CCT 3113
Analysis and Building Structure
STUDENT HANDBOOK

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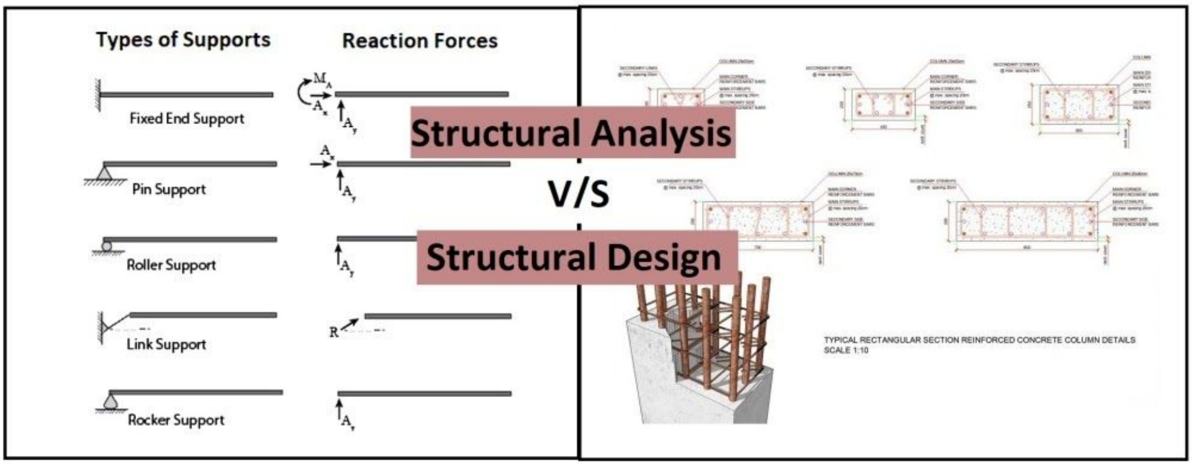
The author created this for the student's guide on the course.

Analysis and Building Structure - CCT3113

Every object is a structure. Structure is made by connecting various member to make it whole to perform the intended function. Natural structures vary from the very smallest part of an atom to the entire creation of the universe. Man-made structures include buildings, bridges, dams, ships, airplanes, rockets, trains, cars, and even large artistic sculptures. Structural engineers design and access structure to ensure that they are functionally efficient and stable.Structural analysis deals with a calculation of load coming on the members and analyze them whereas, structural design decides the dimension (shape and size) of the structural members on the basis of calculated load from structural analysis.Structural engineers are responsible for both “structural analysis” as well as “structural design”. Both are an important part of civil engineering. So, it is essential that one must have clear understanding of structural analysis and design both the terms. Here we have explained the differences between structural analysis and structural design.



Structural Design vs Structural Analysis

Structural Analysis	Structural Design
The process to determine the response or behavior of a structure under some specified loads or combinations of loads is known as structural analysis.	The process to find out the safe, durable and economical specifications of the structure including materials, technology, geometry, the size of structural members sufficient to carry loads of structure during the life period of the structure is known as structural design.
The analysis process is done by making some assumptions. In the analysis, i.e. we assume the dimensions of the all the structural elements, loads, material properties, and support conditions. The sizes are generally assumed either from experience or by thumb rule which have arrived at empirically historically.	The design process of any structure starts with the selection of materials vis a vis construction technology, and of course the structural system, which is core and most important. The choice of material depends on local availability and cost, while technology will depend on the availability of skilled manpower, and plant and machinery needed.

Analysis of a structure involves its study from the viewpoint of its strength, stiffness, stability, and vibration and response of all elements.	Design of structure involves its study from the viewpoint of its serviceability (it means that structure is in that condition in which it is still considered as useful and safe for occupants), safety, and durability.
Response means to find out support reactions, shear forces, bending moment, torsion, deflection, stress, strains etc., that the particular member would undergo due to the applications of loads.	It is process to find out geometry, size and shape of all the members of structure. In structural design individual elements as well as joints are designed.
For structural analysis, one must have knowledge about the behavior of structural elements, and hence basic mathematics, and basically physics i.e. structure mechanics. For assumed section one has to find reactions, moments so that resulting stress, strain etc. can be checked.	The process of design requires not only imagination and conceptual thinking but it basically requires the knowledge of basic mechanics including physics and chemistry of materials. And also, sound knowledge of practical aspects such as basic mechanics, recent design codes, and bye-laws which provide the guideline for the safe structural design.
It is important because it evaluates the different loads on structures, and their effects. It is an accurate method to ensure the capability of the structures to resist the different expected loads, and assist in designing the structures accordingly. Structural analysis is important because it can check out whether a specific structural design will be able to withstand external and internal stresses and forces expected for the design. A basic reason that structural analysis is beneficial is to determine the cause of a structural failure.	The structural design is important as structures are intended for human habitat and related uses for different human activities with structural safety not only for its own sake but for safety and security of human life, as it all depends on the adequacy of the structure. Structural design is important as it provide safety to the structure as well as occupants during its intended life without failure, with minimum repair and maintenance.
● When conducting analysis, civil/structural engineer investigates magnitude of force applied on the structure, direction of force, and the position on which the force acts. Steps for Analysis of Structure ● Structural Idealization ● Applying Loads	In the structural design once reactions are known which we get from the analysis we start the design process. We check whether the selected geometry and assumed dimension and size fulfills the design load criteria or not. If not then, we change the dimensions of the element and redesign it. The process is continued till the design criteria are totally fulfilled i.e. stresses in member do not exceed permissible limits and permissible deflection etc. All the elements are

• Calculating Reactions • Calculating Internal Forces • Calculating Internal Stresses • Evaluating Efficiency and safety	checked for its load resisting capacity i.e. stress of different types i.e. flexure, direct shear and stress etc., strain, deflection, rotation etc. If it exceeds permissible limits it has to be redone again and again until it falls within the permissible limits as per codes of design.
The geometry is assumed to find out reactions.	For given loading, geometry is checked, assured and ascertained.
The structure we are going to build has assumed some specific lifespan. We are going to design it in such a way that it must be capable of taking all applied load (dead as well as live) without failure during its lifespan. So, before the design, we have to determine the behavior of the structure under different load conditions. The structure is analyzed for different load combinations like gravity load, live load, wind load, earthquake load.	The structure must be capable of giving safety to the occupants (human) from heat, rain, earthquake, fire, flood, animals. It means that it must be capable of giving safety to the structure as well as occupants from the all the aspects. So, the main purpose of design is to produce a structure which is capable of resisting all applied loads and give safety to the occupants without fear of failure during its intended life.
Methods of Structural Analysis 01. Analytical Method In analytical method there are three approaches: • The mechanics of material approach also known as strength of materials. • The elasticity theory approach. • And the finite element approach. 02. Method using Numerical Approximation 03. Finite element method	Methods of Structural Design 01. For RCC and Steel Structure • Working stress method • Ultimate load method • Limit state method 02. For Wooden Structure • Allowable stress design • Load and resistance factor design
There is only one specific solution, once the system is frozen.	There can be many possible solutions, with variation in materials and its properties.
From the analysis we can get bending moment diagram, shear force diagram, deflection curve, shear stress and strain etc.	From the design we can prepare detailed drawing for execution with details of reinforcement in case of RCC structures, details of weld or bolts in case of steel structure, and details of joints in case of wooden framed structure.

Result that we get from analysis always remains with structural engineer.	Structural engineer studies the data we get from analysis, and design and finalizes the design of member and prepare the drawing for execution.
Software Used for Structural Analysis • ANSYS • STAAD.Pro • ETABS • SAP • ABAQUS • EdiLus • MasterFrame FEA • Microstran • RISA-2D • RISA-3D etc • Tekla	Software Used for Structural Design • STAAD.Pro • ETABS • SAP • SAFE • STAAD Foundation Advanced etc

Role of Structural Designer in Relation to Construction

Structural engineers design, plan and oversee the construction of new buildings and bridges, or alterations and extensions to existing properties or other structures.

What does a structural engineer do?

Structural engineers are primarily concerned with designing and constructing buildings and structures that are safe and capable of withstanding the elements to which they will be exposed, as well as improving the structural integrity of existing buildings. The job is very closely related to that of civil engineer.

Key tasks of a structural engineer include:

- preparing reports, designs and drawings
- making calculations about loads and stresses
- selecting appropriate construction materials
- providing technical advice
- obtaining planning and/or building regulations approval
- liaising with relevant professional staff such as architects
- monitoring and inspecting work undertaken by contractors
- administering contracts
- managing projects
- inspecting properties to check conditions/foundations.

Most structural engineers work either for construction/engineering consultancies – where they focus on designing structures and tend to work in an office environment – or for contractors, where they will oversee the construction of the structure, working on site. Most engineers will specialise in a type of project (or infrastructure), such as bridges or buildings.

Types of Structures and Structural Components

Structures are everywhere in the built environment. Buildings, bridges, tunnels, storage tanks, and transmission lines are examples of a "structure." Structures differ in their makeup (i.e., the type and configuration of the components), and also in their function . Our approach to describing a structure is based on identifying a set of attributes which relate to these properties.

Structures can be classified in a number of ways:

A. Type of Structure

Different structures have different functions. We can group structures based on their functions. We can also group structures based on their forms. Different structural forms can support different loads.

Structures have five basic forms: solid, frame shell, membrane and composite.

1. Solid Structure - A solid structure uses solid construction materials to support loads. A solid structure usually has a large mass. A well-made solid structure can last a long time. A concrete dam, a wooden telephone pole, and a marble statue are examples of solid structures. The image below is the Magat Dam. The dam has thick concrete at the bottom where the load forces of the water are huge.

2. Frame Structure

   A frame structure uses a network, or skeleton, of materials that support each other. Frame structures can be very strong. The parts of a frame work together to resist forces. Frame structures are also lighter than solid structures. A goalie's net and a spiderweb are examples of frame structures. Many buildings use frame structures; an example is the Philippine Bank of Communications (PBCOM Tower) in Makati City.

A frame structure may have a membrane stretched over it, but the membrane does not help support loads. For example, a tent may be made of a metal frame with fabric stretched over it. The fabric does not help support loads.

3. Shell Structures

   A shell structure has a hollow with a curved shape providing high strength and rigidity Shell structures are strong and rigid, but they can also be very light.

The New Mactan International Airport is an example of a shell structure.

4. Membrane Structures

Structure with a thin, flexible surface (membrane) that carries loads primarily through tensile stresses. There are two main types: tent structures and pneumatic structures.

SM City Cebu Bus Station is an example of a Membrane Structure

5. Composite Structure

Most structures are combination structures. They have solid, shell, frame and membrane parts. For example, most buildings have a solid foundation. They also have a frame of wood or metal that supports a shell of brick or concrete.

B. Structural System

Structural systems are those elements of construction that are designed to form part of a building's structure either to support the entire building (or other built asset, such as a bridge or tunnel) or just a part of it. So, a steel frame is a structural system that supports the building and everything on it and in it. A space frame is a structural system that typically supports the roof.

Types of Structural system

a. Tensile.

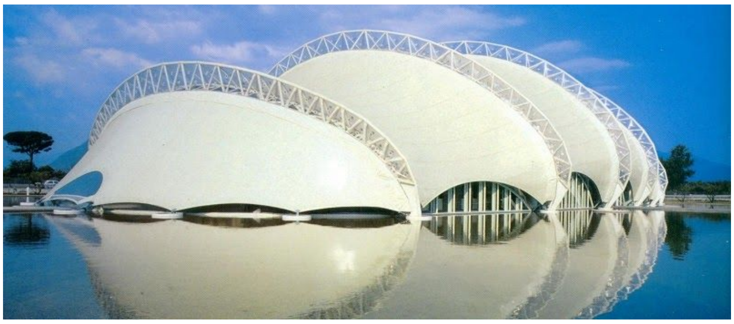
A tensile structure is a structure that is stabilised by tension rather than compression. For example, a piece of fabric pulled in opposite directions.

In practice, structures tend to carry both tension and compression, and it is the degree to which a structure is intentionally tensioned to stabilise it that determines whether it is considered a tensile structure.

Tensioning is usually achieved with wire or cable, opposed by compression elements such as masts, and held in place by foundations, ring beams, ground anchors and so on. Tensioning can also be achieved through inflation.

Structures with tension elements include:

- Fabrics structures

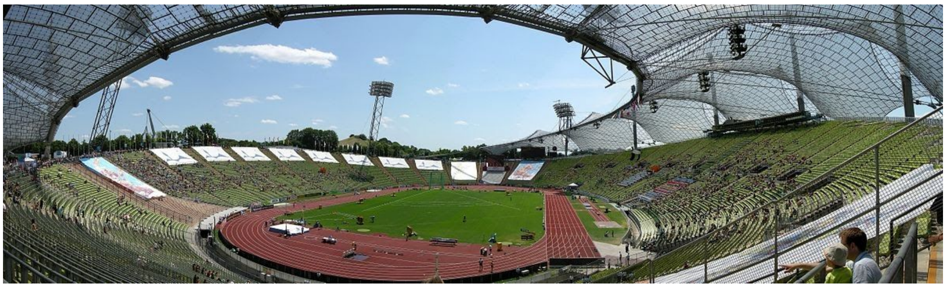


  Fabric structures are tensile structures in which a membrane is 'stretched' to form a three-dimensional surface that can be used to create a roof, shading, or decorative component. Sometimes described as 'modern tents', fabric structures use very little material compared to other forms of construction, and are typically translucent, but they provide little thermal mass or insulation and can have a shorter lifespan than some other materials.

  Typically, the membrane is formed by a structural fabric, consisting of a woven base cloth, coated on both sides, and held in position by tension forces imposed by a structural framework or a cabling system. Unlike conventional roofing systems, fabric structures can cover very large areas with no supporting columns. This makes them particularly suitable for buildings such as sports faculties, auditoriums, shopping centres, transport interchanges, and so on.

- Cable net structures.

A cable net structure is an example of a tensile structure, i.e. a structure that is stabilised by tension rather than compression. For example, a piece of fabric pulled in opposite directions.



To increase height and load capabilities, horizontal cables can be combined with vertical cable arrangements. By doing so, system designs can be developed for double curvature walls as well as flat walls.

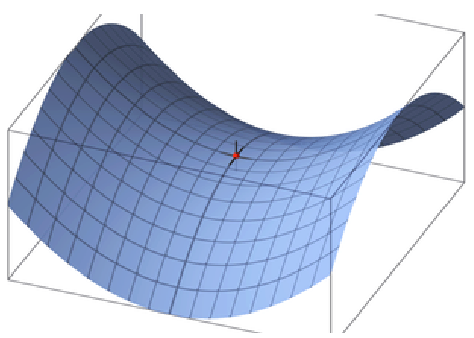
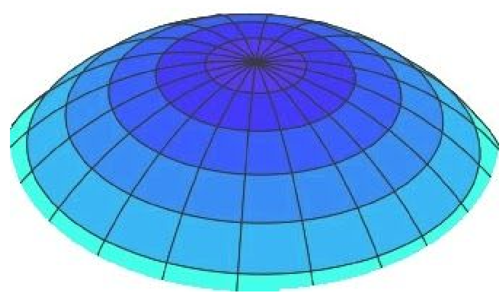
Cable nets are capable of being very simplistic structures. The clean aesthetic and large-spanning potential can be integrated with adjacent structures to reduce the need for conventional supports.

Typically, the cables are locked together at their intersections using a clamping component which may also fix any cladding to the net. Complex hydraulic jacking processes may then be used to apply the cable prestress.

- Suspension bridges.

Suspension bridges consist of towers secured by cables that suspend the central structural span or deck. The tower foundations may be constructed using caisson or cofferdam techniques, whilst the cable anchorages can be secured through anchorage tunnels to suitable ground on either end of the bridge.

Three-dimensional tensile structures typically form doubly-curved shapes that are either anticlastic or synclastic.

	
Anticlastic (saddle-shaped).	Synclastic (dome-shaped)

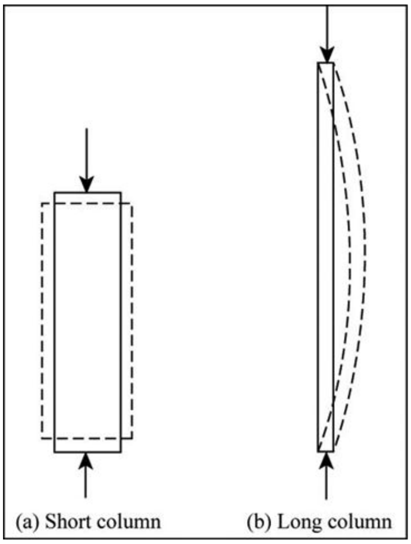
Doubly-curved surfaces can be tensioned without distorting their form, as the opposing curvatures balance each other at every point on the surface. Tensioning the fabric reduces its elasticity so that it will distort less when subsequently loaded, such as under wind load or snow load. In addition, the geometry of the curvature itself means that any extension of the fabric under load results in a relatively smaller deflection than would be apparent in a flatter, or less curved fabric.

So the greater the curvature and the greater the pre-tensioning of the fabric, the less it will distort under load.

Typically, tensile structures use less material than conventional compression structures and, as a result, are lighter and can span larger distances.

b. Compression Structures

Compression structures are those structures on which compressive loads are applied along the length of structure. Compressive force tries to shorten the member. The compression load applied to the cross section of structure produces stress in the compression structure.



When the compression member in a structure is vertical, it is known as a column. Due to the compression load, buckling occurs in compression structures. Some examples of compression structures are column, trusses, bracing members, etc.

Columns or compression structures are of two types, short column and long column, as shown in the right figure.

Buckling is one of the major problems that occurs in a compressive structure, which depends on bending stiffness and length. When the length of compression members is increased, buckling strength will decrease. When compression load acts on the short column, crushing occurs and when the compression load acts on the long column, buckling occurs. Buckling occurs when there is a sudden bending in the structure due to the compression load.

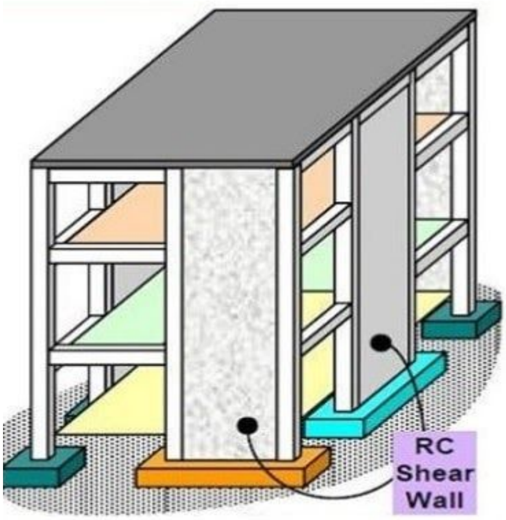
Being built mostly from masonry, Greek and Roman temples, and Romanesque and Gothic

cathedrals, are structures almost entirely under compression.

An arch in brickwork or stonework has simple, uniform compression and no bending (and therefore little or no tension). The thrust of the arch – compressive forces diverging down and either side of the keystone – is absorbed by the abutments on either side.

c. Shear

These are structures such as reinforced concrete or wooden shear walls, which are used in multistory buildings to reduce lateral movements due to wind loads and earthquake excitations. Shear structures develop mainly in-plane shear with relatively small bending stresses under the action of external loads.



Shear is an important engineering element when designing a structural system and engineers are constantly designing new methods of distributing shear loads in efforts to limit any concentration of the force. In addition, the engineering of new and stronger synthetic materials, allows the structural systems to be designed both smaller and lighter, to resist the necessary shear forces.

d. Bending.

Bending structures are structural systems that include curved beam or shell elements that base their geometry on the elastic deformation from an initially straight or planar configuration.

Bending structures develop mainly bending stresses under the action of external loads. The shear stresses associated with the changes in bending moments may also be significant, and should be considered in their design.

Bending structures include the girder, the two-way grid, the truss, the two-way truss, and the space truss. They have varying optimum depth-to-span ratios ranging from 1 : 5 to 1 : 15 for the one-way truss to 1 : 35 to 1 : 40 for the space truss.

e. Composite

A composite structural system or dual structural system is a structural system in which a whole frame provides strength for gravity load and moment-resisting frame or bracings provide support for lateral loadings.

Composite structures are created by combining two or more structural elements to act as a single combined structural unit, where each element behaves in a structurally efficient manner. Various advantages are achieved by composite structures: Higher stiffness and strength, reduced depth and weight of structures, faster construction speed, and structurally more efficient, thus providing an economical solution for a wide range of industrial, residential and commercial buildings and bridges.

C. Structure base on Application

01. Building

The word 'building' is commonly considered to refer to an enclosure within which activities can be carried out. It is a structure, usually consisting of a roof, walls, floors and openings such as doors and windows that is generally (but not always) positioned permanently in one location.

The Building Regulations suggest that the word 'building' refers to: '...any permanent or temporary building but not any other kind of structure or erection'. That is, a tunnel, or bridge for example would not be considered to be a building.

Buildings serve a diverse range of societal needs, but fundamentally they create shelter, providing a physical division between the inside and outside environments to provide:

- Protection from wind, rain, solar radiation, snow and so on.
- Regulation of the indoor environment in terms of temperature, humidity, moisture and so on.
- Privacy for occupants.
- A barrier to the transmission of noise.
- Security for occupants and the building contents.
- Safety, for example preventing the spread of fire or smoke.

In practice the word 'building' is commonly considered to refer to an enclosed structure within which people can perform activities.

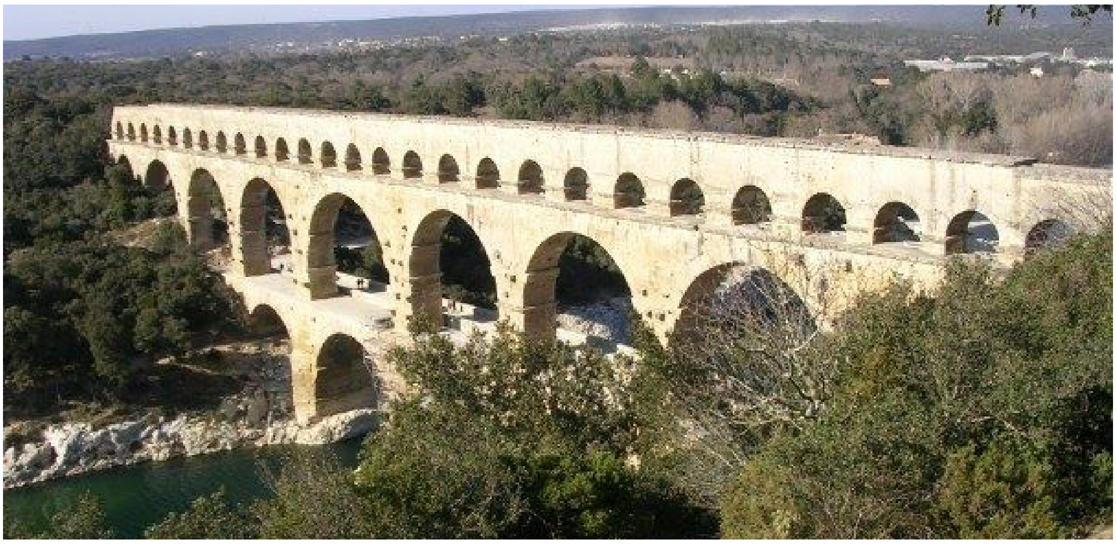
There are many ways of classifying types of building, including:

- Construction type.
- Use class.
- Size.
- Style.
- Period.
- Design (for example, form, structure, etc).
- Performance (for example, energy consumption, accessibility, etc).
- Legal definition.
- Nature of occupancy/ownership.

These are lists of common types of building: A-frame house, Abbey, Air-supported structure, Affordable housing, Airport., Apartment, Assembly and recreation building, Assembly building, Bandstand, Bank, Barn, Bungalow, Bus shelter, Bus station, Cafe, Canteen, Casino, Castle, Cathedral, Cave, Chapel, Church, Cinema, Cluster accommodation, Commercial building, Commonhold, Complex buildings, Condominium, Conservatory, Cottage, Convenience store, Council housing, Covered area, Custom build home, Data centre, Detached, Double fronted building, Duplex, Dwelling, Earth building, Entertainment building, Extension, Fabric structure, Factory, Farm buildings, Ferry terminal, Fire engineered buildings, Fire station, Flat, Freehold, Gallery, Garage, Geodesic dome, Greenhouse, Groundscraper, High-rise building, Hospital, Hostel, Hotel, Household, Houses in multiple occupation, Housing association, Hut, Industrial building, Inflatable building, Institution, Intermediate housing, Kit house, Lean to, Leasehold, Leisure centre, Library, Lighthouse, Live/work unit, Low-rise, Mall, Manse, Maisonette, Meanwhile use, Medium-rise, Megastructure, Megatall, Minor development, Mixed use development, Modern building, Modular building, Mosque, Multi-storey building, Museum, Non-residential institution, Office, Outbuilding, Pavilion, Penthouse, Permanent building, Petrol station, Police station, Portable building, Portaloo, Portakabin, Post office, Power station, Pub, Pumping station, Prefab bungalow, Public building, Railway station, Refinery, Residential building, Residential institution, Retail building, Retail warehousing, School, Secure residential institution, Self build home, Semi-detached / Semi, Shack, Shed, Shelter, Sheltered housing, Shop, Shopping centre, Single-storey building, Simple premises, Skyscraper, Smoking shelters, Social housing, Specialist accommodation for older people, Specialist premises, Speculative development, Stable, Stadium, Stand-alone building, Star building, Stately home, Storage building, Student accommodation, Sui generis, Supermarket, Super-slender, Supertall, Supported housing, Surgery, Swimming pool, Synagogue, Temporary building, Temporary demountable structure, Terminal / terminus, Terraced house, Theatre, Toilet, Tower, Town hall, Traditional building, Train station, Twisting building, Venue, Warehouse, Windmill, Workplace, Yurt, Zero carbon building, Ziggurat.

02. *Aqueducts and viaducts.*

An aqueduct is a channel that has been constructed for the specific purpose of carrying water from one point to another. The source and distribution point may be a significant distance apart, and the water is often transported over an elevated masonry or brick structure - often in the form of a bridge - supported on arches. It can also be carried through a series of tunnels or other underground systems.



History of Aqueducts

Before being adopted by engineers of the Roman empire, this ancient water delivery system had already appeared on a small scale in many different parts of the world including Greece, Egypt, Jordan, Persia, Oman, India and the Americas. These aqueducts were primarily used to supply irrigation systems for farming purposes, but the waterways also provided bathing and drinking water to some parts of the population.

With the rise of the Roman empire, cities expanded rapidly, triggering a need for suitable infrastructure to support the population. This included the reliable delivery of water.

Some of the earliest Roman aqueducts date back to the fourth century BC. The first of these structures, the Aqua Appia, was used to supply water from approximately 10 miles outside of the city. This aqueduct was mostly underground until it reached the edge of the city. At this point, it emptied into a series of reservoirs that distributed water to different parts of the city.

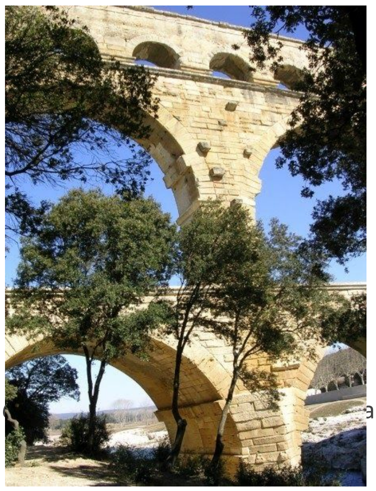
The need for fresh water drove the construction of complex aqueducts. These used the basic properties of gravity and the construction of a series of channels that gradually declined over significant distances (sometimes of 50 miles or more). A steeper gradient allows a smaller channel to carry the same amount of water as a larger channel with a lower gradient, but it must start from a higher point to reach the same distance.

Increasing popularity and sophistication

As the empire grew, so did the sophisticated network of aqueducts along with the construction, maintenance and inspection practices that protected them. Many aqueducts included purification systems in the form of sedimentation tanks. Distribution tanks would control the flow of the water to different locations.

The Roman network of aqueducts became an essential part of the empire's urban planning initiatives.

Despite being partially destroyed by the Moors in 1072, the Aqueduct of Segovia is one of the best-preserved elevated Roman aqueducts.



The Roman network of aqueducts became an essential part of the empire's urban planning initiatives.In Segovia, Spain, the Aqueduct of Segovia is a testament to the importance of good construction and maintenance. At one time the Romans employed more than 700 people just to maintain their aqueduct network.

In France, the Pont du Gard, near Nimes, survives as an example of Roman engineering skill. Each large arch spans approximately 25 metres (82 feet) and is constructed of un-cemented blocks weighing nearly two tons. The small top arches, which carry the channel, were placed in groups of three over the larger arches below.

The finished Pont du Gard aqueduct transported water to Nimes over a distance of 30 miles and provided each resident of the ancient city with about 380 litres (100 gallons) of water per day.

The remains of other ancient aqueducts still stand in many Roman cities, both in Italy and other parts of the former empire. Some have been maintained and are still partially in use, although most fell into disrepair, and some were intentionally destroyed by the enemies of Rome as a tactical measure.

During the Renaissance, architects and others were inspired by the aqueducts that survived, and in medieval times, the gravity-based system was used on a smaller scale to drive water wheels.

How aqueducts are used in modern times

Modern aqueducts are both overground and underground structures. They can be constructed from pipes, ditches, canals, tunnels and other engineered systems.

Complex aqueduct systems of this type have been used to transport water in California, Arizona, New York State and other places throughout the United States. An aqueduct system in China (the South-North Water Transfer Project) will eventually direct water from the Yangtze River to Beijing.

03. Bridges.

A bridge is a spanning structure that creates a passage over an obstacle such as a river, gorge, valley, road, railway and so on.

Bridges are a common feature of the built environment and one of the key elements of civil engineering. The basic principles of bridge design are dependent on the nature of the spanning structure; its shape, materials, means of support, distance spanned, terrain, function, budget, exposure and so on.

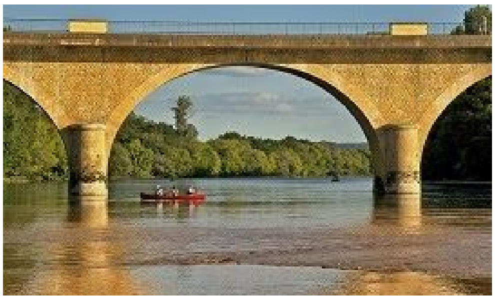
The three basic types of bridge structure are:

1. Beam bridges

Beam bridges are either simple beam or cantilever structures generally constructed from steel truss or pre-stressed concrete units. The simple beam bridge is horizontally self-supporting and transmits loads vertically through piers or abutments. The cantilever bridge transmits loads through piers central to the beam.

2. Arch Bridges

Arch bridges consist of a load-bearing arch in a state of compression, the strength and stability of which allows them to carry greater loads than beam bridges. The arch can support the horizontal deck of the bridge either from above or below.



3. Suspension bridges

Suspension bridges consist of towers secured by cables that suspend the central structural span or deck. The tower foundations may be constructed using caisson or cofferdam techniques, whilst the cable anchorages can be secured through anchorage tunnels to suitable ground on either end of the bridge.

From these three basic options, a very wide range of designs are possible. The choice of bridge design will be determined by the height, ground conditions and the clear span required.

Traditionally, steel construction has been most commonly used for very long spans, however, concrete arches are now also being used for big bridges. For large single-spans bridges, suspension bridges are the most common, with the high-tensile strength of the steel cables providing a design solution that is very economical compared to other support options.

Where there are suitable support points available, multi-span bridges may be used to create long bridges, and these may include combinations of beam, arch and suspension spans.

Moveable bridges are moveable variations of the three basic forms, generally used in situations where greater headroom under the bridge is sometimes necessary, for example to allow the passage of a ship underneath. The most common types of moveable bridge are:

- Swing: The structure pivots on a central pier.
- Bascule or pivoted cantilever: 'Drawbridges' which use a counter-weight behind the pivot point to raise and lower the deck.
- Vertical lift: Simple beams or girders that are raised by cables from towers.

Construction of bridges

Beam bridges

There are a very wide range of construction methods available, however, bridge foundations constructed in water will usually involve the use of cofferdams or caissons. Foundations on land may be piled, often capped off to receive a pier foundation.

Piers will generally be constructed above the foundations, and then beams or girders lifted on to them by crane which can either be erected on falsework around the pier or from ground level. After the main girders have been placed, the bridge deck can be positioned or cast in situ.

Decking to steel bridges:

- Steel trough filled with concrete.
- Steel beams encased with concrete.
- Reinforced concrete slab on steel beams.
- Steel deck on steel beams.

Decking to concrete bridges:

- Integral bridge deck with polystyrene formers.
- Beam and slab deck.

If the bridge is to span water, barges or pontoons may be used to float materials out to the lifting position. A temporary system of trestles may be used as a means of placing the beams or girders. For bridges spanning high drops, plate-girders or trussed-girders may be hauled across the opening using rollers. Alternatively, cantilever launching may be used, where the beam is launched from one bank, with sufficient ballast to counteract the overturning force, and hauled across the span using a winch.

Arch bridges

The construction methods for arch bridges typically include:

- Supporting the arch using trestles until construction is complete. This is suitable for low arch bridges.
- Cantilevering the ribs out from the sides of the span. This is suitable for bridges over high drops which cannot be spanned with trestles.

Where the spans are very large, the arch may be cantilevered in sections using a creeping crane that is mounted on top of the arch. The crane lifts rib sections from barges or pontoons below. The bridge deck is then constructed from both ends, meeting in the middle.

Suspension bridges

The anchorage foundations are usually constructed deep into a hillside on both banks. The towers are typically constructed using steel or in situ concrete, built on large concrete bases. Cable housings generally take the form of massive concrete blocks either positioned in water at either bank or cast deep into the bank itself.

Multi-strands of high tensile wire are used to build up the suspension cables, which are then carried between anchorage points by means of a grooved wheel.

The deck can be erected either by lifting sections from pontoons below or by cantilevering sections out from each end.

Bridge bearings

Bridge bearings provide a resting surface between supporting piers and the deck. They act to reduce the stresses that are involved by allowing controlled movement. They are usually made of metal or flexible materials such as rubber or plastic laminates.

Expansion joints can be formed to accommodate movement in the bridge deck. The most common types are:

Interlocking comb joint - Bolted to the concrete or steel deck at intervals that allow maximum expansion.

Asphaltic plug joint - Buried joints with a strip of surfacing over the joint to accommodate movement. These are inexpensive and quick to install, although their life-span is variable.

Elastomeric in metal runners (EMRs) - Joints formed with elastomeric material fixed in metal runners.

Reinforced elastomeric joints (REJs) - Elastomer reinforced with metal plates on both sides of the joint.

Bridge failures

Early suspension bridges were susceptible to vibration when an external periodic frequency matched the bridge's natural structural frequency. This could cause it to become structurally unstable and ultimately could cause catastrophic collapse.

Famously, this is why marching soldiers 'broke step' as they crossed certain bridges. Broughton Suspension Bridge collapsed in 1831, and more recently, Tacoma Narrows Bridge collapsed in 1940. Whilst modern suspension bridge design should eliminate such instability, in 2000, the Millennium Bridge in London began to vibrate when large crowds walked across it on its opening. It had to be closed for a year whilst dampeners were designed and installed.

In 2018, the Morandi motorway bridge in Genoa collapsed during a rainstorm killing over 40 people.

Other definitions related to bridges include:

a. A green bridge - a crossing that allows the safe passage of wildlife.
b. An overbridge - a bridge crossing over a transport corridor.
c. An underbridge - a bridge crossing under a transport corridor such as a railway.
d. A viaduct - a bridge like structure composed of a series of spans, used to carry roads and railways across valleys and other depressions.
e. A half through bridge - a bridge in which the lower chord carries the vehicular or pedestrian

traffic.

f. A through bridge - a bridge in which the lower chord carries the vehicular or pedestrian traffic and having cross-bracing located above the traffic.' Ref Iron and Steel bridges: condition appraisal and remedial treatment, published by CIRIA in 2008.
g. The span of a bridge is the horizontal distance between its supports.
h. The underside of a bridge is described as a 'soffit'.
i. The surface of a bridge which allows passage is describes as a 'deck'.

04. Canals.

Canals are human-made channels used for water conveyance (supply), or to service water transport vehicles. The oldest known canals were used for irrigation purposes, built in approximately 4000 BC in the region of the Middle East that is now modern day Iraq and Iran.

How canals are constructed

Canals can be constructed in different ways:

- A new canal can be created by excavating the body of the canal and providing water from an external source, such as streams or reservoirs.
- Dredging a channel in the bottom of an existing lake which is then drained.
- A stream can be canalised to make its navigable path more predictable and easier to manoeuvre. This involves dredging, damming and modifying its path.

What canals do

Canals use engineered structures such as:

- Weirs and dams: To raise river water levels to usable depths.
- Looping descents: To create a longer and gentler channel around a stretch of rapids or falls.
- Locks: So that ships and barges can ascend and descend.

Canal locks in action

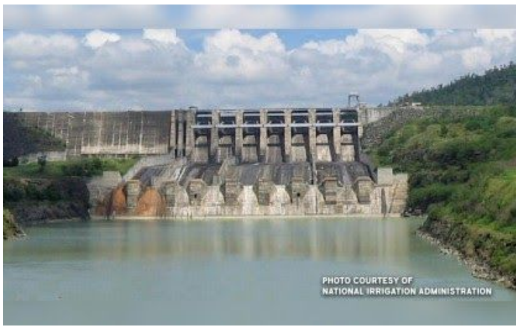
A lock consists of a lock chamber which may be made from brick, stone or metal. This chamber holds the water. There are typically gates at each end of the lock chamber, and these gates control the flow of water.

When a vessel is at a lower point, a gate is allowed to open, which permits water to enter the lock and fill it with water. Once the water level is at the higher height, the vessel can continue on its journey.

The opposite action is used when the vessel is at a higher position and needs to proceed to a lower level. The vessel enters the lock with a high water level and then a gate opens - allowing the water to be released. When the water is at the adjusted lower level, the vessel is able to proceed.

In most instances, the main lock gates can only be opened when the water on both sides is at the same level. This means that the top lock only opens if the lock is full, and the bottom lock only opens when it is nearly empty.

05. Dams.



Dams are barriers, usually constructed across rivers, to hold back and contain water in a lake or reservoir. Dams are usually built using concrete, or natural materials such as earth and rock, and some dams are built in major engineering projects with a construction programme lasting many years.

For centuries, dams have been a vital part of the water infrastructure, serving many different purposes, including:

- Water supply: Reservoirs store rainwater before it is filtered and processed for human use.
- Hydroelectric power: Reservoirs store rainwater to be used in hydroelectric power stations to generate electricity.
- Flood control: Reservoirs control water flow into rivers after heavy rain.
- Irrigation: Water can be stored in reservoirs for irrigating land during dry periods.
- Navigation: Dams can be used to raise the upstream water level to improve navigation conditions.

Types of dam

Arch dams - An arch dam is curved in an arch-shape, with the top of the arch pointing back into the water, to create a very strong structural form, resistant to the water pressure behind the dam. Arch dams are usually made from concrete and require a good rock support for foundations and the sides, so are commonly used in narrow, steep-sided valleys.

Buttress dams have triangular-shaped walls, or buttresses, which are spaced at intervals on the downstream side, resisting water pressure against the upstream side. They must be constructed on sound rock and are typically made of concrete or masonry. Because of the spacing between the buttresses they can be quite efficient in terms of materials.

Embankment dams have historically been quite common in the UK, usually found in sites with wide valleys. They are commonly constructed using natural materials such as compacted earth or rocks which are often locally quarried or excavated. In cross-section, an embankment dam is hill or bank shaped, with a central core made from an impermeable material such as clay soils or concrete, to prevent water passage.

Gravity dams rely on gravity to hold them in place. They are generally made from concrete, masonry, or both, and in cross-section are typically triangular. They need to be built on sound rock and are suited to wide or narrow valleys.

Spillway is a form part of a dam and is used to pass overflow water over, around or through a dam, in a safe and controlled way. The different types of spillway include:

- Overflow spillway: This allows water to flow over and down its front face as it is lower than other dam sections, and is curved to control the flow of water. Most commonly constructed as part of gravity or buttress dams.
- Side channel spillway: This is located a short distance upstream of a dam, and diverts water into a side channel then into the river downstream of the dam. They are mainly used with embankment dams.
- Shaft spillway: This is a circular hollow tower that sits in the reservoir near the dam. When the water level rises, it flows into a funnel at the top of the shaft which diverts the water downstream.

Dam construction

Dam construction is often complex and requires a wide range of professionals from different disciplines.

- Civil engineers are generally responsible for determining the best type of dam for the site, and for producing technical drawings showing the construction process.
- They will consult with engineering geologists and hydrologists on the technical details of the site and the required specifications dependent on the amount of water involved.
- Mechanical engineers will be contracted to design the necessary pipework, valves and floodgates.
- Geotechnical engineers will determine whether the rock or soil below the proposed dam is strong enough to accommodate the weight and for determining possible permeability.

In very broad terms, the typical sequence of events for dam construction is as follows:

- *River* diversion

Water flowing in a river or stream is diverted to create a dry area in which to construct the dam.

Lower flows will be capable of diverting through tunnels or channels built around the side of the dam area, excavated using explosives where necessary.

Higher flows may be too difficult to divert using separate channels, so instead a dry pit is formed on one side of the river, leaving the other side open for water to flow through. The dam is constructed in sections, with dry areas built in sequence. Openings are provided in the dam to allow the river to flow through.

- *Foundations*

The foundation is built below the original ground level, with weaker soils or rock removed and replaced with stronger materials if necessary. Cracks and fissures in the rock foundations must be filled with grout to stop water leakage. Holes are drilled into the rock and grout pumped into them, spreading outwards and filling the cracks.

- *Building the dam*

Concrete dams will need a large quantity of ready concrete, so a concrete batching plant is often built on site. Concrete is then transferred to the dam either using a system of conveyor belts or using trucks and cranes.

The traditional method of placing the concrete is to pour it into a formwork mould made in the required shape of the dam. The dam is built upwards 1-2 m at a time, and the concrete left to cure before the next section is formed on top.

An alternative method is to spread a concrete mix and compact it down using rollers. The dam is raised in steps of around 600 mm at a time. Low concrete walls on the upstream and downstream faces are formed first, with concrete then spread in thin layers in between the walls, before being compacted using rollers.

Embankment dams are constructed in a series of thin layers from the bottom upwards. Bulldozers spread fill material in a thin layer, usually 300 mm thick if using earth, or up to 1 m thick for rock-fill. The core of the dam is also constructed in layers so that it maintains the same height as the rest of the dam. A protective layer is formed on the upstream face once the full height has been achieved. This protects against wave damage and often provides waterproofing.

- *Post-construction*

Once the dam has been constructed the reservoir can then be filled, if it has not been during construction (in the case of high flow rivers). Valves and floodgates must be extensively tested, and the behaviour of the dam must be monitored.

06. Railways.

Railways have been an important part of our transport infrastructure since the 19th century, and their development has enabled the use of trains as an effective and efficient means of travel.

The emergence of railways from around the 1820’s marked the beginning of the end for canals, as trains could carry more goods, more people and travelled much faster. The first steam locomotive to carry passengers began operation in 1825, designed by engineer George Stephenson, on a line between Stockton and Darlington.

Railways spread rapidly throughout the UK with the increased demand for coal and steel, and for distribution of things such as newspapers and post. The railways were built by ‘navvies’ who would dig foundations, lay stones and fix the track. Most of the work was done by hand, using a pick axe.

Types of track. The railway track, also known as the ‘permanent way’, is the long horizontal structure that provides trains with a surface for wheels to roll upon.

Traditional track. The most common type of track used around the world is ‘flat bottom’ steel rails supported on sleepers made of timber or pre-stressed concrete.

Typically, tracks are laid on a bed of stone track ballast which is supported by prepared earthworks, known as the track formation.

Ballast consists of crushed stone and is used to uniformly distribute loads from the sleepers to the formation. Ballast also helps with stabilisation, drainage and prevents the sleepers from moving. It is typically laid to a depth of between 225-300 mm, filled to the top of the sleepers and beyond the ends of the sleeper by around 250-500 mm.

The track formation consists of a subgrade and blanket – a layer of sand or stone dust in impervious plastic. The blanket restricts the upward movement of wet clay or silt. Additional waterproofing is provided if deemed necessary. The subgrade layer is slightly sloped at the sides to help water drainage. Water is channelled away by ditch or other type of drain.

In order to prevent soil and water from 'spoiling' the ballast, some railways can use asphalt pavement below the ballast, which helps to stabilise it. Where track is to be laid over permafrost, measures such as transverse pipes of cold air can be laid through the subgrade to prevent melting.

Ballast-less track

An alternative type of track structure that can be used to alleviate the large demand for maintenance that traditional track requires, is one that does not use ballast. This type of track tends to be used for short extensions that require additional strength such as in rail stations, or in tunnels where maintenance is difficult.

At its simplest, this comprises a continuous slab of reinforced concrete upon which rails are supported directly using a resilient pad. An alternate design is the use of pre-cast pre-stressed concrete units which are laid on a base layer.

The drawbacks of this type of track are its high initial cost, and if it is being used to replace existing track it can require lengthy periods of closure. However, due to the reduction in maintenance it can have a lower whole-life cost.

Continuous longitudinally-supported track

This type of track involves the rail being supported along its length rather than using sleepers. It was experimented with in the 1840s, but proved to be more expensive in terms of maintenance.

A more modern version is the ladder track which uses sleepers which are aligned along the same direction as the rails, with gauge-restraining cross members that resemble the rungs of a ladder. This system can be used with ballast and without.

Types of rail

Modern rail typically uses hot-rolled steel with a profile similar to that of a rounded I-beam. Because of the high stresses to which they are exposed, rails must be manufactured using very high-quality steel alloy. Rail is graded by weight over a standard length, and the train weight and speed capacity is dependent on the strength of the rails.

In addition to flat-bottom rail, other rail profiles include:

- Bullhead rail.
- Grooved rail.
- Bridge rail (inverted U-shape).
- Barlow rail (inverted V-shape).

Flat-bottom rail is the most commonly used due to its stiffness, greater stability and reduced maintenance requirements. However, bullhead rails are easy to fix and unfix to sleepers, making them useful in applications that necessitate frequent replacement.

As rails are produced in fixed lengths (in the UK, usually around 20 m), they must be joined end-to-end to create a surface that is continuous. The main ways in which this can be done are:

Jointed track

This consists of lengths of rail that are bolted together using fishplates – perforated steel plates – that are usually 600 mm long and used in pairs on either side of the rail ends.

Small gaps are left between rail ends to act as expansion joints in high temperatures. When trains pass over them, it is this that leads to the ‘clickety-clack’ sound synonymous with railways.

Jointed track requires a large amount of maintenance and does not provide as smooth a ride surface as welded rail, making it less commonly used for high speed trains. It can be prone to cracking around the bolt holes which, unless addressed, can lead to the breaking of the rail head.

Continuous welded rail

This is a more modern type of rail and consists of rail lengths that are welded together by flash butt welding. This forms one continuous rail without joints, which allows trains to travel at high speeds with less friction. Despite being more expensive to lay welded rails, they have much lower maintenance costs than jointed tracks.

To provide restraint to the rails and prevent movement in relation to the sleepers, clips or anchors are used. A common type of fixing are Pandrol rail clips which fix the rail to the sleeper chair. These are typically manufactured from high quality silicon-manganese steel and, when fixed to concrete sleepers, are fitted with malleable iron shoulders.

The Pandrol ‘Fastclip’ is a fully-captive, pre-assembled, unthreaded rail fastening which means all the components are assembled on concrete sleepers before being delivered to site, eliminating the handling of loose components during track maintenance operations. Hand tools or track-mounted machines are used to tension and de-tension the clips.

Sleepers

A sleeper is a rectangular support which lies horizontally between both rails to which they are fixed. Sleepers transfer loads from the rails to the ballast and the track formation, as well as maintaining the rail gauge (the correct width between the rails). Sleepers tend to be between 2.5 - 2.75 m long.

Traditionally, sleepers were made of timber treated with preservatives, but these have a shorter lifespan than more modern alternatives such as concrete and steel. Concrete sleepers are pre-stressed and provide extra stability to the track due to their increased weight.

Steel sleepers can be used in applications where hot metal processing and chemical spillage are risks, although they are unsuitable on electrified lines and cannot be used where track circuits exist. They typically take the form of a steel plate formed into an inverted trough with flanged ends.

07. Roads.

The methods of constructing roads have changed a lot since the first roads were built around 4,000 BC – made of stone and timber.

The first Roman roads were stone paved, built in North Africa and Europe for military operations. Road construction techniques were gradually improved by the study of road traffic, stone thickness, road alignment, and slope gradients, developing to use stones that were laid in a regular, compact design, and covered with smaller stones to produce a solid layer.

Modern roads tend to be constructed using asphalt and/or concrete.

Very broadly, the construction of roads can be described by three processes:

- Setting out.
- Earthworks.
- Paving construction.

Setting out

This is carried out following the dimensions specified in layout drawings.

A commonly used setting out procedure is the profile board method. A series of boards that show the exact level 1 metre above the completed construction level are placed at intervals along the proposed line of the road. A profile board with a fixed height, called the traveller, is used for controlling the excavated levels between these profile boards. By placing the traveller in the sight-line between two level boards, it can be seen whether or not the excavation has been carried out to correct levels and adjusted accordingly.

The level of each profile board is controlled using a line level which is a short spirit level hung from a nylon string. The line operator moves the string up or down until the bubble is centred.

Junctions, hammer heads, turning bays and intersecting curves are laid out in a similar manner.

Earthworks

Earthwork is one of the major works involved in road construction. It involves the removal of topsoil, along with any vegetation, before scraping and grading the area to the finished 'formation level'. This is usually done using a tractor shovel, grader or bulldozer. Below the formation level, the soil is known as the 'subgrade'. It is essential that the strength of the subgrade is tested prior to earthwork beginning.

Most earthworks are formed by cut-and-fill, and the type of 'fill' material must be considered, not only in terms of its physical properties, but on the conditions in which it is to be used, and the methods of compaction.

Depending on its quality, compressible subsoil may be removed or stabilised. If the cost of full or partial excavation of subsoil is uneconomical and would be likely to result in consolidation, sand wicks or sand drains may be used. Sand wicks are sand-filled boreholes beneath the road embankment that give greater stability to the soil by decreasing the length that water has to travel in a drainage path, so dissipating water pressure. Sand drains alongside the road are used to intercept ground water.

Subsoil drainage should be provided to deal with seepage through pavements and verges, from higher ground and a result of the seasonal rise and fall of the water table.

Subgrade strength

The required thickness of the pavement is determined by the subgrade strength, so it is desirable to make the subgrade as strong as possible.

The strength of the subgrade can be achieved by using the following techniques:

- Removal of poor material in cuttings and replacing with selected fill.
- Compacting subgrade to a high dry density.
- Providing adequate subsoil drainage.
- Soil stabilisation methods such as the use of cement, bituminous materials or chemicals.

The subgrade strength will decrease as moisture content increases so protection may be required if it is to left exposed for any length of time.

Protection covering can be either:

- Medium gauge plastic sheeting with 300 mm laps.
- Sprayed bituminous binder with a sand topping.

Paving construction

Once the subgrade has been prepared and drainage or buried services installed, the paving construction can begin. Paving can be either flexible or rigid. There are pros and cons to each type, with one being selected over the other depending on the specific needs of a project.

Rigid pavements tend to have lower maintenance costs, a longer design life and higher flexural strength; but flexible pavements tend to have lower construction costs and have a higher ability to expand and contract with temperature and so do not need expansion joints.

Flexible paving

Flexible paving consists of materials applied in layers directly over the subgrade to which the traffic loads are distributed. To prevent permanent deformation, and therefore an uneven running surface, the thicknesses of individual layers must be capable of distributing such loads. The subgrade is compacted with the sub-base on top of it. On top of this is laid the surfacing which is made up of the base layer and the wearing course.

Surfacing

The wearing course is the upper layer of bituminous material, often denser and stronger than the base layer. The thickness depends on the material specification and the amount of wear that is expected. Desired properties are good non-skid capabilities, minimal glare and acceptable durability.

The main materials that are used are hot rolled asphalt (HRA), dense bitumen macadam (DBM), dense tar macadam (DTM) and porous asphalt (PA). PA is especially suitable as it is an open-graded material that is designed to allow rapid drainage of surface water, thereby reducing spray as well as tyre noise.

The base will typically have a minimum thickness of 60 mm and is usually made of dense bitumen macadam or asphalt. It is laid with the appropriate crossfalls and gradients.

Sub-base

This is placed in a layer usually not exceeding 150 mm over the subgrade after waterproofing is complete. Various materials can be used but it is common for crushed stone or dry lean concrete (such as 1 : 15) laid and compacted by heavy rollers.

Rigid paving

Rigid paving consists of a reinforced or unreinforced insitu concrete slab laid over a thin granular base course. The rigidity and strength of the pavement enables the loads and stresses to be distributed over a wide area of the subgrade.

Rigid paving is made up of the following layers (from top to bottom):

- Subgrade.
- Sub-base of thick crushed stone. Usually to a thickness of 80 mm.
- Anti-friction membrane normally made of polythene sheeting. Also prevents grout loss from freshly laid concrete.
- Insitu concrete paving slab. Reinforcement in the form of either steel fabric or re-bar may be used.
- Asphalt or similar topping if required.

Longitudinal and transverse joints are required in rigid paving between the slabs, limiting the stresses applied due to subgrade restraint (friction between the pavement and subgrade), and providing room for expansion and contraction movements. The spacing of road joints is determined by:

- Thickness of the slab.
- Whether there is reinforcement in the slab or not.
- The expected traffic load and flow rate.
- The temperature at which concrete is laid.

08. [Retaining walls]

Retaining walls are vertical or near-vertical structures designed to retain material on one side, preventing it from collapsing or slipping or preventing erosion. They provide support to terrain where the soil's angle of repose is exceeded and it would otherwise collapse into a more natural form. The principal characteristic of a retaining wall is being able to withstand the pressure exerted by the retained material, which is usually soil.

Retaining walls may include a parapet that extends above the height of the retained material, often for safety reasons.

The main uses of retaining walls are to help prevent soil erosion, create usable beds out of steep terrain and to provide decorative or functional landscaping features. They may be independent structures, or may be part of a wider construction works, such as a building.

Planning permission is required if the wall is to be over 1-metre high and next to a road or pathway; or over 2-metres high elsewhere. Independent, freestanding retaining walls may not require building regulation approval; however, any structures must be structurally sound and well maintained.

Earth pressure

There are three types of earth pressure that bear upon the movement of the wall:

- Earth pressure at rest: This applies when the wall is at rest and the material is in its natural state.
- Active earth pressure: As the wall moves away from the backfill, there is a decrease in the pressure on the wall which continues until reaching a minimum value that then remains constant.
- Passive earth pressure: As the wall moves towards the backfill, there is an increase in the pressure on the wall which continues until reaching a maximum value that then remains constant.

Hydrostatic pressure

Water can also build up behind retaining walls, increasing the pressure on them, and so they may include weep holes or some other form of drainage. Accumulating water can also reduce the stability of retained soil, and the friction between the retaining wall base and the soil beneath it.

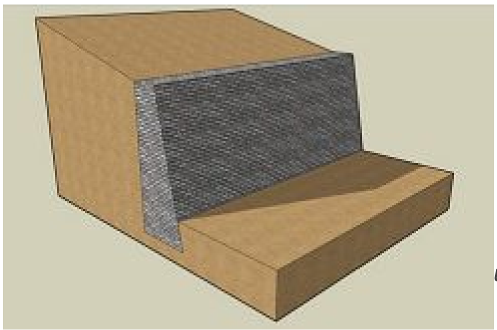
Types of retaining wall

Very broadly, retaining walls are 'cut' walls, in which the wall is cut into the existing slope, and 'fill' walls in which the retaining wall is built in front of the slope, and then the space behind It is filled.

There a wide variety of types of retaining wall:

Gravity retaining wall

This type of wall depends on its mass to retain the material behind it and remain stable. Stone, concrete and brick masonry are the most common materials used in this type of wall construction. To maintain stability, the mass and friction of the



interlocking wall materials must be greater than the force of the material being retained. Gravity walls might be suitable for heights of up to 2 to 3m

To better resisting pressure gravity retaining walls may have a ‘battered’ profile, (that is one face is sloping so that the wall is thicker at the bottom than the top. Either the face or the back of the wall may be battered. Very broadly, the base should be half to three-quarters of the wall’s height.

Sheet piling wall

This type of wall can be made of timber, interlocking steel or vinyl panels, that have been driven into the ground up to the required depth and fixed in place by soil on either side at the base. These are most commonly used where the soil is soft and the space available is restricted. As a general rule, there is usually 1/3 of the pile above ground and 2/3 below ground. The piles must resist the bending forces induced by the retained material.

Concrete pile walls can be used to create permanent or temporary retaining walls. They are formed by placing piles directly adjacent to one another. These can be; closely-spaced contiguous pile walls, or interlocking secant walls, which depending on the composition of the secondary intermediate piles can be hard/soft, hard/firm or hard/hard secant walls.

Reinforced retaining wall

The stability of reinforced concrete and masonry walls can be increased by reinforcement bars.

Cantilever retaining walls, made of steel-reinforced or cast-in-place concrete, are connected to a slab foundation (in the shape of an inverted ‘T’ or ‘L’) which allows horizontal pressures from behind the wall to be converted to vertical pressures on the ground below.

Counterfort buttresses, spaced at equal distances along the wall can be used to create the structural path between the vertical wall and the horizontal base. These are typically used for walls with heights greater than 8-12 m.

Mechanical stabilisation. Mechanically stabilised earth (MSE) walls are walls that can tolerate some differential movement. The wall face is infilled with granular soil whilst retaining the backfill soil. The advantage of MSE walls is the ease of construction, as they do not require formwork or curing.

The use of soil nailing in MSE walls, involves introducing slender steel reinforcing bars to the soil, placed parallel to one another on a slight incline and grouted into place.

Anchored earth walls. Anchored earth walls include cables or rods anchored in the rock or soil behind the wall. Concrete is injected at the end of the rod to bind it into the soil. This method can be used where high loads are to be expected.

Gabions

Gabions are cages, baskets or boxes typically made of wire, filled with earth, sand, crushed rock and so on. They may be woven, or welded. As they are free-draining retaining structures they are frequently used where water will be present, such as along coastal roads and as flood defences.

Crib walls

Where timber, steel or concrete cages or boxes are interlocking, this may be described as a crib wall.

Green retaining walls

Green retaining walls can be used to retain more gentle slopes. A geocellular structure such as a series of 'honeycomb' cells can be embedded into the surface of the slope to stabilise it, and the individual cells can then be planted.

Barrette retaining wall

A barrette retaining wall is constructed from reinforced concrete columns of a rectangular plan form with the long axis in the direction of retention.

09. Tunnels

Tunnels are civil engineering structures that create an underground passage that may pass through a hill, under buildings or roads, under water or even under entire cities. They might be required to traverse an obstacle, create a mass transit systems, provide connections beneath the sea, accommodate pipelines, provide sewage systems and so on.

There are a wide range of methods that can used for the design and construction of tunnels, depending on the scale of the tunnel required, the specific ground and groundwater conditions, the depth, the availability of space and so on. The main considerations include:

- The purpose of the tunnelling: This will influence the size and cross-section of the tunnel.
- The type of ground: This will influence the selection of the route for the tunnel and whether it is economical or feasible to construct where there may be poor conditions or defects in strata.
- The construction method: This will alter depending on the type of tunnel, the ground conditions, the tunnel length required and the project time pressures.
- Removal of debris: The size and length of the tunnel will determine the equipment required for 'mucking out' debris.
- Control of water: Pumping is the most common technique for dealing with the presence of water whilst tunnelling.

Methods of tunnelling

Drill and blast

This is mainly used for hard rock where digging is not possible, and was very common before the development of tunnel boring machines (TBM). The process tends to have a lower capital cost that the use of TBM, but is slower.

Roadheaders

These are track-mounted excavating machines that have powerful cutting booms and are commonly used in coal mining or civil engineering works that require a range of tunnel diameters. They are relatively flexible and can be fitted with extra equipment such as gathering arms for the spoil, water jets to reduce dust, and conveyors for removing debris

Open-cut method

Sometimes referred to as 'cut-and-cover', this is suitable for shallow tunnels. It involves the construction of an open trench within which the tunnel is constructed. The trench is then backfilled. Depending on the ground conditions, the side walls may be constructed before the trench is created, or after.

Cut and cover

Cut and cover involves creating the 'roof' slab of the tunnel first, within a shallow trench. The trench can then be backfilled and the tunnel constructed underneath the 'cover'. The has the advantage of releasing the site above the tunnel for other uses.

Immersed-tube method

This method is suitable for tunnels that cross deep water. Prefabricated sections of either concrete or steel tunnel are lowered into a prepared trench at sea or riverbed level. The trench is then backfilled and any necessary protection constructed above.

Pipe-jacking

Pipe-jacking is a trenchless technology in which a drive pit is constructed and then sections of steel or concrete tube are hydraulically jacked forward from the pit to form the tunnel lining. This is particularly suitable for installing services under canals, railway embankments and roads where it is important that there is little disturbance. Pipe jacking has been adopted widely since its first recorded use in 1892 in USA by the Northern Pacific Railroad Company. It is often preferred because of its simplicity and because it avoids settlement of ground.

Box-jacking

This is a similar process to pipe-jacking, but a box shaped section is jacked forward rather than a pipe, and this can allow a larger tunnel to be created.

Auger-boring

This uses a non-steerable rotating cutting head and is used mainly for conduit installation. A rail-mounted machine augers the soil as it pushes a sleeve or tube into the ground. The auger cuts the face of the borehole as it turns, transporting the excavated spoil back down the sleeve into the shaft. A length of sleeve is inserted by the machine which then withdraws to have another length of sleeve welded on and the auger flight extended. This process is then repeated.

Guided auger boring systems are also now available.

Microtunnelling

Microtunnelling machines are primarily used to bore tunnels that are too small for operatives to enter, such as pipelines, and have been developed to be used in almost any type of ground condition. Microtunnelling machines can be controlled from ground level using laser equipment, and spoil is removed from the cutting face by an auger running through the pipeline as it is installed. This is commonly used where surface disturbance must be kept to a minimum, such as in the construction of urban drainage systems.

Kramer defines microtunnelling as 'those methods that install pipes with a diameter of less than 36 inches (900mm) to a predetermined line and level by remotely controlling the cutting head.'(Kramer et al. 1992)

Mined tunnel

Can be used where a self-supporting subsurface material such as rock or hard clay is

present. It involves the use of drill and blast techniques or excavation/sprayed concrete lining to advance the excavation.

Whole face or 'full-face' boring / tunnel boring machines

This technique uses purpose-designed tunnel boring machines (TBM) to excavate the full cross-section required. There are high costs involved in the purchase and maintenance of such a machine, although it requires fewer operatives and can be very time efficient. Whole face borers grip the side of the tunnel to transmit thrust forward and can cut through hard rock, with debris being removed by conveyor, but they can be inflexible in terms of changing direction or cross-section.

Tunnel linings

The lining process will vary depending on the ground conditions. Linings can be performed segments or insitu concrete that is sprayed in position or cast in place.

In soft ground, linings must support the loads imposed by the ground as well as withstanding jacking pressures from the tunnelling equipment. Segmental cast-iron lining is commonly-used in soft ground as it is durable and has high compressive strength. Precast concrete linings are more economical, although it can be difficult to achieve water tightness.

In ground that is self-supporting, expanding tunnel linings can be used. The tunnelling shield is pushed forward leaving behind it an unsupported space. The lining, made up of precast segments, is then erected and expanded against the ground to predetermined pressure.

In hard ground, the lining can be concrete sprayed between steel ribs or onto mesh which has been fixed to the rock face.

New Austrian Tunnelling Method (NATM)

Also known as the Sequential Excavation Method, NATM first came to prominence in the 1960s, and helped to revolutionise the tunnelling industry.

The main principle behind NATM that differs from other tunnelling methods is that it uses the inherent geological strength available in the surrounding rock mass to stabilise the tunnel and so can be less expensive. The optimal method of support is determined based on actual observed ground conditions, which gives it the moniker of a 'design as you go' approach. The initial ground support is provided by shotcrete in combination with fiber or welded-wire fabric reinforcement, lattice girders and ground reinforcement.

Safety

Tunnelling can be an extremely hazardous operation involving working at height, working in confined spaces, sprayed material and the operation of heavy plant. Careful risk assessment and risk management and a high level of training and supervision are required .

There are a number of safety schemes in place for personnel, and the British Tunnelling Society has produced a Code of Practice for the management of risk in tunnel works, the adoption of which may be required by insurers.

Potential hazards include:

- The movement of soil.
- Rock falls or rock burst.
- Collapse.
- Failure of the working face.
- Heave or settlement.
- Flood or inflow of mud.
- Blasting and explosives.
- Dust and fumes.
- Escape of gas.
- Noise.
- Movement of plant.
- High temperatures.
- Seismic action.

10. Coastal defences.

Coastal defences are a key part of coastal management, in which the land-sea boundary is protected from flooding and erosion, categorised as hard engineering and soft engineering.

Soft engineering can be a more sustainable, long-term and potentially more cost-effective approach to coastal defence, working with natural processes to protect the shoreline.

Techniques include:

- Beach replenishment: This involves the importing of beach-grade sediments to 'top up' beaches.
- Sand dune management: This can include constructing footpaths, ladders and boardwalks to prevent degradation of the beach by humans.
- Beach drainage: Lowering the water table locally beneath the beach face, causing sand accretion above the drainage system.

Hard engineering can be more expensive, and is sometimes less durable and be more intrusive than soft engineering. Hard engineering can also cause issues elsewhere, simply moving the problem along the coast.

Some common examples of hard engineering solutions are set out below:

Groynes

Groynes are walls of concrete, stone or timber that extend out from beaches, acting as barriers. They protect or retain beach material and slow losses through long-shore drift. Steel sheet piling may also be used, but it must be suitably capped and backed with concrete. It is important that the piling penetrates to a depth that will prevent wave action from underscoring the structure.

Despite having a positive local effect, groynes can cause 'sediment starvation' which shifts the erosion further down the coastline.

Sea wall

Sea walls are structures that usually incorporate into a promenade, and are built to limit erosion caused by wave attack. They can be made from materials such as; timber, steel, masonry blocks, precast concrete units and in situ concrete. They are commonly 3-5 m (10-16 ft) high and curved to reflect back the energy of the waves and prevent wave overtopping.

Revetments

Revetments are onshore sloped structures used as an alternative to sea walls to reduce the landward migration of beaches. They limit the energy of the waves as they break and so reduce their erosive power. They can be constructed using stepped concrete, stone or asphalt and should be designed to have a sufficiently high crest to avoid wave overtopping. In their most basic form, they can be constructed using timber with a rock infill.

NB Culvert, screen and outfall manual, (CIRIA C786) published by CIRIA in 2019, defines revetment as: 'Works to protect the bed or banks of a channel against erosion, typically constructed from stone or concrete blocks.'

Breakwaters

Also known as 'moles' are constructed in outer harbour areas to dampen heavy waves and allow vessels to enter and exit with less swell. They can be sloped or vertical and are typically constructed from concrete blocks, rock fill or a combination of both depending on site-specific conditions such as water depth, range of tides, and foundation conditions.

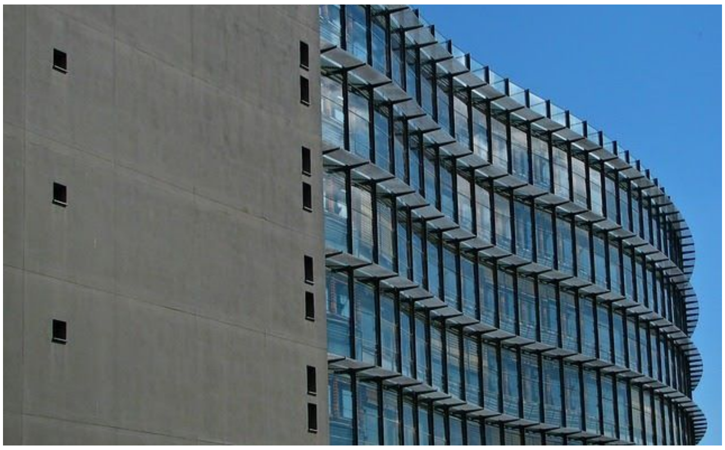
If they are constructed using blockwork, the marine bed may need to be dredged and a concrete bed laid for the foundation. The blocks can then be lowered by cranes operated from pontoons, perhaps with divers to help position the blocks.

Rubble or rock-fill breakwaters generally use heavy stones ranging from 1-5 tonnes. These can be transported and placed by bottom-opening or side-tipping barge

Gabions

Gabions are steel mesh cages that are filled with rocks, concrete and sometimes aggregate, and used to stabilise vulnerable areas, by absorbing wave energy. They can project out at right angles from the coastline like groynes, or can be constructed as retained walls, battered or stepped back rather than being stacked vertically. The strength of the wire used to tie the cages together is the critical factor. Galvanised steel wire is commonly used, but stainless steel and PVC-coated wire can also be used

D. Building Form Structure



When you think of a building you love, what do you think of? It's simplicity, complexity, beauty, usage, ability to serve its purpose while fitting into its surroundings? Form in building architecture is the final output. But it is also more than that. It is the value that output creates including the 'negative space' which fulfills those things. Negative space is a way of describing that things that aren't built are as important as things that are. But it is the value that is created that interests me.

In building architecture form can be readily understood at a visceral level. Value is based on elements that most humans can 'feel' if not conceptualize. The difference between a good house/apartment layout and a bad one is something most adults have experienced at least once. "Who designed this place, I can't even put a sofa in the living room!"

In technology architecture it is something a bit more esoteric. Iasa contents that form in technology architecture is the value, satisfaction and outcomes associated with a technology AFTER it is deployed and running. And this form drives and constrains structural decisions for the architect.

Structure

Now think of the same building during construction. That same beautiful and amazing building would not be very inviting to anyone but a building professional, or in my case a 10 year old boy (I grew up in construction and loved it before they were finished). Why is that? It is because until the building is completed it cannot create its intended value for the owner/customer. You likely do not want to live in a house from the beginning of construction.

The structure of the building again is a very visceral feel. The struts, the foundation, the plumbing, the machinery. For people in the building trade it is forever fascinating. In fact, I believe that this is where our notions of architecture in technology have derailed. For structure is the responsibility of both the architect AND the engineer/developer.

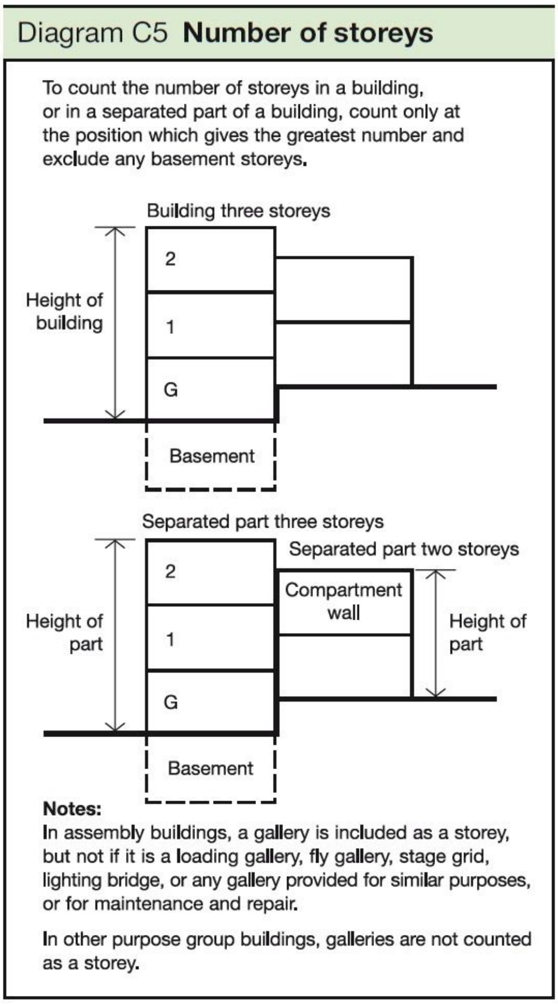
Structure is the set of physical and digital components, their interfaces, and the design rationales that control their evolution. It is this that most people think of when talking about architecture. But therein lies the problem we face today. Structure by itself is not valuable to an organization nor is it the soul responsibility of a single professional. Structure CAN be emergent and most often is.

Different Type of structural building form:

Low-rise A low-rise building is simply defined as one which is not tall enough to be classified as high-rise. However, there is no precise consensus as to what constitutes high rise.

Multi-storey - A multi-storey building is a building that has multiple storeys, and typically contains vertical circulation in the form of ramps, stairs and lifts.

The number of storeys is determined according to the diagram below left:



Depending on their height, multi-storey buildings may have particular considerations and requirements in relation to:

- Access and circulation.
- Fire safety and evacuation.
- Structural design.
- Ventilation.
- External air movement.
- Shading, views and right to light.
- Construction methods.
- Access for maintenance and cleaning.

Classifications of multi-storey buildings include:

- Low-rise: a building which is not tall enough to be classified as high-rise.
- Mid-rise: buildings of five to ten storeys, equipped with lifts.
- High-rise: more than 7 to 10 storeys.
- Skyscraper: 40 storeys or more.

- Supertall: exceeding 300 m.
- Megatall: exceeding 600 m.

Structural types. The basic types of multi-storey structure (which may be used in combination) include:

Framed structure. Network of columns and connecting beams form the structural 'skeleton' of the building and carry loads to the foundations.

Propped structure. Uses a cantilever slab or platform as the seating for columns. It utilises an internal core and external propped columns.

Suspended structure. Has an internal core and horizontal floors which are supported by high-strength steel cables hung from cross beams at the top.

Cantilever structure. Has an internal core from which beams and floors cantilever. This removes the necessity for columns.

Braced structur. Bracing is used to give stability so that columns can be designed as pure compression members. The beams and columns that form the frame carry vertical loads, and the bracing system carries the lateral loads. Braced frames reduce lateral displacement, as well as the bending moment in columns, they are economical, easily erected and have the design flexibility to create the strength and stiffness required.

Shear wall structure. Composed of stiff braced (or shear) panels which counter the effects of lateral and wind pressures. The pressures are transmitted to the shear walls by the floors.

Core structure. Utilises a stiff structural core which houses lifts, stairs, and so on. Wind and lateral pressures are transmitted to the core by the floors.

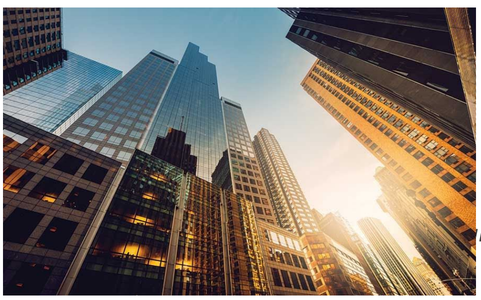
Hull core structure. Also known as 'tube-in-tube' and consists of a core tube inside the structure which holds services such as utilities and lifts, as well as a tube system on the exterior. The inner and outer tubes interact horizontally as the shear and flexural components of a wall-frame structure.

Mid-rise

Mid-rise buildings are considered to be those that fall within a 10–25 m height range. With increasing densification of living within our major urban areas, the numbers of mid-rise residential or mixed-used commercial/residential buildings is likely to increase significantly to meet housing demand.

Mid-rise buildings can be complex and are usually based on one-off specific designs. The main area of concern is where construction components, methods and details typically associated with lower building heights are being applied to mid-rise buildings.

High-rise



A high-rise building is defined variously as a building in which:

- The number of storeys means occupants need to use a lift to reach their destination

- The height is beyond the reach of available fire-fighting equipment.
- The height can have a serious impact on evacuation.

Typically this is considered to include buildings of more than 7-10 storeys or 23-30 m, although the Home Quality Mark defines high rise as a building that is 18 meters or over (the height historically linked with the reach of fire and rescue service equipment) and this height has also been adopted by guidance following the Hackett Review. However, in January 2020, following a fire in a block of student accommodation (which was just under 18m) in Bolton in 2019, the government launched a consultation including proposals to lower the 18m height threshold for 'high-rise' to 11m.

Remember:

There is no hard and fast rule when it comes to classifying buildings as low-rise, mid-rise or high-rise. Every City jurisdiction (planning department) will have its own definition. In many jurisdictions buildings with up to ground + 3 floors are classified as low-rise. These buildings are often walk-up (apartments) type with no lifts (elevators). Buildings with up to ground + 6 floors are classified as mid-rise and those above ground + 6 floors high-rise.

As the number of floors increases, the cost of construction also goes up. Primarily owing to the requirement of better vertical transportation elements (lifts, stairs), larger structural elements such as columns, beams and foundation to withstand wind and seismic loads, pressurized water supply systems, fire fighting systems, ventilation systems etc. The perimeter and height of the floor also play a role in determining the cost depending on the material used for the exterior envelope (walls, windows, roof etc) of the building.

Ground scraper

The term 'Groundscraper' can be used to refer to a building that extends horizontally over a large distance while only being of a low to medium height. The term can also be used, along with 'earthscraper', to describe buildings that are constructed below ground level.

One of the early instances of a building being labeled a groundscraper was the 1930s Merchandise Mart in Chicago, which, having a 372,000 sq. m floor area was almost 50% bigger than the Empire State Building.

The Pentagon, Arlington County, USA

One of the largest and most famous groundscraper buildings, this military complex has around 600,000 sq. m of floor space.

kyscraper

The term ‘skyscraper’ refers to tall, continuously habitable buildings of 40 floors or more. Throughout the history of the built environment, skyscrapers have been developed as prestigious structures demonstrating the power and wealth of a city or nation and producing a sense of wonder.

Although the term ‘skyscraper’ was only coined in the late-19th century – to describe buildings of steel-framed construction of at least 10 storeys – the desire for tall and impressive buildings extends back to the Pyramids of Giza in Egypt and the cathedrals built across Europe. The tall structures built throughout the Middle Ages were intended to fulfill the religious function of acquiring a better connection with the gods, or the military function of enabling a good vantage point.

The development of more modern construction techniques began with the arrival of the Industrial Revolution. Two specific innovations in the 19th century made skyscrapers much more practical:

In 1857, lifts or elevators meant that building height was no longer such a concern to occupants in terms of safe passage between floors.

The introduction of iron frame and glass curtain wall construction instead of stone or brickwork meant that buildings could be designed to be much taller than before.

Skyscrapers are also a feature of urbanisation. From the 19th century onwards, cities started becoming denser, creating the necessity for building upwards to maximise floor space efficiency. Today, skyscraper construction is still largely dictated by economics, with the price and availability of urban centre land justifying building upward.

Early skyscrapers

Although only 5 storeys tall, the Oriel Chambers in Liverpool, built in 1864, was the first building in the world to use an iron frame and glass curtain wall construction which enabled greater load-bearing capabilities.

In 1885, the Home Insurance Building in Chicago was completed and is widely recognised as the first skyscraper, despite being only 10 storeys (42 m) tall.

In 1889, Chicago’s Rand McNally Building became the first all-steel framed skyscraper.

In 1891, St Louis’ Wainwright Building became the first steel-framed building with soaring vertical bands to emphasise the building’s height.

In 1895, New York’s American Surety Building secured the title of world’s tallest skyscraper (21 storeys).

While height restrictions were implemented across Europe in the early-20th century, New York and Chicago led the way in skyscraper construction.

In 1902, the Flatiron Building (20 storeys) was built, and is now one of the most iconic examples of the New York skyscraper boom. This boom saw the completion of the Metropolitan Life Insurance Tower (50 storeys), the Woolworth Building (60 storeys), the Bank of Manhattan (71 storeys) and the Chrysler Building (which, upon completion in 1930, was briefly the world’s tallest building at 77 storeys).

In 1931, New York's Empire State Building was completed. At 102 storeys (381 m) tall, it stood as the world's tallest building for the next 40 years.

Modern skyscrapers

As buildings became ever taller, the techniques and methods of construction changed. Steel beam grids and columns were utilised. Concrete steel and glass were used for their strength, durability, and resistance to the weather. To try and alleviate the risk of wind sway, engineers began installing diagonally-braced steel trusses to ensure a stronger core.

Throughout the 1960s, the structural engineer Fazlur Khan developed a new method of skyscraper construction. He moved most beams and columns to the outside walls, and in so doing creating a stiff tube that offered greater structural stability.

In 1972, the World Trade Center (415 m) became the world's tallest building and was an early adopter of Khan's construction methods.

In 1973, Chicago's Willis (or Sears) Tower (100 storeys, 442 m) was completed.

Over the next decades, the skyscraper boom spread into Asia, South America and Europe, culminating in Malaysia's Petronas Towers becoming the tallest skyscraper in 1998 (452 m), followed by Taiwan's Taipei 101 in 2004 (509 m).

Since 2010, the tallest building in the world has been Dubai's Burj Khalifa (828 m) as shown on the left.

Supertall

The Council on Tall Buildings and Urban Habitat (CTBUH) defines a 'supertall' building as one that is more than 300 m (984 ft) in height. This classification is exceeded by 'megatall' buildings which are those exceeding 600 m (1,968 ft) in height.

The widely recognised CTBUH criteria for determining the height of a building is the '…lowest, significant, open-air, pedestrian entrance to the architectural top of the building, including spires, but not including antennae, signage, flagpoles or other functional-technical equipment.'

The first supertall skyscraper was the Chrysler Building, completed in New York in 1930. Only 15 were built between 1930 and 1995, with a rapid increase in building heights since. Between 2010 and 2015, 50 supertall buildings were built. In January 2016, the 100th supertall building was completed, 432 Park Avenue, again in New York.

There are many structural and technical issues facing supertall buildings, and they must be designed to mitigate the threat of seismic activity, heavy winds (as well as the variation in wind speeds between ground and higher levels), and fire. The ability to use structure-mounted cranes and to lift items to the required heights have enabled more supertall buildings to be built.

Megatall

The Council on Tall Buildings and Urban Habitat (CTBUH) defines a 'megatall' building as one that is more than 600 m (1,968 ft) in height. This classification exceeds 'supertall' buildings which are those exceeding 300 m (984 ft) in height.

The widely recognised CTBUH criteria for determining the height of a building is the '…lowest, significant, open-air, pedestrian entrance to the architectural top of the building, including spires, but not including antennae, signage, flagpoles or other functional-technical equipment.'

As of February 2016, only three megatall buildings had been completed:

- The Burj Khalifa in Dubai.
- Shanghai Tower in Shanghai. (right image)
- Makkah Royal Clock Tower in Mecca.

As the CTBUH has said, this is the 'era of the megatall'. They estimate that the number of buildings classified as megatall will have risen to seven by 2020 with the following projects having been completed:

- Ping An Finance Centre, Shenzhen.
- Greenland Center, Wuhan.
- Signature Tower, Jakarta.
- Kingdom Tower, Jeddah.

Super-slender

A new form of skyscraper has evolved in New York over the past decade: the super-slim, ultra-luxury residential tower. These pencil-thin buildings of 50-90+ storeys use a development and design strategy of slenderness to pile their city-regulated maximum square feet of floor area (FAR) as high as possible to create luxury apartments with spectacular views.

The defining characteristic of these new towers is not height, but slenderness. A tower can be very tall, but not slender, and it can be slender without being very tall.

Many developers believe apartment buyers shop first for neighbourhood, then views, then amenities. But in the new crop of super-slender towers, the views are the driving force. Central Park is the gold standard, but other areas also have great appeal if they can climb to 600-800 ft or taller and command sweeping panoramas of the city.

The above images are slender towers that is located near the southern end of Central Park in New York and in particular on the cross-town commercial 57th Street, nicknamed 'Billionaires' Row.'

Designed by different architectural firms in a wide range of styles from historical to avant-garde and clad in materials from limestone to all-glass curtain walls, these towers underscore the slenderness development strategy as the unifying characteristic of a new typology.

What is slenderness?

'Slenderness' is an engineering definition. Structural engineers generally consider skyscrapers with a minimum 1:10 or 1:12 ratio (of the width of the building's base to its height) to be 'slender'.

The World Trade Center North Tower was the tallest building in the world on its completion in 1971. But at a height of 1,368 ft and with a big square floor plate, 209 ft on each side, the ratio of its base to height was less than 1:7. The eighteen towers on the chart range from a ratio of 1:10 to an extraordinary 1:23 at 111 W. 57 Street.

Lining up the super-slenders by ascending height does not correlate to arranging them by their size in gross floor area (GFA). An extreme example is the difference in floor area of two tallest towers on the chart: Central Park Tower will comprise slightly more than 1 million sq. ft., while 111 West 57th Street will contain less than a third of that total. There is a more than five-fold range of size among the super-slenders: the two towers with the smallest floor areas - less than 200,000 sq. ft. - are 520 Park Avenue and One Madison.

Megastructure

The term 'megastructure' was applied to a range of futurist proposals and experiments in architecture and design during the early 1960s. The main premise of a megastructure was that a single building or structure could be used as a frame to which infrastructure, utilities and additional units could be interconnected and expanded upon, almost as a self-contained 'city'.

The term came to popular attention in Reyner Banham's 1976 book 'Megastructures: Urban Futures of the Recent Past' and was seen as an architectural response from the likes of design group Archigram and Buckminster Fuller to the developing awareness of issues such as urban densification and overpopulation.

According to Douglas Murphy in 'Last Futures: Nature, Technology and the End of Architecture':

'…megastructure also referred to an architectural aesthetic – massive, disparate structures combining strict artificial forms with an organic growth of spaces within. It was a serious attempt at developing the ongoing practice of addressing large urban problems through planning whilst simultaneously incorporating the rapidly changing lifestyles of the post-war era.'

Despite belonging more to theory than actual projects, megastructures had to conform to a number of criteria:

- Capable of extension or reduction after initial construction.
- Modular.
- Built from repeating components.
- A structural framework capable of having smaller elements 'plugged' into it.
- A more durable initial structure than the subsequent 'plugged-in' elements.

Several examples of megastructures were exhibited at events such as Expo 67 and Expo 70. These took the form of giant space frames such as; Buckminster Fuller's geodesic domes, Kenzo Tange's Expo 1970 Theme Pavilion (see top image), and modular units such as the Japanese Metabolist movement.

During the 1970s, megastructure designs were influenced by the environmental movement and the American 'counter-culture', and adopted forms that were intended to be 'floating habitats'. Examples included Buckminster Fuller's design for Triton City (a floating ziggurat housing block with plug-in units); Kenzo Tange's Tokyo Bay project; and Frei Otto's 'Arctic City' proposal for a large envelope structure 2 km across, under which a city could be constructed that would be sheltered from harsh Arctic conditions.

Anticlastic and Synclastic

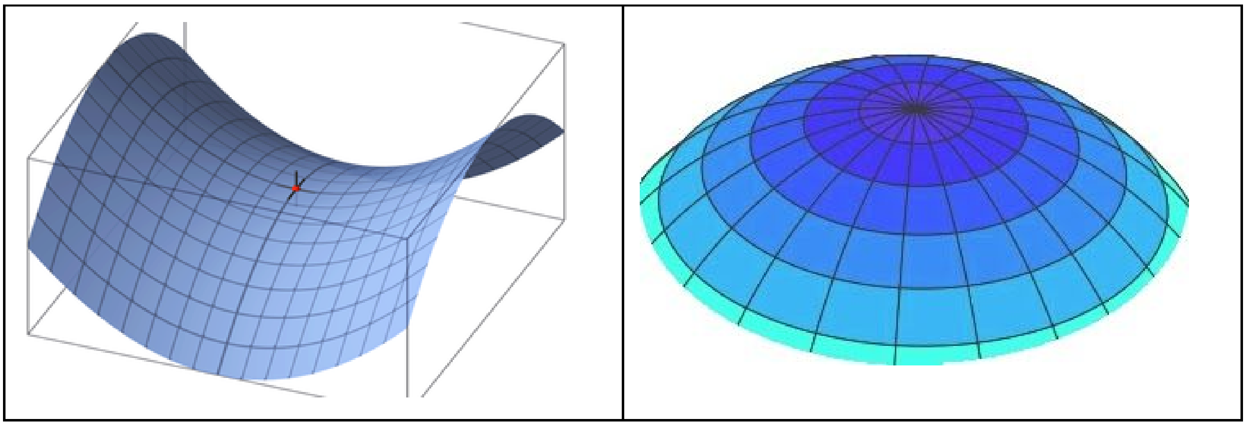
Tensile surfaces, that is, surfaces which carry only tension and no compression or bending, rely on double curvature for their stability. Stability is provided by the opposition of two curvatures which enable the surface to be tensioned without losing its form.

Tensioning the surface reduces its elasticity and so its tendency to deform under load, and the curvature itself means that the surface will deform less for any given extension.

Tensile surfaces can be used in buildings to create thin, long span enclosures, such as roofs for sports stadiums, shopping centres, atria and so on. Typically they are constructed using a PVC coated polyester or PTFE coated glass fabric, typically just 1 mm thick.

Double curvature can be anticlastic or synclastic.

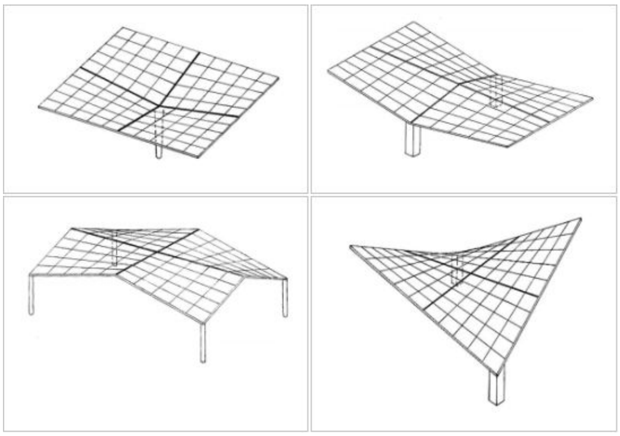
Anticlastic (saddle-shaped). Synclastic (dome-shaped)



Anticlastic surfaces are those in which the centres of curvature are located on opposing sides of the surface. This is commonly-described as a saddle shape. A hyperbolic paraboloid is an anticlastic surface.

Synclastic surfaces are those in which the centres or curvature are on the same side of the surface. This is a dome-shape. This can be created with an architectural fabric by inflation – that is, air pressure within the dome maintains the form of the surface when it is tensioned, rather than the opposition of the curvatures.

Hyperbolic paraboloid



A hyperbolic paraboloid (sometimes referred to as 'h/p') is a doubly-curved surface that resembles the shape of a saddle, that is, it has a convex form along one axis, and a concave form along the other. It is also a doubly-ruled surface, that is, every point on its surface lies on two straight lines across the surface. Horizontal sections taken through the surface are hyperbolic in format and vertical sections are parabolic.

The fact that hyperbolic paraboloids are doubly-ruled means that they are easy to construct using a series of straight structural members. As a consequence they are commonly used to construct thin 'shell' roofs. These can either be formed using timber or steel sections, that are then clad, or they can be constructed using concrete.

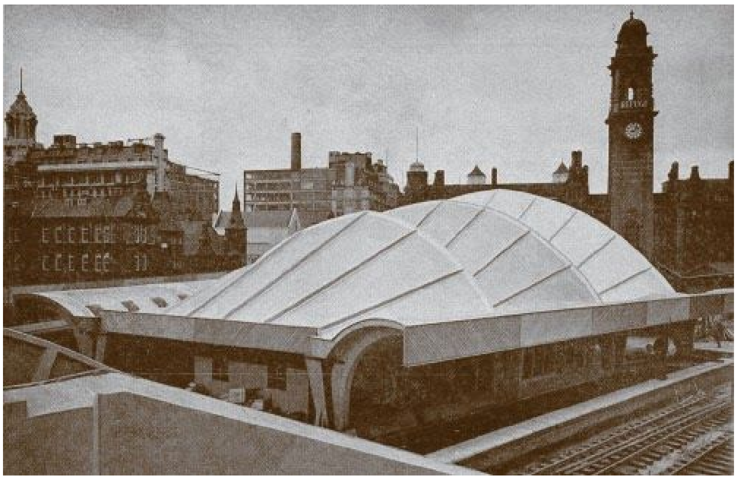
The use of hyperbolic paraboloids as a form of thin shell construction was pioneered in the post-war era, as a hybrid of modern architecture and structural engineering. Being both lightweight and efficient, the form was used as a means of minimising materials and increasing structural performance while also creating impressive and seemingly complex designs.

Rather than deriving their strength from mass, like many conventional roofs, thin shell roofs gain strength through their shape. The curvature of the shape reduces its tendency to buckle in compression (as a flat plane would) and means that they can achieve exceptional stiffness. Being braced in two directions they experience no bending and are able to withstand unequal loading, whether from dead loads (such as equipment hung from the ceiling), or live loads (such as wind).

Hyperbolic paraboloid shell roofs can be constructed using reinforced concrete with a shell thickness of just 50 mm for diagonal spans up to 35 m.

Conoid

A conoid is a special kind of warped ruled surface which, as a curved shell roof, can be used as an alternative to a barrel vault. The basic principle is that one edge of the shell is curved while the opposite edge is kept straight. In architecture, this is referred to as a 'right conoid'.



Two basic geometrical forms are encountered:

- A straight line is moved along a curved line at one end and a straight line at the other end, the resultant shape being cut to the required length.
- A straight line is moved along a curved line at one end and a different curved line at the other end.

The end consists of a reinforced concrete or steel lattice, which serves as a stiffening beam to prevent shell deformation. Support is required at all corners.

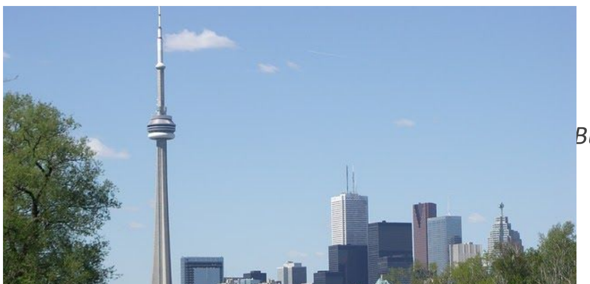
Spans of up to 12 m with chord lengths of up to 24 m are possible. The typical chord-to-span ratio is 2:1.

When conoids are made of reinforced concrete they require formwork on which to set the reinforcing steel and pour the concrete. The initial cost of making the formwork is usually high, but it can be reduced by pouring many shells on the same form.

There can be a solid infill or glazed end diaphragm. Glass panes set between adjacent conoids at the curved front of each conoid can allow for illumination. If the conoids face north they get the best natural light, which can be important for space such as factories.

Conoid shells are an ideal shape for cantilevered roofs covering the stands of stadiums with either a curvature up or a curvature down.

Tower



The correct definition of 'tower' is a type of structure that is tall in proportion to the size of its base, often by a considerable margin. A tower is different from a tall building in that it is not built for habitation or for work, but serves other functions, primarily achieved by its height. However, towers may be intended for regular human access, for example as an observation platform.

Despite this, the term 'tower' is also sometimes applied to tall buildings, such as Trump Tower, Almas Tower, Princess Tower, Sea Sand Tower, and so on, and in the UK, high-rise residential buildings are often referred to as ‘tower blocks’.

Pure towers tend to be free-standing, self-supporting structures that do not use guy-wires (unlike masts). They can however be built attached to a building (such as a church tower or clock tower) or a wall (such as a watchtower).

The form of towers generally tapers upwards to ensure the load of the material at height can be supported by the structure below. They must also have sufficient stiffness to avoid buckling under applied loads such as heavy winds.

Historically, towers tended to be used for defensive or military purposes, and the term could be used to refer to an entire fortress, such as the Tower of London. The Romanesque and Gothic periods incorporated towers within the design of churches and cathedrals, sometimes with a spire or a flat roof. Towers were also commonly built onto prominent structures with clocks, such as town halls and other public buildings.

The development of structural steel as a framing device in the late-19th and early-20th centuries enabled towers to be built much taller, most notably, the Eiffel Tower in Paris.

Other types of tower include; cooling towers, water towers, communications towers, and so on.

Some of the most famous towers in the world include:

- Blackpool Tower.
- BT Tower.
- CN Tower.
- Eiffel Tower.
- Emley Moor transmitting station.
- Fernsehturm Berlin.
- Kobe Port Tower.
- Leaning Tower of Pisa.
- Space Needle.
- Watts Towers.

Dome

The dome has a long history in the built environment, and has been a design feature of many different kinds of architecture around the world. Domes are prominent features of Persian, Roman, Byzantine, Islamic, and Italian Renaissance design.

In its simplest form, a dome is a hollow semi-spherical structural element. However, there are many variations on this basic shape, and The ‘Building Construction Handbook’ describes domes as: ‘Double curvature shells which can be rotationally formed by any curved geometrical plane figure rotating about a central vertical axis.’

Domes evolved from arches, originally being adapted only to small buildings such as huts and tombs; however, as construction and design techniques developed, they became more popular as a means of showcasing grand structures such as cathedrals, legislative buildings and, more recently, leisure buildings such as sports stadiums.

In terms of semiology, by reinforcing centrality and singularity, the form of the dome renders explicit the primacy of the circle of space directly below.

In historical terms, the representational efficiency of the dome has made it popular among those seeking to reinforce the notion of a centralised and singular power system, whether absolute monarchy, monotheism, hegemonic dictatorship, fascism, and so on.

Some of the terminology that is often associated with domes include:

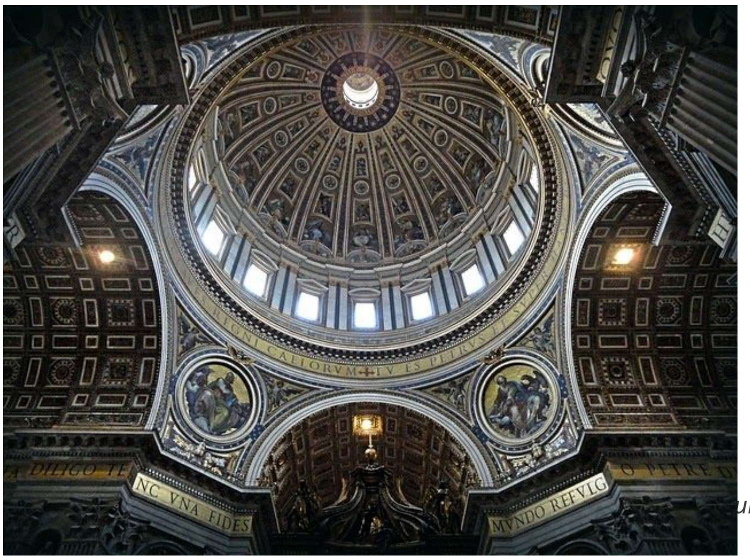
- Apex: The uppermost point of a dome (also known as the 'crown').
- Cupola: A small dome located on a roof or turret.
- Extrados: The outer curve of a dome.
- Haunch: Part of an arch that that lies roughly halfway between the base and the top.
- Intrados: The inner curve of a dome.
- Springing: The point from which the dome rises.

Characteristics

Domes can be constructed from a variety of materials, from traditional masonry and concrete, to cast iron, timber and steel. More recently, lightweight materials such as architectural fabrics and cable structures have also been used to create 'domes'; for the most part these are not true domes as their components have an anticlastic shape, however inflated fabric structures can be dome shaped.

Traditional domes can be highly-efficient structures, similar to arches. They are self-supporting, stabilised by the force of gravity acting on their weight to hold them in compression. They are able to span large areas and require no intermediary columns, creating a free space below.

However, the weight of traditional domes produces downward and outward thrusts. The downward thrust must be transferred to the foundations, whilst the outward thrust must be resisted to prevent the dome from collapsing. This resistance can be provided by the mass of the supporting walls, by buttresses, or by a tension element such as a perimeter ring, cable or chain.



Types of dome

Corbel dome. Dating back to Paleolithic construction, this is one of the earliest dome forms, also known as a 'beehive dome'. They are not domes in the strict sense, as they are formed by horizontal masonry layers that are slightly cantilevered until meeting in the centre.

Cloister vault. Cloister vaults, also known as dome vaults, maintain a polygonal shape in their horizontal cross-section. They arch towards the centre from a constant spring point along a wall.

Crossed-arch dome. This is one of the earliest type of ribbed vault where the ribs, instead of meeting in the dome's centre, are intertwined to form polygons, leaving an empty space in the centre. The earliest known example is in Spain's Great Mosque of Cordoba, dating back to the 10th century.

Geodesic dome

Geodesic domes are sphere-like structures consisting of a network of triangles which provide a self-balancing structural framework whilst using minimal materials. They were developed by the American engineer and architect Buckminster Fuller in the late 1940s.

Monolithic dome. This is a dome structure that is cast in a one-piece.

Onion dome

These domes are characterised by the way they bulge out beyond their base diameters and taper smoothly in an ogee (S-curve) profile. Their height usually exceeds their width and they are often gilded or brightly painted. These are traditionally associated with Russian architecture, in particular their multi-domed churches. For more information, see St. Basil's Cathedral.

Oval dome

An oval dome may be defined as a dome whose plan or profile (or both) has an oval form. The geometry is defined as using combinations of circular arcs that transition at tangential points.

Rotational dome

Also known as 'hemispherical domes', these are one half of a sphere, constructed on a circular ring beam.

Saucer dome

In terms of area these are often some of the largest domes, and are shallower in profile than other forms of dome.

Umbrella dome

Also known as a 'ribbed', 'parachute' or 'scalloped' dome. These are divided into curved segments that follow the elevation's curve. Radial lines of structure that act as the dome's 'ribs' extend down the springing from the apex.

Cable net dome

Whilst not conventional domes in that they are not compression structures, but tension structures, cable net structures can adopt an overall domed shape, albeit individual sections are generally flat or anticlastic in form (rather than the synclastic form of compression domes). The Millennium Dome in London is a cable net dome structure, and at 320m in diameter, is one of the largest domes in the world.

Inflated domes. Inflated structures are formed by pressurising a volume of air enclosed by a lightweight fabric membrane. Inflated structures can adopt a domed shape, and are typically used for spaces requiring a large enclosure uninterrupted by columns, such as radomes, warehouses, sporting facilities, stadia and so on.

E. Building regulations

Planning on building a house? Take a pause from all the planning and calculating because there are still more important things that you have to take care of. Including the National Building Code also known as Republic Act No. 6541.

Not many know that there are certain laws that we need to abide when we're building or constructing a new property. These laws ensure that the property that you're going to build is quality and that it won't obstruct the national safety. A person who does not follow these laws may face certain punishments.

Here are some of the most important parts of the National Building Code of the Philippines to guide you.

1. Scope. The scope of Republic Act No. 6541 includes design, location, siting, construction, alteration, repair, conversion, use, occupancy, maintenance, moving, and demolition of both private and public buildings.

2. Observe public health and safety. One of the main reasons why the National Building Code is created is to ensure public safety. All buildings must abide by certain principles of construction. All materials that are needed must also be environmentally friendly.

3. Maintenance. It's also a must for owners to maintain the orderliness of their properties. Regular maintenance check is a must for all buildings to make sure that everything is in tip top shape.

4. Dangerous sites. The law also forbids construction in lands or sites that are deemed unsanitary of dangerous. Lands that are considered dangerous should undergo certain renovations. The law also notes that an individual's property should be in safe distance to the following elements: polluted streams or bodies of water, volcanic site, and any type of land that can be a source of explosion.

5. Dangerous buildings. The law also defined the characteristics of a dangerous building. These properties usually suffer from poor structure, unsafe degrees, contribute to pollution, have defects, or have been damaged by earthquake or fire.

There are three ways in which an owner can deal with a dangerous building. The first one is that if the building is redeemable, then the owner has the power to repair it. The second one refers to the amount of the repairing cost. Those who wish to repair the property shall spend more than 50% of the current to replacement cost of the building.

The third factor is about those properties that are already a threat to life. The law asks the owner and the people who use it to vacate the property right away.

6. New design. Those who are planning on redesigning their properties are also under this law. Again, the code wants those who are remodeling or redesigning to use good structure and materials.

7. Coordinate with municipal and provincial ordinances. The code asks both owners and the local government to cooperate with each other during the preparation of building the property.

THE NEW NATIONAL BUILDING CODE of the Philippines
IMPLEMENTING RULES AND REGULATIONS

RULE 1: GENERAL PROVISIONS

1. Title
1.1 REVISED IMPLEMENTING RULES AND REGULATIONS OF THE NATIONAL BUILDING CODE OF THE PHILIPPINES (P.D. 1096) referred to as the IRR

2. Declaration of Policy

2.1 To safeguard life, health, property, and public welfare and to provide a framework of minimum standards and requirements to regulate and control the location of buildings, site, design, quality of material, construction, use and maintenance.

3. Scope and Application
3.1 Shall cover architectural, civil/structural, electrical, mechanical, sanitary, plumbing, electronics and interior design. Shall apply to design, location, siting, construction, alteration, repair, conversion, use, occupancy, maintenance, moving, demolition of and addition to public and private buildings and structures except traditional indigenous family dwellings and economic and socialized housing projects.
3.2 Existing buildings without building permits/certificates of occupancy may be issued same provided they conform to these rules and regulations

RULE 11 " ADMINISTRATION AND ENFORCEMENT
1. Responsibility for Administration and Enforcement " Secretary of Department of Public Works and Highways
2. Professional and Technical Assistance " created the National Building Code Development Council (NBCDC) with the Board of Consultants (BOC) " undertake research and development of building systems to develop suitable guidelines, standards, upgrade existing IRR and other codes.

3. Fees

1. Bases of assessment
    1. Character of occupancy or use of building
    2. Cost of construction " 10,000/sq.m (A,B,C,D,E,G,H,I), 8,000 (F), 6,000 (J)
    3. Floor area
    4. Height

4. Administrative Sanctions

4.1 Administrative sanctions for non-compliance of the Code:
4.1.1 Non-issuance, suspension or revocation of permits
4.1.2 Non-issuance, suspension or revocations of certificates of occupancy
4.1.3 Issuance of Work Stoppage Order or Notice.
4.1.4 Issuance of Order for Discontinuance of Use or Occupancy of Buildings or parts thereof

    5. Abatement and/or demolition of dangerous/ruinous buildings
    6. Impositions of administrative fines, surcharges and penalties
5. Grounds for the Non-issuance, Suspension, Revocation of Permit
    1. Non-compliance of plans and specifications with the Code
    2. Incorrect or inaccurate data or information found in the application
    3. Non-compliance with terms and conditions of permit
    4. Failure to commence work within one year
    5. Abandonment of work for 120 calendar days

    6. Unauthorized change in the submitted plans and specifications and in the type of construction
    7. Failure to engage an architect/civil engineer to undertake full time supervision or failure to keep a logbook of the progress of construction
    8. Failure to submit the original design plans stamped by the BO or the as-built plans prior to renovation, alteration, conversion or any change affecting structural stability, architectural presentability and type of construction

6. Grounds for Non-issuance or revocation of Certificates of Occupancy:
    1. Non-compliance with terms and conditions of permits
    2. Incorrect or inaccurate data or information supplied and incomplete requirements in the application
    3. Failure to submit the logbook, duly notarized Certificate of Completion, as-built plans and specifications, and building inspection sheets
7. Issuance of Work Stoppage Order or Notice:
    1. Non-compliance with the terms and conditions of permits
    2. Unauthorized change, modification or alteration in the approved plans and specifications or in the type of construction
    3. Failure to engage the services of an architect/civil engineer to supervise construction
    4. Erecting, constructing, altering, moving, converting or demolishing without permit
    5. Alteration, addition, repair in buildings constructed before the adoption of this code without permit
    6. Unauthorized change during construction from the approved plans and specifications
8. Issuance of Order for Discontinuance of Use or Occupancy " annual inspection
    1. Dangerous or Ruinous Building
    2. Occupancy of building without a Certificate of Occupancy
    3. Change in the existing use or occupancy classification without Certificate of Change of Occupancy
    4. Errors found in the application for Certificate of Occupancy, As-built plan, Notarized Certificate of Completion and Logbook
    5. Maintaining hazardous, dangerous and excessive occupancy loading beyond the designed capacity of the building
9. Non-conforming Use or Occupancy
    1. The use of non-conforming buildings legally authorized under the Code maybe continued.
    2. However, non-conforming buildings cannot be enlarged, increased or extended to occupy a greater area of land than that already occupied.
10. Abatement/Demolition of Dangerous/Ruinous Building
    1. The BO shall order the repair, vacation or demolition of dangerous or ruinous building. Conditions or defects of dangerous or ruinous buildings:
        1. Structural Hazards

2. Fire Hazard
3. Hazardous Electrical Wiring
4. Hazardous Mechanical Installation
5. Inadequate Sanitation/Plumbing and Health Facilities
6. Improper Occupancy and Architectural Eyesore
7. Improper/Unauthorized Location
8. Illegal Construction
9.

RULE III " BUILDING PERMITS AND INSPECTIONS

1. Building Permits

No person, firm or corporation shall construct, alter, repair, convert, use, occupy, move, demolish and add any building without a building permit.

2. Ancillary Permits

2.1.1 Architectural Permit
2.1.2 Civil/Structural Permit
2.1.3 Electrical Permit
2.1.4 Mechanical Permit
2.1.5 Sanitary Permit
2.1.6 Plumbing Permit
2.1.7 Electronics Permit
2.1.8 Interior Design Permit
2.1.9 Other Permits for other professional disciplines

3. Building/Structure Accessory Permits " accessory parts with very special functions indicated or implied in the plans and specifications

3.1 Bank and records vaults
3.2 Swimming pools
3.3 Firewalls separate from the building
3.4 Towers
3.5 Silos
3.6 Smokestacks
3.7 Chimneys
3.8 Commercial/industrial fixed ovens
3.9 Industrial kilns/furnaces
3.10 Water/Waste water treatment tanks, septic vault
3.11 Concrete and steel tank
3.12 Booths, kiosks and stages
3.13 Tombs, mausoleums and niches
3.14 Others

4 Accessory Permits - activities

4.1 Ground preparation and excavation permit
4.2 Encroachment of foundation to public area permit
4.3 Fencing permit for fence exceeding 1.80 m high
4.4 Sidewalk construction permit

4.5 Temporary sidewalk enclosure and occupancy permit
4.6 Erection of scaffolding permit
4.7 Erecting, repair, removal of sign permit
4.8 Repairs permit
4.9 Raising Permit
4.10 Demolition permit
4.11 Moving permit
4.12 Other

5. Exemption from Building Permits

1. A building permit shall not be required for the following minor constructions:
    1. Minor Constructions
        1. Sheds, outhouses, greenhouses, childrens playhouses, aviaries, poultry houses and the like not exceeding six sq.m. completely detached from any building
        2. Addition of open terraces or patios directly on the ground not exceeding twenty sq.m. for private use
        3. Installation of window grilles
        4. Garden pools, aquarium fish not exceeding five hundred mm in depth and for private use
        5. Garden masonry wall not exceeding 1.20 m in height, footpaths, residential garden walks and driveways
    2. Repair works
        1. Repair works not affecting structural members
        2. Repair of non-load bearing partition walls
        3. Repair of any interior portion of a house not involving addition or alteration
        4. Repair/replacement of doors and windows
        5. Repair/replacement of flooring
        6. Repair of perimeter fence and walls
        7. Repair/replacement of plumbing fixtures, fittings or pipings for single detached dwellings and duplexes
        8. Repair/replacement of defective and deteriorated wires, wiring devices, fixtures and safety devices provided that no alterations on the electrical service entrance and the main safety switch or circuit breaker and without additional circuits to existing installations for single detached dwellings

6. Requirements

1. In case the applicant is the registered owner of the lot:
    1. Certified true copy of OCT/TCT, on file with the Registry of Deeds
    2. Tax Declaration
    3. Current Real Property Tax Receipt
2. In case the applicant is not the registered owner of the lot in addition to the above:
    1. Duly notarized copy of the Contract of Lease or Sale
    2. Duly notarized copy of the Deed of Absolute Sale

3. Five sets of survey plans, design plans, specifications signed and sealed by:
    1. Architect, in case of architectural documents
    2. Civil Engineer, in case of civil/structural documents
    3. Professional Electrical Engineer, in case of electrical documents
    4. Professional Mechanical Engineer, in case of mechanical documents
    5. Sanitary Engineer, in case of sanitary documents
    6. Master Plumber, in case of plumbing documents
    7. Electronics Engineer, in case of electronics documents
    8. Environmental Planner who is also an architect or civil engineer in case of developmental/environmental documents
    9. Interior Designer, in case of interior design documents
    10. Geodetic Engineer, in case of lot survey documents

7. Issuance of Building Permit

   7.1 When satisfied that the plans and specifications conforms to the requirements of the Code and its IRR, the BO shall within fifteen days from payment of the required fees, issue the Building Permit.

   2. Non-issuance, Suspension or Revocation of Building Permit
      1. Errors found in the plans and specifications
      2. Incorrect or inaccurate data or information supplied
      3. Non-compliance with the pertinent provisions of the Code and its IRR
   3. Terms and Conditions of Permits
      1. Submitted plans and specifications shall not be changed, modified or altered without the approval of the BO.
   4. Validity of a Building Permit
      1. A building permit shall become null and void if the work is not commenced within one year and if suspended or abandoned for 120 days.

8. Processing of Application for Certificate of Occupancy

1. The owner shall submit to the BO
   1. A duly notarized Certificate of Completion together with the logbook, as-built plans and specifications and the Building Inspection Sheet all signed by the contractor and the architect/engineer who undertook the full time supervision.
   2. As-built plans and specifications signed and sealed by the design professionals, supervisor and contractor.
   3. Changes, alterations and amendatory permit.

RULE IV “ TYPES OF CONSTRUCTION

1.1 Type I “ wood construction

2. Type II “ wood construction with protective fire-resistant materials and one-hour fire resistive all throughout

3. Type III " masonry and wood construction and one-hour fire resistive all throughout
4. Type IV " steel, iron, concrete, or masonry construction and walls, ceiling and permanent partitions shall be of incombustible fire-resistive construction
5. Type V " four hour fire-resistive throughout

RULE V " REQUIREMENTS FOR FIRE ZONES

1. Definition " Fire zones are areas within which only certain types of buildings are permitted to be constructed based on their use or occupancy, type of construction and resistance to fire.
2. Buildings located in more than one fire zone " a building located partly in one fire zone and partly in another shall be considered to be in the more highly restrictive fire zone, when more than one third of its total floor area is located in such zone.

RULE VI " FIRE RESISTIVE REQUIREMENTS IN CONSTRUCTION

1. Definitions
    1. Fire-resistive rating " the degree to which a material can withstand fire as determined by generally recognized and accepted test methods.
    2. Fire-Resistive Time Period Rating " the length of time a material can withstand being burned which may be one hour, two hours, three hours, four hours
2. Fire-Resistive Regulations
    1. Attic access opening shall be provided at the ceiling of a floor of a building with combustible roof construction " 600 mm sq.

RULE VII " CLASSIFICATION AND GENERAL REQUIREMENTS OF BUILDINGS BY USE OR OCCUPANCY

GROUP A " RESIDENTIAL (DWELLINGS)
Division A-1 residential buildings for exclusive use of single family occupants

1. Indigenous family dwelling units
2. single-detached units
3. school or company staff housing
4. church rectories
5. single family dwellings
6. churches or similar places of worship
7. community facilities and social centers
8. parks, playgrounds, pocket parks, parkways, promenades and playlots
9. clubhouses and recreational uses such as golf courses, tennis courts operated by the government or private individuals as membership organizations for the benefit of their members, families and guests.

Division A-2 residential buildings for the exclusive use of non-leasing occupants not exceeding 10 persons

1. single-attached or duplex or townhouse, each privately owned
2. school dormitories (on-campus)
3. convents and monasteries
4. military or pocket barracks
5. all uses in Division A-1
6. pre-schools, elementary and high schools with not more than 16 classrooms
7. outpatient clinics, family planning clinics, lying-in clinics, diagnostic clinics, medical and clinical laboratories
8. branch library and museum
9. steam/dry cleaning outlets
10. party needs and accessories

GROUP B “ RESIDENTIAL (BUILDINGS/STRUCTURES, HOTELS AND APARTMENTS)
Division B-1

1. all uses in Divisions A-1 and A-2
2. Leased single detached dwelling unit, cottage with more than one independent unit and duplexes
3. boarding and lodging houses
4. multiple housing units for lease or for sale
5. townhouses, each privately owned
6. boarding houses
7. accessories, row houses, townhouses, tenements and apartments
8. multiple privately-owned condominium
9. hotels, motels, inns, pension houses and apartels
10. private or off-campus dormitories
11. elementary schools and highschools not more than 20 classrooms

GROUP C- EDUCATION AND RECREATION (INSTITUTIONAL)
Division C-I

1. amusement halls and parlors
2. massage and sauna parlors
3. health studios and reducing salons
4. billiard halls, pool rooms, bowling alleys and golf club
5. dancing schools, disco parks, dance and amusement hall
6. gymnasia, pelota courts and sports complex

Division C-2

1. educational institutions like schools, colleges, universities, vocational, seminaries, convents, including school auditoriums, gymnasia, reviewing stands, little theaters, concert halls, opera houses
2. seminar/workshop facilities

3. training centers/facilities
4. libraries, museums, exhibition halls and art galleries
5. civic centers, clubhouses, lodges, community centers
6. churches, mosque, temples, shrines, chapels and similar places of worship
7. civic or government centers
8. other types of government buildings

GROUP D GOVERNMENT AND HEALTH SERVICES (INSTITUTIONAL)

Division D-I (institutional where personal liberties of inmates are restrained or quarters of those rendering public assistance and maintaining peace and order)

1. mental hospitals, sanitaria and mental asylums
2. police and fire stations, guard houses
3. jails, prisons, reformatories and correctional institutions
4. rehabilitation centers
5. leprosaria and quarantine station

Division D-2 (institutional buildings for health care)

1. hospitals, sanitaria and homes for the aged
2. nurseries for children of kindergarten age or non-ambulatory patients accommodating more than 5 persons

Division D-3 (institutional for ambulatory patients or children over kindergarten age)

1. nursing homes for ambulatory patients
2. school and home for children over kindergarten age
3. orphanages

GROUP E " BUSINESS AND MERCANTILE (COMMERCIAL)

Division E-I (business and mercantile where no work is done except change of parts and maintenance requiring no open flames, welding or use of highly flammable liquids)

1. all uses in Division B-1
2. gasoline filling and station
3. storage garage and boat storage
4. commercial garage and parking buildings, display for cars, tractors, etc.
5. bus and railways depots and terminals and offices
6. port facilities
7. airports and heliport facilities
8. all other types of transportation complexes
9. all other types of large complexes for public services
10. pawnshops, money shops, photo and portrait studios, shoeshine/repair stands, retail drugstores, tailoring and dress shops
11. bakeshops and bakery goods stores

12. construction supplies and building materials such as electrical and electronic stores, plumbing supply stores

Division E-2 (business and mercantile in nature)

1. wholesale and retail stores
2. shopping centers, malls and supermarkets
3. wet and dry markets
4. restaurants, drinking and dining establishments with less than one hundred occupancies
5. day and night clubs, bars, cocktails

Division E-3 (business and mercantile where no repair work is done except exchange of parts and maintenance requiring no open flames, welding or use of highly flammable liquid)

1. aircraft hangars
2. commercial parking lots and garages
3. department stores, shopping malls

GROUP F " INDUSTRIAL (NON-POLLUTIVE/NON-HAZARDOUS INDUSTRIES AND NON-POLLUTIVE/HAZARDOUS INDUSTRIES)
Division F-1 (Light industrial)

GROUP G " STORAGE AND HAZARDOUS INDUSTRIAL (POLLUTIVE/NON-HAZARDOUS INDUSTRIES AND POLLUTIVE/HAZARDOUS INDUSTRIES ONLY)
Division G-1 (Medium Industrial which shall include storage and handling of hazardous and highly flammable materials)
Division G-2 (Medium Industrial buildings for storage and handling of flammable materials)
Division G-3 (Medium Industrial buildings for wood working activities, paper cardboard manufacturers, textile and garment factories)
Division G-4 (Medium Industrial, for repair garages and engine manufacture)
Division G-5 (Medium Industrial for aircraft facilities)

GROUP H " ASSEMBLY FOR LESS THAN 1,000 (CULTURAL AND/OR RECREATIONAL)
Division H-1 (Recreational, which are assembly buildings with stage and having an occupant load of less than 1,000.

1. Theaters and auditoriums
2. concert hall and opera houses
3. convention halls
4. little theater, audio-visual room

Division H-2 (Recreational which are assembly buildings with stage and having an occupant load of 300 or more)

1. dance halls, cabarets, ballrooms
2. skating rinks

3. cockfighting areas

Division H-3 (Recreational which are assembly buildings with stage and having an occupant load of less than 300

1. dance halls, ballrooms
2. skating rinks

GROUP J

Division J-1 agricultural structures

1. sheds
2. barns
3. poultry houses
4. piggeries
5. hatcheries
6. stables
7. greenhouses
8. granaries

Division J-2 Accessory

1. private garages, carports
2. towers and silos, smokestacks and chimneys
3. swimming pools including shower and locker room
4. stages, platforms and similar structures
5. pelota, tennis or basketball courts
6. tombs, mausoleums, niches
7. fence over 1.80 m high
8. steel or concrete tanks
9. aviaries and aquariums and zoo structures
10. banks and record vaults

3. Occupant loads
1. Determination of occupant load “ the occupant load shall be determined by dividing the floor area assigned to that use by the unit area per occupant set forth in Table VIII.3.1 or in the Architectural Code of the Philippines whichever required more exits.
2. The occupant load of any area having fixed seats shall be determined by the number of fixed seats installed.

4. Parking Slot, Parking Area and Loading/Unloading Space Requirements “ refer to attached Table VII.5.1

1. In computing for parking slots, a fraction of 50% and above shall be considered as one car parking slot.

2. In areas where adequate public parking lots/multi-floor parking garages are available within 200 m of the proposed building, only 30% of parking requirements need to be provided within their premises.
5. Allowable Maximum Total Gross Floor Area (TGFA)
    1. General. The Allowable Maximum Total Gross Floor Area (TGFA) of any proposed building shall only be as allowed under this Rule
    2. TGFA Limitation " In Table Vii.6.1. the percentages indicated in the 3rd through 8th columns are the percentages of the Total Lot Area (TLA) that may be used to determine the Allowable Maximum TGFA while the multiplier numbers 3, 5, 12, 18 and 30 represent the number of storeys.
    3. The Allowable Maximum TGFA should not exceed the Allowable Maximum Volume of Building (AMVB). If exceeded, the Allowable Maximum TGFA must be adjusted since the AMVB must always prevail.
6. Allowed Height of Buildings/Structures
    1. General. The maximum height and number of storeys of proposed building shall be dependent upon the character of use or occupancy, on the type of construction, on end-user population density, light and ventilation, width of road right-of-way, building bulk, off-street cum off-site parking requirements and local land use plan and zoning regulations.
    2. The Building Height Limit (BHL) shall only be as allowed under this Rule or under the duly approved city zoning ordinance, whichever is more restrictive (refer to Table VII.7.1)

RULE VIII LIGHT AND VENTILATION

1. Definitions
    1. Maximum Allowable PERCENTAGE OF SITE OCCUPANCY (PSO) " Maximum Allowable Building Footprint (AMBF) divided by Total Lot Area (TLA). Percentage of the maximum allowable enclosed floor area of any building at the ground floor in relation to the TLA. (Table VIII.4.1)
    2. Maximum Allowable IMPERVIOUS SURFACE AREA (ISA) " percentage of the maximum allowable floor area of any paved, tiled or hardscaped surface at the ground floor in relation to the TLA.
    3. Maximum Allowable Construction Area (MACA) " the combined total of the Maximum Allowable PSO and the Maximum Allowable ISA.
    4. Maximum Allowable Unpaved Surface Area (USA) " portion of the lot that shall remain unpaved and reserved for softscaping/planting
    5. Total Open Space Within Lot (TOSL) " the total open space required for each type of use.
2. General Provisions
    1. Every building shall be designed, constructed and equipped to provide adequate light and ventilation

2. All buildings shall face a street or public alley or a private street which has been duly approved.
3. No building shall be altered nor arranged so as to reduce the size of any room or the relative area of windows to less than that provided for buildings, or to create an additional room unless it conforms to the requirements of this Rule.
4. No building shall be enlarged so that the dimensions of the required court or yard would be less than what is prescribed for such building lot.

3. Percentage of Site Occupancy (PSO)
   1. Maximum site occupancy shall be governed by use, type of construction and height of the building and the use, area, nature and location of the site and subject to local zoning requirements.
4. Minimum Requirements for Total Open Spaces within Lot (TOSL)
1. Group A buildings or Residential 1 (R-!) uses shall follow the minimum yard standards in Table VIII.6.1 to comply with the TOSL.
5. Sizes and dimensions of courts and yards
   1. Minimum horizontal dimension of courts and yards shall be not less than two m. all inner courts shall be connected to a street or yard, either by a passageway with a minimum width of 1.20 m or by a door through a room or rooms.
   2. Abutments on the side and rear property lines may be allowed provided that the following requirements are first complied with:
      1. Open space as prescribed in Tables VIII.5.1 and VIII.6.1
      2. Window opening as prescribed in Section 10
      3. Firewall with a minimum of two hours fire-resistive rating constructed with a minimum height clearance of 0.40 m above the roof. Fig. VIII.6.1
      4. The required open space shall be located totally or distributed anywhere within the lot in such a manner as to provide maximum light and ventilation into the building (Fig. VIII.6.2 to VIII.6.5).
      5. Every court shall have a width of not less than 2 m for one or two storey buildings, however this may be reduced to 1.50 m in case of quadruplexes, rowhouses with adjacent courts with an area of not less than 3.00 sq.m. provided that the separation fence shall not be higher than 2.00 m. irregularly-shaped lots may be exempted from having a minimum width of not less than what is required in Table VIII.5.2 and as shown in Figures VIII.6.6, VIII.6.7, VIII.6.8 and VIII.6.9.
      6. For buildings of more than two storeys in height, the minimum width of the rear or side court shall be increased at the rate of 300 mm for each additional storey up to the fourteenth storey. For buildings exceeding 14 storeys in height, the required width of the court shall be computed on the basis of 14 storeys.
6. Ceiling Heights
   1. Habitable rooms provided with artificial ventilation shall have ceiling heights not less than 2.40m. For buildings of more than 1 storey, the minimum ceiling height of the first storey shall be 2.70 m, for the second storey, 2.40 m. and for the succeeding storeys,

2.10 m. Above-stated rooms with natural ventilation shall have ceiling heights of not less than 2.70m.

2. Mezzanine floors shall have a clear ceiling height of not less than 1.80 m above and below it.

7. Sizes and Dimension of Rooms
    1. Minimum sizes of rooms and their least horizontal dimensions shall be as follows:
        1. Rooms for human habitation “ 6.00 sq.m. with a least dimension of 2.00 m.
        2. Kitchen “ 3.00 sq. m. with a least dimension of 1.50 m.
        3. Bath and Toilet “ 1.20 sq. m. with a least dimension of 900mm.
8. Window Openings
    1. Rooms intended for any use not provided with artificial ventilation shall be provided with a window with a total free area equal to at least 10% of the floor area of the room but not less than 1.00 sq.m. Toilet and bath rooms and laundry rooms shall be provided with window with an area not less than 1/20 of the floor area but not less than 240 sq.mm. Such windows shall open directly to a court, yard, public street or alley or open watercourse.
    2. Eaves, canopies, awnings over required windows shall not be less than 750 mm from the side and rear property lines.
    3. There shall absolutely be no openings on/at/within/through all types of abutments (firewalls) erected along property lines except for permitted vent wells (3.00 m x 1.50 m).
9. Roads Right-of-Way (RROW) Access Streets

9.1 No building shall be constructed unless it adjoins or has direct access to public space, yard or street/road on at least 1 of its sides. All buildings shall face a public street, alley or a road.

RULE IX SANITATION

1. All buildings shall be provided with adequate and potable water supply, plumbing installation and suitable wastewater treatment or disposal system, storm water drainage, pest and vermin control, noise abatement device and other measures for protection and promotion of health of persons occupying the premises and others living nearby.

RULE X BUILDING PROJECTION OVER PUBLIC STREET

1. Footings and foundations may be permitted to project into alleys or streets provided the same shall not obstruct any existing utilities/services such as power, water, sewer, gas, communication, and drainage lines
2. The horizontal clearance between the outermost edge of marquee and the curb line shall be not less than 300 mm while the vertical clearance shall be not less than 3.00 m.

RULE XI PROTECTION OF PEDESTRIANS DURING CONSTRUCTION OR DEMOLITION

1. No person shall use or occupy a street, alley or public sidewalk for the performance of work covered by a building permit except in accordance with the provisions of this Rule.

RULE XII GENERAL DESIGN AND CONSTRUCTION REQUIREMENTS

1. All buildings shall be placed in or upon private property or duly designated public land and shall be securely constructed in conformance with the requirements of this Code.

See Separate sheet of the National Building Code of The Philippines standard measurements.

E. Building Structural Components

All buildings have similar components such as foundation, plinth, walls, floors, doors, windows and roof. Every component has its own function.

These building components are classified in two categories

(i) Non-structural Components - Non-structural components are parapet walls, door and windows, furnishings fixtures, partitions or partition walls, tiles, paint etc.

(ii) Structural Components

Structural components are the primary load bearing components of a building, and each have their own structural properties which need to be considered. Such components are

01. Foundation

The foundation is the most critical structural component of any structure and many failures are probably due to faulty foundations rather than any other cause. A good foundation must remain in position without sliding, bending, overturning or failing in any other way. To achieve this, the designer must make sure that the superstructure, foundation and soil act together. It is also important to study the nature, strength and likely behavior of soils under loads along with the knowledge of materials for foundations and superstructure. The main function of foundation is to transfer the load of the entire building to the underlying soil. The foundations of any structure should be laid much below the surface of the ground, for these four purposes

- To secure a good natural bed
- To protect the foundation courses from atmospheric influences and, and
- To increase the stability of structure against overturning due to wind uplift.
- To reduce risk of failure due to settlement of soil

Foundation is the lowest part of a structure below the ground level which is in direct contact with the ground and transfers all the dead, live load and other loads to the soil on which the structure rests. The provision of foundation is made in such a manner that the soil below the foundation is not stressed beyond its safe allowable bearing capacity. Depending upon the type of soil existing at site, its safe bearing capacity and the type of building which is required to constructed, a structure may need shallow or deep foundations. In case of load bearing walls, the foundation could be in the form of spread footings. For framed structures, the foundation could be in the form of independent column footings, combined footing, rafts or piles.02. Plinth

The portion of the structure between the surface of the surrounding ground and surface of the floor, immediately above the ground known as a plinth. The level of the surrounding ground is known as formation level or simply ground level and the level of the ground floor of the building is known as a plinth level.

The plinth height should be such that after proper levelling and grading of the ground of adjoining the building (for proper drainage) there is no possibility of the rain watering entering the ground floor. The built covered area measured at the ground floor level is termed as plinth area.

03. Wall

Walls are provided to enclose or divide the floor space in desired pattern. In addition, walls provide security, privacy, and give protection against sun, rain, cold and other adverse effects of weather. The division of floor space varies depending on the functions required to be performed in the building. In a well-planned layout, the walls divide the space in such a manner so as to achieve maximum carpet area and minimum area of circulation. Walls are constructed by use of building units like bricks, stones, concrete blocks (hollow or solid) etc. The building units are bonded together with mortar in horizontal and vertical joints and construction is termed as masonry. When bricks are used as building units it is known as brick masonry and when stones are used as building units it is termed as stone masonry.

Walls can be broadly divided in two categories:

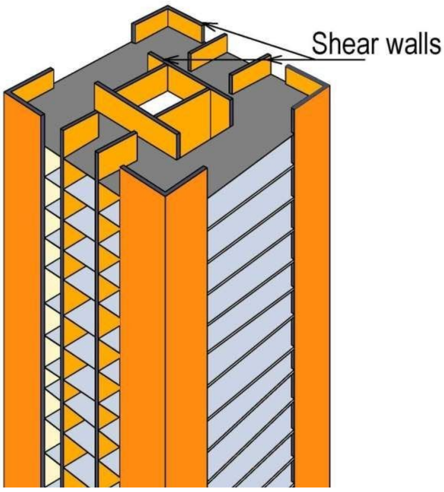
(i) Load bearing walls and

(ii) Non-load bearing walls.

A load bearing wall supports its own weight as well as the super-imposed loads transfer it through floors/roofs.

A non-load bearing wall on the other hand carries its own weight and is not designed to carry super-imposed load from the structure. They are normally provided as partition walls.

04. Shear Wall



Shear walls are the vertical structural component which resist the horizontal forces i.e. wind, earthquake acting on a building structure. Shear wall can also be defined as a wall which are reinforced and made of braced panels to carry lateral forces. Shear wall must provide lateral shear strength to the building to resist the horizontal earthquake loads, wind loads and transfer these loads to the foundation. Shear Walls provide great stiffness to building in the direction of their orientation, which reduces lateral sway of the building and thus reduces damage to structure during earthquake or cyclone.

05. Column

A column may be defined as vertical load bearing member the width of which is neither less than its thickness nor more than four times its thickness. Pier is a vertical load bearing structural component similar to a column except that it is bonded into load bearing wall at the sides to form an integral part of the wall and extends to full height of the wall. A pier is introduced to increase the stiffness of the wall to carry additional load or to carry vertical concentrated load. Pier also strengthens the wall to resist pressure without buckling.

06. Floor

Floors are flat supporting structural components of a building. They divide a building into different levels so that creating more accommodation on a given plot of land. The basic purpose of a floor is to provide a firm and dry platform for people and for other items like furniture, stores, equipment etc. Floor is generally referred to by its location.

A floor provided for accommodation below the natural ground level is termed as basement floor. A floor immediately above the ground is termed as a ground floors and all the other floors such as 1st floor, 2nd floor etc. are termed as upper floors. A floor basically consists of two parts namely (i) sub floor (ii) Flooring The sub-floor is the structural component of the floor which supports all the loads (dead and super-imposed) and flooring is the covering layer of desired specification (cement concrete, terrazzo, tiles etc.) provided over the sub-floor as a finishing layer for aesthetics.

07. Slab

A Slab is used as a base as well as a ceiling/ roof to transfer the load of the structure to the beams/walls. The ceiling or roof of the structure is a slab. A slab is a structural component that is used to create flat horizontal surfaces such as floors, roof decks and ceilings. A slab is usually several inches thick and supported by beams, columns, walls, or the ground. It is a horizontal structural component, with top and bottom surfaces parallel and near. Depth of slab is small as compared to its length and breadth.

08. Beam

A beam is a horizontal structural element/member spanning a distance between one or more supports, and carrying vertical loads across (transverse to) its longitudinal axis that is capable of withstanding load primarily by resisting against bending. A beam is a laterally loaded member, whose cross-sectional dimensions are small as compared to its length. Beams are structural components on which the slabs rest. The beams transfer the load of the slab to the columns.

09. Roof

It is the uppermost component of a building and its main function is to cover the space below and protect it from rain, snow, sun, wind etc.

A roof basically consists of two components namely

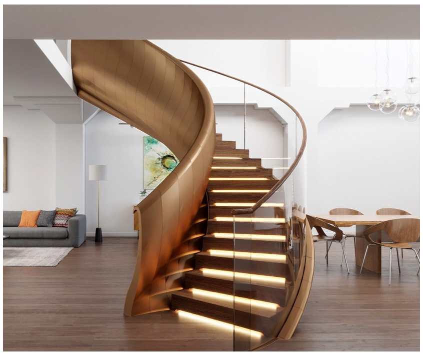
(i) The roof decking

(ii) The roof covering

A roof can be either flat, curved or pitched in shape. The choice of the type of roof is made keeping in view the location of the building, weather conditions, funds available and functional and aesthetics requirements. The structural components of roof decking in case of pitched roof is generally a truss, in case of curved roof it is a shell or dome and in case of flat roof it is a flat slab. The roof covering or roofing which is provided over pitched roof could be in the form of tiles, slates, A.C. sheets, G.I. sheets, etc. In case of flat roofs, the roof covering is termed as terracing, which could comprise a layer of varying thickness of material like lime, concrete, mud phuska etc.

The terracing serves dual purpose i.e. (i) Providing suitable slopes on the roof top for draining of rain water. (ii) of acting an insulation layer for providing thermal comfort to the users of the space below.

10. Staircase



A stair may be defined as a structure comprising of a number of steps connecting one floor to another. The stair should be constructed in such a manner that it is safe and comfortable to use and it should be so located as to permit easy communication. The selection of the type of material to be used depends upon the aesthetical importance, funds available, durability and fire resisting qualities desired.

11. Lintel, and Weather Shade

The openings are provided in the wall of a building to accommodate the doors or windows. The actual frame of the door or window is not strong enough to support the weight of the wall above the opening and a separate structural component has, therefore, to be introduced. This is known as a lintel, and is similar in character to beam.

Weather Shades or chhajjas are generally combined with lintels of windows to protect them from the weather elements such as sun, rain, frost etc.

Windows sills are usually weathered and throated to throw the rain water off the face of the wall. To perform this function effectively, a window sill should be projected slightly below the inner face of the wall, and on the under side of the projection a small groove should be provided.

Each of these structural components are an essential part of a building and require due consideration in design and construction for their functional and structural performance.

Building Foundation

Foundations provide support for structures, transferring their load to layers of soil or rock that have sufficient bearing capacity and suitable settlement characteristics to support them.

There are a very wide range of foundation types suitable for different applications, depending on considerations such as:

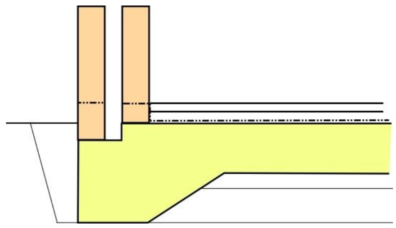
The nature of the load requiring support.

- Ground conditions.
- The presence of water.
- Space availability.
- Accessibility.
- Sensitivity to noise and vibration.

Very broadly, foundations can be categorised as shallow foundations or deep foundations.

- Shallow foundations are typically used where the loads imposed by a structure are low relative to the bearing capacity of the surface soils.
- Deep foundations are necessary where the bearing capacity of the surface soils is not adequate to support the loads imposed by a structure and so those loads need to be transferred to deeper layers with higher bearing capacity.

Types of shallow foundations

Trench fill foundation.	Rubble trench foundation.	Raft foundation.
		

Strip foundations (or footings)

Strip foundations provide a continuous strip of support to a linear structure such as a wall.

Trench fill foundations are a variation of strip foundations, in which the trench excavation is almost completely filled with concrete.

Rubble trench foundations are a further variation of trench fill foundations, and are a traditional construction method which uses loose stone or rubble to minimise the use of concrete and improve drainage.

Pad foundations

Pad foundations are rectangular or circular pads used to support localised loads such as columns.

Raft foundations

Raft foundations are slabs that cover a wide area, often the entire footprint of a building, and are suitable where ground conditions are poor, settlement is likely, or where it may be impractical to create individual strip or pad foundations for a large number of individual loads. Raft foundations may incorporate beams or thickened areas to provide additional support for specific loads.

Types of deep foundations

Pile Driver	Sheet Piles	Diaphragm Wall
		

Piles

Pile foundations are long, slender, columns typically made from steel or reinforced concrete, or sometimes timber.

Generally piles are classified as; end-bearing piles (where most of the friction is developed at the toe of the pile, bearing on a hard layer), or friction piles (where most of the pile-bearing capacity is developed by shear stresses along the sides of the pile, suitable when harder layers are too deep).

Piles are most commonly; driven piles prefabricated off site and then driven into the ground, or bored piles that are poured in situ. If the boring and pouring takes place simultaneously, the piles are called continuous fight augured (CFA) piles.

Mini piles (or micro piles/micropiles)

Mini piles are used where access is restricted, for example underpinning structures affected by settlement. They can be driven or screw piles.

Pile walls

By placing piles directly adjacent to one another, a permanent or temporary retaining wall can be created. These can be closely-spaced contiguous pile walls, or interlocking secant walls, which depending on the composition of the secondary intermediate piles can be hard/soft, hard/firm or hard/hard secant walls.

Diaphragm walls

Diaphragm walls are made by excavating a deep trench that is prevented from collapsing by being filled with engineering slurry such as bentonite and then the trench is filled with reinforced concrete panels, the joints between which can be water-tight.

This is commonly used for top-down construction, where a basement is constructed at the same time as above ground works are carried out.

Caissons

Caissons are watertight retaining structures sunk into the ground by removing material from the bottom, typically this might be suitable for building structures below water level.

Compensated foundations

If a very large amount of material is excavated (for example, where there is a deep basement), it may be sufficient that the relief of stress due to the excavation is equal to the applied stress from the new construction. As a result, there should be little effective change in stress and little settlement.

Ground anchors

Ground anchors transfer very high loads by using a grouted anchor to mechanically transfer load from a tendon to the ground. They can be pre-tensioned, or can be tensioned by the applied load.