MATERIALS

Structural Engineering: The Art Of Using Materials to Build Real Structures to Withstand Forces So That Our Responsibility With Respect To Public Safety Is Satisfied.

Chapter 3

Material Selection




- Construction material has consequences for the structure's overall form and the building it supports. Additionally, the aesthetic makeup of the building is deeply affected by the construction material type.

- Accordingly, the selection of the material for a structure is one of the most crucial aspects of its design.

- Material selection criteria include Economy; the Physical and Mechanical properties of materials (Density, Strength, Stiffness or Rigidity, Ductility, Fire Resistance, Sustainability and Durability); Production and Construction Considerations, and Aesthetic Characteristics.

Environmentally Preferable Products (Epps)

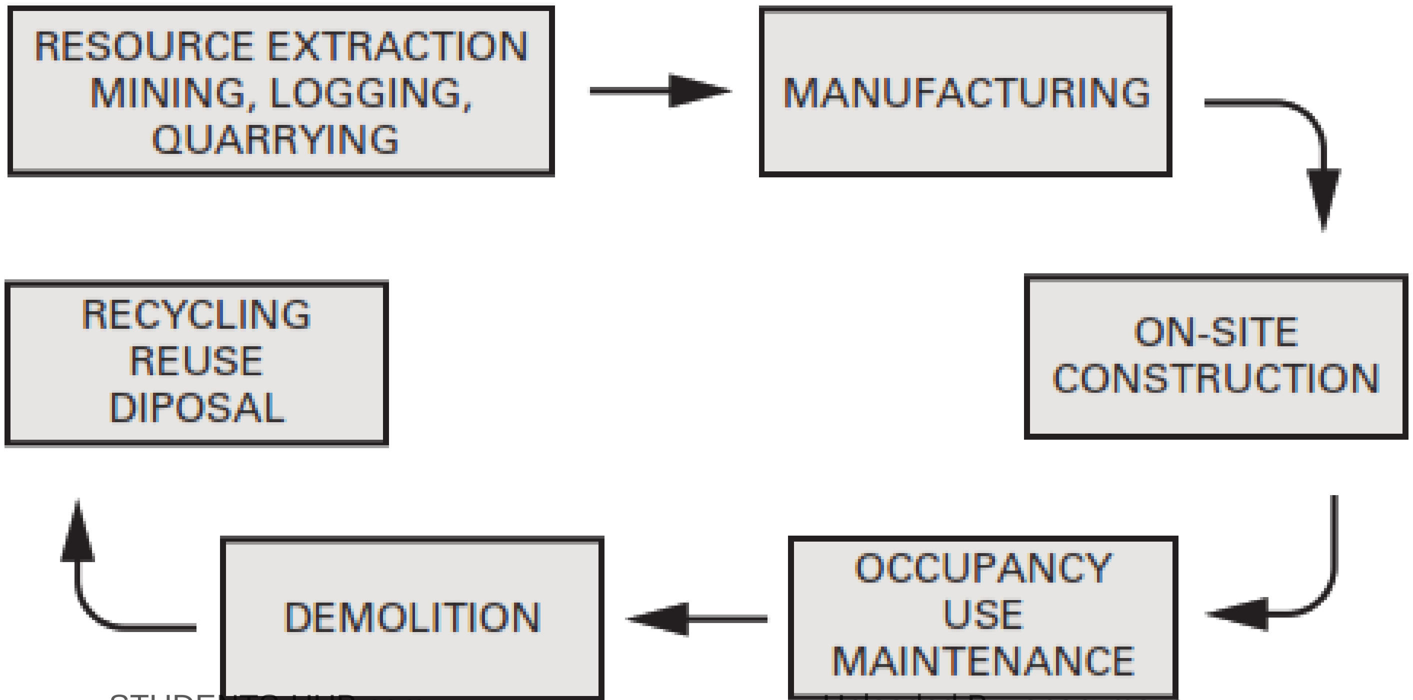
Section 3.1

Sustainable Materials

- Environmentally preferable products (EPPs) or Sustainable Construction Materials are defined as those that have "a lesser or reduced effect on human health and the environment when compared to competing products that serve the same purpose."
- Designers and builders should strive to specify materials that protect the natural environment, are renewable and recyclable, minimize resource and energy consumption, and are healthy and nontoxic.
- A complete life cycle assessment of proposed choices is recommended for a thorough understanding of the larger impacts of material selection.
- Life Cycle Analysis (LCA) is a comprehensive method that evaluates all resource and energy inputs, as well as emissions and waste produced throughout the entire life cycle of a material.

Embodied Energy

Embodied Energy refers to the total energy consumed throughout the entire life cycle of a construction material, from the extraction of raw resources to its manufacturing, use, and eventual reuse or demolition. Unlike the operating energy of a building, embodied energy is more complex to measure and requires a full life cycle analysis (LCA).



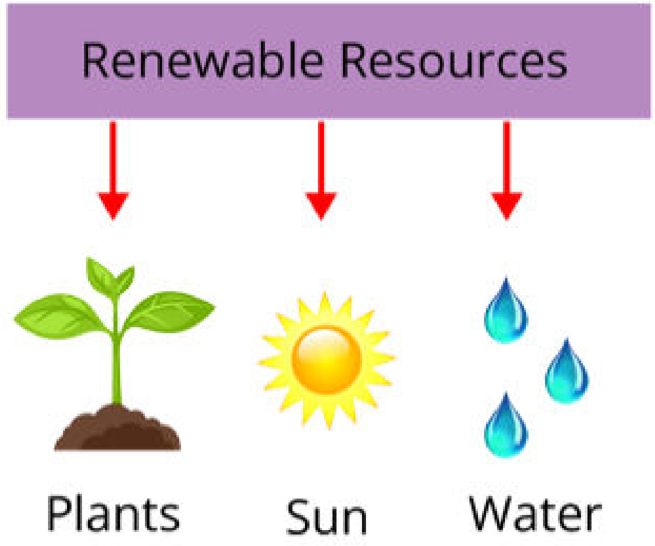
Natural Resources/Habitat Degradation

- The extraction and use of construction materials significantly impact ecosystems and natural resources.
- To minimize habitat degradation, it’s important to choose materials that reduce erosion, salinity, vegetation loss, soil nutrient changes, and landscape damage. Additionally, materials should be selected to avoid negative effects on water systems, such as nutrient and toxin pollution.

سلبيات صناعة الحجر في فلسطين

Renewable Materials

- Renewable materials come from living sources that can regenerate, such as plants, animals, or ecosystems. They are preferred because they can be sustained over time without depleting resources.



- Renewable materials often result in biodegradable waste and have lower CO_2 emissions throughout their lifecycle compared to fossil-fuel-based materials.
- Examples include sustainably harvested wood, bamboo, cork, and certain composites from agricultural products. These materials are environmentally friendly, as they can clean air and water, use low-energy processes, and are recyclable.

Recycled Materials

Materials that utilize the waste products from a variety of processes results in a reduced use of natural resources and energy consumption. Recycled content is generally classified into two categories:

- Post-consumer recycled materials: These materials have been used by consumers, collected, and then reprocessed for new uses. For example, PET plastic bottles can be recycled into carpeting, fabrics, and other building materials.
- Post-industrial recycled materials: These are created from industrial waste or by-products, repurposing them into new products and keeping them out of landfills. An example is using fly ash, a by-product from coal-fired power plants, as a substitute for Portland cement in concrete.

Toxicity to the Environment

- Non-toxic building materials should be used to ensure safer indoor environments, especially since humans spend over 80% of their time indoors. Several organizations now provide certifications to label this type of materials.

- Many synthetic materials contain volatile organic compounds (VOCs) that off-gas, releasing pollutants into the air at room temperature. These pollutants, found in over 500 common building materials, can cause health problems such as asthma, allergies, cancer, and disorders of the reproductive and nervous systems.

- Materials with high contamination risks, often used in recent decades, include polyvinyl chloride (PVC), formaldehyde products like plywood and particleboard, synthetic carpets, and sheet vinyl.

Toxicity Materials

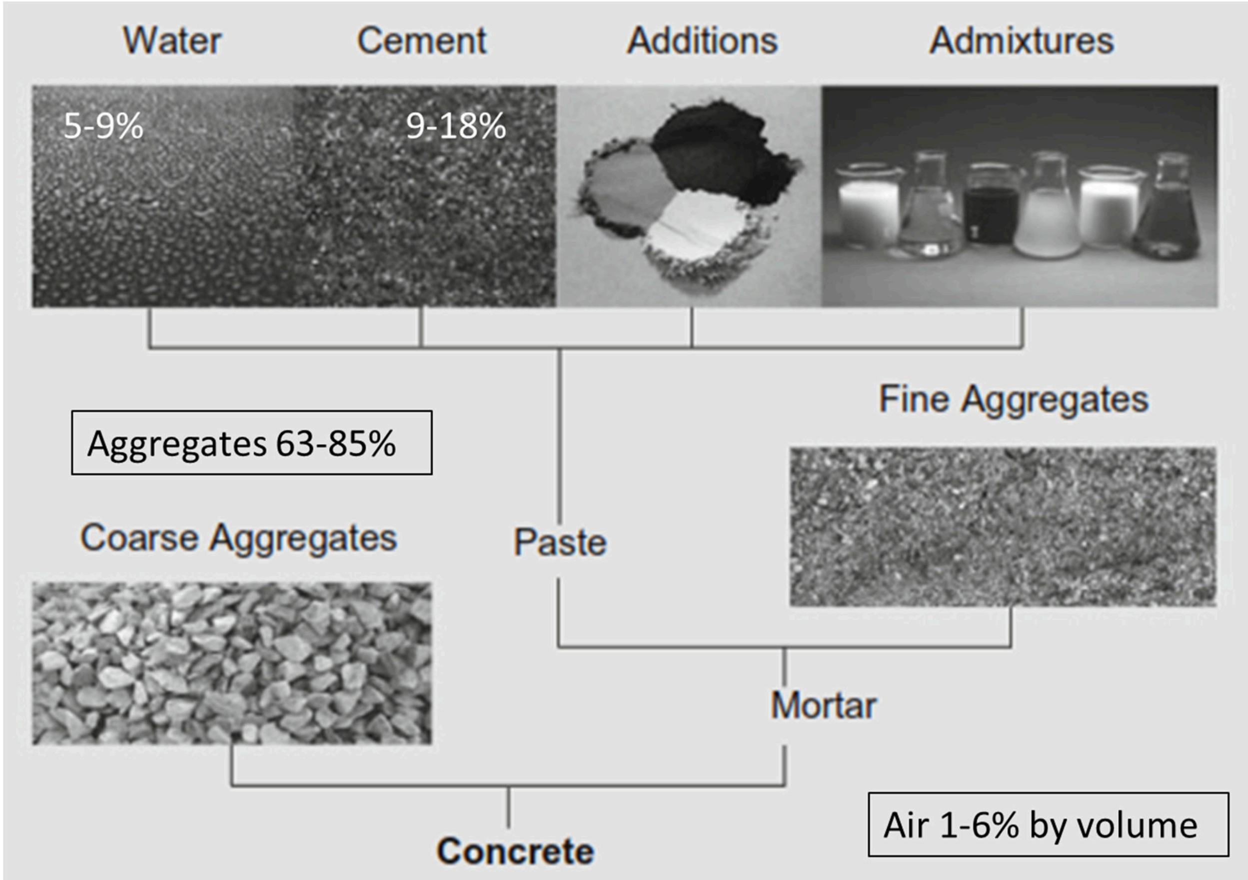
CONCRETE

Section 3.2

Importance of Concrete

- CONCRETE MAKES THE MODERN WORLD POSSIBLE.
- It is the basis of much of civilization's infrastructure and much of its physical development.

Concrete Components



- Twice as much concrete is used throughout the world than all other building materials combined. However, concrete still a sustainable building material because there is currently no better alternative

Advantages of Concrete

1. Ability to be Cast

Concrete is available in semi-liquid form during the construction process and this has three important consequences:

- First, it means that other materials can be incorporated into it easily to augment its properties.
- Second, the availability of concrete in liquid form allows it to be cast into a wide variety of shapes.
- Third, the casting process allows very effective connections to be provided between elements and the resulting structural continuity greatly enhances the efficiency of the structure.

Advantages of Concrete

2. **Economical:** concrete raw materials are widely available in great quantities, and concrete can be constructed by unskilled or semiskilled workers with relatively simple or unsophisticated equipment.

3. **Durable:** among the traditional construction materials, concrete is the most durable material as it requires Low maintenance, does not need protective coating except in very corrosive environments, and is an excellent fire-resistant material.

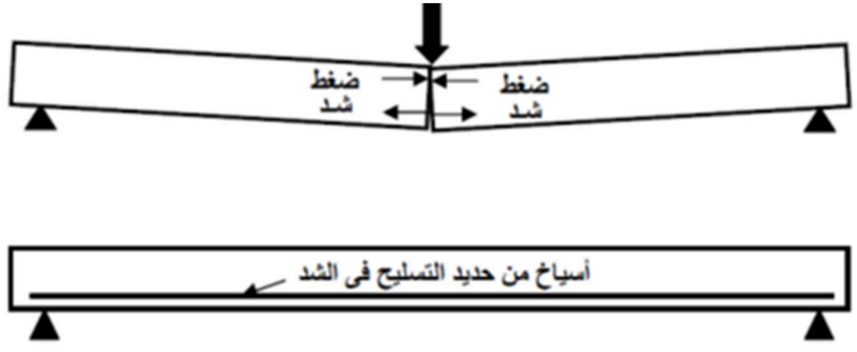
4. **Energy efficient:** Energy efficient: compared to other construction materials, concrete is a low-impact material with low energy requirements. Additionally, concrete buildings can be more energy–efficient to operate due to the thermal properties of concrete.

Advantages of Concrete

5. **Aesthetic possibilities**
   Concrete is very versatile and adaptable it can be colored, textured, and shaped easily. For the greater part of the Modern period it was the only material in which large-scale, free forms could be constructed.

Limitations of Concrete

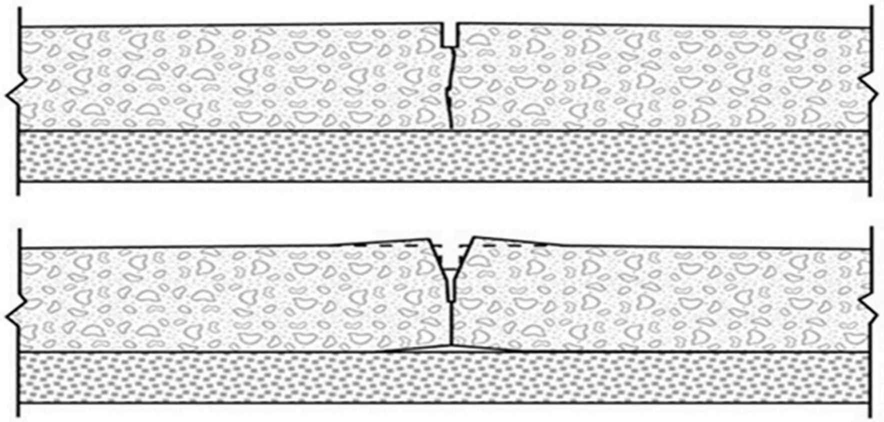
- Concrete has very low tensile stress, so it Can not be loaded in tension without reinforcement.



- The weight of concrete is high compared to its strength (low strength-to-weight ratio).

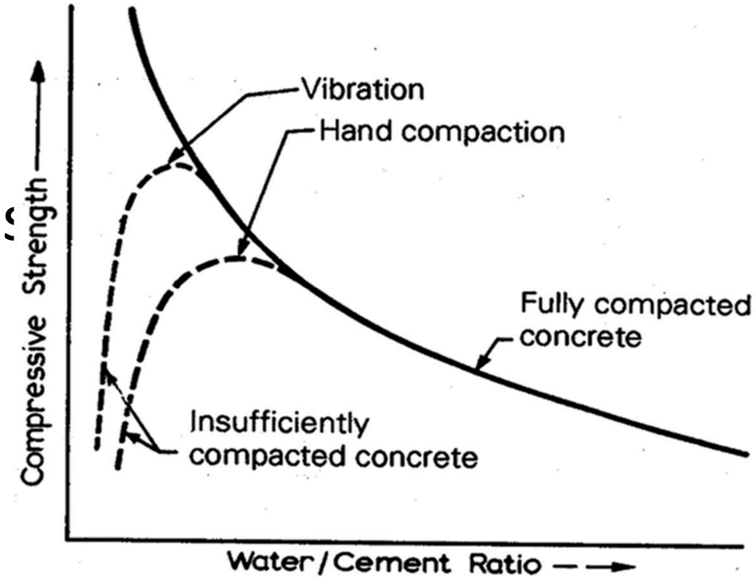
- Concrete is a brittle material and can suddenly fail.

- Volume instability: concrete undergoes considerable irreversible shrinkage due to moisture loss and also creeps significantly.



Concrete Strength

- **Compressive strength** of concrete is inversely proportional to the water/cement ratio according to Abrams law.



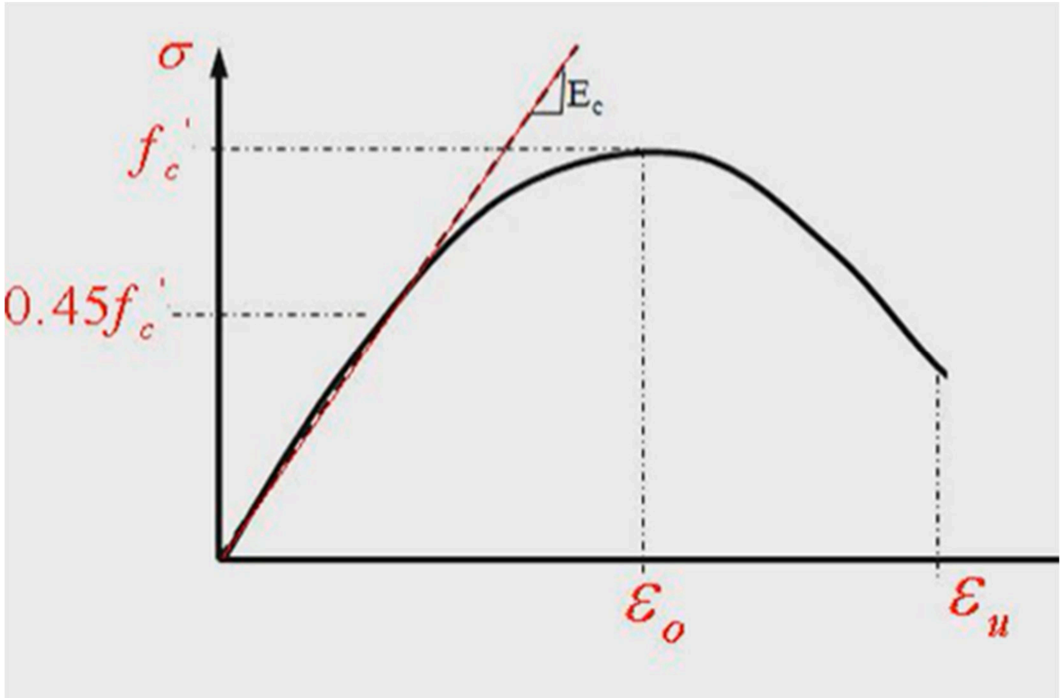
- **Concrete modulus of elasticity, Ec**: according ACI 318, for normal weight concrete $E_c = 4700\sqrt{f'c}$
- **Tensile strength**. The tensile strength of concrete is relatively low. It is approximate equals to about 0.1 f'c.

Typical concrete grades

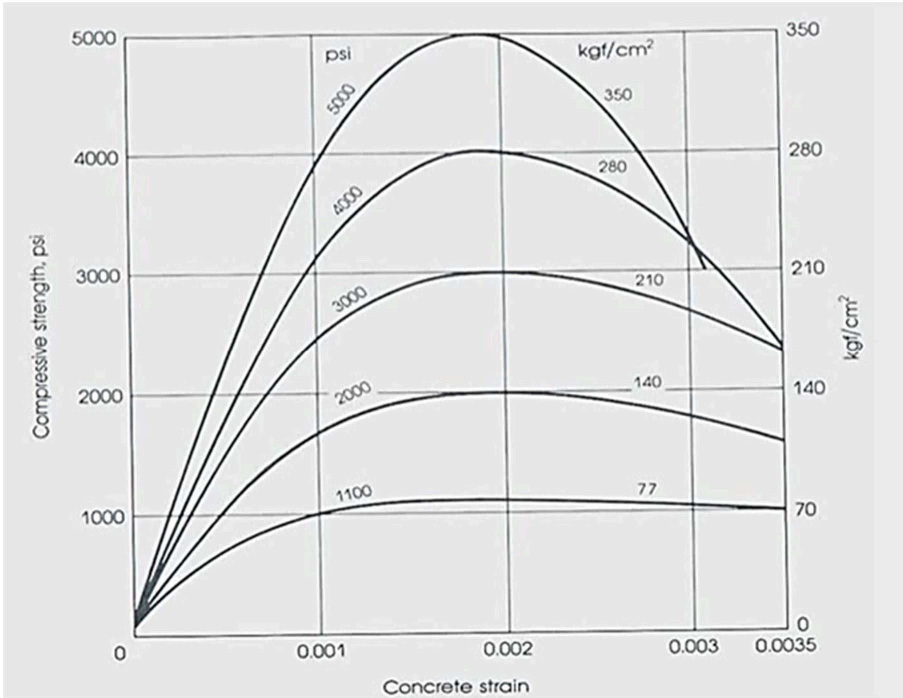
Compressive strength class	Min. Char. cylinder strength N/mm²	Min. Char. cube strength N/mm²	Compressive strength class	Min. Char. cylinder strength N/mm²	Min. Char. cube strength N/mm²
C8/10	8	10	C40/50	40	50
C12/15	12	15	C45/55	45	55
C16/20	16	20	C50/60	50	60
C20/25	20	25	C55/67	55	67
C25/30	25	30	C60/75	60	75
C28/35	28	35	C70/85	70	85
C30/37	30	37	C80/95	80	95
C32/40	32	40	C90/105	90	105
C35/45	35	45	C100/115	100	115

Stress-strain curve of concrete

- The first portion of the curve to about 40-45% of the ultimate strength, f'c, can be considered liner for all practical purposes.
- Usually concrete can reach a strain of 0.003 or larger before actual crushing occurs. Typically $\varepsilon_o = 0.002 \; and \; \varepsilon_u = 0.003$



Modified



Typical

High-Performance concrete

- High-performance concrete (HPC) exceeds the properties and constructability of normal concrete. Some of the characteristics include: enhanced durability, enhanced engineering properties, such as high strength, high early strength, high modulus of elasticity, toughness and impact resistance, and volume stability; and other enhanced properties, such as ease of placement, temperature control, compaction without segregation, and inhibition of bacterial and mold growth.

- High strength concrete. The definition of high strength changes over the years as concrete strength used in the field increases. Concrete with a design strength of 130 MPa has been used in buildings.

High-Performance concrete

Tadao Ando: emphasizing nothingness and empty space to represent the beauty of simplicity

High-Performance concrete

High Rise
Buildings

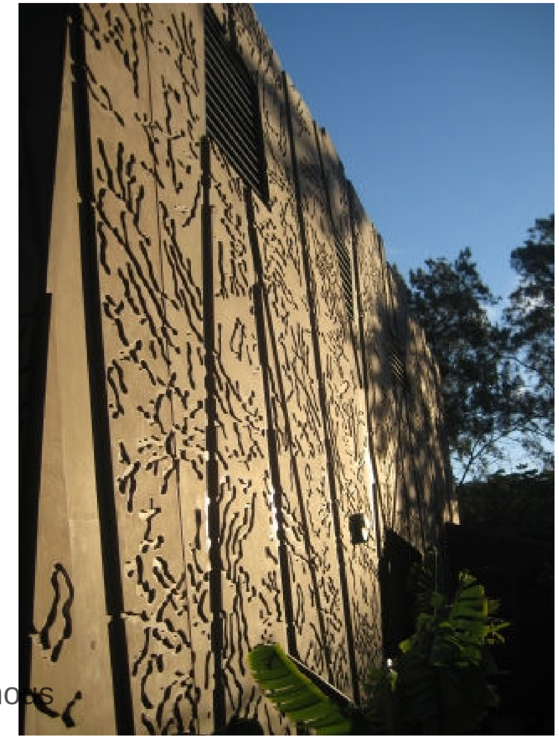
Pre-stressed Concrete

- Pre-stressed concrete is a form of concrete used in construction that is "pre-stressed" by being placed under compression before supporting any loads beyond its own dead weight.

- Pre-stressing removes several design limitations conventional concrete faces on span and load and permits building roofs, floors, bridges, and walls with longer unsupported spans.

Precast Concrete

- Precast concrete is created off-site, and poured into a wooden or steel mold with wire mesh or rebar. This mold may also have prestressed cables if needed. It is cured in a controlled environment and once finished, the precast concrete is transported to a construction site and put into place.



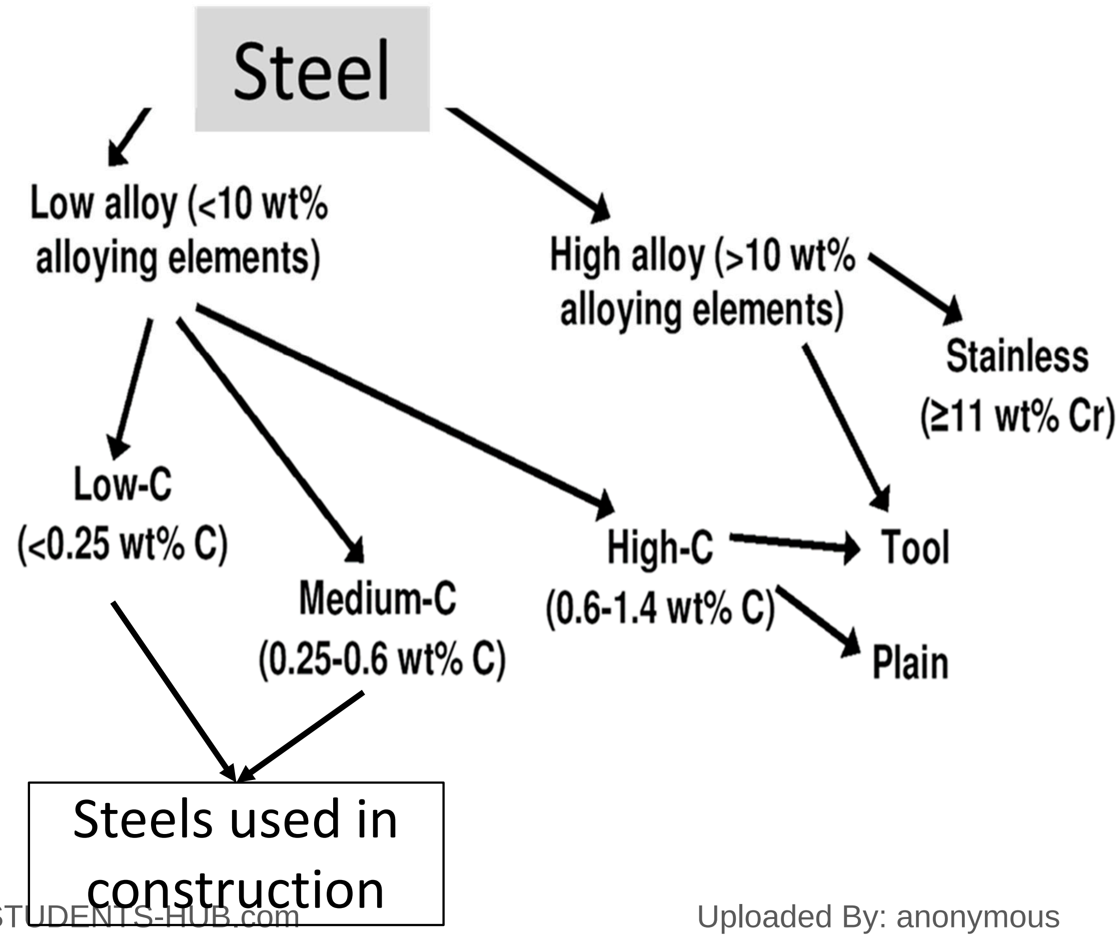
- Precast concrete is usually used in various structures ranging from parking garages, bridges, and office buildings to stadiums, retail shops, and housing. In addition to several infrastructure applications such as culverts and retaining walls.

STEEL

Section 3.3

Steel

Steel is mainly an alloy of iron and carbon, however other elements such as Aluminum, Nickel, Chromium …etc, can be added to alter the characteristics of steel further.



Steel Advantages

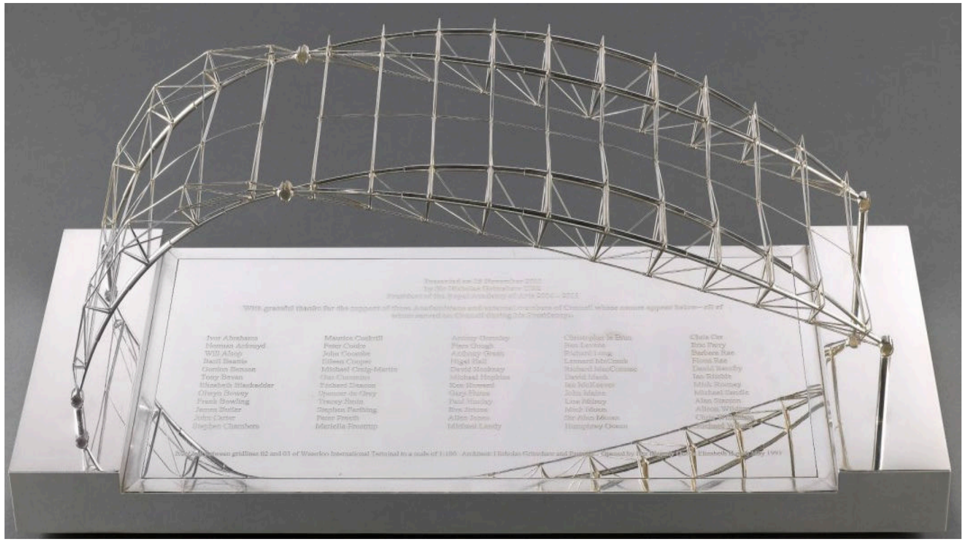
- Steel is the strongest of the commonly used structural materials, and has a high strength-to-weight ratio, thus used for the tallest buildings and the longest spans.
- Steel has more-or-less equal strength in tension and compression and is, therefore, able to resist tension, compression, and bending well.
- Steel is ductile, therefore can be utilized to resisted earthquake loads effectively.
- The ability to join members either with welding or mechanical fastening.
- The properties of steel can be tailored through alloying and heat treatments.

Steel in Architecture

- Steel properties has allowed steel to be used in all types of structural configurations and, since its introduction at the beginning of the Modern period, has released architects from many of the constraints on form which had formerly been imposed by the limitations of the traditional structural materials.
- Recent developments in steel fabrication technology has allowed its use to be extended to large-scale and very complex curvilinear shapes.
- Much of the free-form architecture of recent decades involves the use of inefficient semi-form active structural configurations that would have required impossibly bulky elements for support were it not for the use of a very strong structural material.

Steel in Architecture

Steel in Architecture



Steel Limitations

- Steel is a material that carries a very high environmental cost, with a large carbon footprint and high embodied energy. Although recyclable, the energy input required is considerable.
- Two problems associated with steel are:
  - its poor performance in fire, due to the loss of mechanical properties at relatively low temperatures, and
  - its high chemical instability, which makes it susceptible to corrosion.
- Both of these have been overcome to some extent by the development of fireproof and corrosion protection materials, especially paints, but the exposure of steel structures, either internally, where fire must be considered, or externally, where durability is an issue, is always problematic.

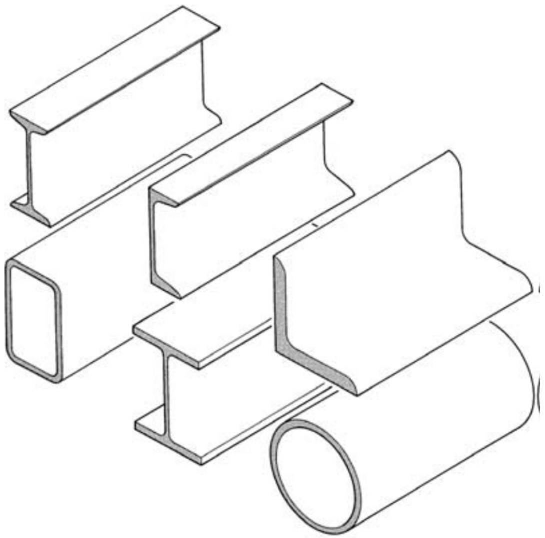
Steel Limitations

- Most of the structural steelwork used in building consists of elements of the hot-rolled type and this has important consequences for the layout and overall form of the structures.

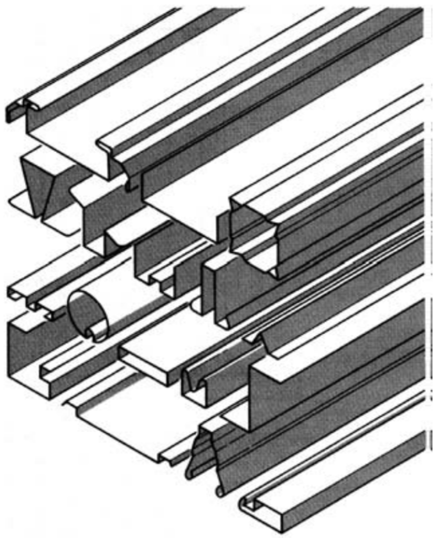
- A consequence of the rolling process is that the constituent elements are prismatic (straight, parallel-sided with constant cross-sections) and this tends to impose a regular, straight-sided format on the structural forms for which it is suitable. However, in recent years, methods have been developed for bending hot-rolled structural steel elements into curved profiles and this has extended the range of forms for which it can be used.

Structural Steel Elements

Steel is available for construction in the form of ready-made elements. The shapes of steel elements are formed by hot-rolling, cold-forming, and casting.



Hot-rolled steel elements

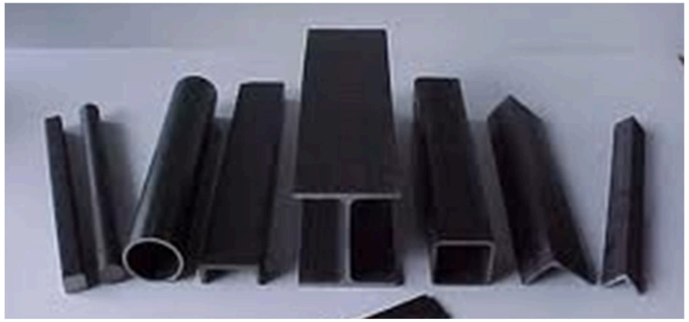


Cold-formed sections

Fabrication by casting: very complex tailor-made shapes are possible.

Hot-Rolled Shapes

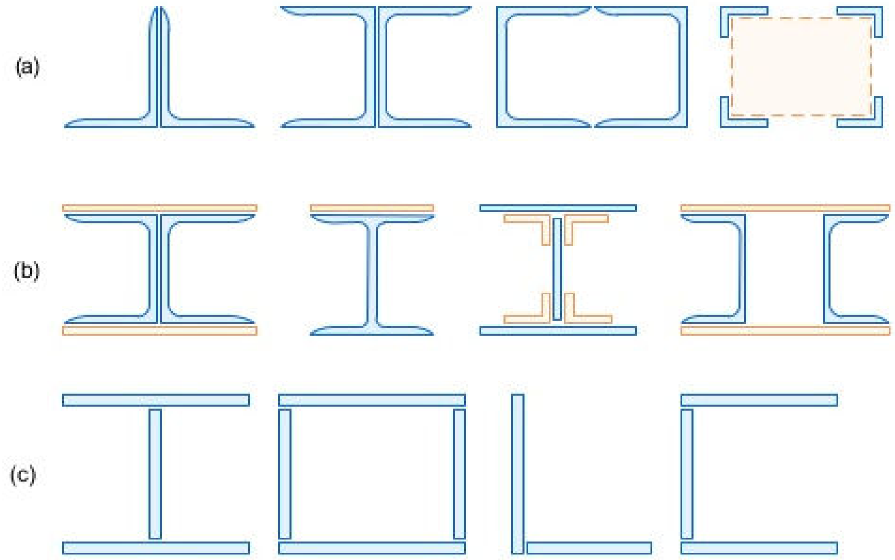
- Hot-rolling is a primary shaping process in which massive red-hot billets of steel are rolled between several sets of profiled rollers.
- Elements that are intended for structural use have shapes in which the second moment of area is high in relation to the total area
  - I- and H-shapes of cross-section are common for the large elements that form the beams and columns of structural frameworks.



  - Channel and angle shapes are suitable for smaller elements such as secondary cladding supports and sub-elements in triangulated frameworks
  - Square, circular and rectangular hollow sections are produced in a wide range of sizes. Details of the dimensions and geometric properties of the sections are available from manufacturers.

Built Up Sections

Alternatively to standard sections it is possible to form welded sections with various cross section configurations using standard sections and plates or from welding different plates together.



Some typical built-up shapes and sections (a) made from standard shapes, (b) made from standard shapes and plates, (c)made from plates

RC Concrete Vs Steel Structures

No	Difference	RC Structures	Steel Structures
1	**Material**	The basic material used is reinforced cement concrete to take up the load	Steel is the material used to take the load
2	**Cross-section of Structural Element**	In RC structures, the cross-section of the structural elements is large	The structural elements of steel structures have small cross-sections.
3	**Durability**	The durability of concrete is high. High-quality RC structure is less affected by common weather and environmental conditions.	The steel structures are prone to rust when exposed to environmental conditions. Hence steel structures have less durability.
4	**Resistance to Earthquake/ Dynamic Loads**	RC structures are highly brittle in nature. These type of structure have less resistance to dynamic loads like earthquakes and wind.	Steel structures are ductile in nature thus increasing their resistance to dynamic loads.
5	**Load Carrying Capacity**	RC structures have low load-carrying capacity compared with steel structures.	The steel structures have an appreciable load-carrying capacity.

RC Concrete Vs Steel Structures

No	Difference	RC Structures	Steel Structures
6	**Self-Weight**	Construction of structures with concrete consumes large amount of raw materials. Hence the self-weight of reinforced concrete structures are high.	The steel, in general, has 60 percent less weight compared to concrete.
7	**Foundation**	Reinforced concrete structure possesses huge dead weight which hence demands a strong foundation to support.	Steel structures do not demand heavy foundation.
8	**Tensile Strength**	In RC structures, the tensile strength of the concrete elements is less compared to steel structural elements.	Steel structural elements have high tensile strength compared to RC structures.
9	**Labour Requirement**	The construction of reinforced concrete structures is labor-intensive.	Construction of steel structures requires less labor. Most of the components are fabricated in the workshop and assembled at the site.
10	**Construction**	Construction of RC structure is simple.	Construction of steel structure is tough.

No	Difference	RC Structures	Steel Structures
11	**Cos of construction**	Economical	Costly
12	**Construction Speed**	Reinforced concrete structures require time for concreting, curing etc. which is a slow process.	Steel structures are constructed with high speed.
13	**Quality control**	It is tough to maintain quality through concrete construction.	Better quality control can be obtained in steel structures.
14	**Fire Resistance**	The fire resistance of the concrete structure is high.	The fire resistance of steel structure is less.
15	**Scrap Value**	Concrete does not have any scrap value.	The steel scraps have a good scrap value.
16	**Corrosion**	A properly designed and constructed reinforced concrete structure is not prone to corrosion.	The steel frame structure has chances to deteriorate due to corrosion.
17	**Repair and Maintenance**	The repair and cost of maintenance of the concrete structure are tough and time taking.	Steel structures can be repaired very easily and hence their cost of maintenance is less.

TIMBER (WOOD)

Section 3.4

Advantages of Timber

- lightweight material with a high ratio of strength to weight.
- It can, be relatively easily joined together which allows the build up of large structures.
- It can resist tension and compression with equal facility and therefore also bending.
- Of the four principal structural materials timber is the only one that is sourced from raw material that is renewable and potentially inexhaustible provided that the forests from which it is extracted are appropriately managed.
- Timber components can also be re-used, if carefully removed from obsolete buildings, and are suitable for various forms of recycling. It is therefore likely that the importance of timber, as a structural material, will increase with the need to develop sustainable forms of architecture.

Advantages of Timber

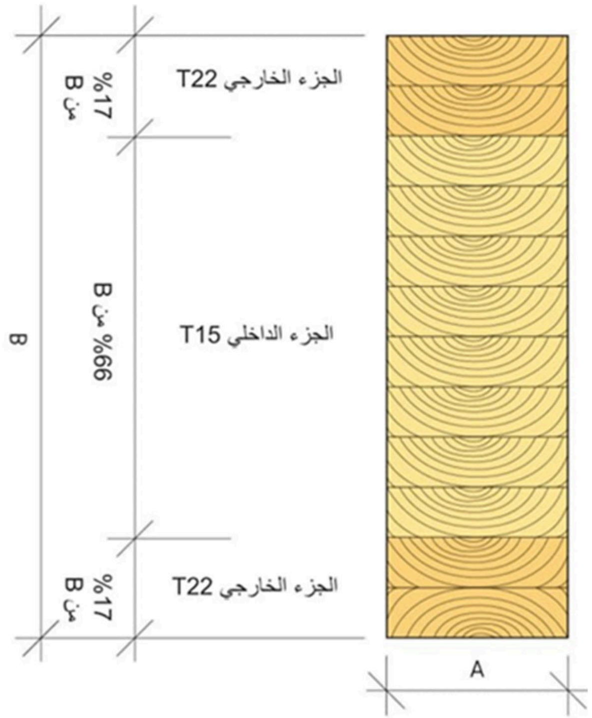
Limitations of Timber

Principal disadvantages are variability, dimensional instability, the restrictions in the sizes of individual components and anisotropic behavior.

- Its use involves the acceptance of certain restrictions, such as those imposed by the forms in which it becomes available. Additionally, the structurally weak nature of the joints imposes restrictions that have to be respected.
- Perpendicular to the grain it is much less strong because the fibers are easily crushed or pulled apart when subjected to compression or tension in this direction.
- Volume change due to moisture content variations

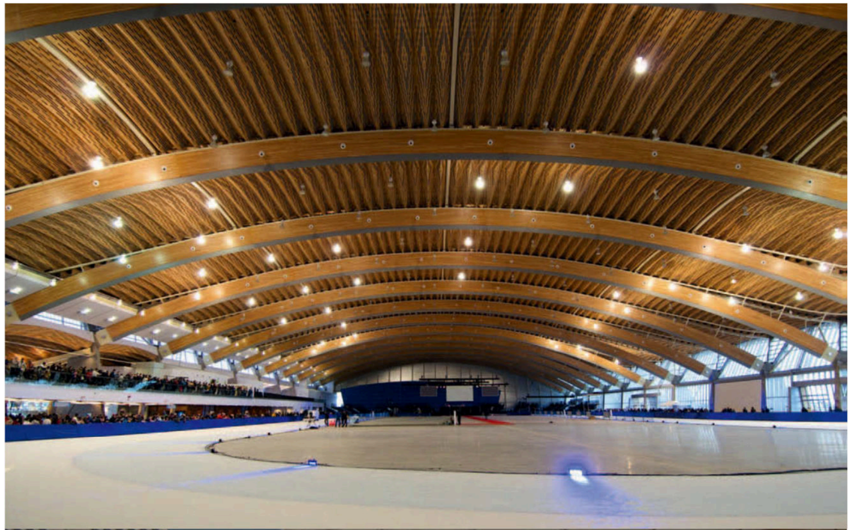
Engineered Timber

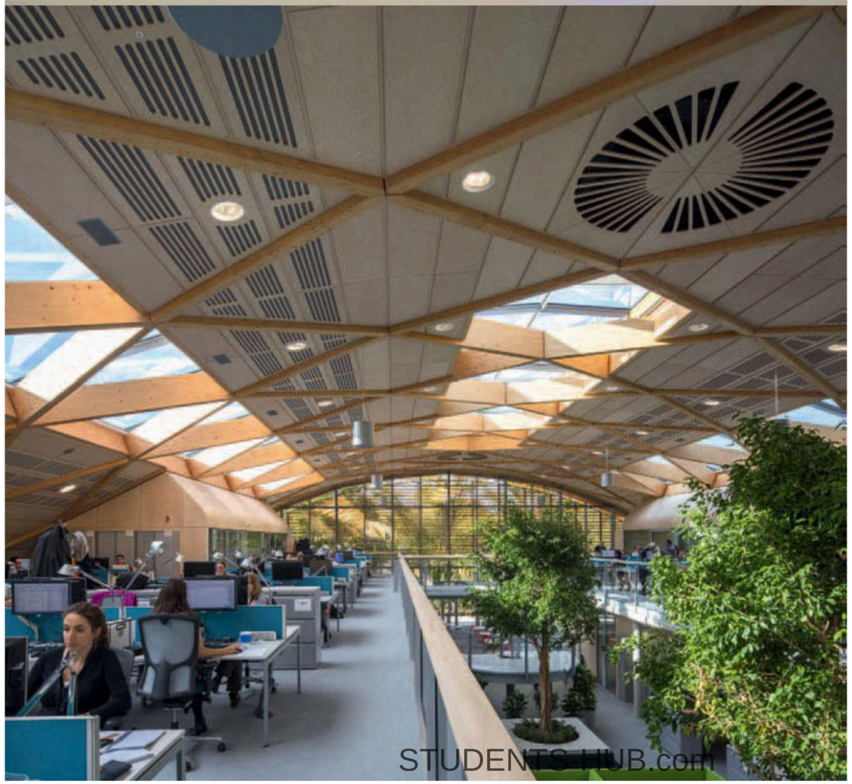
- Manufactured by gluing small elements together in conditions of high quality control. They are intended to exploit the advantages of timber while at the same time minimizing the effects of its principal disadvantages.



- The obvious advantage of the process is that it allows the manufacture of solid elements with much larger cross-sections than are possible in sawn timber. Very long elements are also possible.
- The laminating process also allows the construction of elements that are tapered or have curved profiles

Timber In Architecture





- Its most widespread application in architecture has been in buildings of domestic scale in which it has been used to make complete structural frameworks, and for the floors and roofs in post-and-beam loadbearing masonry structures.
- Rafters, floor beams, skeleton frames, trusses, built-up-beams of various kinds, arches, shells and folded forms have all been constructed in timber

Mechanical Properties Of Materials

	Weight Density		Ultimate Stress				Modulus of Elasticity		Coefficient of Thermal Expansion	
			Tension		Compression					
	kN/m³	(lb/ft³)	N/mm²	(10³ psi)	N/mm²	(10³ psi)	10³ N/mm²	(10⁶ psi)	10⁻⁶/°C	(10⁻⁶/°F)
Acrylic Glass (PMMA)	12	(77)	80	(12)	120	(17)	3	(0.4)	110	(61)
Aluminium	27	(172)	270	(39)	270	(39)	70	(10)	24	(13.3)
Clay Brick Masonry	19	(120)	-	-	10	(1.5)	10	(1.5)	5	(2.8)
Concrete	23	(144)	-	-	20-140	(3-20)	30-50	(4-7.5)	10	(5.6)
Glass Fiber Reinf. Polymer (GFRP)	19	(121)	500	(72)	500	(72)	45	(6.5)	25	(13.9)
*Glass Fiber Fabric, PTFE coat.**	*0.012 kN/ m²*	*(0.25 lb/ft²)*	*16N/mm*	*(91 lb/in)*	-	-	-	-	-	-
Float Glass	25	(160)	30	(4.5)	200	(29)	70	(10)	8.5	(4.7)
Polycarbonate (PC)	12	(77)	65	(9)	80	(12)	2.4	(0.3)	65	(36)
Steel - Structural (typical)	77	(490)	400	(58)	400	(58)	210	(27)	12	(6)
Steel - High Strength (typical)**	77	(490)	600	(87)	600	(87)	210	(27)	12	(6)
Stone	25	(160)	-	-	60-130	(9-19)	20-100	(3-15)	12.5	(6)
Wood (softwood, fiber direction)	5	(32)	30	(4.5)	30	(4.5)	11	(1.6)	5	(2.8)

Examples of mechanical properties of a number of materials.
Note: Numbers given for stress and elasticity, especially, are highly approximate; in reality these vary substantially according to the quality/type of the material. For a more precise and detailed account, see specialized literature.