Dynamics and Structural Analysis (ARCH 206)
Overview: Structures
ARCHES & CABLES
An arch is a structure that spans a space and supports structure and weight above it. Ancient arches were made of stone.
Stone (steel and concrete) work well in compression. A material is in compression when its particles are being pushed together.
The fixed arch - often used in reinforced concrete bridge and tunnel construction
The two-hinged arch - often used to bridge long spans. Pinned connections at the base.
The pinned base is able to rotate allowing the structure to move freely and compensate for the thermal expansion and contraction caused by changes in outdoor temperature.
The three-hinged arch is hinged at its base and at the mid-span. The connection at the mid-span allows the arch to move in two opposite directions, and compensate for any expansion and contraction. This type of arch is thus not subject to additional stress caused by thermal change.
The shape of an arch depends on the type of load applied on the arch. If it is just a point load at the center then it will be two straight lines as shown in figure 2. If two point loads then the shape will be as shown in figure 4. If it is uniformly distributed load then the shape of the arch will be a parabolic one.
Catenary is the curve described by a flexible chain or a rope if it is supported at each end and acts upon the uniform gravitational force due to its own weight.
Cable study model Gaudi
Casa Mila - Gaudi

Casa Batllo - Gaudi
The Gateway Arch is a 192 m monument. Clad in stainless steel and built in the form of a flattened catenary arch. It is the world's tallest arch and largest monument.
There are three modes of transportation up the arch: two sets of emergency stairs (one in each leg), 12-passenger elevator to 113 m height, and a tram in each leg.
The arches, ranging from 3 m to 15 m in width, are formed along intersecting arcs, with the columns being at intersection points. They are spaced evenly enough to provide adequate structural integrity.
Tama Art University Library - Toyo Ito
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Agora Greece - Calatrava
Agora Greece - Calatrava
Dublin - Bridge on Liffey River - Calatrava
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The scheme proposes an undulating ribbon of structure that wraps around the 6 lane road deck in a continuous sculptural loop form creating 2 triangulated arch forms.
Infinity Loop Bridge - 10 Design & Buero Happold
Infinity Loop bridge - 10 Design& Buero Happold

- Internally accessible
- Fabricated box section (cross section transition through length)
- Reinforced cable anchorage point
- Stiffened steel plate construction
- Trough for arch feature lighting
- Hanger cable
Simple suspension bridge
Suspension Bridge  Golden Gate Bridge – Joseph Strauss, Irwing Morrow, Charles Ellis
Cable Stay Bridge - UN Studio – Erasmus Bridge
Structural design aims to achieve an air of weightlessness, most notably in the form and visual impression of the four roof trusses of the main multi-purpose space.

The desired effect is to have a light, floating roof, for this reason, the points of the trusses that appeared to hold a great deal of weight are honed. By sculpting out the material we were able to reveal the structure’s true force lines.
A grid of tension cables supports the structural trusses.
Cable suspended stairs

1. Godzilla House by Korea Chae-Pereiera Architects in Seoul Korea
2. Suspended Stair by Tense Architecture Network
Suspended Installations
Soo Sunny Park - SSVT Vermont vapeur Slide (2007)
Suspended Installations
Jeahyo Lee, Suspended Stone
TENSEGRİTY STRUCTURES
Reference: Buckminster Fuller Tensegrity Model
Tensegrity Octahedron; Triangulated network except for its six square faces.

Tensegrity Tetrahedron
Total Triangulation
Kenneth Snelson describes Tensegrity as a closed structural system composed of a set of three or more elongate compression struts within a network of tension tendons, the struts do not touch one another, but press outwardly against nodal points in the tension network to form a firm, triangulated, prestressed, tension and compression unit.
Kurilpa Bridge is the world’s largest hybrid tensegrity bridge. The Kurilpa Bridge is a multiple-mast, cable-stay structure. The bridge is 470 m long, main span of 128 m, the width is 6.5 m. Principles of tensegrity: producing a synergy between balanced tension and compression components.
Tensegrity: Producing a synergy between balanced tension and compression components, light structure and incredibly strong. Large viewing and relaxation platforms, resting areas, and a continuous all-weather canopy for the entire length of the bridge.
To design a bridge which is a blending of architecture and structures based on absence of foundation piles,
- a cable structure stiffened by strut elements (tensegrity),
- structural elements with a reduced section (optimization).
Suspended Tensegrity Bridge by Stefano Paradiso
TENSILE STRUCTURES
Constructed in six weeks, 8,000-square-metre pavilion was made from a flexible polyester material draped over a net of steel cables.
Expo 1967 Montreal German Pavillion - Frei Otto
SPACEFRAMES
- A **space frame** or **space structure** is a truss-like, lightweight rigid structure constructed from interlocking struts in a geometric pattern.
- Space frames can be used to span large areas with few interior supports.
- A space frame is strong because of the rigidity of the triangle

SPACE FRAME STRUCTURES

• Structural solution that provides freedom in large span areas while providing strong resistance.

• Providing column-free space, aesthetic appearances while offering flexibility and adaptability.

• Satisfying the needs of a diverse range of spatial demands from municipalities to aviation, from sport halls to shopping centers for their own specific project needs.
Space Frame Structure Typologies

- Single layer grid. All elements are located on the surface.

- Double-layer grids, or flat surface space frames. The elements are organized in two parallel layers with each other. Each of the layers form a lattice of triangles, squares or hexagons. They have the diagonal bars connecting the nodes of both layers in different directions in space.

- Triple layer grid. Elements are placed in three parallel layers,
Curvature classification

- Space plane covers. These spatial structures are composed of planar substructures.
- Barrel vaults. Barrel vaults has a cross section of a simple arch.
- Spherical domes and other compound curves

A Double-Layer Braced Barrel Vaults
A Free Form spatial curve

http://www.setareh.arch.vt.edu/safas/007_fdm_21_spatial_structure.html
Double-layer grids, or flat surface space frames, consist of two planar networks of members forming the top and bottom-layers parallel to each other and interconnected by vertical and inclined members.

Double-layer grids have commonly hinged joints with no moment or torsional resistance; therefore, all members can only resist tension or compression. Even in the case of connection by comparatively rigid joints, the influence of bending or torsional moment is insignificant.

Basic elements of double-layer grid
A space frame is a structure system in the form of a flat or curved surface which is assembled of linear elements so arranged that forces are transferred in a three-dimensional manner.
Designed by Grimshaw Architects, the two Biome buildings - the Rainforest Biome and the Mediterranean Biome - each consist of several domes joined together, and are joined in the middle by the Link building.

The complex consists of:
- Entrance and the visitor centre
- Humid topic Biome (HTB)
- Warm Temperature Biome (WTB)
- The Link
The project has design criteria such as column free space, maximum sunlight intake, optimum volume for required function and visual appearance. The primary design for the project was single layered domes. But the single layered structures of the given project had large deformations.
Under uniform loading in a hemisphere geodesic dome, all upper members those about approx 45 degrees will be in compression, lower near horizontal members will be in tension, while near vertical members will be in compression.
Heydar Aliyev Centre, Zaha Hadid Architects
The main structure of the Heydar Aliyev Cultural Centre is a mix of reinforced concrete, steel frame structures, and composite beams and decks.
Rigid space frame and the free-formed exterior cladding seams.
Glass Fibre Reinforced Concrete (GFRC) and Glass Fibre Reinforced Polyester (GFRP)
The expansive roof – stretching across 163m supported only by a single Double Cone, cylinder-shaped structure without any additional supporting columns – created an open three-dimensional, urban landscape.
The ceiling’s underside is made of aluminium louvers