

“DESIGN AND ANALYSIS OF GEODESIC TUNNEL DOME FOR AN AUDITORIUM”

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Abstract - The Geodesic Tunnel Dome is a transformational form of the geodesic dome which is design in semicircular shape or parabolic shape. It is the convex roof and many memorable structures throughout the history have been built using Geodesic Dome. The study shows the result of static analysis and design of geodesic tunnel dome. We collected the dimension of an auditorium, the length is 40m & width of the inner side is 20m with the height of the crown is 10.63m. We built the model required for the project. We calculated the forces acting (i.e. Wind load, Dead load, Live Load &, etc.) on each panel of the structures for designing purpose, this load is resisted by two hinged arches which are further transferred to the RCC column to soil strata through the foundation. Wind intensity as per (IS 875-1987 part-3) is 44 m/s. Tempered curved laminated glass roof panels are used for the given structure as a roofing material. We used round steel tubes for dome structure according to IS: 806-1957. Technology engages the latest engineering & architectural technologies to produce an aesthetic view. It gives the maximum volume with the minimum construction material with no interrupting column in the middle with an efficient shape would be more economical. Dome roof is the lightest structure to cover semicircular shape. Therefore, the structure is more economical.

Key Words: Geodesic Tunnel Dome, Heavy Wind Load, Arch Truss, Aesthetic View, Energy Efficient, Economical, Steel tubes

1. INTRODUCTION

"Geodesic tunnel dome is a transformational form of a geodesic dome which is design in semi-circular shape or parabolic shape". A Geodesic dome is a hemispherical thin-shell structure based on a geodesic interconnected triangle. The triangular elements of the dome are structurally rigid and distribute the structural stress throughout the structure, making geodesic tunnel domes able to withstand very heavy loads for their sizes. Geodesic tunnel domes can be exceptionally suitable for covering assembly halls, exhibition centres, fish-farming aqua pods, swimming pools, and industrial buildings, forgetting large unobstructed areas with minimum interference from internal supports. A dome is one of the oldest structural forms and it has been used in architecture from earliest times but, geodesic tunnel dome is the newest form of the structure of this era. Geodesic tunnel domes are of special interest to engineers and architects as

they enclose a maximum amount of space with a minimum surface and have proved to be very economical in the consumption of construction materials.

1.1 HISTORY

The first geodesic dome was designed by Walther Bauersfeld chief engineer of the Carl Zeiss Optical Company, after the First world War .R. Buckminster Fuller named the dome" geodesic" from field experiments at Black Mountain College in 1948 and 1949. Although Fuller Was not the one with an original idea, still he received the patent (patent no.2682235) 29th June 1954. The dome was used for a special purpose in Canada in 1956, Louisiana 1958, which was designed by Thomas C. Howard do synergetic Inc. And specialty building such as Kaiser Aluminium Domes. The US Marine experimented with a helicopter-deliverable geodesic dome in 1954. The Construct 30-foot wooden plastic geodesic dome which was lifted successfully and carried by Helicopter without any damage. The dome was introduced as Pavilion for a wider audience for the 1964 world's fair in New York City designed by Thomas C. Howard. In 1970's Zone works licensed plan for structures based on a geometric solid whose faces were not triangular, being Square or other polygons. In 1975, a dome was constructed at South pole, where its resistance to snow and wind load. One of the most famous geodesic domes, Spaceship Earth in Florida Opened on October 1, 1982. In 2000, the world's first fully sustainable geodesic dome hotel, Eco-Camp Patagonia, was built in Chilean Patagonia opened in 2001.

1.2 OBJECTIVE

- To enclose an enormous amount of space without the help of a single column.
- To make structure energy efficient and cost-effective.
- To make structure stable against forces by interconnected triangles which distribute the forces evenly along its three sides.
- To resist heavy wind load as compared to other structures.
- To live people in harmony with their environment by its aesthetic look.

2. LITERATURE REVIEW

Pandey Gaurav et al. (Comparison of the Geodesic Dome) (2017) etc. stated that modern insulated concrete dome

construction combines several materials to concrete make it strong, efficient and weatherproof. He analyses different dimensions of parameters for modern concrete dome roofs are the lightest structure to cover circular shape. Domes are used in a variety of structure such as the roof of circular areas, circular tanks, exhibition halls, auditoriums, etc. Domes are constructed of masonry, steel, timber, and reinforced cement concrete. He works on parameters like STAAD PRO, the diameter of the column, beam, plate thickness, and analysis. He takes 125 mm minimum thickness of RCC domes. Dead load and live load consider as IS 456:2000 various variable for considered for RCC domes such as different diameter, tie beam, roof beam, plate thickness, self-weight of the structure is generated by STAAD PRO. Dead load also generated by signifying the plate thickness and load on the floor per square meter. Live load is generated in a similar manner as dead load. In this different dimension of the parameter for the modern concrete dome are analyzed. It shows for a concrete dome take the different dimension of beam. He shows a relative percentage change in axial force shear force and bending moment due to change in dimensions.

Gaikwad Bharath et al. (DESIGN consideration for Geodesic Dome) it defines geodesic domes in such way it is efficient, minimum use of materials, lightweight, easy installation, and dismantling resist high winds. It also states the geodesic dome consists of only 38% surface area of box shape building that encloses the same floor area. Simply dome may be built by PVC pipe or galvanized steel covered with plastic sheets. Large, permanent structures may build by aluminum and steel frames structure covered with aluminum, copper, acrylic, structural gypsum. Most dome built with concrete (RCC). While designing the lowest row of the triangle is removed without weakening the structures, so that door and windows openings can be provided. The dome sits directly to the ground level footing. The RCC dome constructed in two steps. First is Substructure – Foundation Construction and second is Super Structure – 60 triangular panels. It states the structure can be failed in 3 modes which are Strut Buckling, Ties Yielding, and Connection Bolt Shear Failure. The dome develops compressive or tensile stress. Tensile Stress at the base and compressive at the higher upside. Since geodesic domes use self-bracing triangles, it is highly profitable structure so this causes the least uses of the material. It is a light structure with ease implementation of high strength, architectural appearance, etc. Due to the simplicity of erection, these domes are gaining popularity. By minimizing defects, it gives a better option of the roof of larger span structures and these are economical.

Robart Szmit (2017) etc. he stated that geodesic dome also known as geodesic spheres. Fuller domes build now a day's span to over 200 m. there are of course other types of the dome for comparison with the bearing capacity of geodesic dome amounting to 100% the bearing capacity of a Lamella Dome is approximately 75% with the bearing

capacity of spiral-latitudinal dome amounting to 50%, and the bearing capacity of Schwedler dome is 30%.

Mandali Divyesh etc. (Comparative study for the geodesic dome of class1) (2016) stated that geodesic dome enclosed a maximum amount of space with the minimum surface. Domes are suitable for covering sports stadia, assembly halls, exhibition centers, fish-farming aqua ponds, swimming pools, and industrial building. They compared geodesic dome of 20 m diameter and 10 m height for a different class method and for different frequencies. He considered both class-1 method-1 and class-1 method-2. They analyzed and designed dome by STAAD PRO V8ISS5. They calculate wind load by IS-875-3(1987) and applied on models. Load combination is considered as per IS-1893 (Part-1): 2002 (clause-6.3.1.2). They considered dome covered by non-structural covering roof. It has no stiffness and can only pass the load into members of the structure. The modulus of elasticity is taken as 205 KN/sq.mm. Various rings are formed in the dome. It is observed that bottom rings are having the maximum compressive axial force and can be grouped together. Various section size is obtained for each group after optimizing the structure for the model. The weight for each model with different frequency is calculated and the graph is plotted (frequency on the x-axis, weight on the y-axis). From the graph, they concluded formulas for each method for calculating the weight of the dome.

$$T = (4.0611f^4) - (48.348f^3 + 195.78f^2) - (292.5f + 358.38) \quad \dots$$

(For class-1 method-1)

$$T = (0.7567f^4) - (8.894f^3 + 39.714f^2) - (66.691f + 273.4) \quad \dots$$

(For class-1 method-2)

Where, T = Quantity in tonnes
f = Frequency

As frequency increases tonnage is increases simultaneously for class-1 method-2 but member size reduces as frequency increases.

Vocalism Yu. A laptop et al. (Trial Design of Roof Truss for Church) (2016) etc. stated that dome structure often used in Rounded building. Dome roof can be classified according to different characteristics such as their purpose, Design shape, Size, Rising Height, Materials used, etc. According to dome structure construction, they are divided into the Ribbed, Ribbed Ring-Shaped, Webbed, Radial Beam and Grid Domes. Design of Domes depends upon technical and [1] economic properties, complexity/simplicity, manufacturing, fitting above all weight and price of dome depend on this dome design. They applied trial design method. While designing they used Ribbed-Shaped, Grid and Webbed geodesic domes for comparative analysis. They calculate structural design, Strength and Proportioning of members, weight index as well as geometrically arranged elements of each dome. Geometrically arrangement of dome structure was made using AutoCAD and Solid Works software. Static analysis of the dome was made using LIRA software. The joint connection was made by Solid Work

software. Dome elements weight and whole weight is calculated by Excel application. For calculating efficiency, they used Ya. M. Likhtarnikov's methodology. According to this methodology, determining the cost of construction, one has to calculate construction weight and units weight, labor hours, transport operation and construction assembly. The total cost of assembling Grid Dome is 7% more than Ribbed Ring-Shaped Dome. The total cost of Webbed Dome is 2 times Ribbed Ring-Shaped Dome

Mohamad Aidil Bin ABD Kassim et al. (Finite Element Analysis of a Geodesic Dome Structure by Using STAADPRO Software) (2015) etc. stated that the dome is a structural system that can withstand a larger span with minimum interference between supports at the end of his structure. The geometry of dome support itself without needing internal columns or interior load-bearing walls. Dome structure is usually as the top of mosque and church because it has high aesthetic value while the geodesic dome is usually used as greenhouse structure, storage, and arenas such as Tacoma Dome in Washington, USA. Engineer and architect have an interest in a structure that can cover a large span with minimum interference (M. Kubic, 2009). In this case, the geodesic dome has a pattern that very unique in term of structure arrangement making the geodesic dome are already high aesthetical value before it decorated by any plate that uses as the shell of the dome. STAAD PRO programmed used to analyses the strength behavior of geodesic dome structure under a certain loading. In STAAD PRO, analyses of the structure are divided into two major parts which are modeling and post-processing. In the modeling stage, the model will have built geometry, define the general element material and loading and also define the type of analysis and code used in the design. While for the post-processing stage, the further processing and viewing of the results will see such as the list of nodal displacement, element force and moments, and deflection plots.

Ladan Assadi (Geodesic Dome in Modern Cappers: The Case of Iran) (2014) etc. stated that the modern cappers are considered as the most stable, simplest and chipset architectural design. The cappers primitive human beings when they left caves and before they constructed villages. Cappers are the first's social institution which has excited along with the development of the villages and cities for 40000 years without destroying the ecosystem. While observing all the factors of sustainability. He said the capper built in the pass had a desirable function since they set up with regard cold naturally. He also said that innovation of the cappers with regards to preserving their architectural values by using new construction materials not only helps revive a part of Iran's history but also assist human beings to have an impermanent accommodation. The plan of the modern cappers based on designing recommendations unit with a geodesic dome which look like a dome of the ancient cappers is the typical life architecture in Iran. The geodesic domes used in modern cappers are very efficient due to having a high-performance structure to cover small

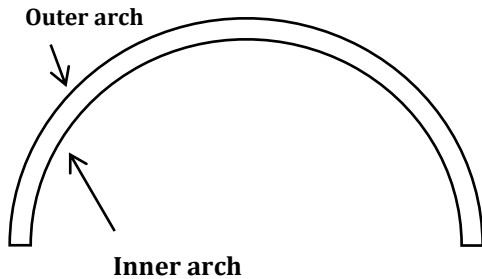
integrated space without pillars. They said these domes physically have the most efficient resistant against exterior forces like strong winds in Iran. Moreover, this kind of covers is light and can be manufactured easily and install quickly. They said in this study they will focus on studying the sustainability of cappers, the most resting structure, and the modern local design of such structures are studied by taking the climate capabilities of environmental architectural into considerations by sing the climate techniques and modern technology which corresponds with the local architectures as to provide more conveyances for the residence.

The Concept behind the Design of Geodesic Dome – An Overview sets started that the geodesic domes are hemispherical thin shell structures, in which great circle intersect to form triangular elements. They explain the concepts behind the design of geodesic domes. The geodesic dome was first invented by R. Buckminster Fuller, in the year 1954. This dome was built to house the US exhibit Pavilion Tensegrity, Platonic Solids, Great circles are the concepts behind the design of the geodesic dome. Tensegrity is a structural principle based on the use of isolated components in compression. Due to Tensegrity, loading members are only in pure compression or pure tension. It provides mechanical stability to members. A geodesic dome can be made from tetrahedron, octahedron, and icosahedron. An icosahedron is safe. When the icosahedron is exploded into a sphere, it forms twenty equilaterals spherical triangles. Subdivision, frequency, chord factor are the characteristics of the dome. Subdivisions are of the two classes, Class1 – Dividing parallel to the edges of primary bracing. Class2 – Dividing perpendicular to the primary bracing. Class1 Subdivision geometry where the edges of the triangles lie on a great circle. Class2 Subdivision smaller number of bar length. Frequency can be defined as the number of triangles by which each edge of the primary bracing is divided. The frequency is denoted by 'V'. A chord is a (straight) lie in segment joining two points on a curve. They conclude the concept behind elements of the geodesic dome

Kenner, author of Geodesic Math and How to Use it (1976), defines the geodesic dome as a domicile, shell-like structure that holds itself up without supporting interior columns. Both Fuller (Introduction to Geodesic Domes and Structure, November 2008), inventor of geodesic domes, and Knauer (October 2008) agree that the geodesic dome is defined as an approximate hemisphere formed by connecting a mesh of triangles, which provide a self-supporting structure, which offers an open interior for maximum space and light. Self-supporting is defined as a structure that requires no load-bearing interior walls to bear the weight of the roof or dome. The dome structure is both stable and strong when compared to a rectilinear shaped structure. Fuller (2008) was convinced that by applying modern technology to the design and construction of homes, geodesic dome homes could also be built to ensure comfort, as well as economic and energy efficiency.

3. LOAD CALCULATIONS:

Length of inner arch = 31.94 m
 Length of outer arch = 32.87 m
 Crown height = 10.63 m



No. of truss = 5 nos
 Spacing between two truss = 8 m

Load between two intermediate truss

Wt. of two hinged arch = 2×15175.01 N
 = 30350.02 N
 Wt. of purline = 20906.4 N
 Wt. of roofing material = 75360.42 N
 Wt. of wind bracing = 27256.32 N
 Wt. of circular bracing = 5080.14 N
 Total dead load = 158953.4 N
 Dead load on each panel of outer truss = 2.56 KN
 Dead load on each panel of intermediate truss = 5.12KN

Total wind load on arch = 2.405 KN
 Total wind load on each panel = 0.078 KN

Live load = 450 kg per truss
 Live load on each panel = 0.14 KN
 Total Factored load on each panels of outer truss = 4.175 KN

Total Factored load on each panels of intermediate truss = 8. KN

Table no. 1 - diameters and thickness of steel tube

| Sr no. | Members | Size of steel tube member according to IS:1161-1963 | |
|--------|----------------|---|----------------|
| | | Outer (mm) | Thickness (mm) |
| 1 | Outer Arch | 165.3 | 5 |
| 2 | Inner Arch | 165.3 | 5 |
| 3 | Purlin | 88.9 | 4 |
| 4 | Wind Bracing | 60.3 | 3.6 |
| 5 | Vertical panel | 88.9 | 4 |
| 6 | Inclined panel | 88.9 | 4 |

4. ESTIMATION OF DOME STRUCTURE:

Table no. 2 - Estimation of tubular pipe steel

| Sr no. | Member | Length (m) | Rate per m | Total rate (Rs.) |
|--------------|------------------|------------|------------|------------------|
| 1 | Outer arch | 167.5 | 3450 | 577702/- |
| 2 | Inner arch | 159.7 | 3450 | 550965/- |
| 3 | Vertical panels | 46.5 | 1380 | 64170/- |
| 4 | Inclined Panel | 156 | 1380 | 215285/- |
| 6 | Purlin | 1240 | 1240 | 1711200/- |
| 7 | Bracing | 400.8 | 744 | 298195/- |
| 8 | Inclined Bracing | 2488.73 | 744 | 1851614/- |
| Total amount | | | | 5269126/- |

Estimation of roofing material

Rate of tempered laminated glass is 150 Rs. Per square feet

Total area of roof = 14380.58 square feet

Total amount required for roofing material is 2157087/-

(Note: we adopt rates from latest price list 2019 pipe tube, authorized distributors of JINDAL PIPES LID., MAHARASHTRA SEAMLESS LTD., SANT INDUSTRIAL VALVES, "VS" FORGED FITTINGS)

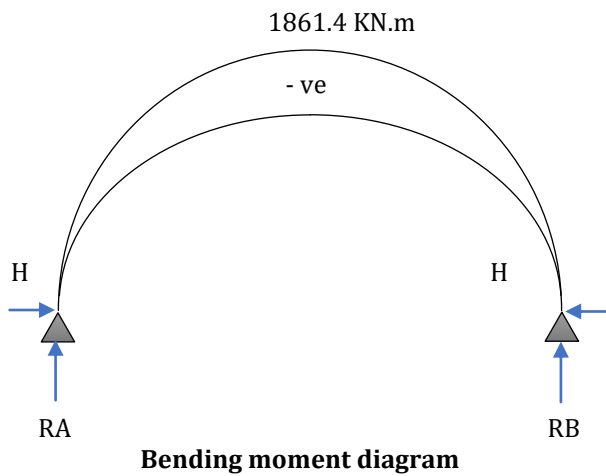
5. RESULTS:

For intermediate two hinged arch
 Reaction at support (RA) = 124 KN

$$\text{Horizontal thrust (H)} = \int_0^s \frac{my}{y^2} dx$$

Horizontal thrust for intermediate truss (H) = 228.3 KN

Bending moment at crown (BM) = 1861.46 KN-m



Where,

H = horizontal thrust in KN
 RA = Reaction at A in KN
 RB = Reaction at B in KN

Table no.3 – bending moment on panel points

| Sr no. | Member | \bar{Y} (m) | Moment (KN-m) | Horizontal Thrust |
|--------|--------|------------------|------------------|----------------------|
| 1 | AC | 0.8 | -170.24 | 16.935 |
| 2 | AD | 1.8 | -396.34 | 3.58 |
| 3 | AE | 2.8 | -599.44 | 9.6 |
| 4 | AF | 3.7 | -774.91 | 9.436 |
| 5 | AG | 4.7 | -957.61 | 11.04 |
| 6 | AH | 5.5 | -1103.8 | 6.67 |
| 7 | AI | 6.3 | -1239.4 | 8.53 |
| 8 | AJ | 7.1 | -1374.5 | 8.23 |
| 9 | AK | 7.7 | -1453.5 | 6.34 |
| 10 | AL | 8.4 | -1586.9 | 5.31 |
| 11 | AM | 8.9 | -1661.4 | 5.93 |
| 12 | AN | 9.3 | -1720 | 5.32 |
| 13 | AO | 9.6 | -1759.4 | 5.43 |

| | | | | |
|----|----|-------|---------|------|
| 14 | AP | 9.9 | -1807.9 | 4.98 |
| 15 | AQ | 10.00 | -1820 | 4.18 |
| 16 | AR | 10.20 | -1861.4 | 4.74 |

6. CONCLUSION:

This type of structure with steel tube is rarely constructed in Mumbai. We used this type of structure for resisting heavy wind load, it is economical than RCC structure. This structure required less time to construct as compare to other structure. It also gives an aesthetic view and energy efficient.

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