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Instability Analysis and Design of Braced Barrel Vault

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Abstract

Barrel vaults are a popular way of spanning large open areas with few intermediate supports. It is a simple structural formation made up of a network of longitudinal, transverse and bracing members with curvature in one direction. The configuration of the vault, or in other words the way in which the members are positioned and connected, has a major effect on the vault's structural performance, aesthetics and cost. In this paper braced barrel vaults which was exposed to the different load such as live load, wind load and the combination of the load where the wind directions are changed and analysis was performed using the Staad.Pro V8i. The forces on the members are obtained from the Staad.Pro V8i software and the tension and compression member was designed as per IS 800-2007.

Keywords

Barrel Vault, Buckling analysis, wind load calculation, Staad.Pro V8i.

I. Introduction

Structural Members such as shallow Truss and arches find many applications in the field of civil engineering. These form an important part of various structures like air plane hangars, bridges, railways, roof structures etc. Arches are used for underground structures such as drains and vaults are widely used in structural members like bridges and buildings too. The arch can carry a much greater load thus making it more significant.

The past four decades saw an expanding interest in this form of construction. This is understandable because these structures can provide a form of roof construction combining low cost and rapid erection with a pleasing appearance. Hundreds of successful barrel vault applications for basement, intermediary and ground floors now exist all over the world covering public halls, exhibition centre, airplane hangars and many other buildings. This barrel vaults structure can adopt in all types of environment such as urban, rural, plain, mountain or seaside.

In this paper barrel vault with a width of 22.9 m and the span of 27 m are taken to analysis the behaviour of barrel vault(Fig.1)

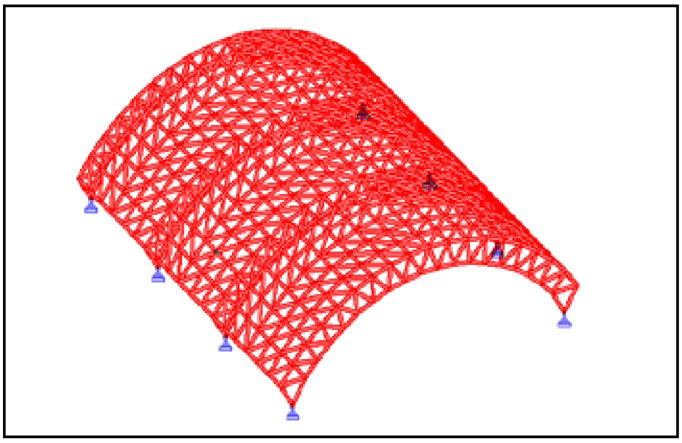

Fig.1: Braced Barrel Vault

A. Components Of Braced Barrel Vault

- Members
- Member Connectors
- Support members

1. Members

A space frame consists of axial members, which are preferably tubes, also known as circular hollow sections. In this analysis barrel vault is provide with Tubular Member.

2. Member Connectors

In this barrel vault, MERO node connector was used to connect members. It is a threaded spherical ball of hot forged steel with as many as 18 tapped holes, at different angles, distributed evenly over its surface, to receive tubular members at different angles. The sphere has flat surfaces around the threaded holes to improve the seating of the spanner sleeve. The holes are precisely drilled so that the centre lines of the tubes at a node meet at the centre of the sphere. A bolt, which is inserted through a hole in the tubular member and passes through a cone welded to the end of the tube.

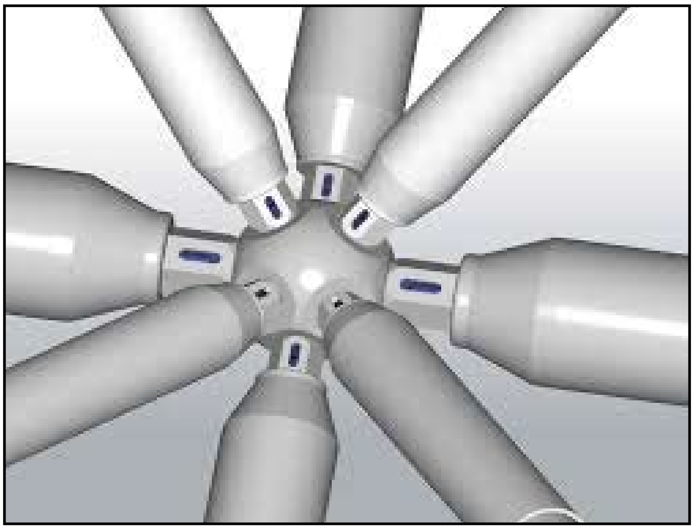

Fig. 2: Mero Node Connector

3. Support Members

Barrel vault are rested on the column and it will be steel column section or a concrete column, here the vaults are rested on the steel column and the buckling analysis were carried out for the structure.

II. Load Calculation

The following loads are considered:

Dead load: The dead load includes self-weight of the structure and the weight of the roof covering materials. Galvanized Steel Sheets are used for roofing.

Live load: The live load depends upon rise/span ratio and it is calculated as per table-2 of IS-875 (Part-II) in curved roof for

access not provided condition.
The dead and live load are applied as area load.

Wind load: Wind load is the most important of all and it often controls the design. The Wind load is calculated as per IS: 875–1987(Part-III). ,

As per Indian code, Design For wind Load $V_z = V_b*K_1*K_2*K_3$ Where V_z is the design wind speed at any height in m/s; K_1 is risk coefficient=1.06 for this case (table-1 IS: 875 Part- 3); K_2 is terrain, height and structure size factor = 0.88 for catagory.4 and class B case (table-2 IS: 875 Part-3); K3 = topography factor =1 for this case. So, V_z = 36.3792 m/s, Design Wind Pressure P_d =

$0.6\ V_z^2$ kN/m^2, P_d = 794.0677 N/m^2
Wind force $F = (C_{pe} - C_{pi}) *A * P_d$
Where, C_{pe} = External pressure coefficient and C_{pi} = Internal pressure coefficient. The external pressure coefficient C_{pe} is taken considering the case of roof on elevated structure as per table-15 of IS: 875,Part-III (fig.3).In the table15 of IS-875 values of external pressure coefficients are given at interval of 0.1 of H/l ratio. The Excel sheet is used for calculation of the intermediate values of C_p by linear interpolation. Internal pressure coefficient is based on the permeability of structure and in this problem, it taken as ±0.2. In this case surface design pressure varies with height, the surface areas of the structural element may be sub-divided so that the specified pressures are taken over appropriate areas. Here the total height of the structure was divided into ten equal parts and wind force per sq.m area was calculated. Positive wind load indicates the force acting towards the structural element (pressure) and negative away from it (suction)

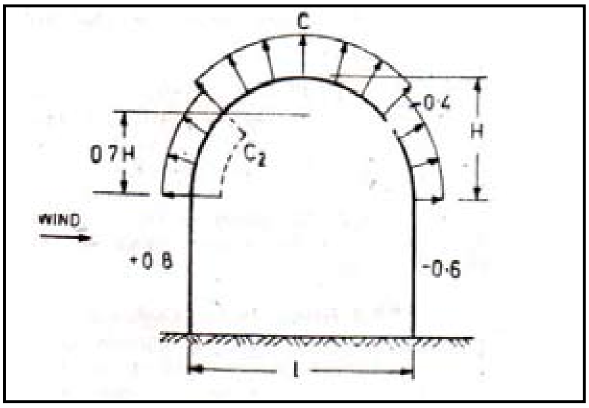

Fig 3: Wind pressure distribution for roof on elevated structure as per IS: 875(part-3) - 1987

A. Load Combinations

1. Strength Conditions

1. DL
2. LL
3. I.5DL+1.5LL
4. 1.5DL+1.5WL acting along left to right
5. 1.5DL+1.5WL acting on top portion
6. 1.5DL+1.5WL acting along right to left
7. 1.5DL+1.5WL acting on front to back side
8. 1.5DL+1.5WL acting on back to front
9. 1.2DL+1.2LL+0.6WL acting along left to RIGHT
10. 1.2DL+1.2LL+0.6WL acting on top portion
11. 1.2DL+1.2LL+0.6WL acting along right to left
12. 1.2DL+1.2LL+0.6WL acting on front to back side
13. 1.2DL+1.2LL+0.6WL acting on back to front side

2. Serviceability Conditions

1. DL+LL
2. DL+0.8LL+0.8WL acting on left to right
3. DL+0.8LL+0.8WL acting on top portion
4. DL+0.8LL+0.8WL acting on right to left
5. DL+0.8LL+0.8WL acting on front to back side
6. DL+0.8LL+0.8WL acting on back to front side
7. DL+WL acting on left to right
8. DL+WL acting on top portion
9. DL+WL acting on right to left
10. DL+WL acting on front to back side
11. DL+WL acting on back to front side

III. Modelling

The structure was modelled in the AutoCAD 2010 (Fig:-4). The created structure will be saved in DXF format and then it was imported to Staad.Pro V8i for the analysis

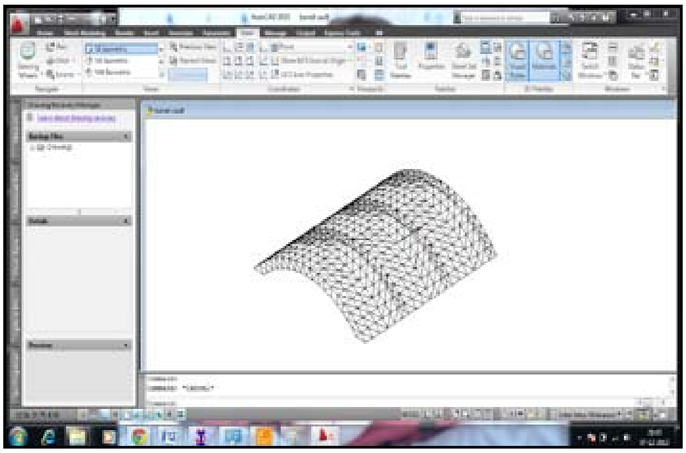

Fig. 4 : AutoCAD Modelling

IV. Analysis

STAAD.Pro is an analysis and design software package for structural engineering, used in performing the analysis and design of a wide variety of types of structures. This implies that it addresses all aspects of structural engineering including model development, verification, analysis, design and review of results. It includes advanced dynamic analysis and push over analysis for wind load and earthquake load.

After importing the structural model in the STAAD.Pro the following steps are followed

- Defining the member property
- Assigning Support condition
- Defining the loads with load combinations
- Analysis of the structure

From the analysis the maximum forces were found and are shown in the table 1.

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Table 1:- Maximum forces in members

Beam	Load Case	Max Axial force	Member
1279	4 CL STRENGTH I.5DL+1.5LL	-224.848	Chord
470	14 CL STRENGTH 1.2DL+1.2LL+ 0.6WL-Z	95.447	Bracing

A. Buckling analysis

"Buckling" is used as a generic term to describe the strength of structures, generally under in-plane compressions and/or shear. It is particularly dangerous because it is a catastrophic failure that gives no warning. The buckling strength or capacity can take into account the internal redistribution of loads depending on the situation.

A buckling analysis is used to find the lowest multiplication factor for the load that will make a structure buckle. The result of such an analysis is a number of buckling load factors (BLF). The first BLF (the lowest factor) is always the one of interest. If it is less than unity, then buckling will occur due to the load being applied to the structure. The analysis is also used to find the shape of the buckled structure.

From this buckling analysis the maximum forces on the member is greater than the applied load hence the structure is safe against buckling.

V. Design

Design of members

The bracing and chord members are designed for the maximum forces values obtained from the analysis. Design of members is done as per IS 800 -2007 and the permissible load carrying capacity of the section assumed during the analysis is sufficient enough to carry loads applied (table 2).

Design of Node Connectors

Maximum number of bars connected to the node will be 8

Yield strength of node material =563.2N/mm^2

Arc length between centre line of pipe=1.5d

Sphere Radius:

External radius of the sphere Ro is obtained from the relation

$$1.5nd=2\pi Ro$$

$$Ro=1.5nd/2\pi =92mm \sim 90\ mm$$

Thickness of Sphere:

Axial force transferred to the sphere

$$P_b = (360)\ (731*10\text{-}3) =492.46KN$$

$$P_y = 0.864\ t^2,$$

$$t = 23.86\ mm$$

Thickness of the sphere is t=25 mm

Table 2: Design forces

Member	Section (mm)	Max force (KN)	Design Force (KN)	Remarks
Chord	Tubular- 89.89*4.9	- 224.848	360.23	SAFE
Web	Tubular- 40.40*4.0	95.447	121.58	SAFE

VI. Conclusion

- The barrel vault for various Load combinations was studied for both Strength and Serviceability conditions.
- Based on these values, the barrel vault analysis done by using STAAD Pro.V8i and design was carried out manually.
- Instability analysis was carried out to find the buckling behaviour of braced barrel vault was analysed by using STAAD Pro V8i. Since the buckling load is greater than the applied load then the structure is said to be safe in buckling analysis for instability condition.
- In future the study can be extended by varying the configuration of the barrel vault and the behaviour can be analysed.

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