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The Concepts behind the Design of Geodesic Domes – An Overview

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***Abstract**: Geodesic domes are hemispherical thin-shell structures based on network of geodesics (great circles) on the surface of a sphere or a hemisphere. Great circles intersect to form triangular elements which make domes stronger to resist wind loads. They are made from platonic solids especially from icosahedron. The design of geodesic dome is quite difficult without understanding the basic concepts. This paper aims at explaining the concepts behind the design of geodesic domes.*

***Keywords:** geodesics; great circles; platonic solids; icosahedron.*

1. Introduction

The geodesic dome was first invented by R. Buckminster Fuller, an engineer, architect, cartographer and geometrician, in the year 1954. This dome was built to house the United States exhibit pavilion „Expo" in 1967. Now, it is called as
Epcot dome and located in Florida. The philosophy of Buckminster Fuller is "doing more with less" because of which he had chosen sphere to make dome which encloses large volume with least materials. Bucky used tensegrity concept to design the epcot dome.

Figure 1. Epcot dome, Florida

The following are the concepts behind the design of geodesic domes.

2. Tensegrity:

Tensegrity or tensional integrity is a structural principle based on the use of isolated components in compression inside a net of continuous tension, in such a way that the compressed members (usually bars or struts) do not touch each other and the prestressed tensioned members (usually cables or tendons) delineate the system spatially. Bucky expressed this concept in his words as "islands of compression in an ocean of tension". Tensegrity structures are structures based on the combination of a few simple design patterns:

- loading members only in pure compression or pure tension, meaning the structure will only fail if the cables yield or the rods buckle
- preload or tensional prestress, which allows cables to be rigid in tension
- mechanical stability, which allows the members to remain in tension/compression as stress on the structure increases
- Because of these patterns, no structural member experiences a bending moment. This can produce exceptionally rigid structures for their mass and for the cross section of the components.

3. Platonic Solids:

There are six platonic solids namely tetrahedron, octahedron, hexahedron, icosahedron and dodecahedron. Geodesic domes can be made from tetrahedron, octahedron and icosahedron. Though they are approximations to sphere, icosahedron is very close and also beginning with a tetrahedron can create serious problems and with an octahedron will make a very complex structure. Hence, it is safe to begin with an icosahedron

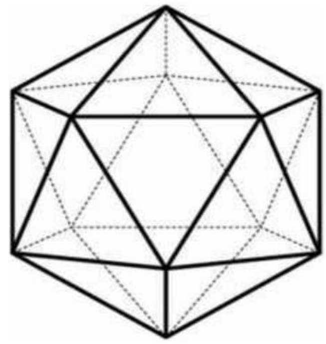

Figure 2. Icosahedron

4. Great circles:

When the icosahedron is exploded into sphere, it forms twenty equilateral spherical triangles. The vertices of such triangles are similar to the geodesic points formed by the intersection of three circles of diameter equal to that of sphere (great circles). Fifteen great circles are enough to produce the primary bracing of geodesic dome.

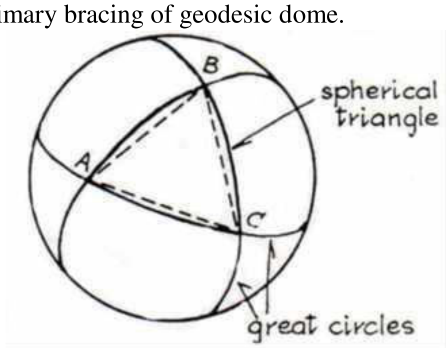

Figure 3. Great circles

5. Dome Characteristics:

5.1. Subdivision:

The primary bracing alone in the geodesic dome is impractical to use as the members develop excessive slenderness ratios with the increase in diameter of dome. Hence, secondary bracing is introduced by dividing each triangle into number of subdivision. The subdivision can be of two classes

Class I – dividing parallel to the edges of primary bracing

Class II – dividing perpendicular to the primary bracing

Class I subdivision produces geometry where the edges of the triangle lie on a great circle, which leads to simple design of a hemisphere with planar connections. This cannot be achieved with class II subdivision. Class II subdivisions require a smaller number of bar lengths. Though it is advantageous for fabrication, the differences between individual bar lengths are resultantly greater and this produces a less uniform stress distribution. So, it is desirable to use class I subdivision.

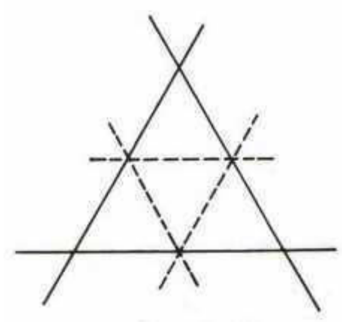

Figure 4. Class I subdivision

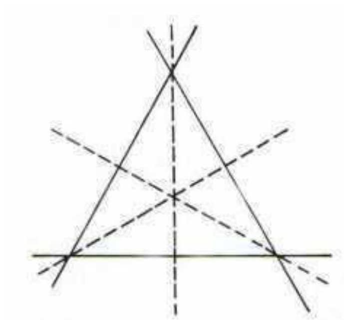

Figure 5. Class II subdivision

5.2. Frequency:

Frequency can be defined as the number of triangles by which the each edge of the primary bracing is divided. The frequency is often referred to in shorthand as a number, with the prefix "V". It is an indication of secondary bracing. If secondary bracing is introduces, the triangles are no longer equilateral. The length of struts forming the skeleton will vary. The number of different length of struts required for construction increases with the increase in frequency. In single layer domes, which are vulnerable to snap buckling, it is good rule to adopt frequencies less than 12.

As an equatorial perimeter ring is only produced for even order frequencies, odd order frequencies are generally avoided. Based on the position of perimeter ring (whether above or below the equator), the suffixes can be attached as 3/8ths or 5/8ths for odd order frequencies and 1/2ths or full sphere for even order frequencies.

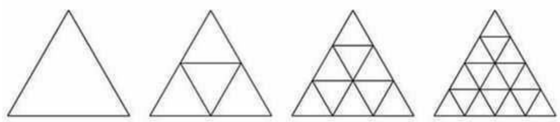

Figure 6. Frequency

5.3. Chord factor:

A chord is a (straight) line segment joining two points on a curve. For simple geodesic domes, curves follow the surface of a sphere circumscribing a regular polyhedron with triangular faces (tetrahedron, icosahedron, or octahedron). The desired frequency of the subsequent geodesic sphere or dome is the number of parts or segments into which a side (edge) of the underlying polyhedral triangle is subdivided. By connecting like points along the subdivided sides, a natural triangular grid is formed on each face of the polyhedron. Each segment of the grid is then projected as a "chord" onto the surface of the circumscribing sphere. The technical definition of a chord factor is the ratio of chord length to the radius of the circumscribing sphere. It is therefore convenient to think of the circumscribing sphere as scaled to radius = 1 in which "chord factors" are the same as "chord lengths" (fractional values less than one).

For geodesic spheres, a well-known formula for calculating any "chord factor" η

$$\eta = 2 \sin(\theta/2)$$

where "θ" is the corresponding angle of arc for the given chord, that is, the "central angle" spanned by the chord with respect to the center of the circumscribing sphere.

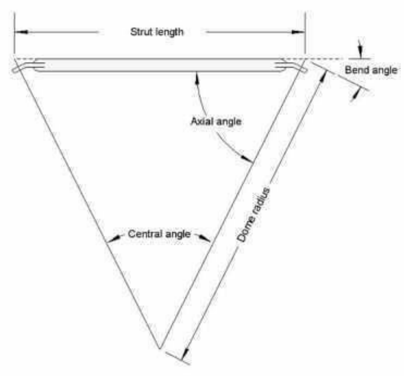

Figure 7. Chord factor

The no. of different lengths of struts required for various frequency domes can be summarized as follows

Table 1: No. of struts for varying frequency

Frequency	No. of different length of strut required
1V	1
2V	2
3V	3
4V	6
5V	9
6V	9
7V	16
8V	20
9V	18
10V	30
11V	36
12V	30
13V	49
14V	56
15V	45
16V	72
17V	81
18V	63
19V	100
20V	110

6. Advantages:

The following are the few advantages of geodesic domes

1. Geodesic domes require minimum amount of materials than required for ordinary domes.
2. They are structurally simple and light in weight.
3. They can be constructed with no interior supports for a long span.
4. Ease of handling and transportation is high because of their lightweight.
5. They are strong and aesthetically beautiful structures.

7. Design of geodesic domes:

The following are the basic steps in designing a geodesic dome

1. Select the diameter and height of the dome
2. Choose the frequency and subdivision according to the shape and requirements of the dome
3. Calculate the number of struts and their lengths using chord factor
4. Find the dead load through the weight of struts.
5. Calculate the snow load, wind load and seismic loads according to codal specifications.
6. Include live load for erection and repair purposes.
7. Choose the appropriate load combinations
8. Generate the geodesic domes using software such as Geodesica, CADRE Geo, GEODOME, and GOOGLE SKETCHUP etc…can be used.
9. Analyze the dome using Finite element analysis or through software such as Strand7, STAAD Pro v8i etc…

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