Civil Engineering Materials

SAB 2112

Introduction to Steel

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UTM *International Campus*

October 9, 2010

CONTENT SCHEDULE – 5th Meeting

1. Types and application of steel in construction
2. Non-ferrous metal - types and characteristics, use of non-ferrous metal in construction
3. Latest construction materials - polymer, glass, composite material, cement based products

Learning Objectives

1. Understand different types of structural steels used in construction.
2. Discuss about the stress-strain relationship of structural steel.
3. Highlight the advantages and disadvantages of using steel as structural material.
4. Discuss fatigue failure and it's significance.
5. Brittle fracture of steel.
6. Fire performance and protection of the steel.
7. Corrosion of steel and it's protection.

Introduction: Steel

- Steels are essentially alloys of iron and carbon but they always contain other elements, either as impurities or alloying elements.
- Steel is man made metal containing 95% or more iron and 1 – 2% carbon, smaller amounts (around 1.6%) of manganese, nickel to improve certain properties.
- Carbon improves strength/hardness but reduces ductility and toughness.
- Low carbon steels are not used as structural materials.
- Alloying nickel, the tensile strength can be increased while retaining the desired ductility.

Types of Steel

Steel

- Low carbon steel (mild steel)
- Medium carbon steel
- High carbon steel (tool steels)
- Cast iron

Alloy Steels

- Stainless steel
- High speed steel

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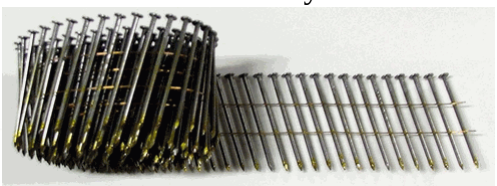
Low Carbon Steel

Also known as mild steel
Contain 0.05% -0.32% carbon

1. Tough, ductile and malleable
2. Easily joined and welded
3. Poor resistance to corrosion
4. Often used a general purpose material

- Nails, screws, car bodies,
- Structural Steel used in the construction industry



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Medium Carbon Steel

Contains 0.35% - 0.5% of carbon

Offer more strength and hardness BUT less ductile and malleable

Structural steel, rails and garden tools

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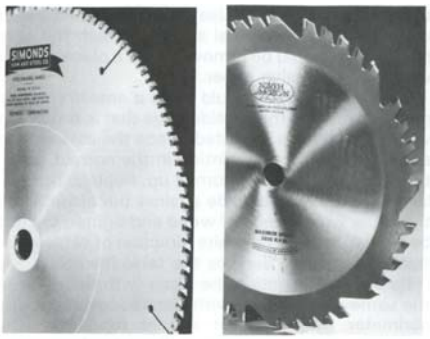
High Carbon Steel

Also known as 'tool steel'
Contain 0.55%-1.5% carbon

Very hard but offers Higher Strength Less ductile and less malleable

Hand tools (chisels, punches)
Saw blades



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Cast Iron

Contains 2%-4% of carbon

Very hard and brittle
Strong under compression
Suitable for casting [can be pour at a relatively low temperature]

Engine block, engineer vices, machine parts

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Introduction: Steel

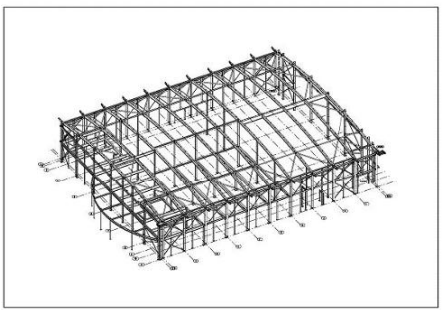
- Steel as building material has been used in various types of structures:

Introduction: Steel

1. **Multi-storey building skeleton**

Introduction: Steel

- Steel as building material has been used in various types of structures:



Introduction: Steel

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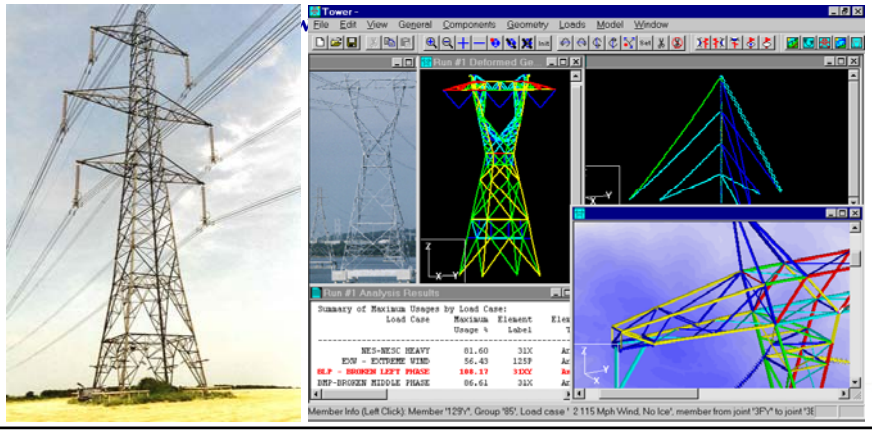


Introduction: Steel

- Steel as building material has been used in various types of structures:

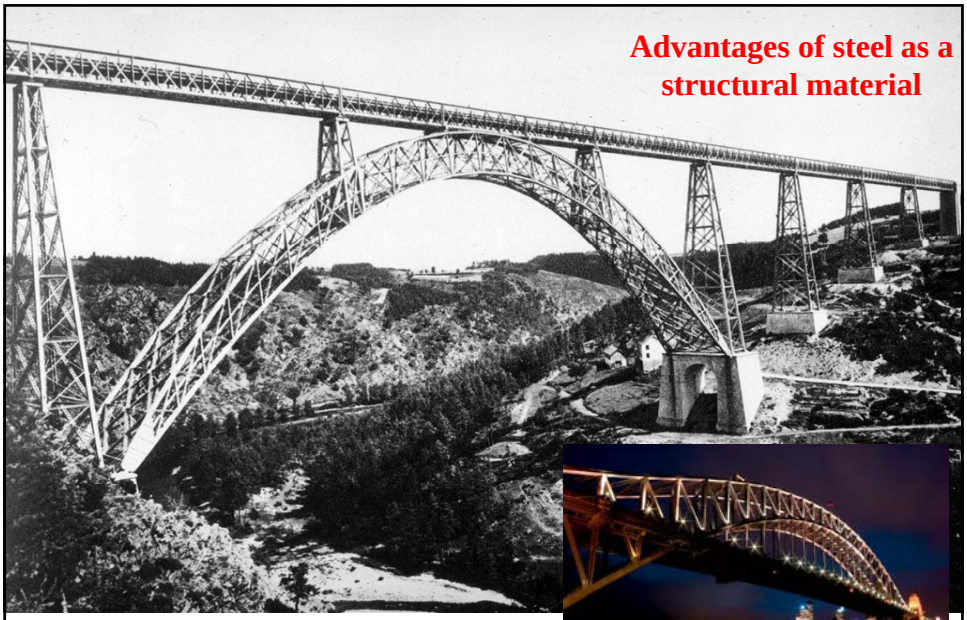
Introduction: Steel

- Steel as building material has been used in various types of structures:

Advantages of steel as a structural material

1. High strength to low weight - good for long span bridges, tall buildings.
2. Lightweight compared to concrete - can be handled and transported, and prefabricated.
3. Properly maintained have a long life.
4. Uniformity properties do not change with time.
5. A ductile material, does not fail suddenly, but gives visible evidence of failure by large deflections.
6. Additions and alterations can be made easily.
7. They can be erected at a faster rate compared to reinforced concrete.
8. Steel has the highest scrap value.
9. Can be even reuse on demolition.

Advantages of steel as a structural material



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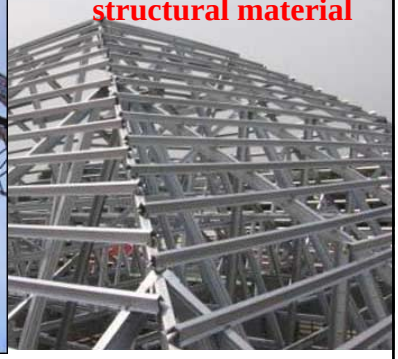

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Disadvantages of steel as a structural material

1. When placed in exposed conditions, are subjected to corrosion. They require painting, hence induce high maintenance cost.
2. Needs fire proof treatment, which increase cost
3. Fatigue – strength reduced if large number of stress reversals..

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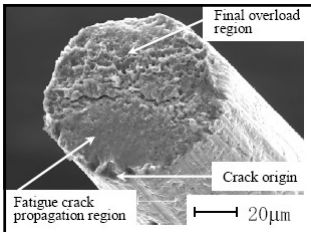

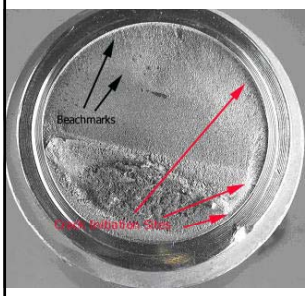

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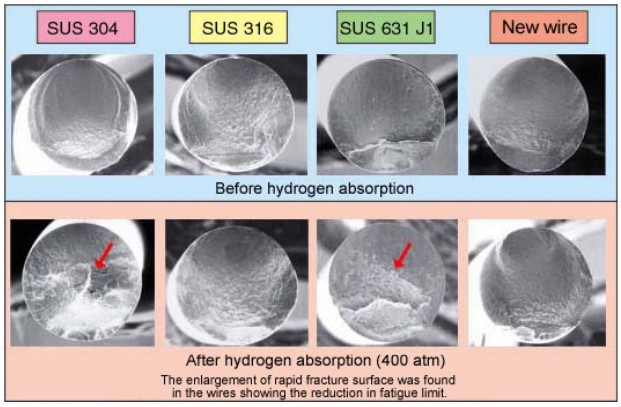
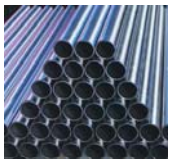


▲Fatigue fracture surface before and after hydrogen absorption

Source: http://global-sei.com/sn/2007/352/4.htm

3. Fatigue – strength reduced if large number of stress reversals.

Types of steel

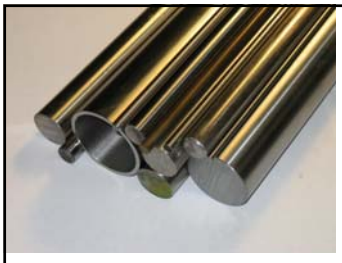


- **Carbon steel**, also known as **plain carbon steel**, is steel where the main alloying constituent is *carbon*.
- According to American Iron and Steel Institute (AISI), they defines carbon steel as: "Steel is considered to be carbon steel when
  - **no minimum content** is specified or required for *chromium, cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium or zirconium, or any other element* to be added to **obtain a desired alloying effect**;
  - when the specified minimum for **copper does not exceed 0.40 percent**; or when the maximum content specified for any of the following elements does not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.60."
- Carbon has the maximum influence on the mechanical properties of steel. Steel with a low carbon content has properties similar to iron.

Types of steel

Carbon Steel

- As the carbon content rises, the metal becomes harder and stronger but less ductile and more difficult to weld.
- In general, higher carbon content lowers the melting point and its temperature resistance.
- There are generally 3 classes depend on carbon content:
  - Mild Steel (up to 0.25%)
  - Medium Carbon Steel (0.25% to 0.45%)
  - High Carbon Steel (0.45% to 1.50%)
- Mild steel is the most common use because its price is relatively low while it provides material properties that are acceptable for many applications.



Types of steel

Alloy Steel

- **Alloy steel** is steel alloyed with a variety of elements in amounts of between 1 and 50% by weight to improve its mechanical properties.
- Alloy steels are broken down into two groups:
  - Low Alloy Steel
  - High Alloy Steel
- Most commonly used alloy steel are **low alloy steel**.
- Alloy steels have greater strength, hardness, hot hardness, wear resistance, hardenability, or toughness compared to carbon steel.
- However, they may require heat treatment to achieve such properties. Common alloying elements are molybdenum, manganese, nickel, chromium, vanadium, silicon and boron.

Types of steel

Tool Steel

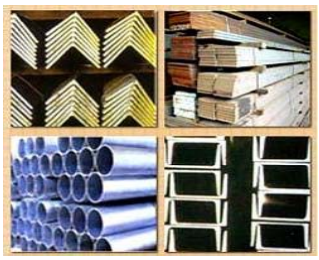
- **Tool steel** refers to a variety of carbon and alloy steels that are particularly well-suited to be made into tools.
- Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and/or their resistance to deformation at elevated temperatures.
- Tool steel is generally used in a heat-treated state.

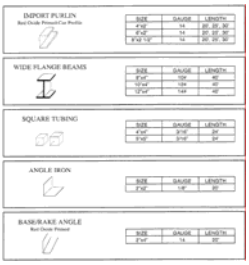
Types of steel

Stainless Steel

- In metallurgy term, **stainless steel**, also known as **inox steel** or **inox** from French "inoxydable", is defined as a steel alloy with a minimum of 10.5 or 11% chromium content by mass.
- Stainless steel does not stain, corrode, or rust as easily as ordinary steel (it *stains less*, but it is not stain-proof). It is also called **corrosion-resistant steel** or **CRES** when the alloy type and grade are not detailed, particularly in the aviation industry.
- There are different grades and surface finishes of stainless steel to suit the environment to which the material will be subjected in its lifetime. Stainless steel is used where the properties of steel, and resistance to corrosion are required.
- Stainless steel differs from carbon steel by the amount of chromium present.
- Carbon steel rusts when exposed to air and moisture. Stainless steels contain sufficient chromium to form a passive film of chromium oxide, which prevents further surface corrosion and blocks corrosion from spreading into the metal's internal structure.

Structural Steels

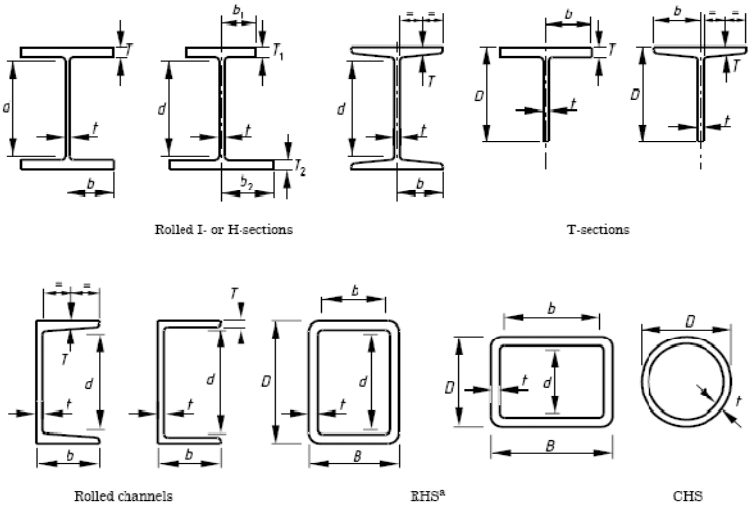




- Structural steel is made up of about 98% of iron with the main alloying elements – carbon, silicon and manganese.
- Copper and chromium are added to produce weather-resistant steels that do not require corrosion protection.
- Main design property of structural steel is based on the **yield strength** of the steel, but other properties including ductility, toughness, impact resistance and weldability are also important.

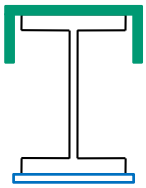
Structural Steel Sections

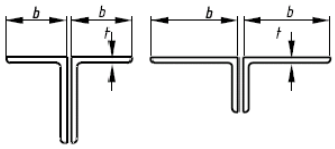
- **Hot Rolled Section** – UB, UC sections, channel, T, angle, tube, bars, flats, plates, sheets, and strips.



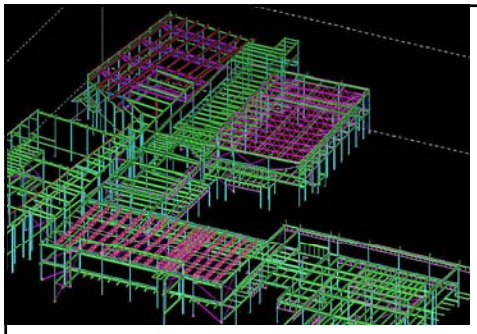
Structural Steel Sections

- **Compound Section** – combination of two or more sections to strengthen the structural member.

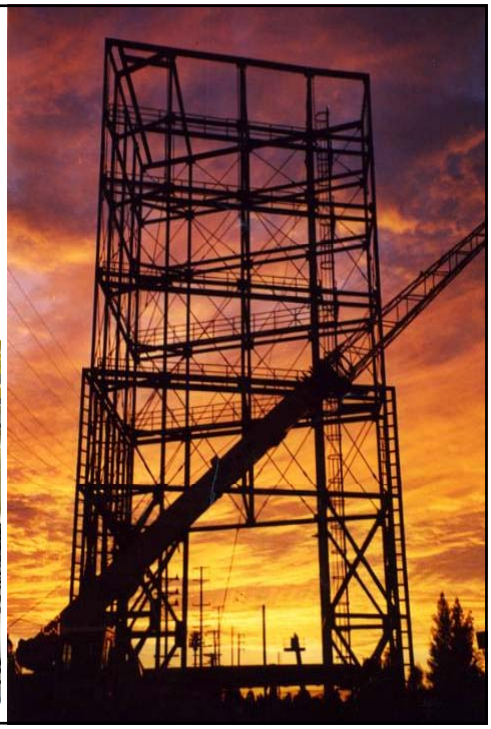




Double angles[b]

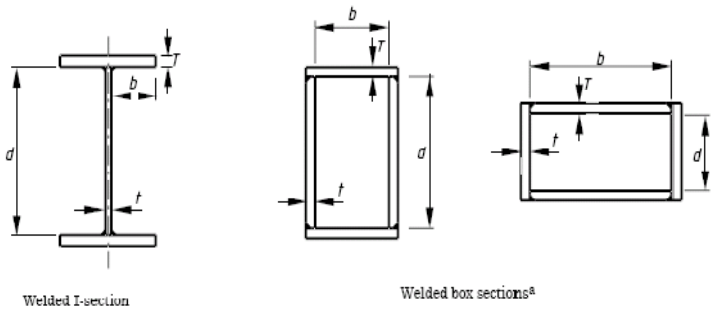


Bianco Structural Steel Bianco's Automated Structural Steel Processing Plant in Adelaide



Structural Steel Sections

- **Built-up/Fabricated Section** – Built-up sections are made by welding plates together to form I, H or box members which are termed plate girders, built-up columns, box girders or column, respectively.



Welded I-section

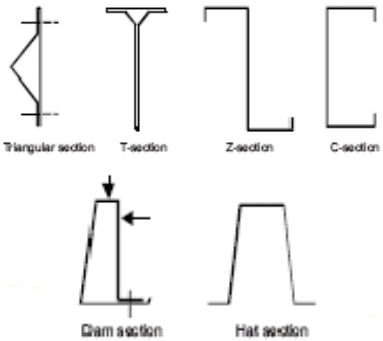
Welded box sections[a]

Fabricated sections can be welded or bolted

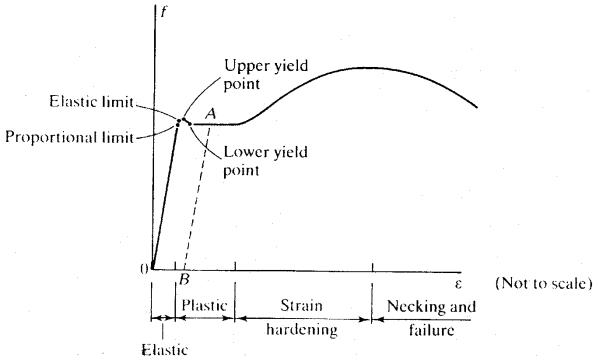
Structural Steel Sections

- **Cold Rolled/Formed Section** – Cold-formed steel structural members are shapes commonly manufactured from steel plate, sheet or strip material. Examples of the cold-formed sections are corrugated steel roof, floor decks, steel wall panels, storage racks and steel wall studs.

Cold formed RHS



Stress-Strain Relationship of Steel



Prior to the yield point, the material will deform elastically and will return to its original shape when the applied stress is removed.

Once the yield point is passed some fraction of the deformation will be permanent and non-reversible.

- **Yield strength** is defined as the stress at which a material begins to deform plastically. The stress at which material strain changes from elastic deformation to plastic deformation, causing it to deform permanently.

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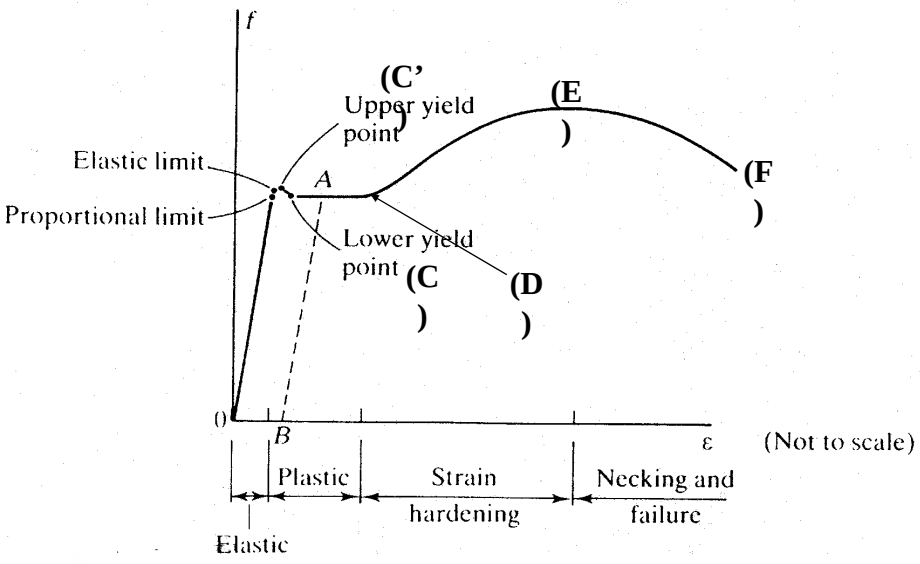


Grade of Steel and Design Strength

Grade of Steel		Yield Strength or Design Strength(N/mm^2)
Grade 55	S460	460
Grade 50	S355	355
Grade 43	S275	275

- Structural steel is basically produced in 3 strength grades; there are S275, S355 and S460.
- S460 is the strongest, but the lower grade S275 is the most commonly used in structural applications.
- S stands for "Structural".
- The number indicates the yield strength of the material in N/mm^2.

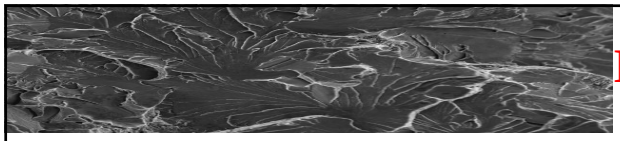
Steel Properties

- The mechanical properties of steel largely depend on its chemical composition, rolling methods, rolling thickness, heat treatment, stress history, and thermal expansion (α)

Property	**Value**
Yield stress f_y	220 – 540 N/mm^2
Ultimate tensile strength	1.2 f_y
% Elongation (Low carbon steel)	20
Modulus of elasticity (E)	2 X 10^5 N/mm^2
Shear modulus (G)	0.4 E
Poisson's ratio (μ) a) elastic range b) plastic range	 0.3 0.5

Fatigue

1. Fatigue failure can occur in members or structures subjected to fluctuating loads such as crane girders, bridges and offshore structures.
2. Fatigue is damage caused by repeated fluctuations of stress leading to gradual cracking of a structural element.
3. Failure occurs through initiation and propagation of a crack that starts at a fault or structural discontinuity and the failure load may be well below its static value.
4. Welded connections have the greatest effect on the fatigue strength of steel structure. On the other hand, bolted connections do not reduce the strength under fatigue loading.
5. To help avoid fatigue failure, detail should be such that stress concentrations and abrupt changes of section are avoided in regions of tensile stress.



Brittle Fracture

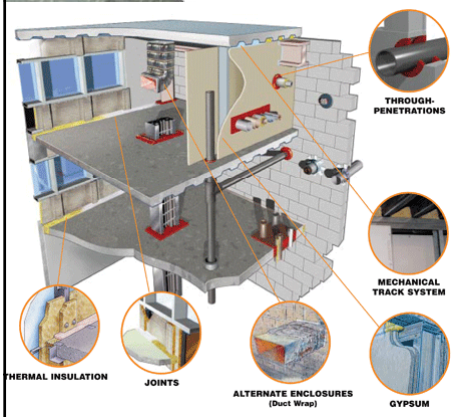
1. Structural steel is ductile at temperatures above 10^{o}C but it becomes more brittle as the temperature falls, and fracture can occur at low stresses below 0^{o}C.
2. The Charpy impact test is used to determine the resistance of steel to brittle fracture.
3. Brittle fracture can be avoided by using steel quality grade with adequate impact toughness. Quality steels are designated JR, J0, J2, K2 in order of increasing resistance to brittle fracture.
4. Beside the selection of steel grade, attention should also be focused on design details. Such as:
    1. Thin plates are more resistant than thick ones.
    2. Abrupt changes of section and stress concentration should be avoided.
    3. Fillet welds should not be laid down across tension flanges.
    4. Intermittent welding should not be used.

Brittle Fracture

- Brittle fracture occurs when critical combinations of the following exist:
  - A severe stress concentration due to severe structural discontinuity.
  - A significant tensile force occurs.
  - Low fracture toughness at service temperature.
  - Dynamic loading.

- In general, designing structures so that they only incorporate details that provide good fatigue performance is a very effective way of reducing brittle fracture.

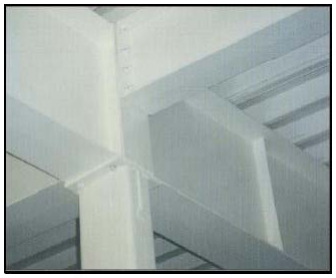
Fire Performance and Protection

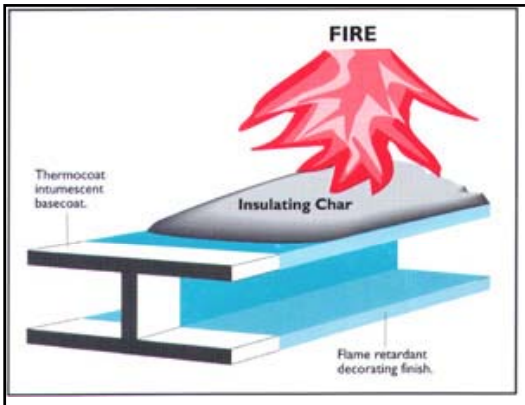


- Structural steelwork **performs badly in fires**, with the ***strength decreasing with increase in temperature***.
- At 550^{o}C, the yield stress has fallen to approximately 0.7 of its value at normal temperatures – that is, it has reached its working stress and failure occurs under working loads.

Fire Performance and Protection

- **The performance of steel in fire depends on:**
  1. The severity of the fire
  2. The protection applied to the steel
  3. The loads applied to the steel
  4. The size and properties of the steel members





Fire Performance and Protection

- Fire protection can be provided by encasing the member in concrete, fire board or cementitious fibre materials.
- Recently, ***intumescent*** paint is being used especially for exposed steelwork.

Intumescent paint :

- *It means that the paint does a lot more than simply decorate. At the first lick of a flame, the properly-coated surface that looks like any standard good quality paint job instantly starts to "intumescent"- to swell, to bulge-up into a solid foam. A film six mils thick (about 2 cigarette papers) will swell up to make almost an inch thick layer of black foam. With the first hot flash, on any surface protected*

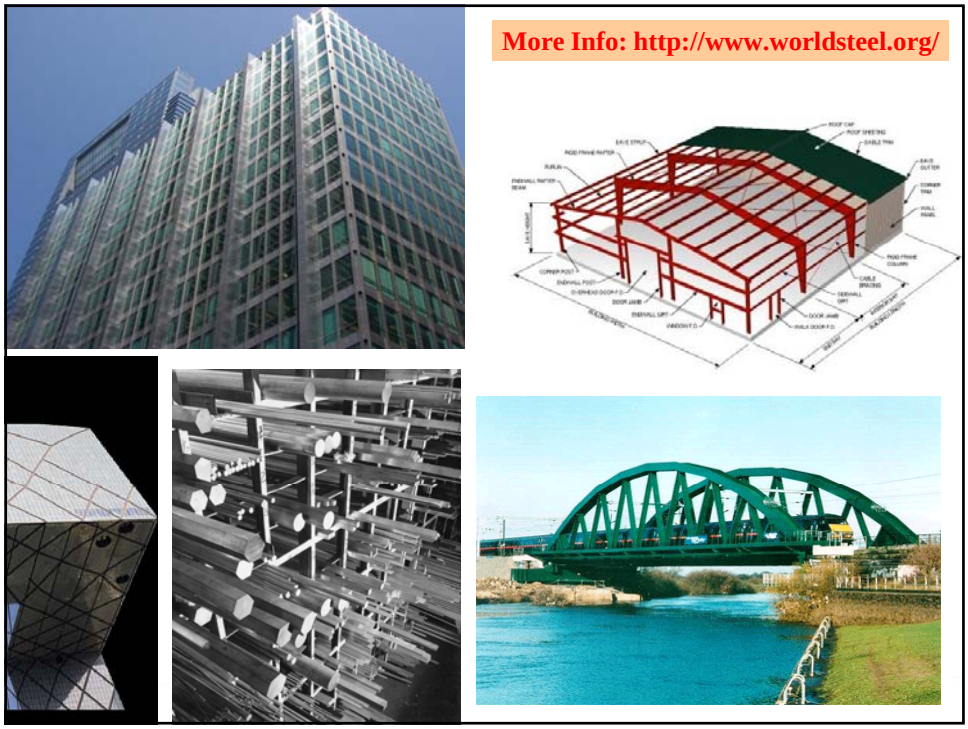
Corrosion Protection

1. Exposed steelwork can be severely affected by corrosion in the atmosphere, particularly if pollutants are present, and it is necessary to provide surface protection in all cases.
2. Many types of steel, including most common grades of structural steel will **corrode** if exposed to **moisture** and **oxygen**. If either or both of these are prevented from contacting the steel it will not corrode under normal circumstances.

Corrosion Protection

3. The type of protection depends on the **surface conditions** and **length of life required**.

4. The main types of protective coatings are:
   1. **Metallic coatings:** Either a sprayed-on in line coating of aluminium or zinc is used or the member is coated by hot-dipping it in a bath of molten zinc in the galvanising process.
   2. **Painting:** Where various systems are used. One common system consists of using a primer of zinc chromate followed by finishing costs of micaceous iron oxide. Plastic and bituminous paints are used in special cases.


More Info: http://www.worldsteel.org/