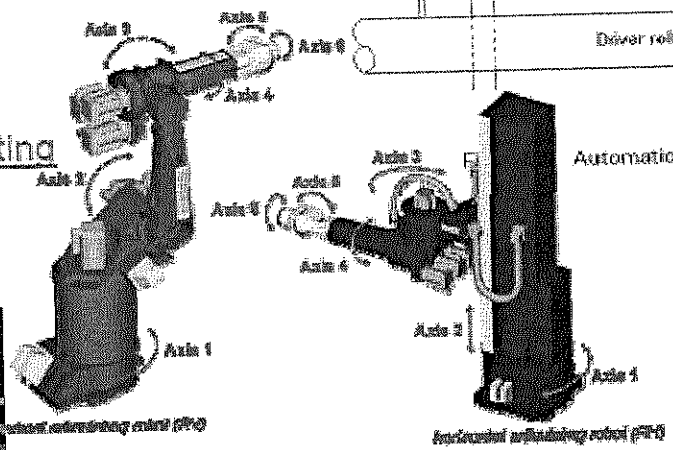


Automated Welding



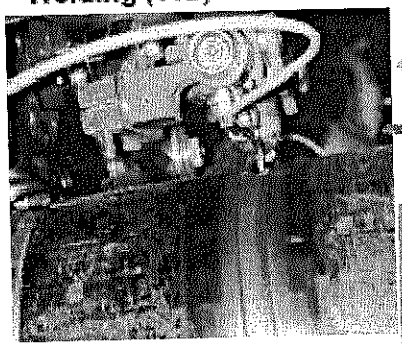
Plasma Welding & Cutting

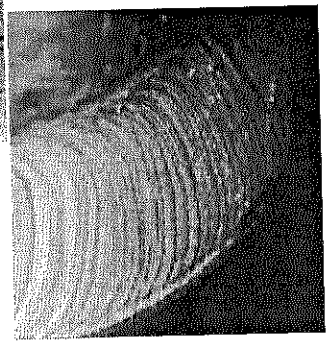


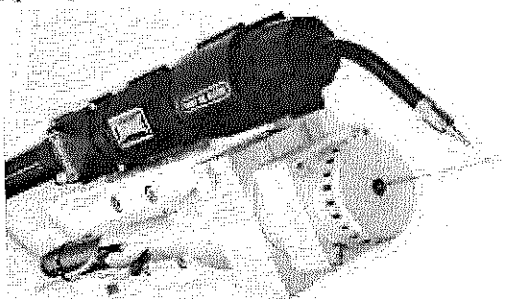


Automatic welding equipment

Tungsten Inert Gas Arc Welding (TIG)

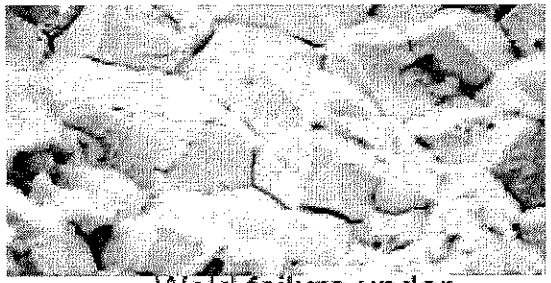






laser welding wire feed system

Welds



Weld failure under electron microscope

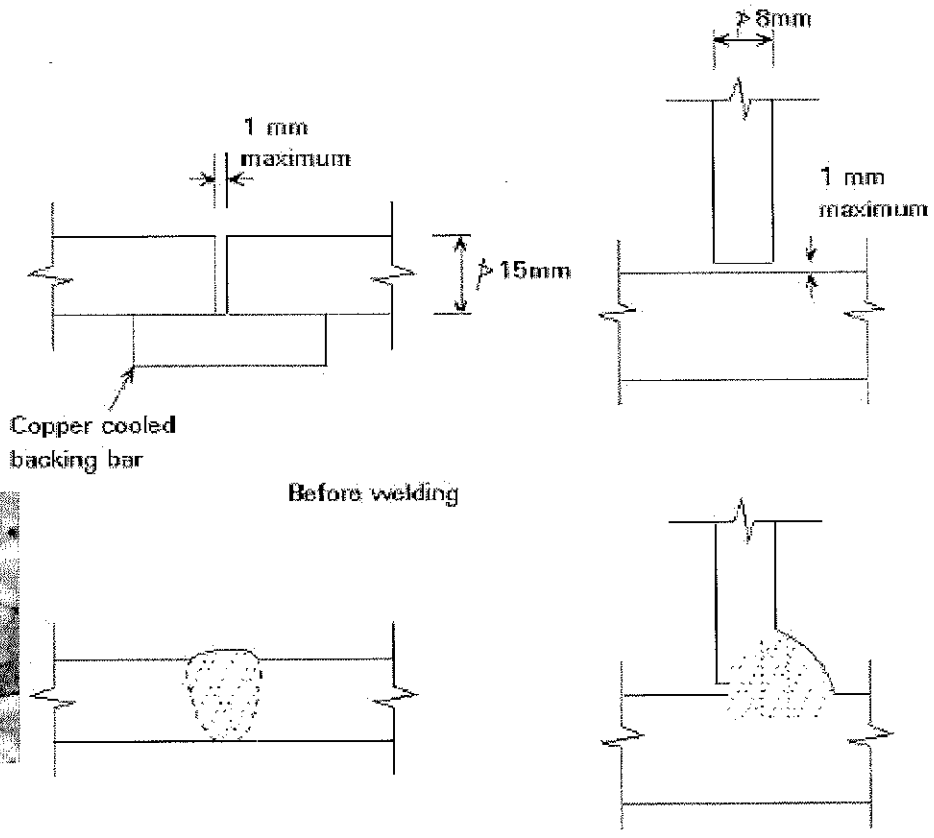
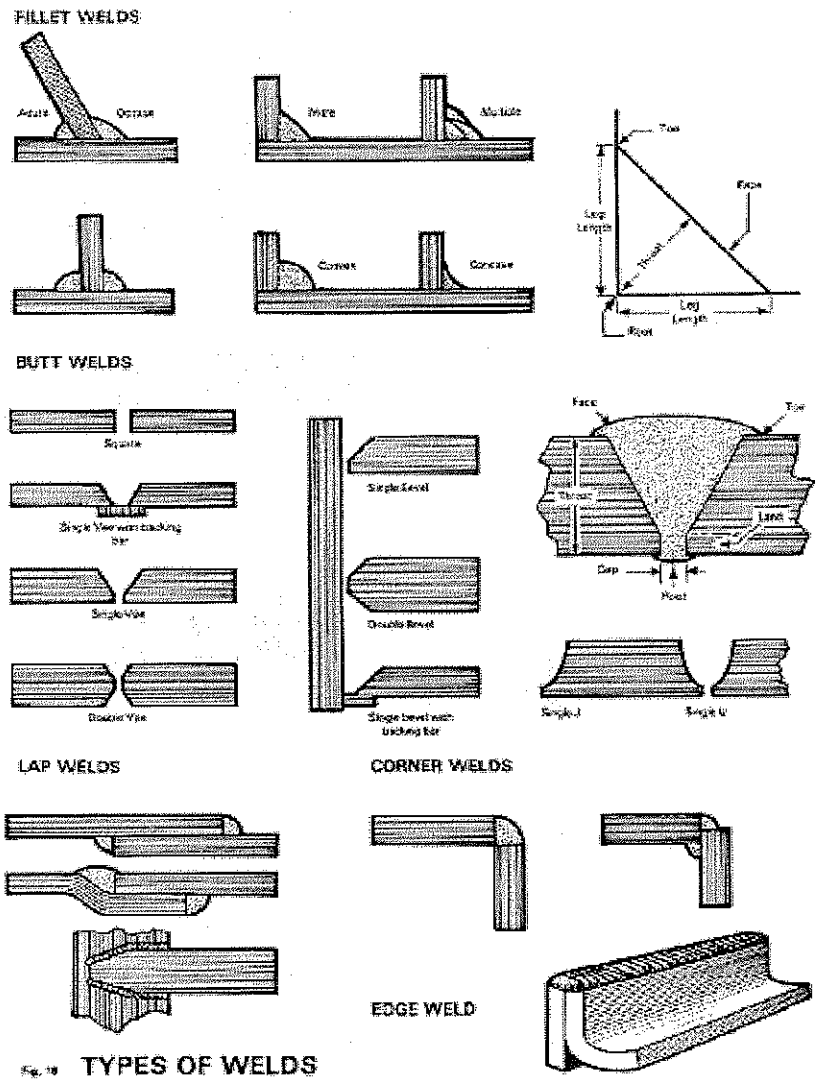


Figure 14 Single-sided welding

Types of welds



TYPES OF WELDS

Fillet welds

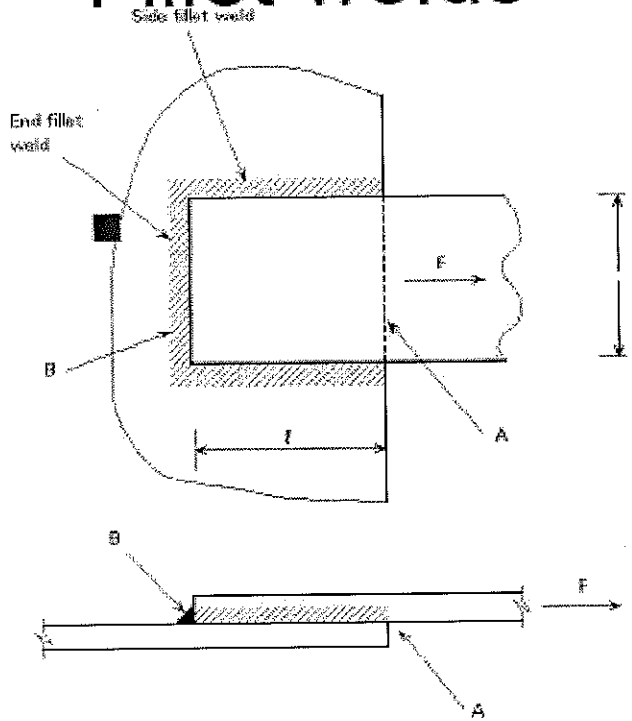


Figure 12 Lap joint

Butt Welds

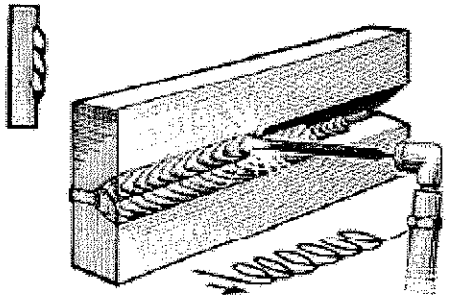


Fig. 19

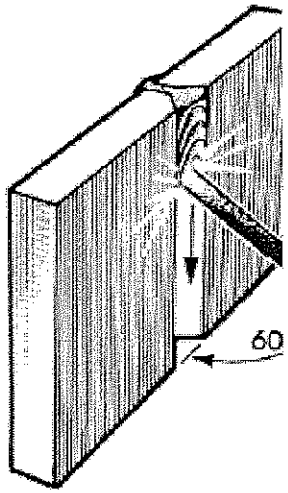


Fig. 20

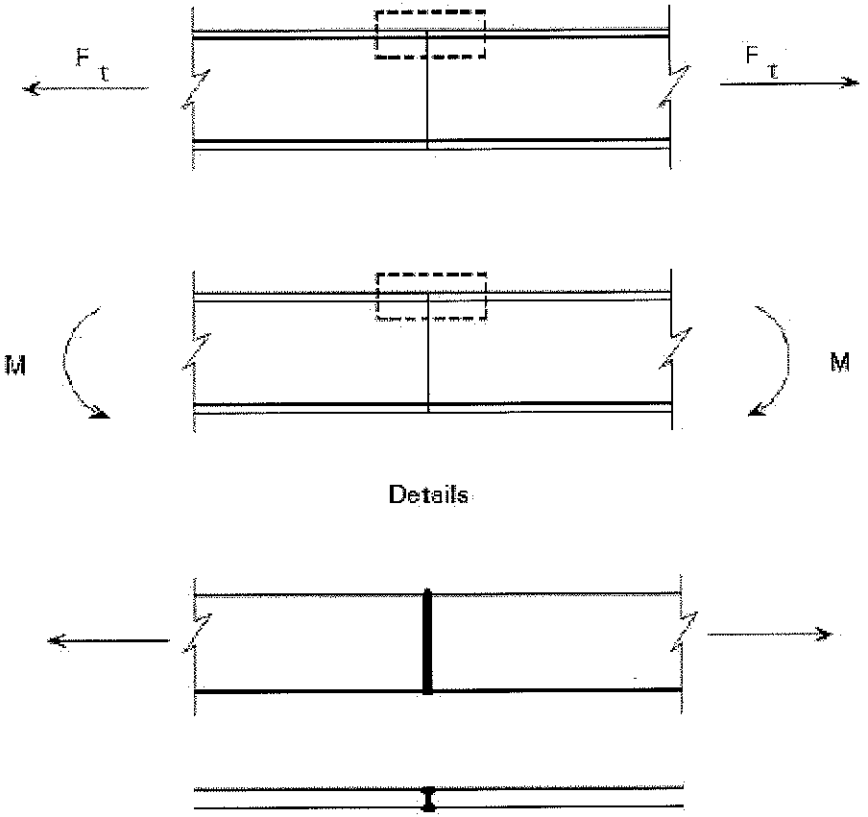
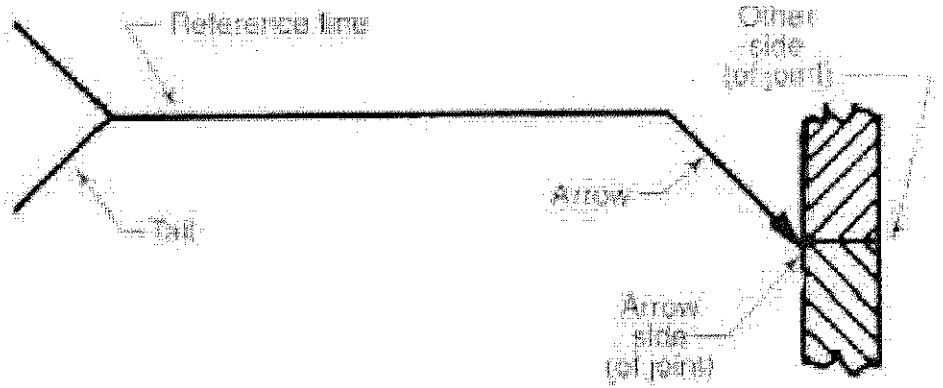
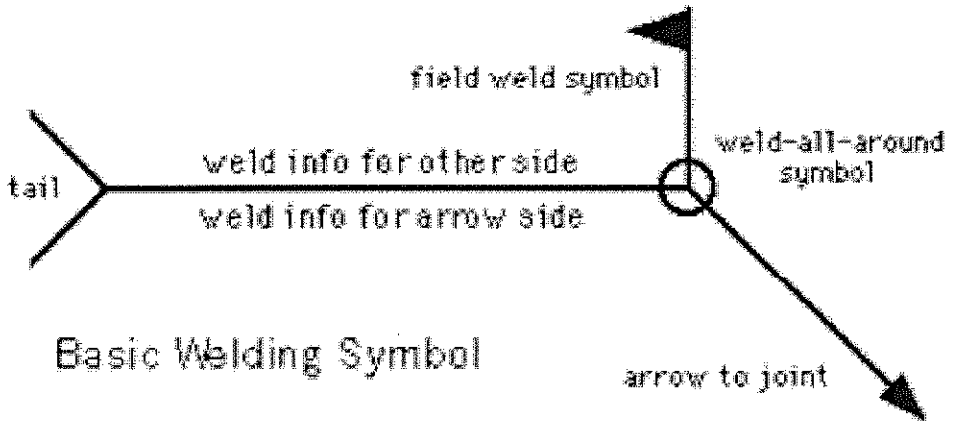


Figure 1 Transfer of axial forces with butt welds

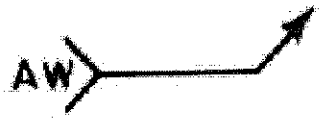
Welding symbols



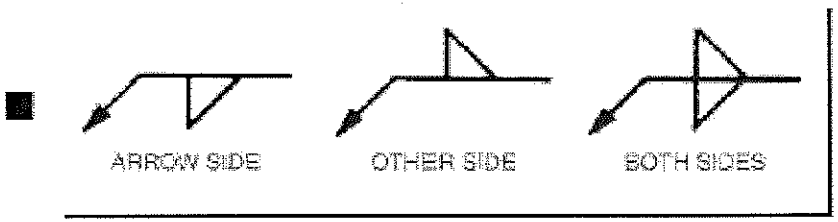


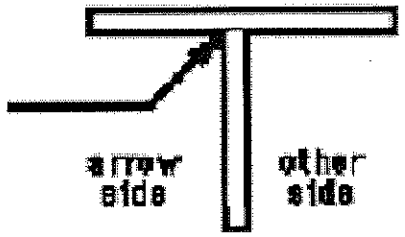
Steel Connections -Dr. Seshu Adluri

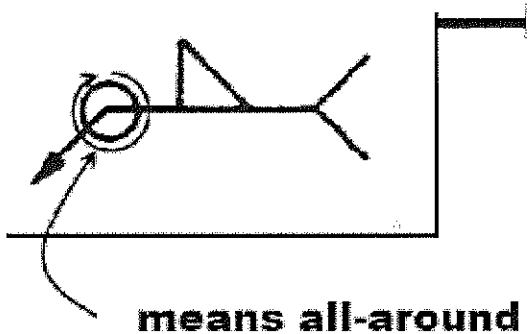
Welding symbols



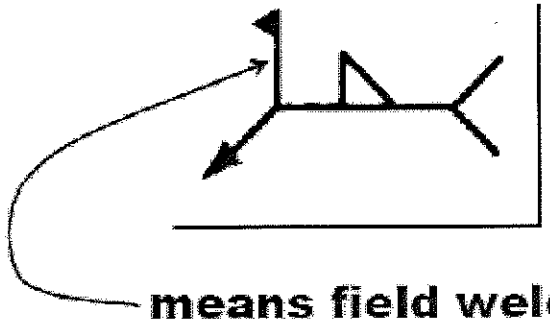
Tail section designating arc welding





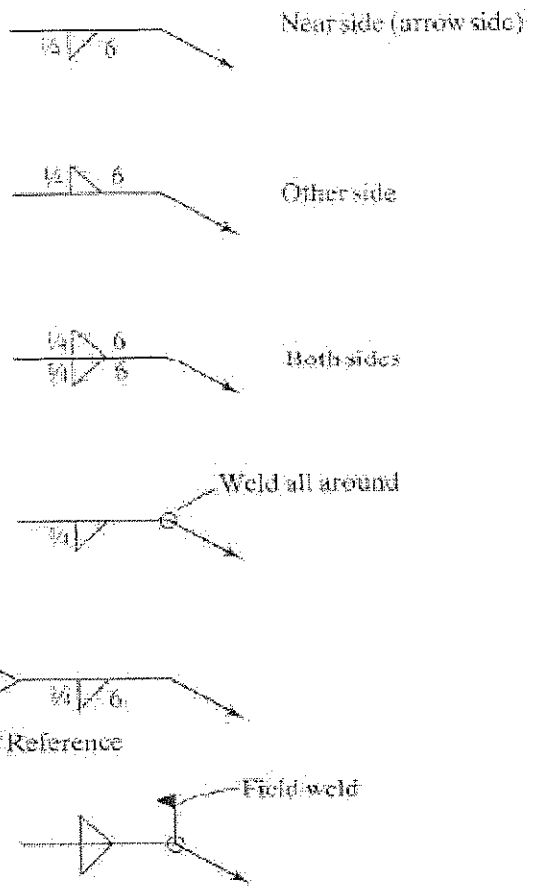


means all-around

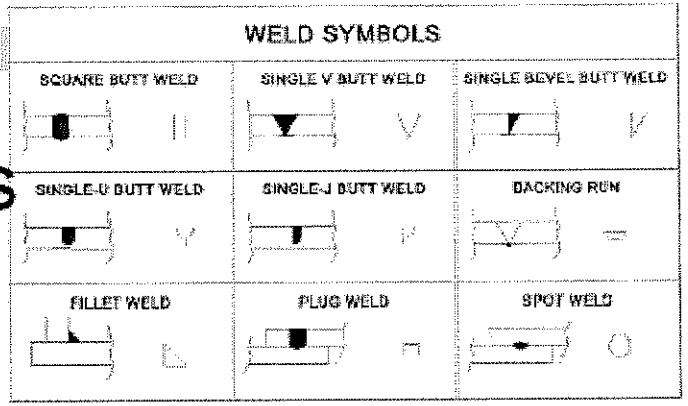


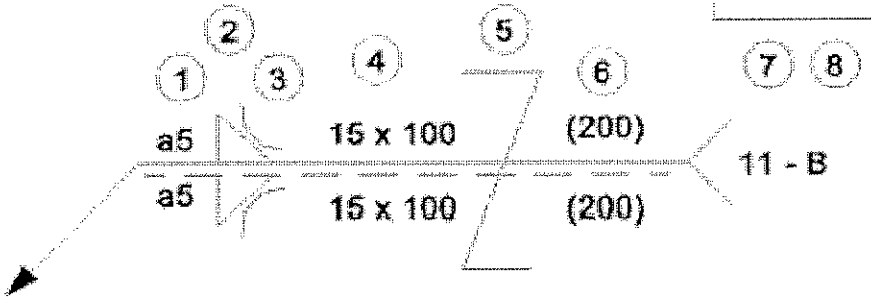
means field weld

Welding symbols



Welding symbols

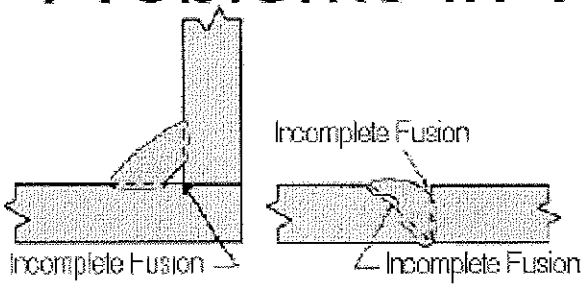


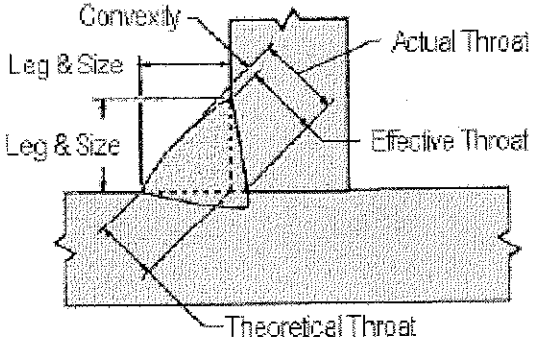


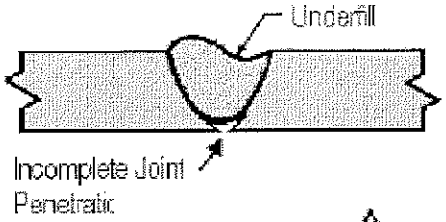
Information above reference line identifies weld on same side as symbolic representation
Information below reference line identifies weld on opposite side to symbolic representation.

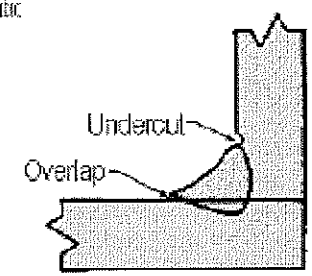
1) Dimension referring to cross section of weld
2) Weld Symbol
3) Supplementary symbol
4) Number of weld elements x length of weld element
5) Symbol for staggered intermittent weld
6) Distance between weld elements
7) Welding process reference
8) Welding class

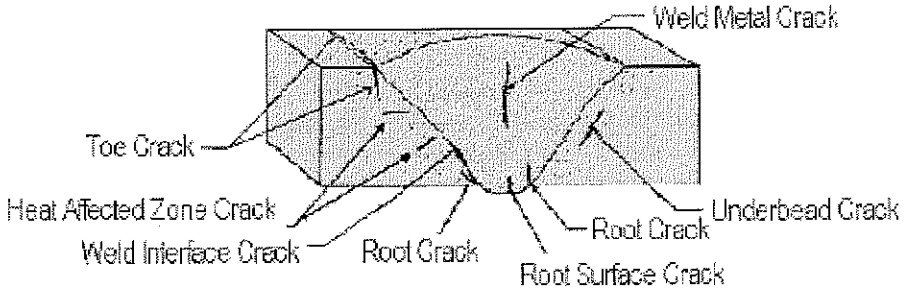
Problems in Weld placement



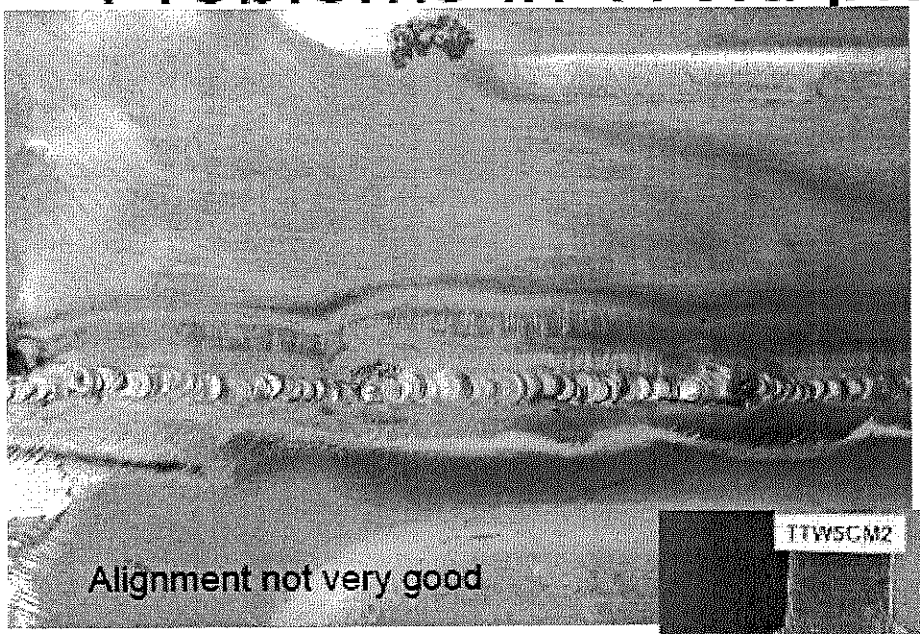


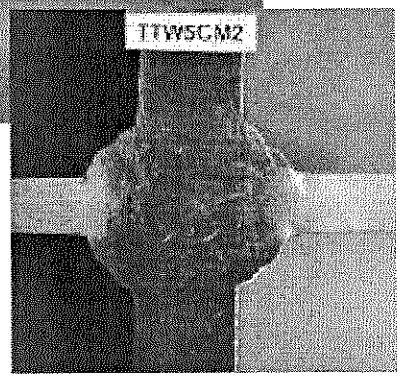


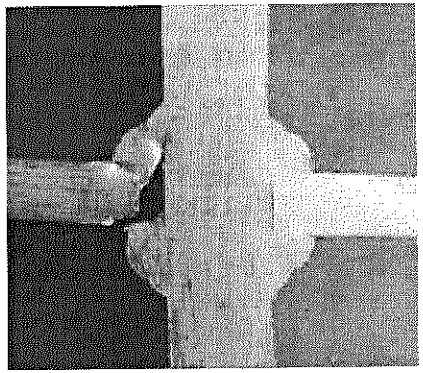




Problems in Weld placement







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http://web.itu.edu.tr/~haluk/celik.html
http://www.engr.mun.ca/~adluri/courses/steel/index.htm (Dr.Seshu Adluri)
Limit State Design of Steel Structures by DUGGAL