

THEORY & DESIGN OF STRUCTURES IV



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SHELLS AND DOMES



UNIT IV



SHELL - DEFINITION

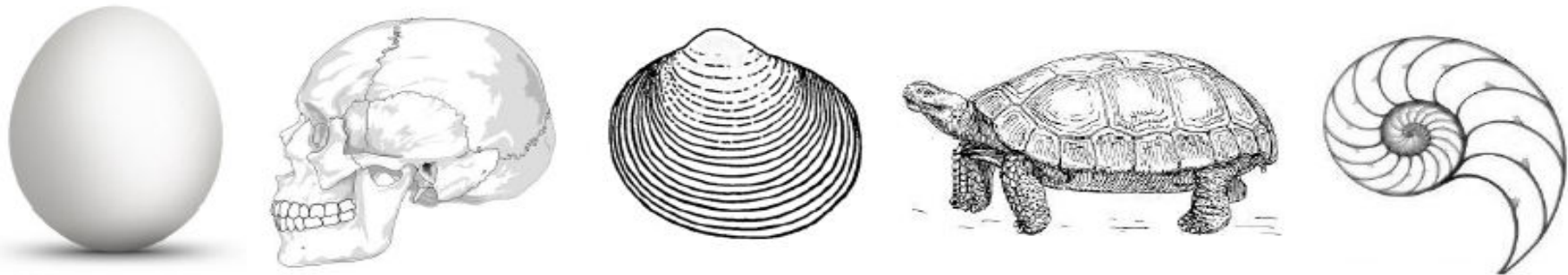
- A **shell** is a type of structural element which is characterized by its geometry, being a three-dimensional solid whose thickness is very small when compared with other dimensions, and in structural terms, by the stress resultants calculated in the middle plane displaying components which are both coplanar and normal to the surface. Essentially, a shell can be derived from a plate by two means: by initially forming the middle surface as a singly or doubly curved surface, and by applying loads which are coplanar to a plate's plane which generate significant stresses.

INTRODUCTION

LATTICE AND PORTAL FRAME BUILDINGS CONSIST OF A STRUCTURAL FRAME WHICH SUPPORTS SLAB, ROOF AND WALL COVERING. THIS FRAME SERVES PURELY AS THE STRUCTURAL SUPPORT AND PROVIDES PROTECTION AGAINST WEATHER. THE ROOF AND WALL COVERING ADD NOTHING TO THE STRENGTH THE RIGIDITY OF STRUCTURAL FRAME.

A SHELL STRUCTURE IS A THIN CURVED MEMBRANE OR SLAB USUALLY OF REINFORCED CONCRETE THAT FUNCTIONS BOTH AS STRUCTURE AND COVERING.

THE TERM “SHELL” IS USED TO DESCRIBE THE STRUCTURES WHICH POSSESS STRENGTH AND RIGIDITY DUE TO ITS THIN, NATURAL AND CURVED FORM SUCH AS SHELL OF EGG, A NUT, HUMAN SKULL, AND SHELL OF TORTISE.



SHELLS OCCURING IN NATURE

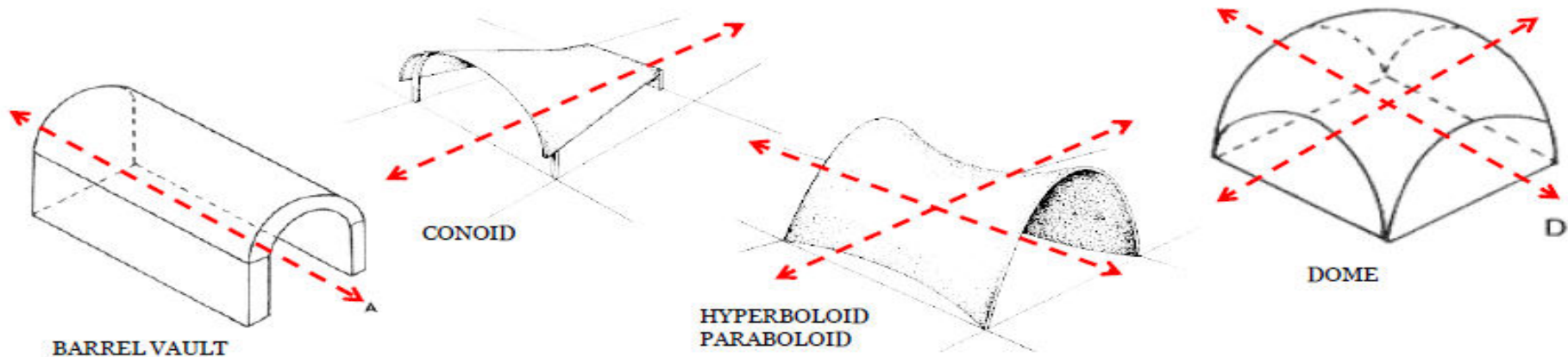
SINGLE OR DOUBLE CURVATURE SHELLS

SINGLE CURVATURE SHELL: ARE CURVED ON ONE LINEAR AXIS AND ARE A PART OF A CYLINDER OR CONE IN THE FORM OF BARREL VAULTS AND CONOID SHELLS.

DOUBLE CURVATURE SHELL: ARE EITHER PART OF A SPHERE, OR A HYPERBOLOID OF REVOLUTION.

THE TERMS SINGLE CURVATURE AND DOUBLE CURVATURE DO NOT PROVIDE A PRECISE GEOMETRIC DISTINCTION BETWEEN THE FORM OF SHELL BECAUSE A BARREL VAULT IS SINGLE CURVATURE BUT SO IS A DOME.

THE TERMS SINGLE AND DOUBLE CURVATURE ARE USED TO DISTINGUISH THE COMPARATIVE RIGIDITY OF THE TWO FORMS AND COMPLEXITY OF CENTRING NECESSARY TO CONSTRUCT THE SHELL FORM.



FORMS OF CURVATURE:

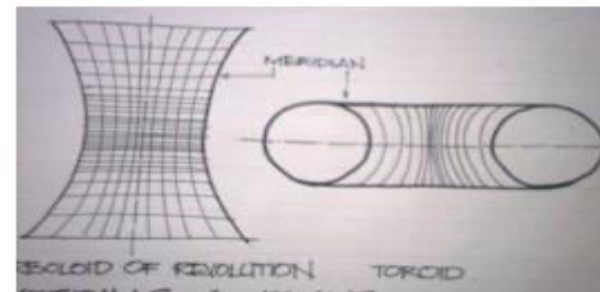
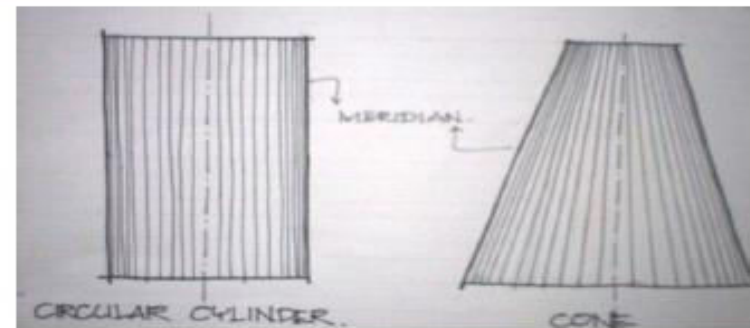
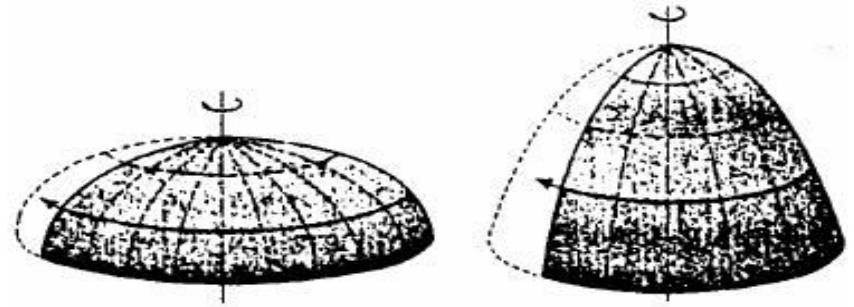
SURFACES OF REVOLUTION:

SURFACES OF REVOLUTION ARE GENERATED BY THE REVOLUTION OF A PLANE CURVE, CALLED THE MERIDIONAL CURVE,

ABOUT AN AXIS, CALLED THE AXIS OF REVOLUTION.

IN THE SPECIAL CASE OF CYLINDRICAL AND CONICAL SURFACES, THE MERIDIONAL CURVE CONSISTS OF A LINE SEGMENT.

E.G. : CYLINDERS, CONES,
SPHERICAL OR ELLIPTICAL DOMES,
HYPERBOLOIDS OF REVOLUTION, TOROIDS.



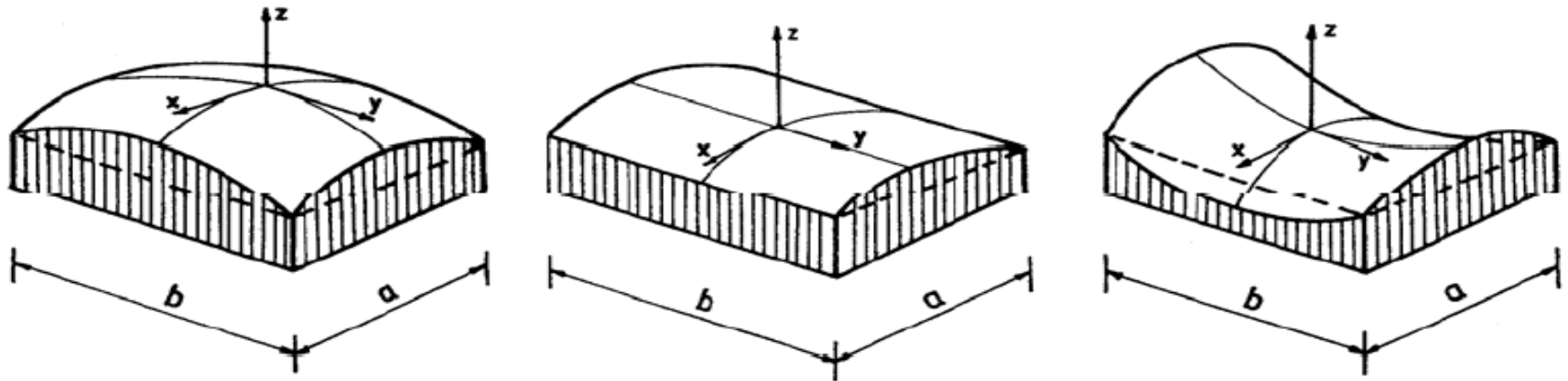
FORMS OF CURVATURE:

SURFACES OF TRANSLATION :

SURFACES OF TRANSLATION ARE GENERATED BY SLIDING A PLANE CURVE ALONG ANOTHER PLANE CURVE, WHILE KEEPING THE ORIENTATION OF THE SLIDING CURVE CONSTANT.

THE LATTER CURVE, ON WHICH THE ORIGINAL CURVE SLIDES, IS CALLED THE GENERATOR OF THE SURFACE.

IN THE SPECIAL CASE IN WHICH THE GENERATOR IS A STRAIGHT LINE, THE RESULTING SURFACE IS CALLED A CYLINDRICAL SURFACE.



SURFACES OF TRANSLATION WITH RECTANGULAR PLAN:

(A) ELLIPTIC PARABOLOID (B) CYLINDRICAL PARABOLOID (C) HYPERBOLIC PARABOLOID

FORMS OF CURVATURE:

RULED SURFACES :

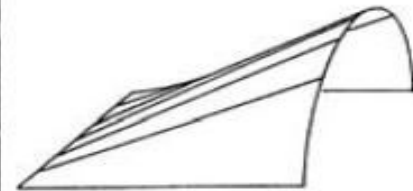
RULED SURFACES ARE GENERATED BY SLIDING EACH END OF A STRAIGHT LINE ON THEIR OWN GENERATING CURVE. THESE LINES ARE NOT NECESSARILY AT RIGHT ANGLE TO THE PLANES CONTAINING THE END CURVES.

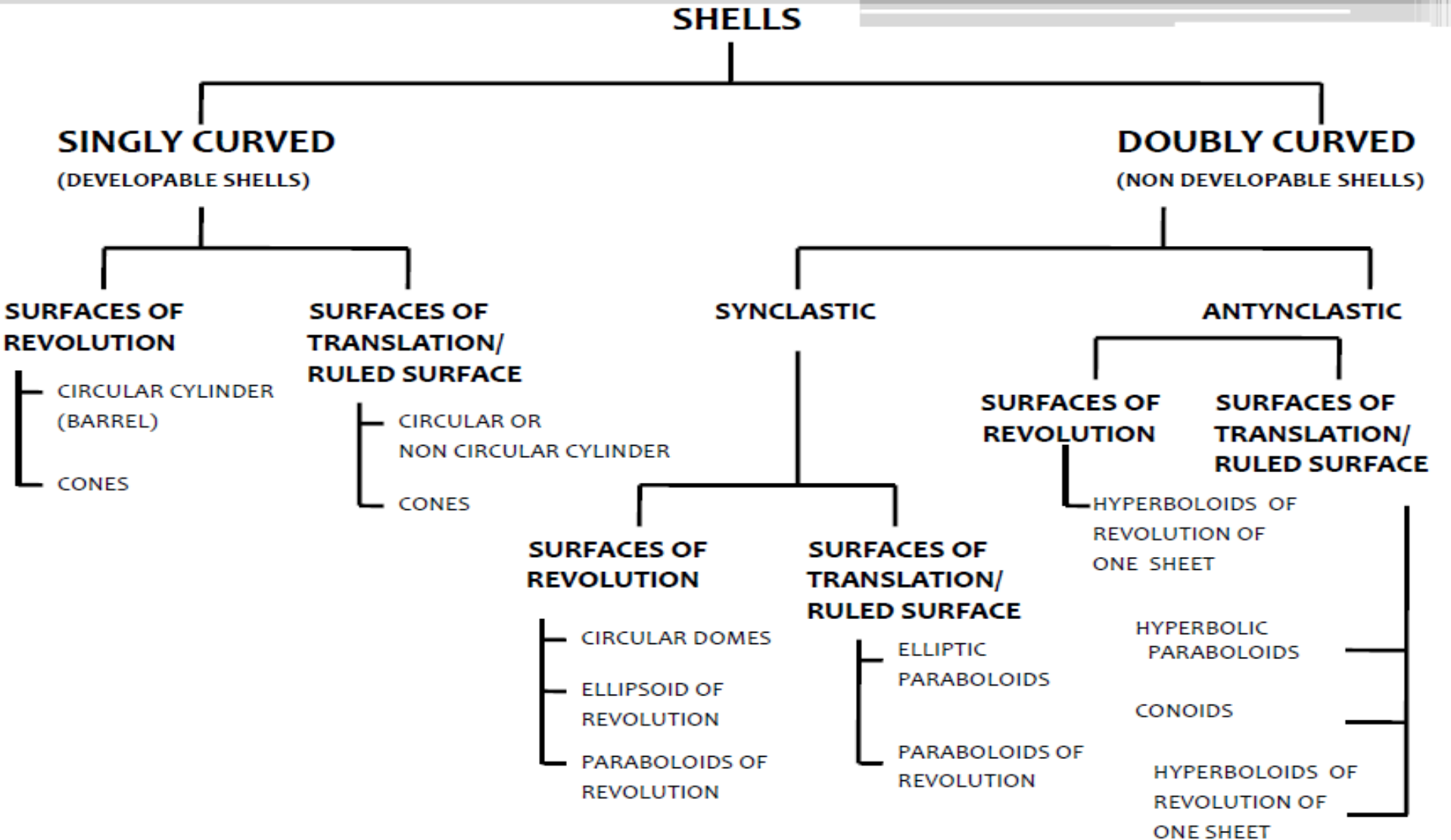


COOLING TOWER, GENERATED BY STRAIGHT LINES GOULD 1988



CONOID, GENERATED BY STRAIGHT LINE TRAVELING ALONG ANOTHER STRAIGHT LINE AT ONE END AND CURVED LINE AT OTHER END. JOEDICKE 1963





FORMS OF CURVATURE:

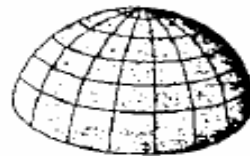
DEVELOPABLE AND NONDEVELOPABLE SURFACES :

SURFACES WITH DOUBLE CURVATURE CANNOT BE DEVELOPED, WHILE THOSE WITH SINGLE CURVATURE CAN BE DEVELOPED.

DEVELOPED



NONDEVELOPED



IN OTHER WORDS, SURFACES WITH POSITIVE AND NEGATIVE GAUSSIAN CURVATURE (I.E. SYNCLASTIC AND ANTICLASTIC SURFACES) CANNOT BE DEVELOPED, WHILE THOSE WITH ZERO GAUSSIAN CURVATURE CAN BE DEVELOPED.



(A) POSITIVE GAUSSIAN



(B) ZERO GAUSSIAN



(C) NEGATIVE GAUSSIAN

TYPES OF GAUSSIAN CURVATURE.

FORMS OF CURVATURE:

DEVELOPABLE SURFACES (SINGLY CURVED):

DEVELOPABLE SURFACE IS A SURFACE THAT CAN BE UNROLLED ONTO A FLAT PLANE WITHOUT TEARING OR STRETCHING IT.

IT IS FORMED BY BENDING A FLAT PLANE, THE MOST TYPICAL SHAPE OF A DEVELOPABLE SHELL IS A BARREL, AND A BARREL SHELL IS CURVED ONLY IN ONE DIRECTION.

BARREL :

ARCH ACTION & BEAM ACTION TOGETHER MAKE A BARREL.

THERE ARE MAINLY TWO TYPES OF BARREL :

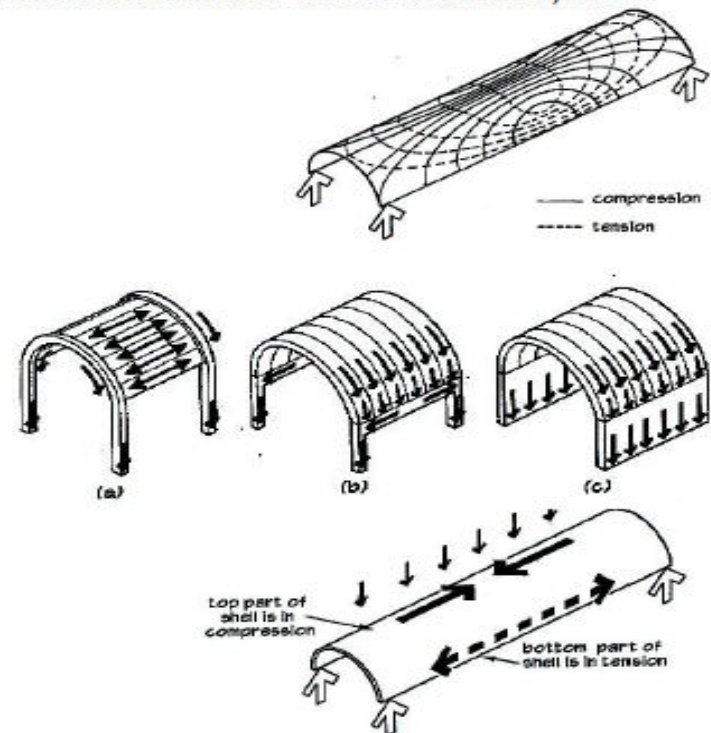
- LONG BARRELS , ARCH ACTION IS PROMINENT
- SHORT BARRELS, BEAM ACTION IS PROMINENT

STRUCTURAL BEHAVIOR OF SHORT BARREL SHELLS:

THESE SHELLS ARE TYPICALLY SUPPORTED AT THE CORNERS AND CAN BEHAVE IN ONE OR A COMBINATION OF THE FOLLOWING WAYS:

STRUCTURAL BEHAVIOR OF LONG BARREL SHELLS:

THESE ARE TYPICALLY SUPPORTED AT THE CORNERS AND BEHAVE STRUCTURALLY AS A LARGE BEAM.



FORMS OF CURVATURE:

NON-DEVELOPABLE SURFACES (DOUBLY CURVED):

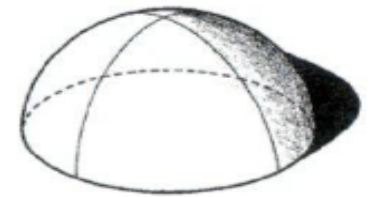
E.G., SPHERE OR HYPERBOLIC PARABOLOID.

THEY ARE MAINLY CLASSIFIED AS : 1) SYNCLASTIC 2) ANTICLASTIC

SYNCLASTIC SHELLS:

THESE SHELLS ARE DOUBLY CURVED

AND HAVE A SIMILAR CURVATURE IN EACH DIRECTION. E.G. DOMES



SYNCLASTIC

A DOME IS A GOOD EXAMPLE OF A SYNCLASTIC SHELL, IT IS DOUBLY CURVED AND CAN BE FORMED BY ROTATING A CURVED LINE AROUND AN AXIS.

A DOME CAN BE SPLIT UP INTO TWO DIFFERENT DIRECTIONS; VERTICAL SECTIONS SEPARATED BY LONGITUDINAL ARCH LINES (ALSO CALLED MERIDIANS), AND HORIZONTAL SECTIONS SEPARATED BY HOOPS OR PARALLELS.

STRUCTURAL BEHAVIOR :

SIMILAR TO ARCHES UNDER A UNIFORM LOADING THE DOME IS UNDER COMPRESSION EVERYWHERE, AND THE STRESSES ACT ALONG THE ARCH AND HOOP LINES.

FORMS OF CURVATURE:

NON-DEVELOPABLE SURFACES (DOUBLY CURVED):

ANTICLASTIC SHELLS : ARE DOUBLY CURVED BUT EACH OF THE TWO CURVES HAVE THE OPPOSITE DIRECTION TO THE OTHER. E.G. SADDLE POINTS.

CONOIDS, HYPERBOLIC PARABOLOID AND HYPERBOLOIDS ARE ALL CONSIDERED TO THE ANTICLASTIC SHELL BECAUSE THEY ARE SADDLED SHAPE WITH DIFFERENT CURVATURE IN EACH DIRECTION AND STRAIGHT LINES CAN BE DRAWN OF THE SURFACE.

CONOIDS: FORMED BY MOVING A ONE END OF A STRAIGHT LINE ALONG A CURVED PATH AND THE OTHER ALONG A STRAIGHT PATH.

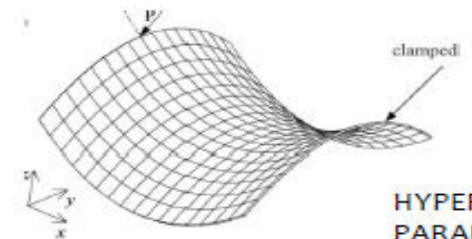
HYPERBOLOIDS: FORMED BY ROTATING A STRAIGHT LINE AROUND A VERTICAL AXIS.



ANTICLASTIC



CONOID



HYPERBOLOID
PARABOLOID



FORMS OF CURVATURE:

NON-DEVELOPABLE SURFACES (DOUBLY CURVED):

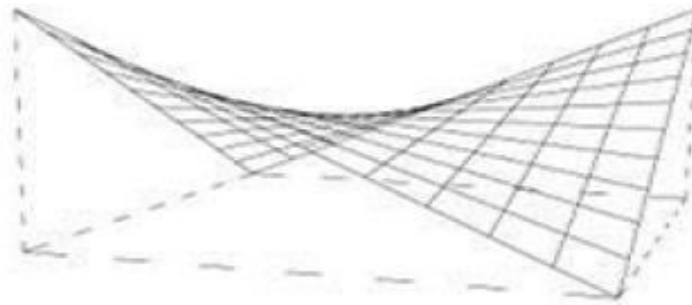
HYPERBOLIC PARABOLOID:

FORMED BY SWEEPING A CONVEX PARABOLA ALONG A CONCAVE PARABOLA OR BY SWEEPING A STRAIGHT LINE OVER A STRAIGHT PATH AT ONE END AND ANOTHER STRAIGHT PATH NOT PARALLEL TO THE FIRST.

STRUCTURAL BEHAVIORS:

DEPENDING ON THE SHAPE OF THE SHELL RELATIVE TO THE CURVATURE, THERE WILL BE DIFFERENT STRESSES.

SHELL ROOFS, HAVE COMPRESSION STRESSES FOLLOWING THE CONVEX CURVATURE AND THE TENSION STRESSES FOLLOW THE CONCAVE CURVATURE.



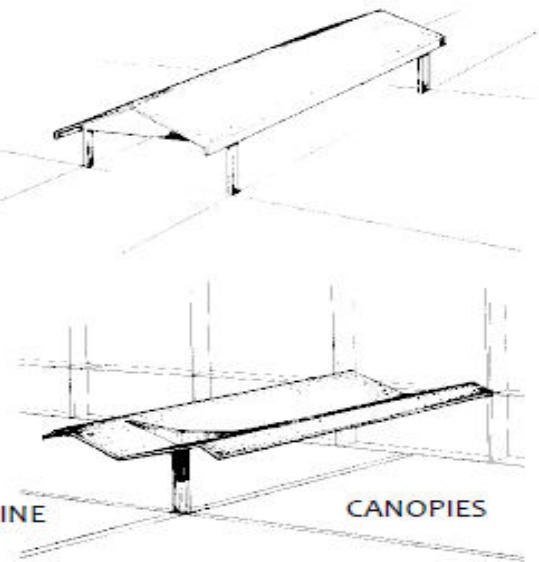
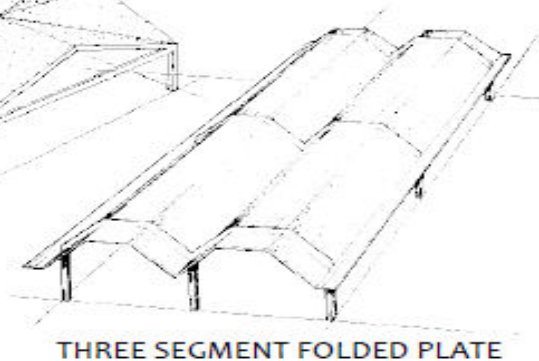
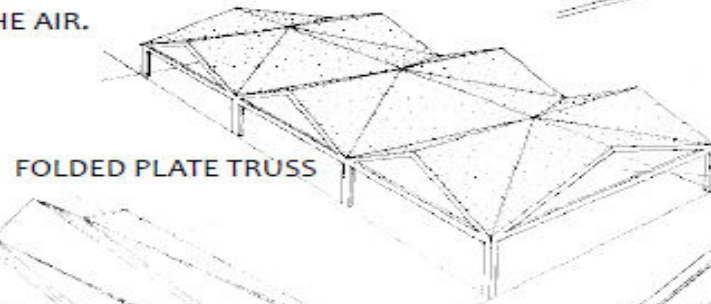
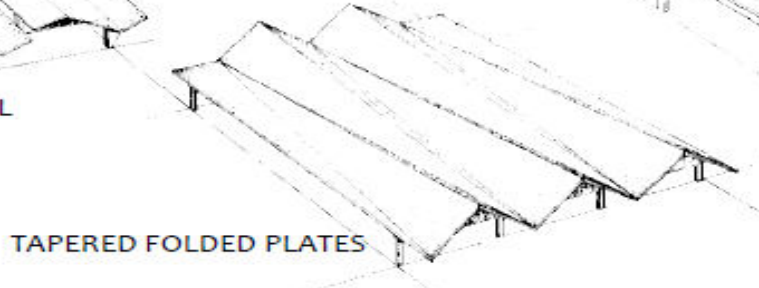
TYPES OF SHELL STRUCTURES:

FOLDED PLATE SHELLS:

THE DISTINGUISHING FEATURE OF THE FOLDED PLATE IS THE EASE IN FORMING PLANE SURFACES. A FOLDED PLATE MAY BE FORMED FOR ABOUT THE SAME COST AS A HORIZONTAL SLAB AND HAS MUCH LESS STEEL AND CONCRETE FOR THE SAME SPANS.

THE PRINCIPLE COMPONENTS IN A FOLDED PLATE STRUCTURE CONSIST OF :

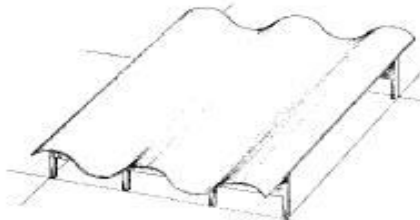
- 1) THE INCLINED PLATES
- 2) EDGE PLATES WHICH MUST BE USED TO STIFFEN THE WIDE PLATES
- 3) STIFFENERS TO CARRY THE LOADS TO THE SUPPORTS AND TO HOLD THE PLATES IN LINE
- 4) COLUMNS TO SUPPORT THE STRUCTURE IN THE AIR.



TYPES OF SHELL STRUCTURES:

CYLINDRICAL BARREL VAULTS:

BARREL VAULTS ARE PERHAPS THE MOST USEFUL OF THE SHELL STRUCTURES BECAUSE THEY CAN SPAN UP TO 150 FEET WITH A MINIMUM OF MATERIAL. THEY ARE VERY EFFICIENT STRUCTURES BECAUSE THEY USE THE ARCH FORM TO REDUCE STRESSES AND THICKNESSES IN THE TRANSVERSE DIRECTION.



CORRUGATED CURVES

Corrugated Curves



UNSTIFFENED EDGES



MULTIPLE BARRELS -
OUTSIDE STIFFENERS



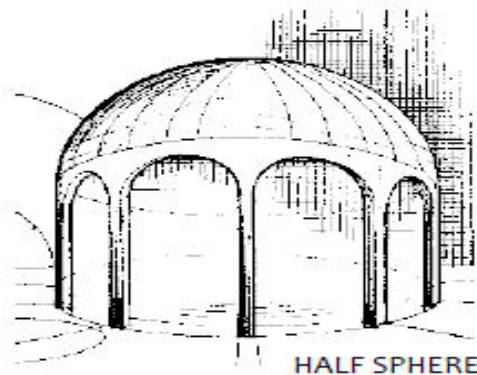
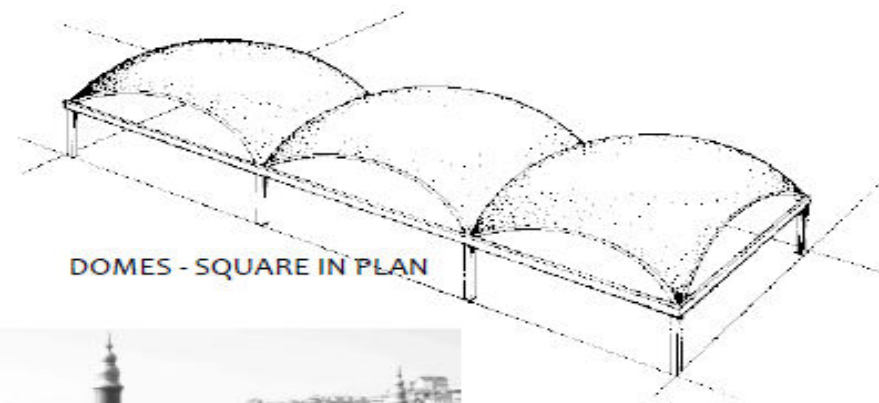
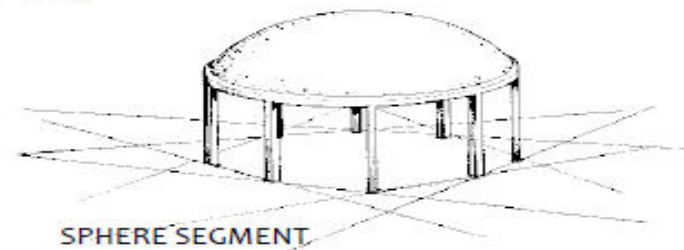
THE LAZY S



TYPES OF SHELL STRUCTURES:

DOMES OF REVOLUTION:

A DOME IS A SPACE STRUCTURE COVERING A MORE OR LESS SQUARE OR CIRCULAR AREA. THE BEST KNOWN EXAMPLE IS THE DOME OF REVOLUTION, AND IT IS ONE OF THE EARLIEST OF THE SHELL STRUCTURES. EXCELLENT EXAMPLES ARE STILL IN EXISTENCE THAT WERE BUILT IN ROMAN TIMES. THEY ARE FORMED BY A SURFACE GENERATED BY A CURVE OF ANY FORM REVOLVING ABOUT A VERTICAL LINE. THIS SURFACE HAS DOUBLE CURVATURE AND THE RESULTING STRUCTURE IS MUCH STIFFER AND STRONGER THAN A SINGLE CURVED SURFACE, SUCH AS A CYLINDRICAL SHELL.



ADVANTAGES AND DIS-ADVANTAGES OF SHELLS:

ADVANTAGES:

1. VERY LIGHT FORM OF CONSTRUCTION. TO SPAN 30.0 M SHELL THICKNESS REQUIRED IS 60MM
2. DEAD LOAD CAN BE REDUCED ECONOMIZING FOUNDATION AND SUPPORTING SYSTEM
3. THEY FURTHER TAKE ADVANTAGE OF THE FACT THAT ARCH SHAPES CAN SPAN LONGER
4. FLAT SHAPES BY CHOOSING CERTAIN ARCHED SHAPES
5. ESTHETICALLY IT LOOKS GOOD OVER OTHER FORMS OF CONSTRUCTION

DIS-ADVANTAGES:

1. SHUTTERING PROBLEM
2. GREATER ACCURACY IN FORMWORK IS REQUIRED
3. GOOD LABOUR AND SUPERVISION NECESSARY
4. RISE OF ROOF MAY BE A DISADVANTAGE

DOMES STRUCTURES

- A **dome** is an architectural element that resembles the hollow upper half of a sphere. Dome structures of various materials have an architectural lineage that extends into prehistory.
- Corbel domes and true domes have been found in the ancient Middle East in modest buildings and tombs. The construction of the first technically advanced true domes began in the Roman Architectural Revolution, when the Romans frequently used them to shape large interior spaces of temples and public buildings, such as the Pantheon.

DOMES STRUCTURES

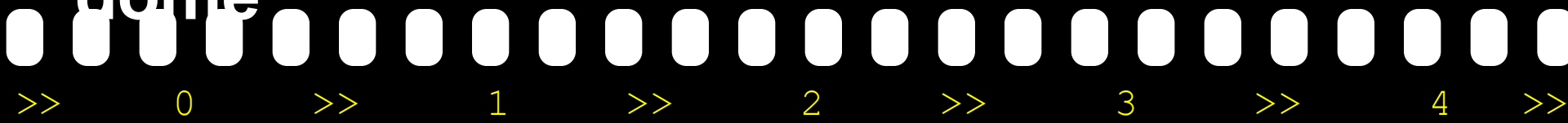
- An original tradition of using multiple domes was developed in the church architecture in Russia, which had adopted from Byzantium.
- Russian domes are often gilded or brightly painted, and typically have a carcass and an outer shell made of wood or metal. The onion dome became another distinctive feature in the Russian architecture, often in combination with the tented roof

DOMES - DEFINITION

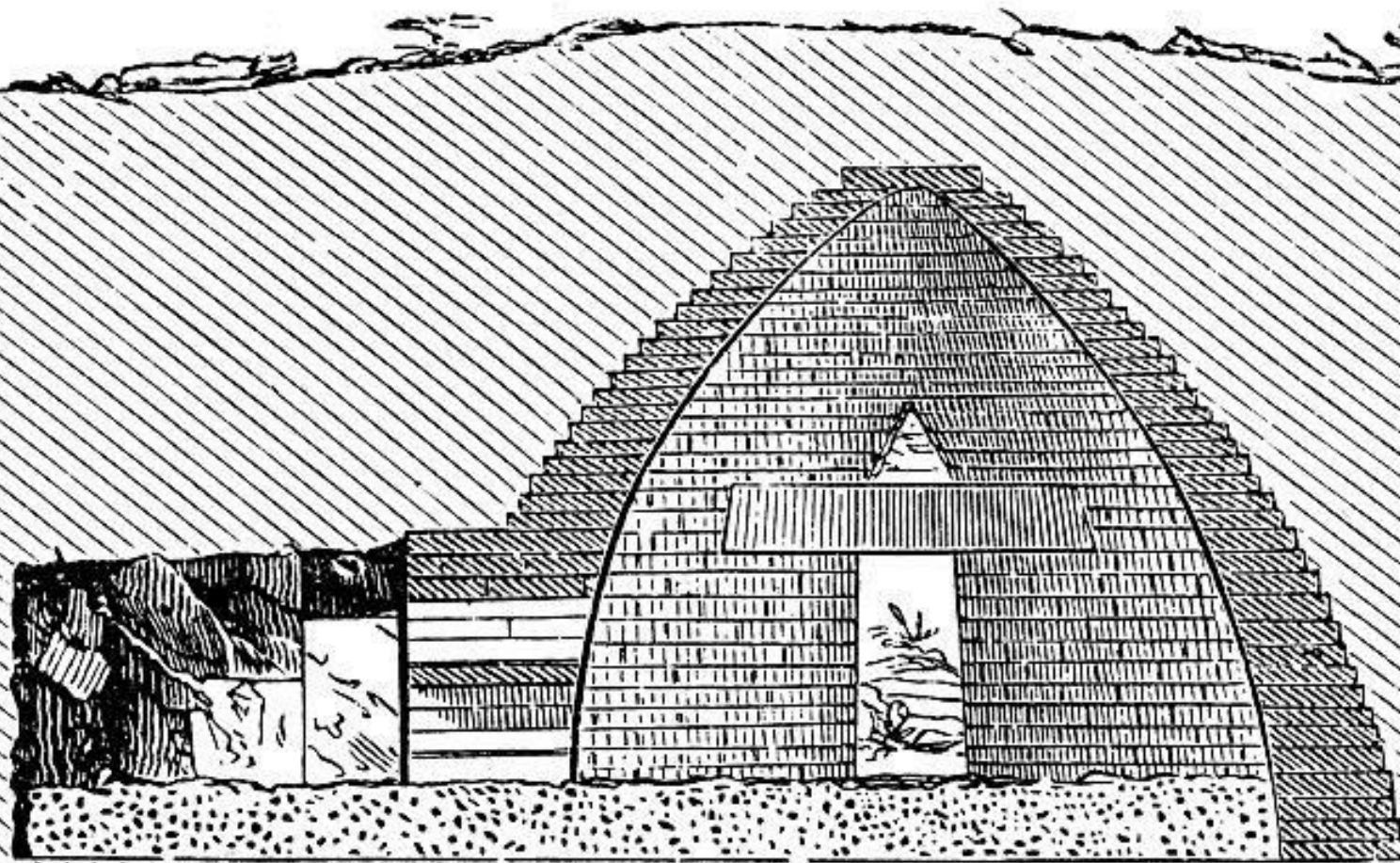
- A dome is a rounded vault made of either curved segments or a shell of revolution, meaning an arch rotated around its central vertical axis. The terminology used has been a source of controversy, with inconsistency between scholars and even within individual texts, but the term "dome" may be considered a "blanket-word to describe an hemispherical or similar spanning element."
- Sometimes called "false" domes, corbel domes achieve their shape by extending each horizontal layer of stones inward slightly farther than the lower one until they meet at the top.
- A "false" dome may also refer to a wooden dome. "True" domes are formed with layers of wedge-shaped voussoirs, the joints of which align with a point at the center of the base.

TYPES OF DOMES

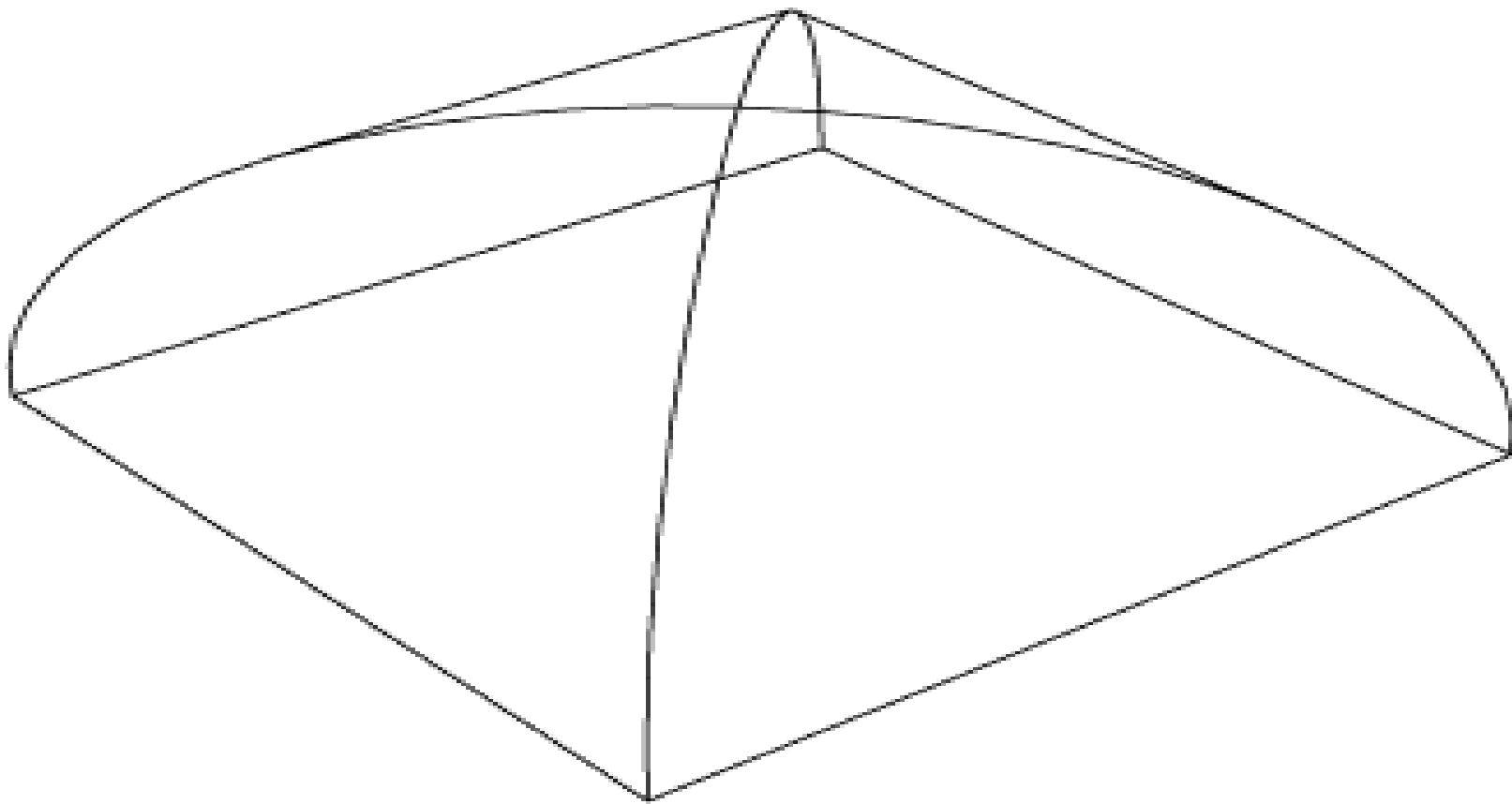
- 1.) Beehive dome or corbelled dome
- 2.) Cloister vault or domical vaults
- 3.) Compound dome
- 4.) Crossed-arch dome
- 5.) Geodesic dome
- 6.) Hemispherical dome
- 7.) Onion dome
- 8.) Oval dome
- 9.) Sail dome
- 10.) Saucer dome
- 11.) Umbrella dome



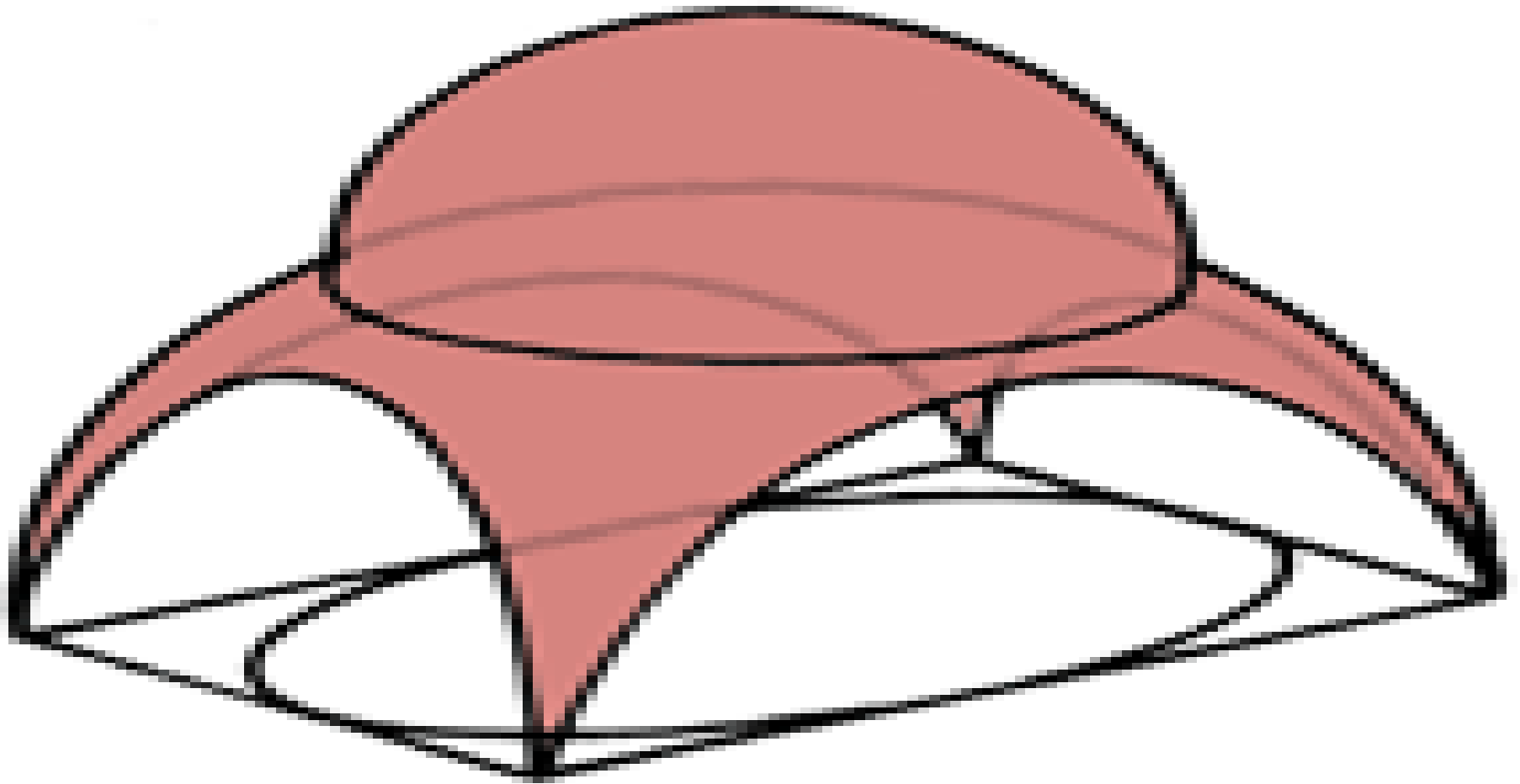
Beehive dome or corbelled dome



Cloister vault or domical vaults



Compound dome



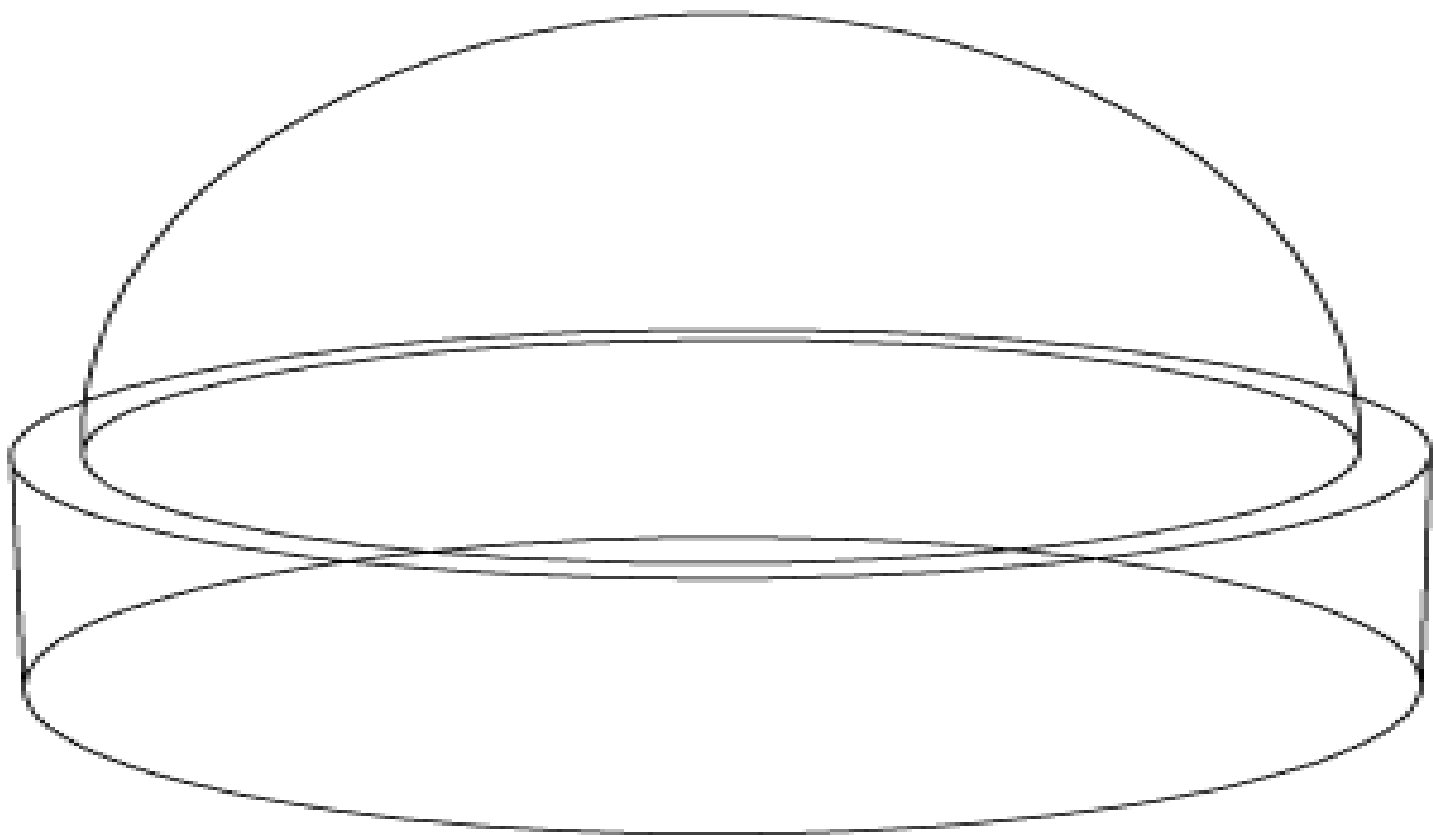
Crossed-arch dome



Geodesic dome



Hemispherical dome



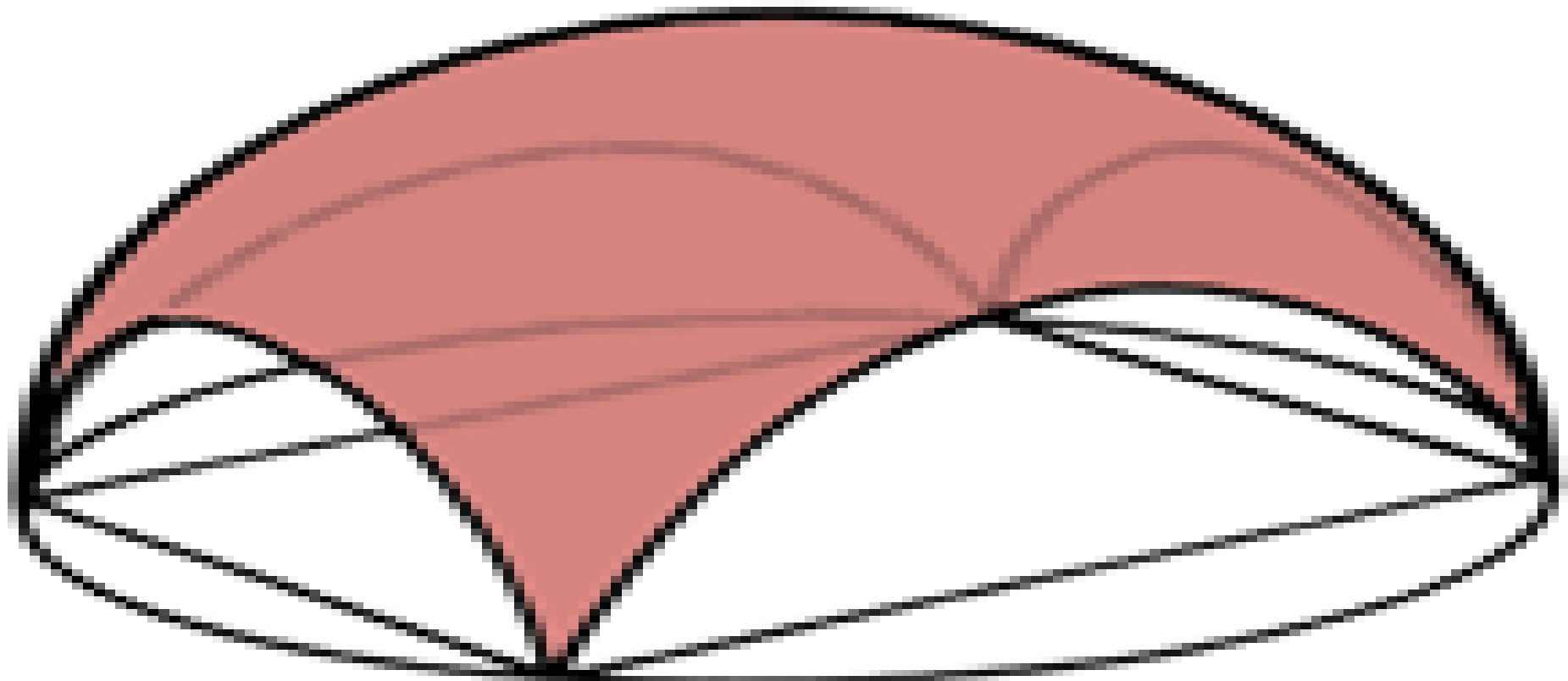
Onion dome



Oval dome



Sail dome



Saucer dome



Umbrella dome

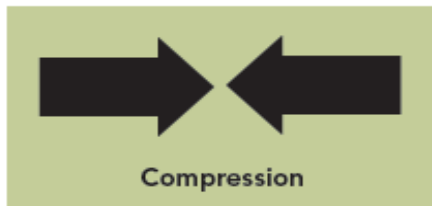


What's Keeping that Dome from Crashing?



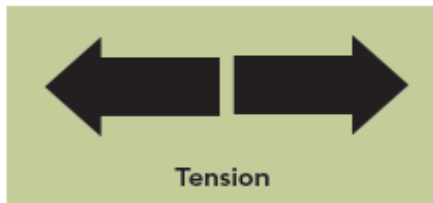
Pantheon – 2nd century CE

Hang on a minute! If a dome, like the one in the Pantheon, is unsupported by columns, then what on earth is keeping it from tumbling down? Don't panic! The unseen forces of nature are holding all of that concrete in place.

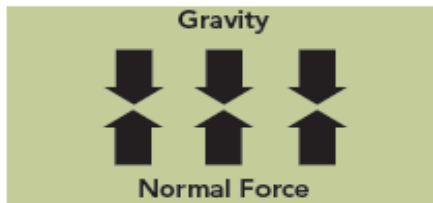


Although you can't see them, the normal force, along with the forces of gravity, compression, and tension, are acting against one another to hold the Pantheon, and most domes in place.

Compression forces are two forces which act on one object by moving in opposite directions toward each other. Imagine pressing or pushing the palms of your hands together. This is the compression force.



Tension forces are two forces which act on one object by moving in opposite directions away from each other. Imagine clasping the curled fingertips of both of your hands together and pulling. This is the tension force.



The force of **gravity** pushes downward on an object. And the **normal force** pushes in the opposite direction, upward.

Diameter, Radius, Circumference, and Area of Circles

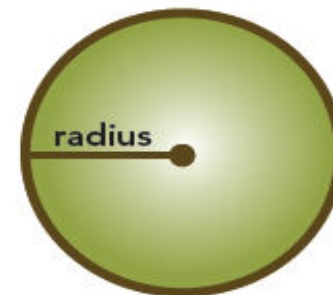
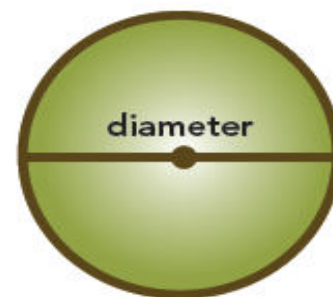
Diameter, radius, circumference and area are different ways in which to measure circles. If you know one of these measurements, then you can figure out the others.

The **diameter** is the distance across a circle through its center point. If you know the diameter of a circle, then you can calculate the radius, the circumference, and the area of a circle.

The **radius** of a circle is the distance from its center to any point along its edge. It's easy to find the center of the Chinese Rotunda. Just look for the 49-pound crystal ball!

The **circumference** of a circle is the distance around it. It is the circle's perimeter.

The **area** of a circle is the number of square units it would take to fill the circle.



Famous Domes

FAMOUS DOMES IN EARTH

Dome	Diameter	Radius	Circumference	Area
Chinese Rotunda	90 feet	45 feet	282.6 feet	
The Pantheon		71 feet	445.88 feet	15828.74 sq. feet
Astrodome	710 feet	355 feet		395718.5 sq. feet
Georgia Dome		420 feet	2637.6 feet	553,896 sq. feet
Hagia Sophia	102 feet			8167.14 sq. feet
U.S. Capitol	96 feet	48 feet		7234.56 sq. feet
Mihrimah Mosque		33 feet	207.24 feet	3419.46 sq. feet
St. Peter's Basilica	138 feet	69 feet	433.32 feet	

FAMOUS DOMES IN EARTH

Dome	Diameter	Radius	Circumference	Area
Chinese Rotunda	90 feet	45 feet	282.6 feet	6358.5 sq. feet
The Pantheon	142 feet	71 feet	445.88 feet	15828.74 sq. feet
Astrodome	710 feet	355 feet	2229.4 feet	395718.5 sq. feet
Georgia Dome	840 feet	420 feet	2637.6 feet	553,896 sq. feet
Hagia Sophia	102 feet	51 feet	320.28 feet	8167.14 sq. feet
U.S. Capitol	96 feet	48 feet	301.44 feet	7234.56 sq. feet
Mihrimah Mosque	66 feet	33 feet	207.24 feet	3419.46 sq. feet
St. Peter's Basilica	138 feet	69 feet	433.32 feet	14949.54 sq. feet

Thank you ...

A close-up of a pen nib, likely a fountain pen, positioned at the end of the handwritten text 'Thank you ...'. The nib is black with a silver-colored tip and is in the process of completing the final dot of the ellipsis. The background is a white, torn piece of paper with a red surface visible underneath.