Structural System in Architecture
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Lecture No -30
Structural Concept and Application of Dome in Architecture

Welcome to the NPTEL online certification course on structural systems in architecture. This is the 30th lecture and this is the last lecture of the module 6 or the week 6. And this lecture's topic is Structural Concept and Application of Dome in Architecture.

Concepts Covered

- Definition and Historic Examples
- Support System of Dome
- Structural Concept
- Types of Dome
- Geodesic Dome
- Case Studies

Learning Objectives

- Outlining the parts and types of dome.
- Illustrating the structural action of dome.
- To understand the application of dome in modern buildings.

Definition

Dome is the simplest type of synclastic shell. It has Gaussian curvature as Positive ($K > 0$). It is used as a roof and ceiling. From the architectural element point of view dome resembles the hollow hemisphere. Dome has been used in various ways in Classical European Architecture, Islamic Architecture and in the Modern Architecture as well.

Historical Examples

Figure 1 Pantheon, Rome (120AD)

Figure 2 St. Peter's Basilica, Vatican City (1626)

Figure 3 Hagia Sophia, Istanbul (537 AD)

Figure 4 Taj Mahal, Agra (1632 AD)

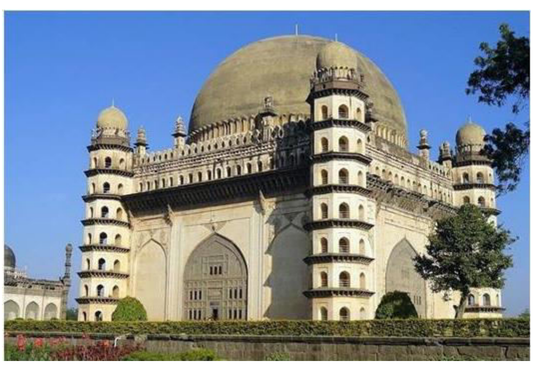


Figure 5 Gol Gumbaz, Bijapur (1653)

Figure 6 Matri Mandir, Auroville (2008)

Support System of Dome

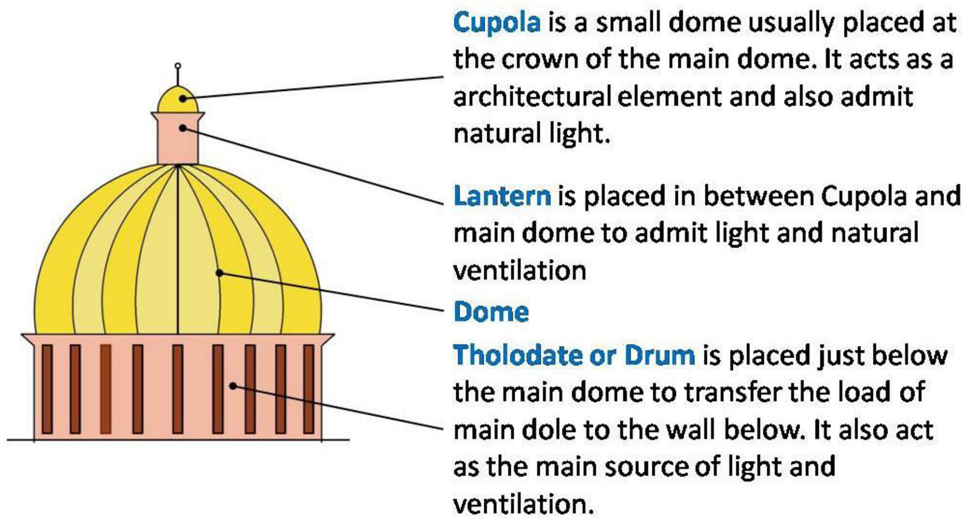


Figure 7 Structural system of dome

Sometimes these domes which are circular in shape have to be built over rooms or spaces which are square in shape. This was done with the help of two techniques viz., pendentive and squinch.

Pendentive

Smooth and gradual filling of a hemispherical dome over a square or octagonal base in the external side is termed as pendentive.

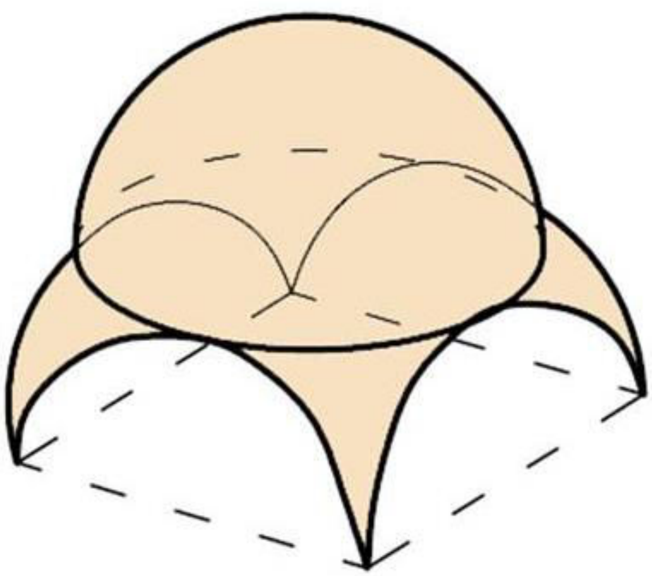


Figure 8 Pendentive

Squinch

Smooth and gradual filling of a square base to a hemispherical dome in the internal side to make a continuity to receive the dome is known as a squinch.

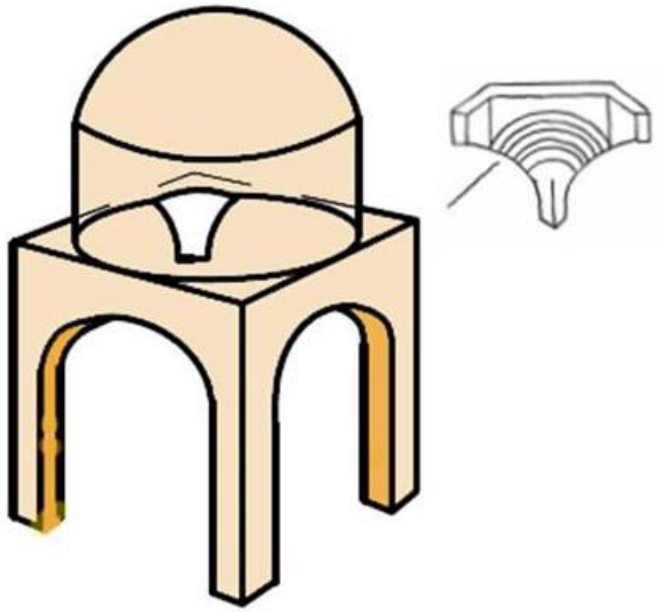


Figure 9 Squinch

When two similar elongated arches are criss-crossed together, a vault is formed. Given below are two such examples namely, the groin vault and the rib vault. Clearly, the former is formed when two elongated semi-circular arches are criss-crossed together while the latter is formed criss-crossing two elongated pointed arches.

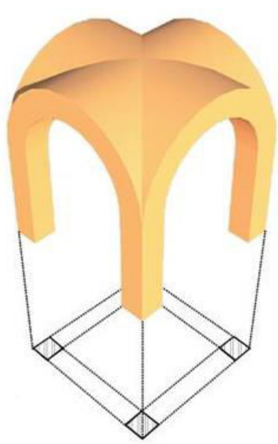


Figure 10 Groin Vault

Figure 11 Rib Vault

More Examples of Domes

Hagia Sofia

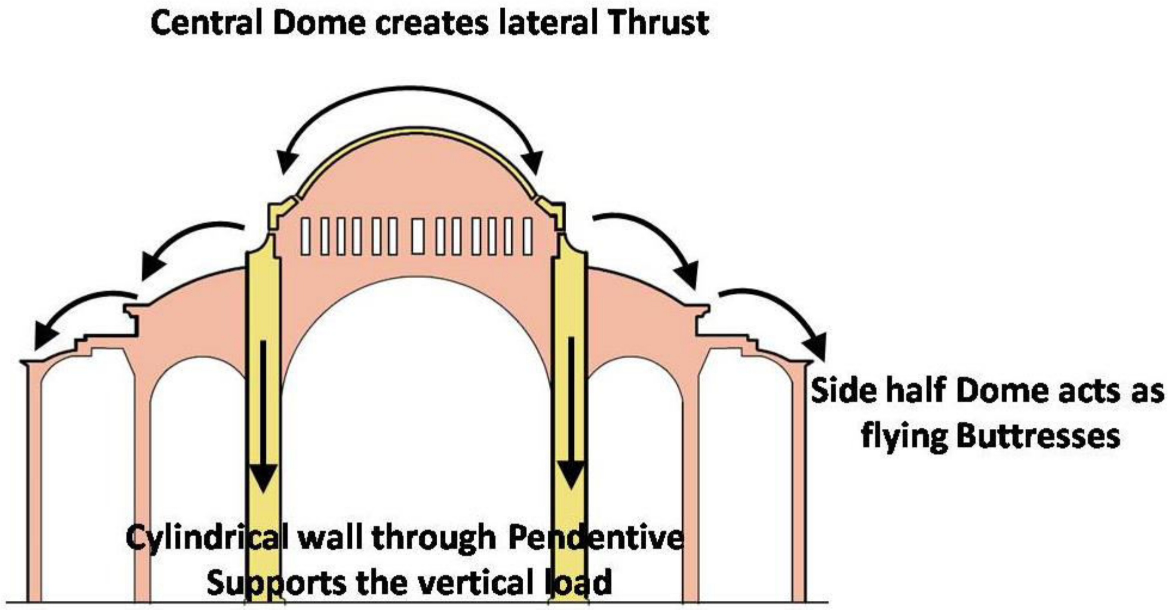
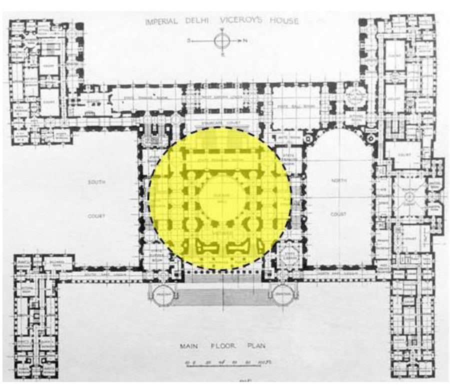
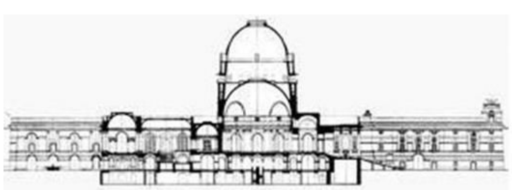


Figure 12 Thrust action in Hagia Sofia

Rashtrapati Bhawan





Here the thrust action present in the central larger dome is balanced mini domes surrounding it. This can be observed in all of the given drawings such as the plan, elevation and the section.

Figure 13 Rashtrapati Bhawan

Structural Concept

Under downward gravity loading a dome shows stresses in two mutually perpendicularly direction (Figure 14). Additionally, a dome shows a complete arch action wherein the top portion sinks down and the bottom portion bulges out (Figure 15).

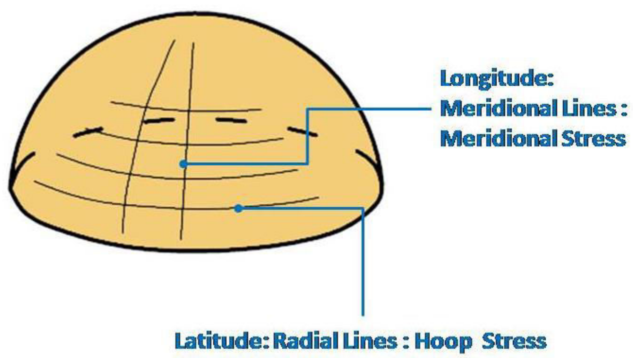


Figure 14 Meridional and Hoop stresses in a dome

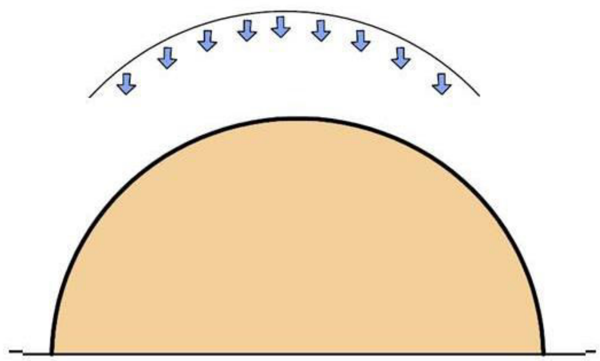


Figure 15 Arch action in a dome

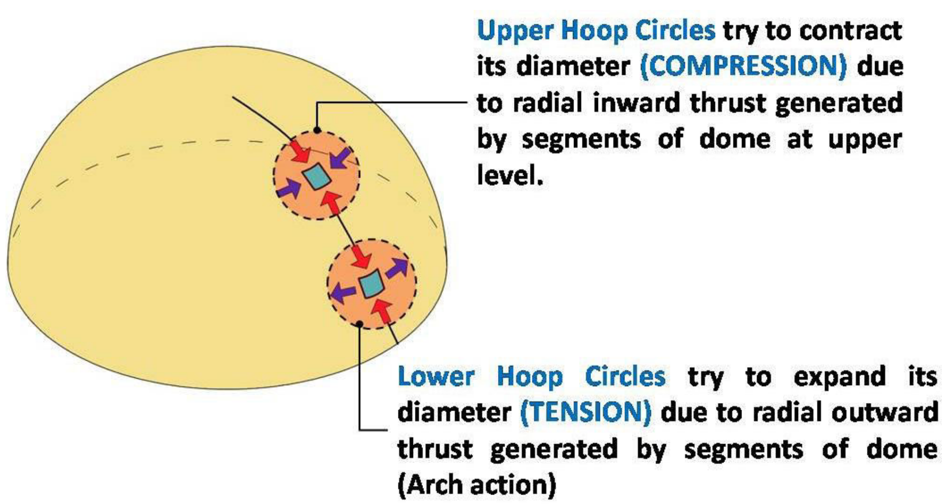


Figure 16 Structural phenomena in a dome

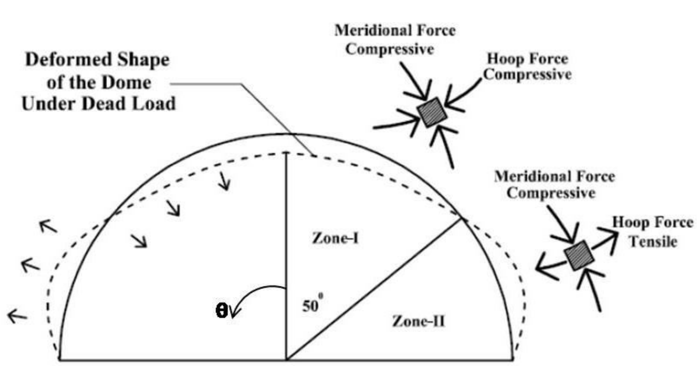


Figure 17 Structural phenomena in a dome

Hoop stress:

$$F_k = \frac{wr(cos^2\theta + cos\theta - 1)}{(1 + cos\theta)}$$

Meridional stress:

$$F_m = \frac{wr}{(1 + cos\theta)}$$

Where,

w = loading intensity in KN/m^2

r = radius

The hoop forces are compressive in zone-I and tensile in zone-II. Hence the latter would require more reinforcement as compared to the former. Also, it is important to note that the meridional stress will be positive always whereas the hoop stress will vary. The graph below shows this clearly.

Meridional Stress is always Compressive — Hoop Stress become Tensile at 50^0

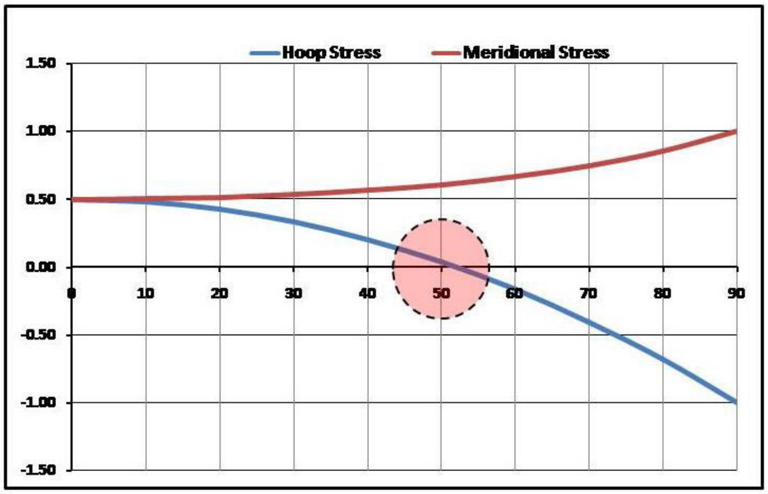


Figure 18 Graphical representation of Hoop and Meridional stresses

Types of Domes

Radial/Ribbed Dome:

Rings and Radials

Schwedler Dome:

Rings and Radials + one Diagonal

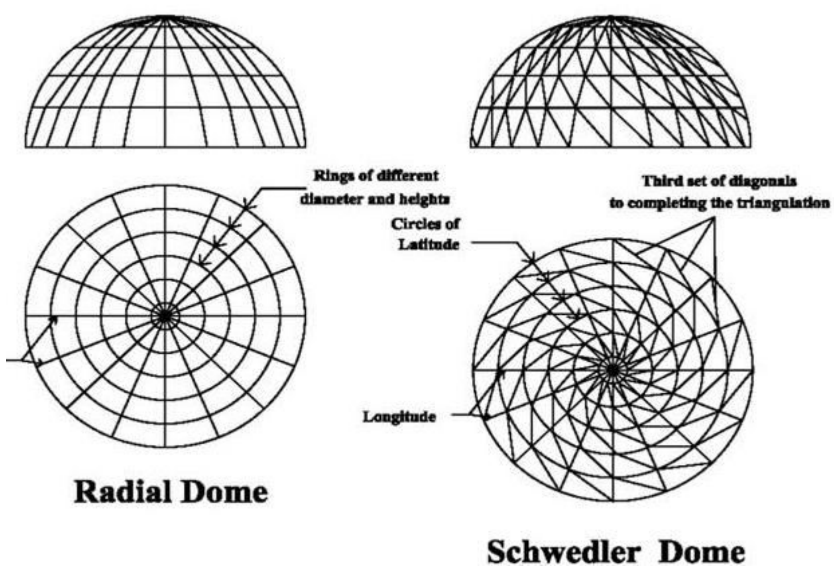


Figure 19 Radial and Schwedler domes

Lattice/ Lamella Dome:

Rings but No Radials + two Diagonal

Geodesic Dome:

Spherical Equilateral Triangle

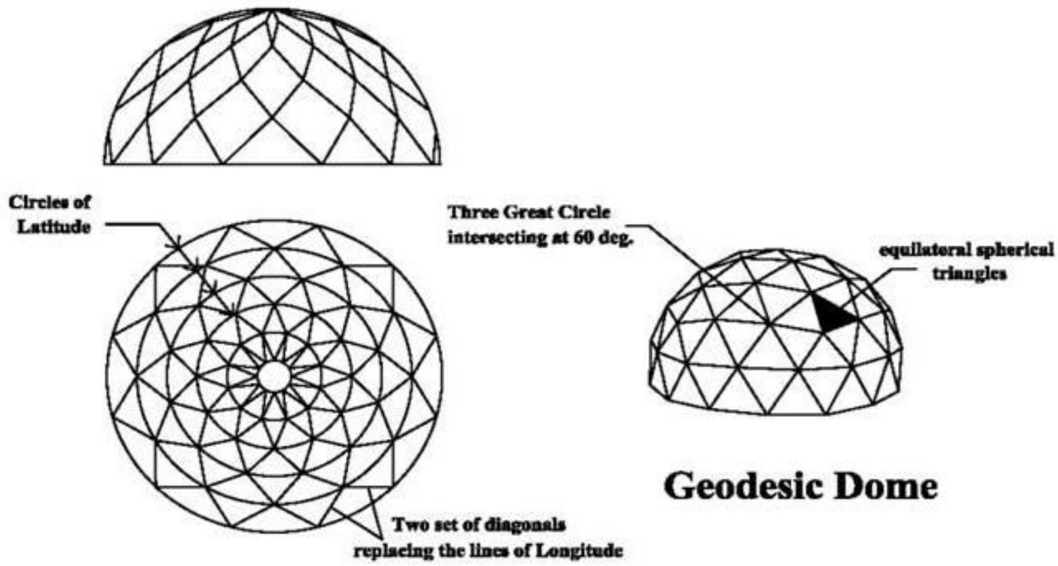


Figure 20 Lattice and Geodesic domes

Geodesic Dome

Geodesic domes are formed by a combination of many spherical equilateral triangles. And three circles intersecting each other and form a spherical equilateral triangle. The following figure shows an architectural marvel by the architect Richard Buckminster Fuller wherein a giant geodesic dome has been used as the building envelope.

Figure 21 US Pavilion at expo 67, Montreal, Architect: Richard Buckminster Fuller

Another example has been shown in the Figure 22 where a geodesic dome has been constructed by the students of the Department of Architecture and Regional Planning in IIT Kharagpur as a part of their construction lab exercise.

Figure 22 Geodesic dome at IIT Kharagpur

Geodesic dome frequency

An icosahedron, as most geodesic domes are based on this basic form. Icosahedrons have 20 equilateral triangle faces that form very roughly a sphere. Each triangular face if divided into further triangles then a smoother sphere can be obtained.

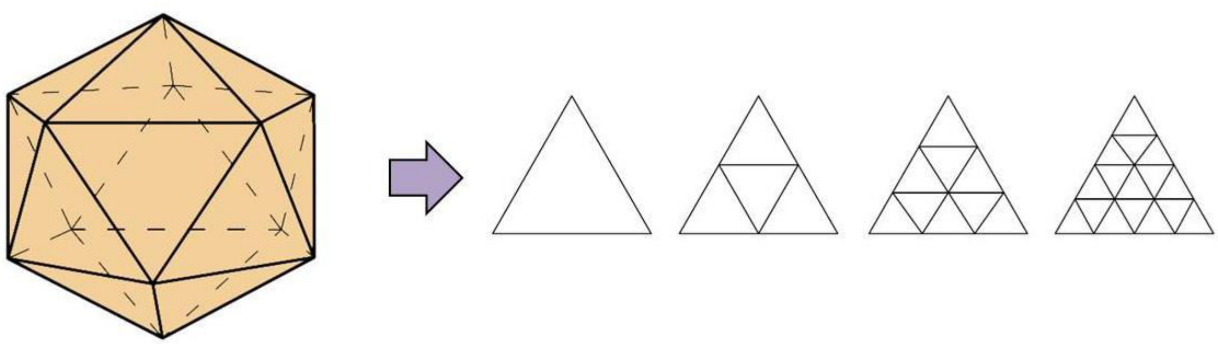


Figure 23 Icosahedron

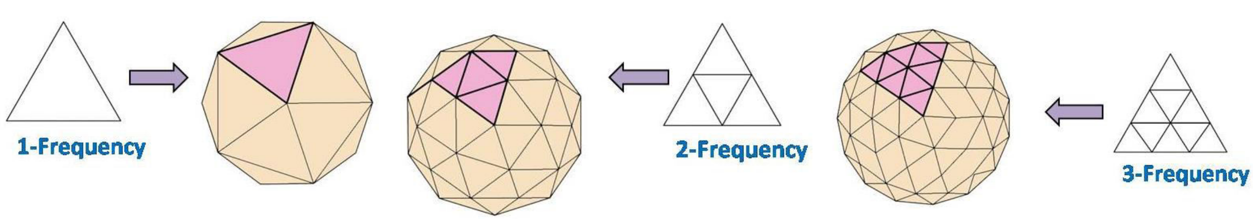
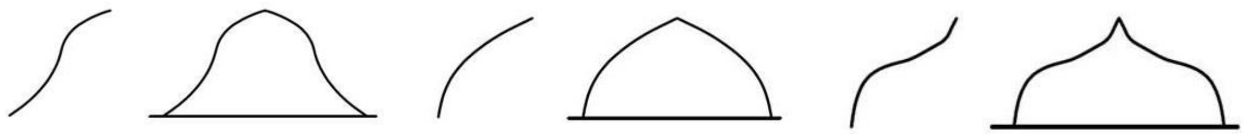


Figure 24 Frequency of geodesic dome

Variation in Onion Dome

As you already know that a dome is formed by rotating a generator about an axis. Hence, changing the shape of the generator multiple types in different ways will give that many variations in an onion dome.



Case Studies

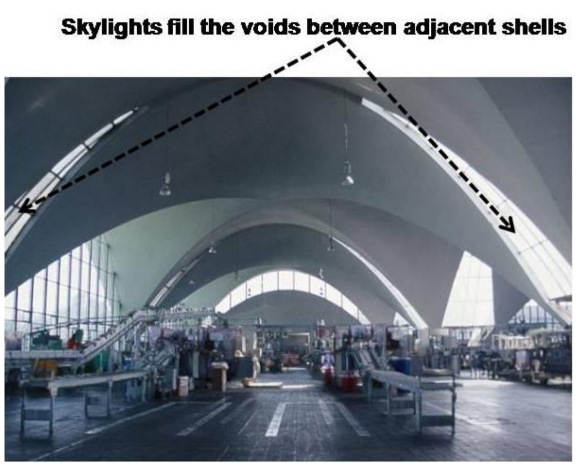
Bacardí Factory in Cuautitlán, Mexico

The factory roof consisted of three adjacent hyperbolic paraboloid groined vaults 4cm. thick and 26 m. square in plan with 2.5 m. overhangs on each side.

Bacardí Factory in Cuautitlán, Mexico

Félix Candela (1910-1997)

Groined Vaults



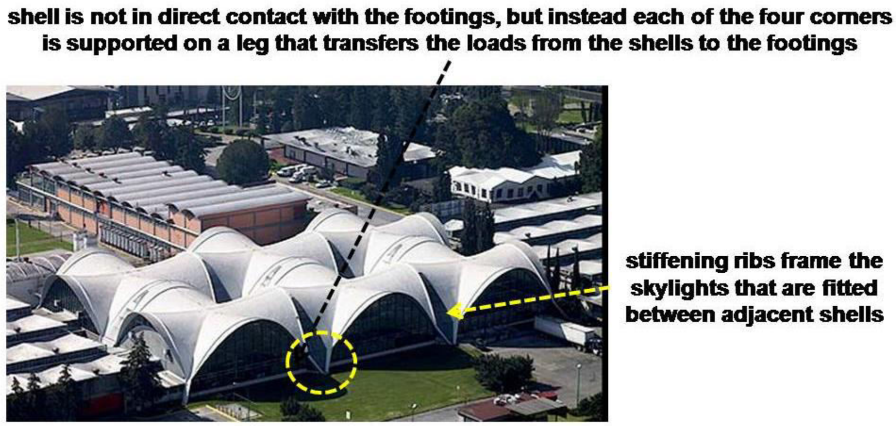


Figure 25 Bacardí Factory in Cuautitlán, Mexico

Sometimes an interesting profile can be created by using only a portion of the dome and not the whole of it. The following example is that of one such building wherein the roof profile is created by using only the half portion of the dome and not the whole of it.

Indira Gandhi Rashtriya Manav Sangrahalaya, Bhopal

Figure 26 Indira Gandhi Rashtriya Manav Sangrahalaya, Bhopal

References

- **Structure as Architecture** By Andrew W. Charleson, Elsevier Publication
- **Structure Systems** By Heino Enge, Hatje Cantz Publisher
- **Structure and Architecture** By Meta Angus J. Macdonald, Elsevier Publication
- **The Structural Basis of Architecture by** Bjørn N. Sandaker, Arne P. Eggen, Mark R. Cruvellier, Routledge
- **Building Structure Illustrated** by Francis D.K. Ching, Willy

Conclusion

In conclusion I'd like to state the following:

- Dome is the simples type of double curvature shell.
- Hoop and Meridional stress are predominate in the dome.
- Domes are classified into mainly four types.

Homework

1. Sketch a dome over a square hall. Name the various parts.
2. A hemispherical dome of 12m diameter is under $10KN/m^2$ loading. Find the Hoop and Meridional stress at $\theta = 0^0, 45^0$ and 90^0.