STEEL & OTHER METALS

A preparatory course assembled for the
Architectural Record Examinations

Data accumulated from Kent Ballast's "Architecture Exam Review," and various sources of the Internet

(This is only for educational purposes)

AVANT-GARDE ENGINEERING LLC
CONSULTING ARCHITECTS/ENGINEERS

METALS IN CONSTRUCTION

- Engineering with metals:
  - Joseph Paxton's Crystal Palace:
    - Great Britain believed they were the leader of the Industrial Revolution and felt very confident of that. To mark this, Queen Victoria opened the Great Exhibition of the Works of Industry of All Nations, in May 1851.

METALS IN CONSTRUCTION

- Engineering with metals:
  - Joseph Paxton's Crystal Palace:
    - Covered an area of about 100,000 square meters and was 500m long.
    - "Crystal Palace " because it was made of iron and glass - 4,500 tons of iron and nearly 300,000 parts of glass.
    - It was like a jigsaw because it was made in parts all over the country and then brought to Hyde Park to be put together. And it fitted exactly.

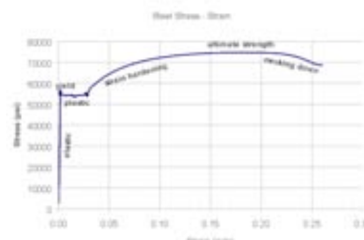
METALS IN CONSTRUCTION

- Engineering with metals:
  - Designed as the entrance arch for the Exposition Universelle of Paris in 1889, marking the centennial of the French Revolution.
  - Gustav Eiffel originally planned to build it in Barcelona, for the Universal Exposition of 1888, but the city hall of Barcelona considered it awkward and expensive construction.
  - Inaugurated on March 31, 1889, and opened on May 6th.
  - Three hundred workers / 18,038 pieces of puddled iron using two and a half million rivets.
  - Only one fatality.

Composite image of the Tour Eiffel by Ran Dom (http://aftnn.org/stuff/images/tour-eiffel.jpg)

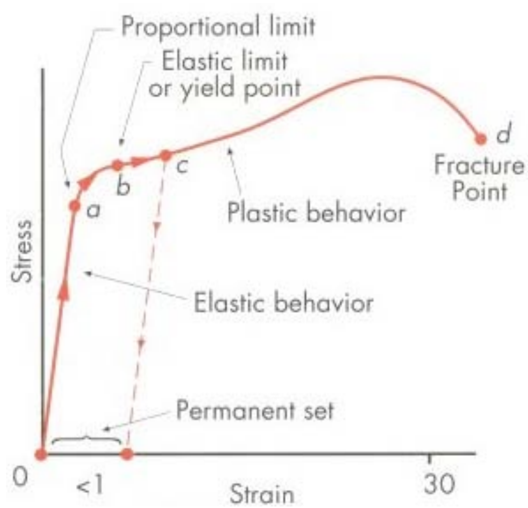
WHY USE STEEL?

- Main characteristics and advantages:
  - Since the age of iron, the first “wide flange” elements were not rolled until 1908.
  - We will be surprised to consider what was happening before compared to today's standards.
  - The versatility, ease of fabrication, ease of construction, perfection of form, lightness, stiffness, minimal volume and a series of other qualities of this material are unprecedented.



WHY USE STEEL?

- Main advantages:
  - Strength:
  - Homogeny:
  - Elasticity:
  - Ductility:
  - Speed of erection:
  - Defined set of forms (dimensions):
  - Adaptability:
  - Longevity:
  - Simplicity:
  - Quality control:
  - Scrap value:



WHY NOT USE STEEL?

- Main disadvantages:
  - Corrosion:
  - Fireproofing:
  - Susceptibility to buckling:
  - Fatigue:
  - Brittle fracture:

EARLY USE OF STEEL

- What is steel:
  - Steel - combination of iron and carbon (approximately 1%) and some other elements in smaller quantities.
  - The formation of steel took place accidentally when the other elements that are necessary to produce it were accidentally present.

EARLY USE OF STEEL

- Wrought and Cast Iron and Steel:
  - Steel is an alloy that falls in the bracket between **wrought iron** and **cast iron**
  - Wrought iron has less than 0.15% carbon content
  - Cast iron has carbon content above 2%.
  - Steel has carbon content between 0.15% and 1.7%.

THE BESSEMER PROCESS

- Volume process for steel production:
  - The first process for volume production of steel was based on the UK patterned method of Sir Henry Bessemer*.
  - By blasting air through molten iron, most impurities were burnt. Yet, that method eliminated some desirable elements like carbon and manganese.
  - Then it was discovered that by adding spiegeleisen, an alloy of iron, manganese and carbon, replenished these elements.
  - Later on it was found that the addition of limestone in the converter, removed the phosphorus and much of the sulphur.
  - The Bessemer process reduced the cost of steel manufacturing by 80%. The converter was used until the early 20th century when it was replaced by the "open hearth" and the "oxygen" process.
  - Today, most of the structural steel produced in the US is by melting of scrap steel from discarded refrigerators, cars, bed springs, typewriters etc. The molten steel is poured into molds that produce forms as close as possible to the final shapes. By rolling them into the final shapes, the result is such of better surface and very little residual stress.

*William Kelly of Kentucky, produced steel by the same method seven years earlier so no US patent was awarded to Bessemer.

STEEL SECTIONS

- Steel Forms:
  - The first structural shapes made in the US were angle irons rolled in 1819,
  - I shaped sections were rolled in the US in 1884.
  - The Home Insurance Company Building in Chicago was built in 1884, designed by Engineer William LeBaron Jenney. He was inspired to design by using this new material when the bricklayers were on a strike.

COMMON STRUCTURAL SHAPES AND SIZES PRODUCED IN USA

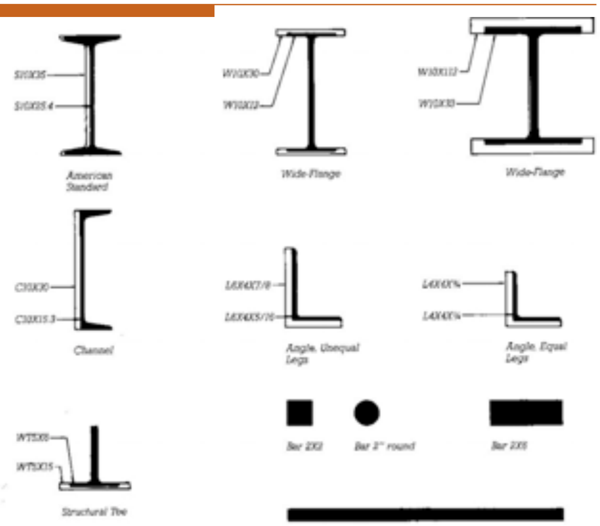
Shape	Sample Designation	Explanation	Range of Available Sizes
Wide-flange	W21 × 83	W denotes a wide-flange shape. 21 is the nominal depth in inches, and 83 is the weight per foot of length in pounds.	Nominal depths from 4 to 18″ to 2 increments, and from 18 to 36″ in 3″ increments
American Standard	S18 × 70	S denotes American Standard. 18 is the nominal depth in inches, 70 is the weight per foot of length in pounds.	Nominal depths of 3″, 4″, 5″, 6″, 7″, 8″, 10″, 12″, 15″, 18″, 20″, and 24″
Angle	L4 × 3 × $^3/_8$	L denotes an angle. The first two numbers are the nominal depths of the two legs, and the last is the thickness of the legs.	Leg depths of 2″, $2^1/_2$″, 3″, $3^1/_2$″, 4″, 5″, 6″, 7″, 8″, and 9″. Leg thicknesses from $^1/_8$″ to $1^1/_8$″
Channel	C9 × 13.4	C denotes a channel. 9 is the nominal depth in inches, and 13.4 is the weight per foot of length in pounds.	Nominal depths of 3″, 4″, 5″, 6″, 7″, 8″, 9″, 10″, 12″, and 15″
Structural tee	WT13.5 × 47	This is a tee made by splitting a W27 × 94. It is 13.5 inches deep and weighs 47 pounds per foot of length. Tees split from American Standard shapes are designated ST rather than WT	Nominal depths of 2 to 9″ in 1″ increments, and $10^1/_2$ to 18″ in $1^1/_2$ increments

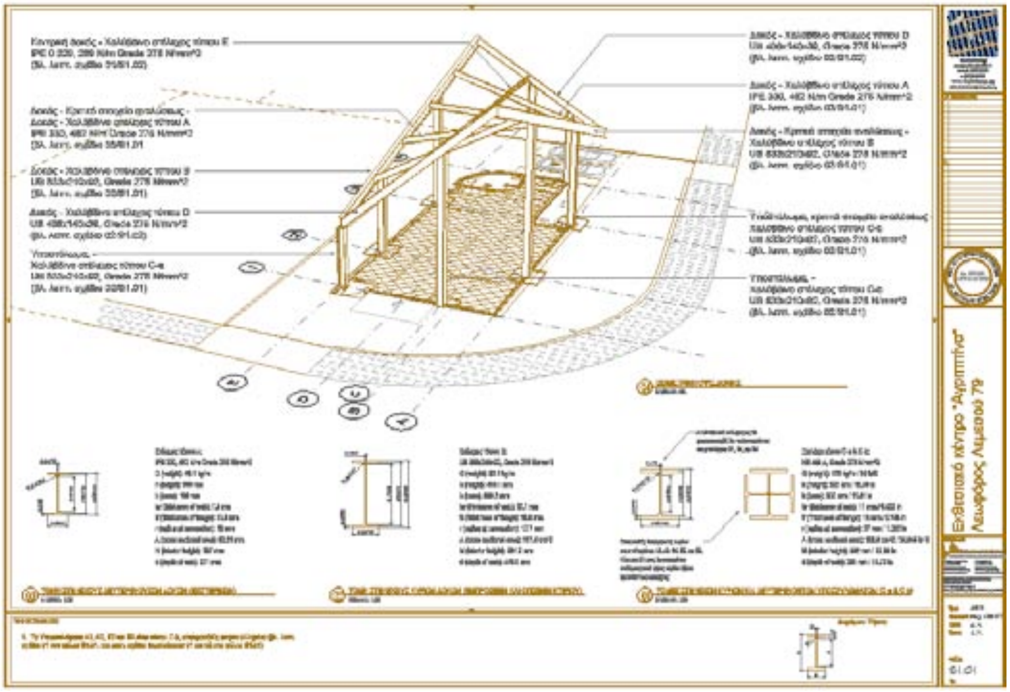
STEEL ALLOYS USED IN CONSTRUCTION

Alloy	Yield Strength	Allowable Stress in Bending	Modulus of Elasticity
ASTM A36 Carbon steel	36,000 psi (248 Mpa)	22,000 psi (152 MPa)	29,000,000 psi (200,000 MPa)
ASTM A242 High strength, low alloy; corrosion resisting	42,000–50,000 psi in 3 grades (290–345 MPa)	25,200–30,000 psi (174–207 MPa)	29,000,000 psi (200,000 MPa)
ASTM A441 High strength, low alloy; structural manganese-vanadium	40,000–50,000 psi in 3 grades (276–345 MPa)	24,000–30,000 psi (165–207 MPa)	29,000,000 psi (200,000 MPa)
ASTM A572 High strength, low alloy; columbium-vanadium steels of structural quality	42,000–65,000 psi in 4 grades (290–448 MPa)	25,200–39,000 psi (174–269 MPa)	29,000,000 psi (200,000 MPa)
ASTM A572 Gr. 50 (with special requirements)	65,000 psi (448 MPa)	39,000 psi (269 MPa)	29,000,000 psi (200,000 MPa)
ASTM A588 High strength, low alloy; corrosion resisting	42,000–50,000 psi in 3 grades (290–345 MPa)	25,200–30,000 psi (174–207MPa)	29,000,000 psi (200,000 MPa)

STEEL SECTIONS

- Steel Forms:
  - S shapes
  - Wide Flanges
  - Channels
  - Angles
  - T shapes



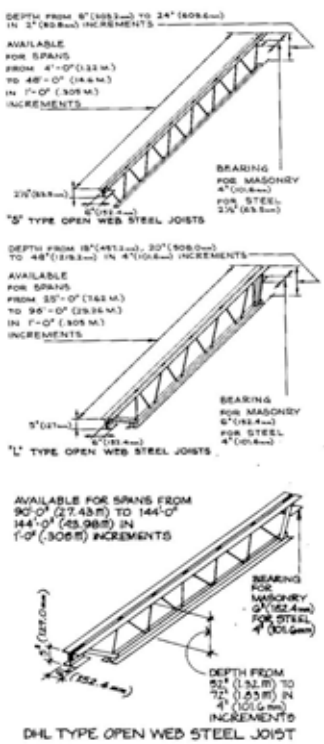


STEEL SECTIONS

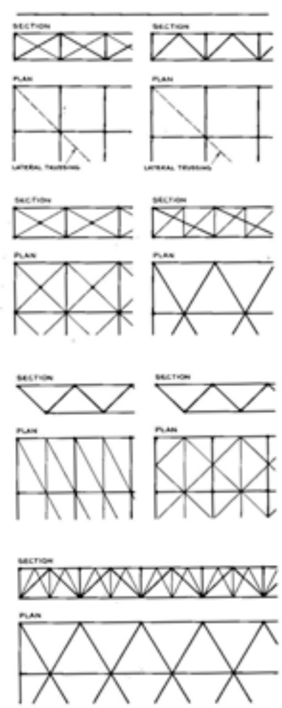
- Steel Forms:
  - Cold forms made by bending sheets of carbon or low-alloy steels into almost any desired cross section.
  - Light members used in roofs, floors and walls, vary in thickness between 0.01″ – 0.25″.
  - Cold working decreases ductility / increases strength - permissible under certain conditions to specify.

STEEL TRUSS FORMS

- Steel trusses :
  - Triangular assemblies of steel elements subjected only to axial stresses carrying the loads through the nodes
- Open web steel joists:
  - Lightweight truss beams composed of small T-shapes, angles, or bars, spanning through floors and roofs.



Open-web steel joists



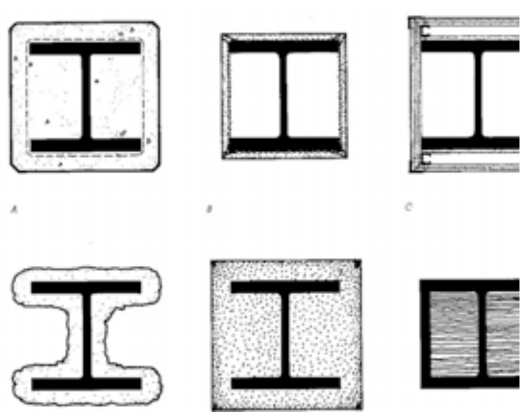
Various types of space frames formed with 3-D trusses

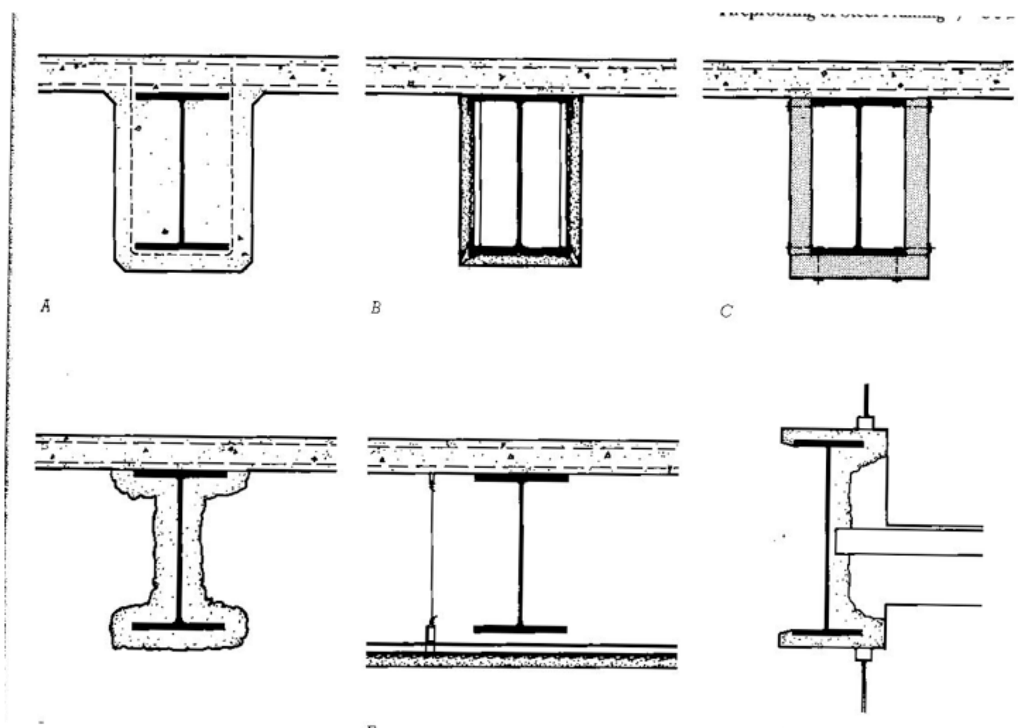
Forms of Fire Protection

- Early methods to provide fire protection included encasement of the steel members with concrete, plaster, brick, and concrete masonry. (This method adds excessive amount of extra weight to a structure, especially to a multi-story building structure)
- Other techniques include:
  - Enclosure with multiple layers of gypsum board
  - Enclosure in metal lath and plaster
  - Spray-on fireproofing (mix of vermiculite with gypsum/cement)
  - Loose insulating fill contained in sheet metal
  - Concrete slabs

TYPES OF FIRE PROTECTION

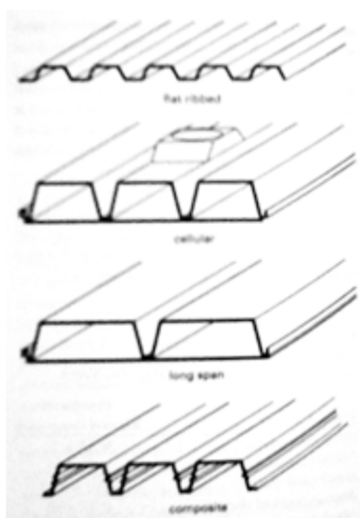
- Encasement in R. concrete
- Enclosure in metal lath and plaster
- Enclosure in multiple layers of gypsum board
- Spray-on fireproofing
- Loose insulating fill in metal enclosure
- Water-fill box column





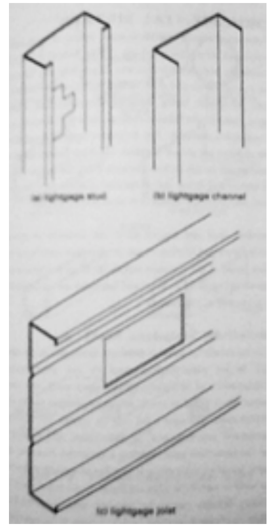
METAL DECKING

- Metal decking is available in steel or aluminum, the latter being the most common form of the two. It consists of formed panels that are laid over beams or trusses to serve as formwork for poured concrete slabs.
- The decking serves as a convenient platform before the concrete is poured.
- Decking like cellular serves as a composite component (composite material – metal combined with concrete) that can also provide raceways for cabling and power.



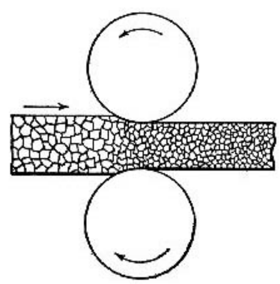
LIGHTGAUGE METAL FRAMING

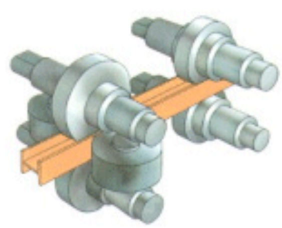
- Light gage metal framing consist of steel members with thicknesses from 10 to 25 gage. These framing elements are used for interior partition walls, the most common of which is that of sandwiching steel frame between two sheetrock panels yielding a standard 4 7/8 wall.
- These standardized elements are noncombustible, easily cut and and do not decay easily.
- Studs come in depths of 1⅝, 2½, 3 ⅝, 4 and 6 inches. Joists are made available in 6 through 14 inches and 10 – 20 gauge.
- Light gauge joists and rafters are available in depths of 6 to 14 inches and thicknesses of 10 – 20 gauge and can span up to 40 ft



FABRICATING METALS

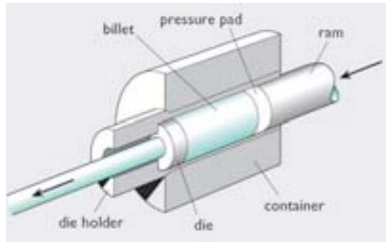
- There are several methods followed for the fabrication of metals. Although casting is the first method that comes to mind, today this is mainly used for decorative elements, pipe valves and some hardware.
  - Rolling: Metal forms pass through rollers to produce the desired shape. Hot rolling eliminates flaws better than cold rolling. The latter however increases elastic strength and reduces ductility as mentioned earlier.





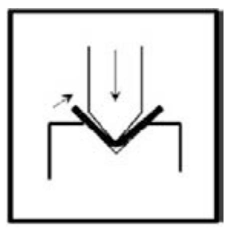
FABRICATING METALS

- Extruding: This process is where Metal is pushed through die to form a shape. Many aluminum sections are formed this way, especially for decorative purposes. The advantage of this process is when a significant quantity is required, special dies can be formed for a particular job.
- Drawing: Is similar to extruding but the metal is pulled instead of pushed through the die. The advantage over extruding is that there is improvement on the strength and the surface qualities of the material



FABRICATING METALS

- Bending: This process changes the shape of tubes and extruded shapes by passing them through various kinds of rolling machines and presses.
- Brake forming: Takes plates and sheets of metal and makes successive one directional bends to produce the final shape.
- Embossing: This process produces patterns of flat sheets of metal by passing them on a machine with the embossing pattern on rollers.



FABRICATING METALS

- Part of fabrication includes heat treatment, a process that modifies the strength and workability of rolled shapes. This process is mainly used on steel.
  - Annealing: This is the process of heating and slowly cooling to obtain a more ductile material.
  - Quenching: The process involves heating the metal to a certain temperature and rapidly cooling it by submersion in water or other liquid.
  - Tempering is similar to quenching without the submersion in liquid.
  - Casehardening produces hard-surface steel over a softer core

FINISHING METALS

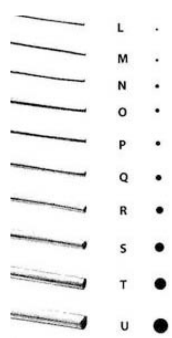
- There are three major types of metal finishing. Not all apply to all metals.
  - Mechanical: These finishes simply alter the surface of the metal element. They may be as simple as just keeping the metal as it came from the factory to grinding, sand-blasting or buffing.
  - Coating: These finishes consist of applied materials that may be used for protection or for purely decorative purposes. Coatings may be clear or opaque and there is a vast number of substances that can provide exceptional results

FINISHING METALS

- Chemical: These finishes alter the surface of the metal by chemical reaction. They may simply clean the surface in preparation for another process like coating, or simply may protect the metal by themselves. Aluminum anodizing is one of those chemical methods. The aluminum is immersed in an electrolytic bath and a current is applied to the metal. The process can include various colors and becomes integral part of the structure of the metal.
- In deciding the type of finish there are several considerations to be addressed including appearance, protection, cost, effectiveness, longevity, and required maintenance.

PROPERTIES OF METALS

- Rudimentary knowledge of the unique properties of these elements is needed for designing and specifying metals. These include coefficients of expansion, galvanic action, and gage sizing.
  - Thickness of large steel members is expressed in fractions or decimals of an inch.
  - Sheets of metals, tubing and strips are expressed in gage #.
  - The weight of an element would vary according to the metal used and the different coatings incorporated such as the case of galvanized steel



	Gauge	1/1000"	Approx. mm
L.	22	.025	.65
M.	21	.028	.71
N.	20	.032	.80
O.	19	.036	.92
P.	18	.040	1.00
Q.	16	.051	1.30
R.	14	.064	1.60
S.	12	.081	2.00
T.	10	.102	2.60
U.	8	.128	3.25

PROPERTIES OF METALS

- Galvanic action is corrosion that results when dissimilar metals come to contact in the presence of an electrolyte like atmospheric moisture.
- In electrolysis, a mild electric current is produced between the two. One acts catalytically and gradually corrodes while the other remains intact.
- The list on the right represents the galvanic series. The farther apart the metals are, the greater the possibility for corrosion when they come in contact.
- Either identical metals need to be used or use other elements, like plastic, rubber etc. between the contacts that will eliminate this effect.

IN GALVANIC SERI

CORRODED END
Anodic or less noble
Magnesium
Zinc
Aluminum
Cadmium
Steel
Lead
Tin
Nickel
Brass
Bronzes
Copper
Nickel-Copper Alloys
Stainless Steels (passive)
Silver
Gold
Platinum
PROTECTED END
Cathodic or most noble

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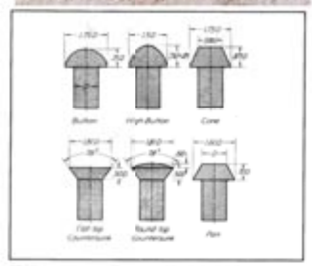
PROPERTIES OF METALS

- The effect of expansion and contraction according to the temperature on metals is more noticeable on metals than other elements.
- Slip joints or expansion joints are used to accommodate movement of the built elements.
- Allowances must be made for the differential movement.
- On the table:
  - coefficients of expansion for a series of construction materials based on temperatures ranging between 20C-100C or 68F-212F

Metal	Coefficient of Expansion	
	x10 in/F	x10^-6 mm/C
Structural Steel	6.5	11.7
Copper, Alloy110	9.3	16.8
Stainless Steel, 302	9.9	17.9
Comm. Bronze, Alloy 220	10.2	18.1
Red Brass, Alloy 230	10.2	18.1
Aluminum	12.8	23.1
Lead	15.9	28.6
Other Materials		
Wood	2.7	4.9
Glass	5.1	9.2
Concrete	5.5	9.9

JOINING METALS

- Method and type of metal joining depends on the types of metal that may be used.
  - Common to use mechanical methods to hold metal elements together. Most common is the use of bolts. When two dissimilar metals are joined bolts will allow a layer of rubber or plastic set between them.
  - Screws are used mainly on light gage metal. Self tapping screws can be applied for fastening metal or other materials on steel studs. Screws are generally good for fastening light sheet metal to wood.
  - Rivets are a thing of the past. Think of all the noise!!!



JOINING METALS

- Soldering is another process of joining two pieces of metal by heat. The joining takes place through the melting of lead based or tin based alloy solder filler metal that melts below 500F.
- Metals can of course be fastened with adhesives. This method is not anticipated to provide a very strong bond although more and more epoxy chemical adhesives are produced recently and can generate stronger bonds.

JOINING METALS

- Welding: This is the process of joining two pieces of metal by heating them above their melting point. By cooling, the metals form one piece. This method is usually applied for the joining of structural steel members. It is however not appropriate for thin metals or situations where appearance is important.
- Brazing is the joining of two metal elements at an intermediate temperature using nonferrous filler metal with a melting point above 800F. Brazing is usually used for brass, bronze or aluminum. With a little buffing, a very smooth joint can be achieved.