Structural System in Architecture
Prof. Shankha Pratim Bhattacharya
Department of Architecture and Regional Planning
Indian Institute of Technology, Kharagpur

Lecture No -28
Shell Structures

Welcome to the NPTEL online certification course on Structural Systems in Architecture. We are in the module number 6 i.e., the week 6 and this is the 28th lecture in serial and the lecture topic of today's half an hour will be on the shell structure.

Concepts Covered

- Introduction, Examples and Development of a Shell
- Stress in Shell
- Structural Advantages of Shell
- Classification of Shell

Learning Objective

- Outlining the structural behavior of a shell.
- To illustrate the classification of shell structures.

Introduction

Figure 1 Examples of shells found in nature

A shell is a thin curved surface functioned both as structure and roof coverings. The shell structure is typically found in nature as well as in classical and modern architecture.

Examples

Egg

Pressure Vessel

Human Skull

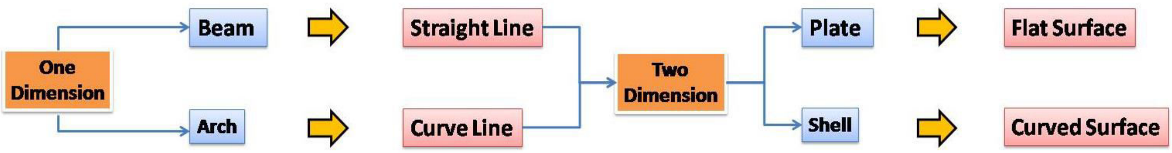
Silos

Tyre

Nuclear Reactor

Development of a Shell

A curved two-dimensional structure is called a shell.



Stress in Shell

A shell's curvilinear profile produces the ability to resist the membrane stresses in the form of tensile, compressive and shear forces. It transfers loads to its supports through its membrane surface. Its efficiency is based on its curvature, which allows different alternative stress paths. Most shells in the built forms are constructed by reinforced concrete although other materials can be used, such as plywood, metal and glass-reinforced plastics.

The surface of the shell exhibits membrane stresses. It is generated in the shell thickness to resist the external force and bending moment. The membrane stress corresponds to forces that are tangent to the surface defining the shell. The membrane stresses in a shell is equivalent to axial stress (mainly compressive) in an arch. The thickness of the shell is designed based on the developed membrane stress and material capacity.

The existence and nature of the membrane stress can be well understood by a loaded fabric bag or hanging garden chair as shown in the following figures.

Figure 2 Examples for the existence of membrane stress

Notice the stretch in certain portions of the bag/chair due to the load, particularly towards the downward portion. This is characteristic in a shell structure. This is true even if the loading is reversed.

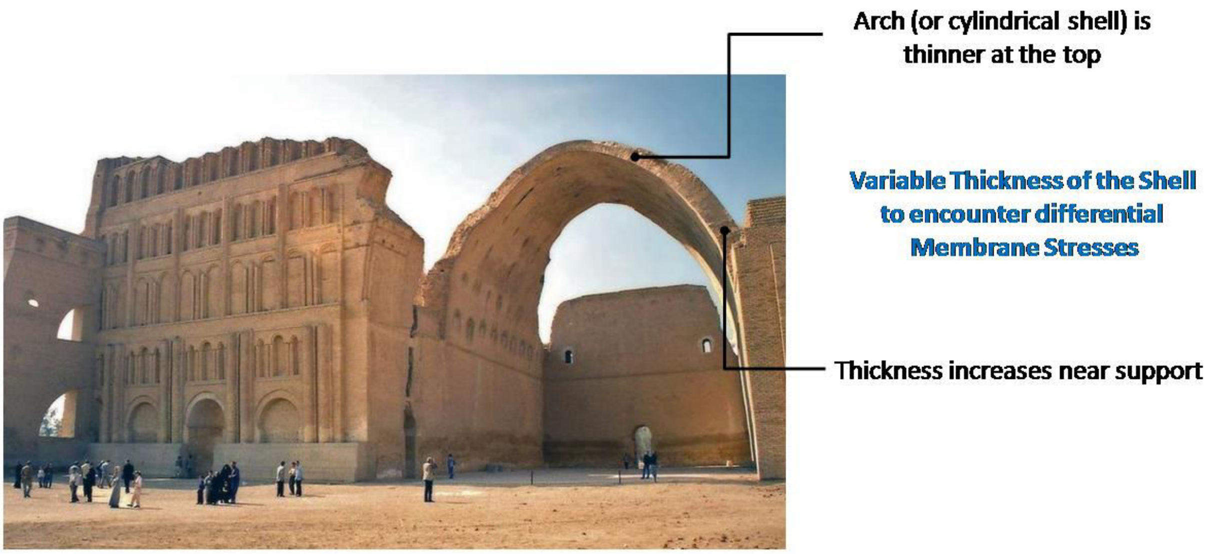


Figure 3 Taq-i Kisra or the Great arch of Ctesiphon, Iraq

The amount of membrane stress acting upon the arch (Figure 3) is different in top and bottom; hence the variability in thickness.

Structural Advantages of Shell

The structural advantages of a shell are listed below.

1. Due to its curve profile shell can be treated as a natural stable and strong structure.
2. It can give as a wonderful structural solution to long span applications.
3. For long span application is gives better strength to material consumption ratio as a structural system.
4. Reinforced Concrete can be widely and efficiently used in shell structure.
5. As it is curve in profile, it can impart a better aesthetic look to the built environment.
6. Typical circular shell can be precast and used widely as prefabricated material.

Classification of Shell

In Differential geometry Gaussian curvature or Gauss curvature (K) of a surface at a point is the product of the principal curvature (k_1 and k_2) at the same point.

Mathematically,

Gaussian curvature, $K = k_1 k_2$

The sign of the Gaussian curvature can be used to characterize the surface:

If both principal curvatures are of the same sign, i.e. same directional vector curvature, then the Gaussian curvature become positive ($K = k_1k_2 > 0$). The surface is said to dome like and to have an elliptic point.

For example, a sphere of radius *r* has Gaussian curvature $1/r^2$ everywhere.

If both principal curvatures are of the different sign, i.e. opposite directional vector curvature, then the Gaussian curvature become negative ($K = k_1k_2 < 0$). The surface is said to a hyperbolic and to have a saddle point.

If one of the principal curvatures is zero, i.e. any one direction the curvature does not exist, then the Gaussian curvature is zero ($K = 0$). The surface is said to have a parabolic point.

For example, a cylinder has Gaussian curvature zero everywhere.

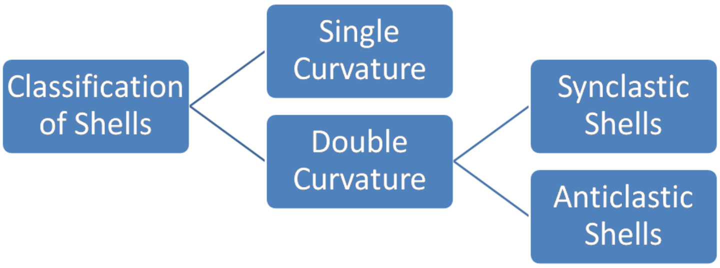


Figure 4 Classification of shells

Single Curvature Shells

The shell which is curved along one linear axis can be termed as single curvature shells. Profile of curvature can be circular, elliptical or parabolic.

Singly curved shells are developable and their Gaussian curvature is zero (K = 0).

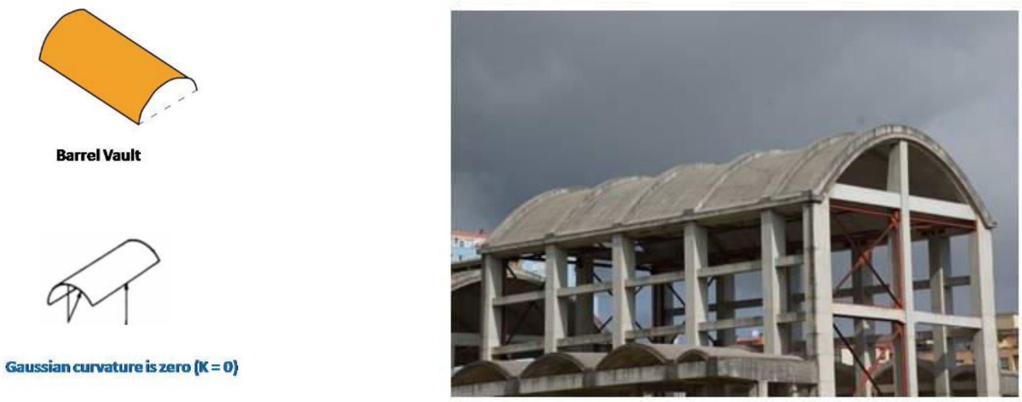


Figure 5 Examples of single curvature shells

Double Curvature Shells

The shell which is curved along both the axis can be termed as a double curvature shells. They are either part of a sphere, or a hyperboloid.

The doubly curved shells are non-developable. The Gaussian curvature of these kind of shells is not zero; it is either positive or negative (K > 0 or K < 0).

Synclastic Shells

In synclastic shells, the centers of curvature of both the surfaces are on the same side.

Gaussian curvature is positive (K > 0) for all synclastic shells.

Figure 6 Examples of double curvature, synclastic shells

Anticlastic Shells

In Anticlastic shells, the center of curvature of both the surfaces are located on the opposite sides.

Gaussian curvature is Negative (K < 0) for all anticlastic shells.

Figure 7 Examples of Double curvature, Anticlastic shells

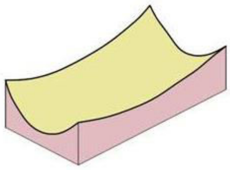
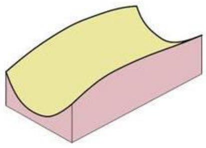
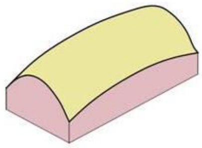
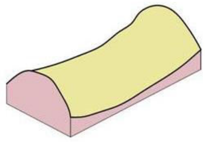
Synform

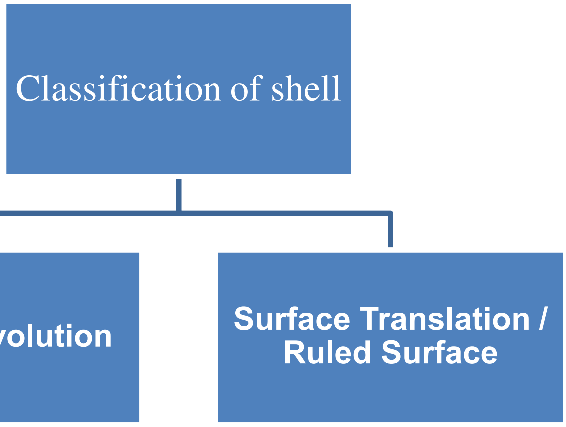
A convex-downward fold is a synform which dips inward toward a central point. It is also termed as a basin.

Antiform

A convex-upward fold is an antiform whose surface dips outward from a central point. It is also is termed as a dome.

Table 1 Synform and Antiform

Synform		Antiform	
Synclastic	**Anticlastic**	**Synclastic**	**Anticlastic**
			



Surface Revolution

These shapes are formed when a particular two-dimensional shape or a generator is rotated about an axis. E.g., a dome can be formed by rotating a semi-circle about an axis. The following figure shows some of the examples of surface revolution shells.

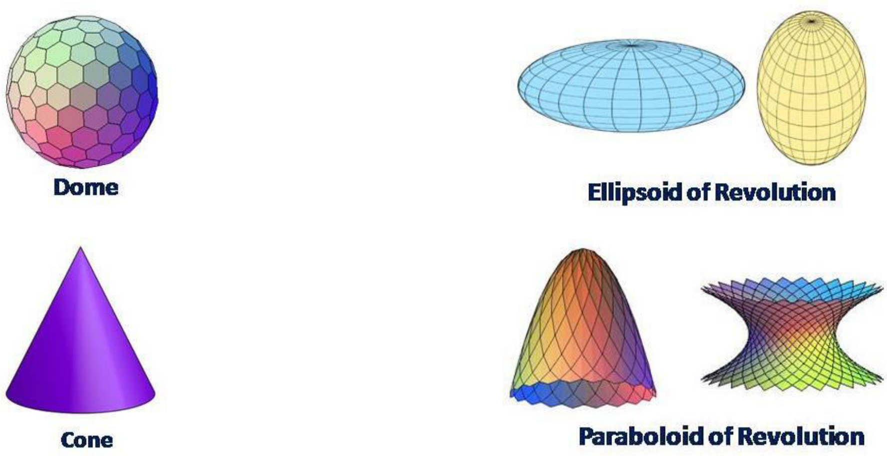
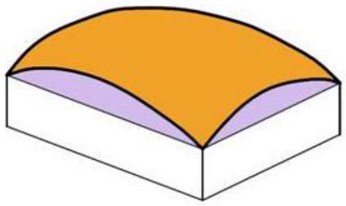
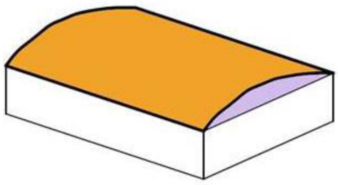
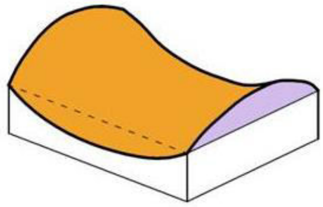


Figure 8 Surface revolution shells

Surface Translation / Ruled Surface

Elliptic Paraboloid	Cylindrical Paraboloid	Hyperbolic Paraboloid
A parabolic profile line runs over two elliptical edge lines.	A parabolic profile line runs over two straight edge lines	A parabolic profile line runs over two hyperbolic edge lines
		

The following figure shows some examples of the surface translation/ ruled surface shells.

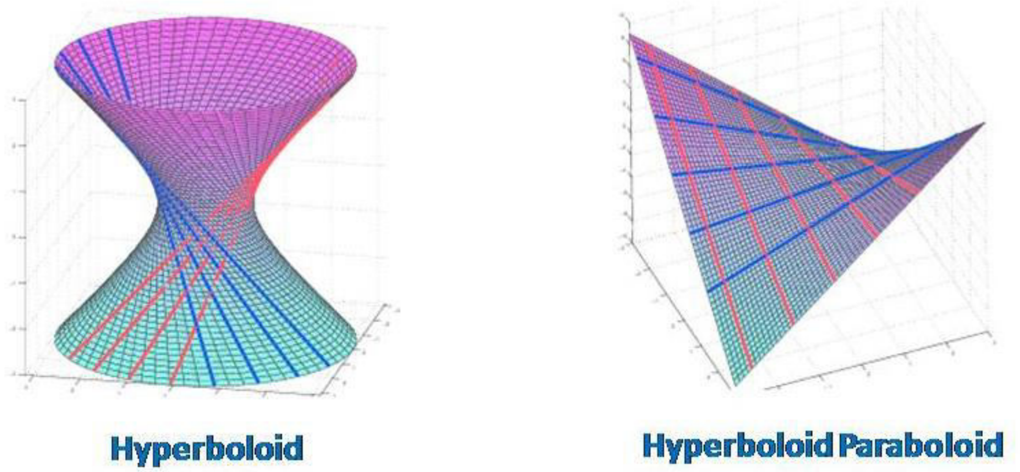


Figure 9 Examples of Surface Translation/ Ruled Surface

Barrel shell

1. Roof in the multiple bays in each direction is covered with Barrel shell.

2. One single unit is composed with two circular elements.

3. Shell roof system is rested over a roof tie beam and column.

The barrel shell was first used by the US structural engineer Milo Ketchum.

Hyperbolic Paraboloid Roof

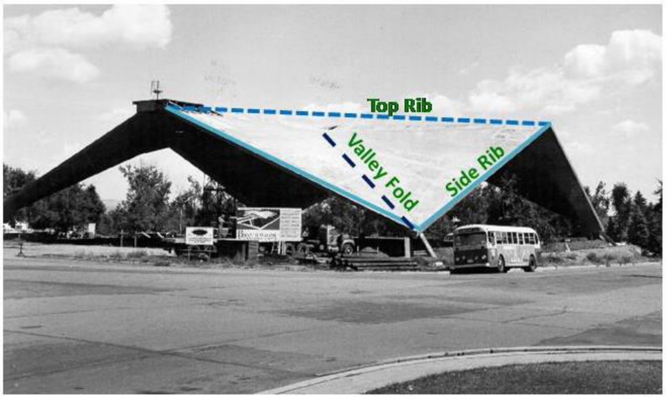


Figure 10 Hyperbolic Paraboloid Roof

About 185 by 185 ft. square roof is supported on steel tripod elements.

The structure has eight sides in plan (not square).

The length of the top rib is roughly the same length as the sloping side ribs.

The roof thickness is 3 inches, except for the ribs.

Shopping Centre Dome

An area unit of 40 by 40 feet square is covered by each translation dome. One such translation dome creates four segmental arch at the end. There are no interior ties at the springing of the domes and thrusts are carried by diagonal braces at the exterior.

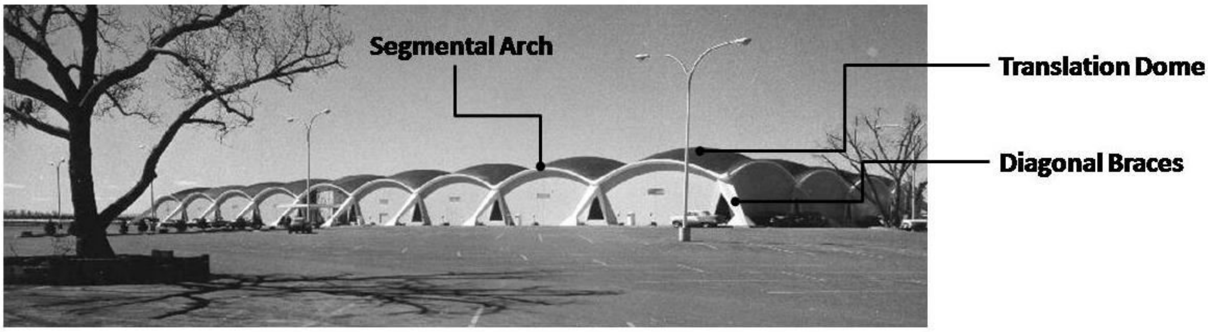


Figure 11 Shopping Centre Dome

Hanger for Small Aircraft

This structure is a square in plan. The side ribs are converged to the two diagonally opposite abutments. The central rib acts as an additional stiffening member and act as a perfect arch. It is a shell constructed by pre-stress concrete.

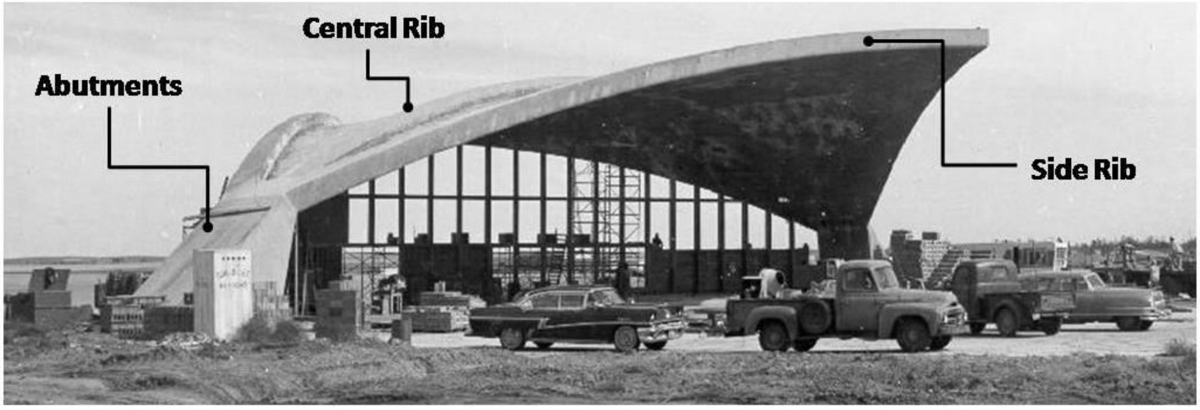


Figure 12 Hanger for small aircraft

References

- **Structure as Architecture** by Andrew W. Charleson, Elsevier Publication
- **Basic Structures for Engineers and Architects** by Philip Garrison, Blackwell Publisher
- **Structure and Architecture** by Meta Angus J. Macdonald, Elsevier Publication
- **AVD Construction** by Auroville Earth Institute

Conclusion

Shell structure is the two dimensional derivative of arch. It generates membrane stress in its both the orthogonal surface directions. Shell structure can be classified based on curvatures and surface revolution / surface translation.