Parametric Investigation of Double-Layer Braced Barrel Vault Trusses: Structural Optimization and Management Implications

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Abstract

Long-span roof systems play a vital role in modern infrastructure, particularly in industrial, sports, and exhibition facilities. Among such systems, double-layer braced barrel vault trusses provide superior stability and material efficiency, but their indeterminate nature and geometric complexity make design optimization challenging. This paper presents a parametric investigation of four geometric configurations—Square-on-Square, Two-way Grid, Diagonal-on-Diagonal, and Square-on-Diagonal—under varying span-to-height ratios. The study employed STAAD Pro software for modeling and analysis, with loads applied according to IS 875 guidelines. Validation was performed against an existing industrial shed design to ensure accuracy. Results indicate that the Square-on-Square arrangement exhibits the lowest nodal deflections and more uniform axial force distribution, while a span-to-height ratio of 0.33 offers an optimal balance between structural stiffness and material usage. The findings highlight not only technical performance but also managerial implications in terms of cost reduction, project efficiency, and design decision-making. The outcomes provide a decision-support framework for engineers and project managers engaged in the planning and execution of large-span structures.

Keywords

Barrel vault, Space truss, Structural optimization, Axial forces, Deflection, STAAD Pro, Indian Standards, Engineering management

1. Introduction

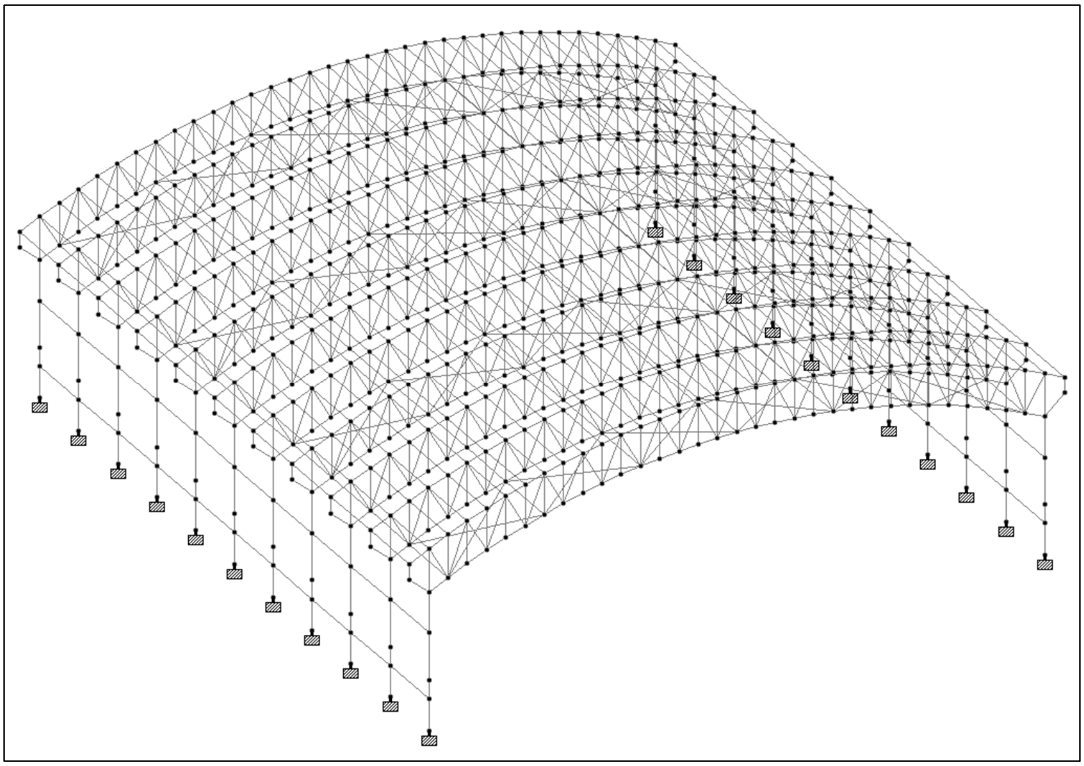
The pursuit of efficient long-span structures has driven engineers to adopt innovative spatial systems that combine structural efficiency with economic feasibility. Double-layer braced barrel vaults, comprising top and bottom chord layers connected by bracings, represent one such solution. Their curved geometry enhances stiffness, stability, and load transfer through axial mechanisms rather than bending. Despite these benefits, their high degree of indeterminacy necessitates computational tools for analysis and optimization. Previous reliance on single-layer vaults often resulted in higher deflections and underutilization of material strength, while the double-layer system allows improved load sharing and greater span capacity. However, optimal configuration depends on geometry, rise-to-span ratio, and bracing type. This study explores the influence of these variables to determine efficient and reliable designs for long-span applications, linking findings to engineering management practices.

2. Literature Review

Several researchers have addressed the behaviour of barrel vault systems. Milosevic and Kostic examined tensile membrane vaults under various loads, noting significant deflection sensitivity. Chrust et al. studied different bracing patterns in single-layer vaults and emphasized the influence of boundary conditions. Kevadiya and Bhavsar highlighted material optimization in truss-type barrel vaults for Indian conditions. Roudsari et al. explored probabilistic effects of geometric imperfections, stressing the importance of reliability in lightweight structures. Shinde et al. compared slab-type and truss-type vaults, pointing out cost and weight trade-offs. Pathak investigated buckling sensitivity to span ratios and support conditions. Sheidaii et al. analyzed collapse under uneven settlements, while Grigorian proposed performance control methodologies incorporating plastic analysis for grids. Jadhav and Patil evaluated geometric alternatives using STAAD Pro, while Chybinski investigated wind pressure modelling challenges. Collectively, these works reveal critical gaps in parametric optimization under Indian standards, motivating the present study.

3. Methodology

The study focused on four geometric layouts: (i) Square-on-Square, (ii) Two-way Grid (Lattice), (iii) Diagonal-on-Diagonal, and (iv) Square-on-Diagonal. A constant span of 60 m was considered, with span-to-height ratios of 0.25, 0.33, and 0.41 to assess the effect of rise variation. Modelling and analysis were performed using STAAD Pro, applying dead, live, and wind loads in accordance with IS 875 (Parts 1–3). Structural steel pipe sections (E = 200,000 MPa; Fy = 250 MPa) were used. Boundary conditions were modelled as fixed supports. Wind loads were computed per IS 875 (2015), including external and internal pressure coefficients. Validation was achieved by comparing simulation results with data from an industrial shed project executed by Vastech Consultants, showing close agreement in deflections and axial forces. This validation step ensured confidence in the subsequent parametric analysis.



Geometric Details

I. Span – 39.45m

II. Height (eave) – 6.8m

III. Length – 42.85m

IV. Type of section – pipe

V. Type of column - Rectangular RCC Column with fixed bottom base

VI. Type of Truss -Curved Roof Truss

VII. Slope of Roof – 26 degrees

VIII. Wind Speed = 47 m/

4. Results and Discussion

The comparative analysis revealed that the Square-on-Square geometry consistently outperformed the other layouts. On average, lattice and diagonal-based geometries exhibited 51–57% greater deflections. The uniform and orthogonal arrangement of members in the Square-on-Square system enabled more efficient load paths and minimized stress concentrations. Regarding rise-to-span ratios, the 0.33 configuration provided the most balanced behaviour, maintaining serviceability while limiting material demand. These outcomes demonstrate that both geometry and rise are critical design parameters. From a project management perspective, the results translate into lower steel consumption, reduced fabrication complexity, and improved cost-effectiveness. Such parametric insights can aid managers in selecting design alternatives that align with both technical and economic objectives.

Result Of Maximum Nodal deflection and axial forces Are the Industrial Shade & validation result For Above Geometry

3.5.1 Nodal deflection

Table No 3.2 Nodal Deflection

Maximum Nodal Deflection In mm	
Industrial Shade Result	9.68
Validation Result	10.32
% Difference	6.20%

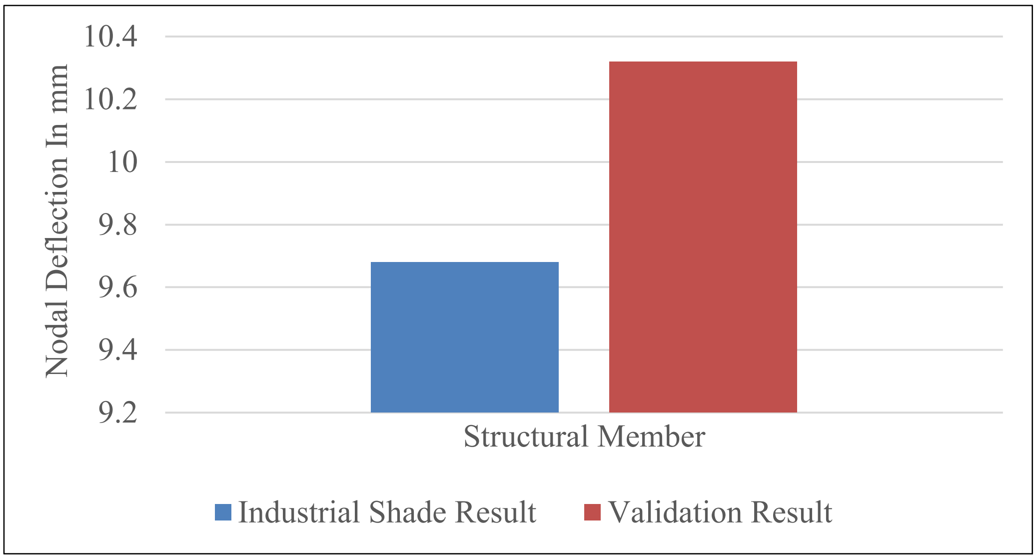


Figure 3.6: Nodal Deflection

3.5.2 Axial Forces

Table No. 3.3 Axial Force

Maximum Axial Force In KN			
	Top Chord	Bottom Chord	Bracing
Industrial Shade Result	184.42	137.17	148.51
Validation Result	203.59	148.77	137.81
% Differences	9.41%	7.79%	7.20%

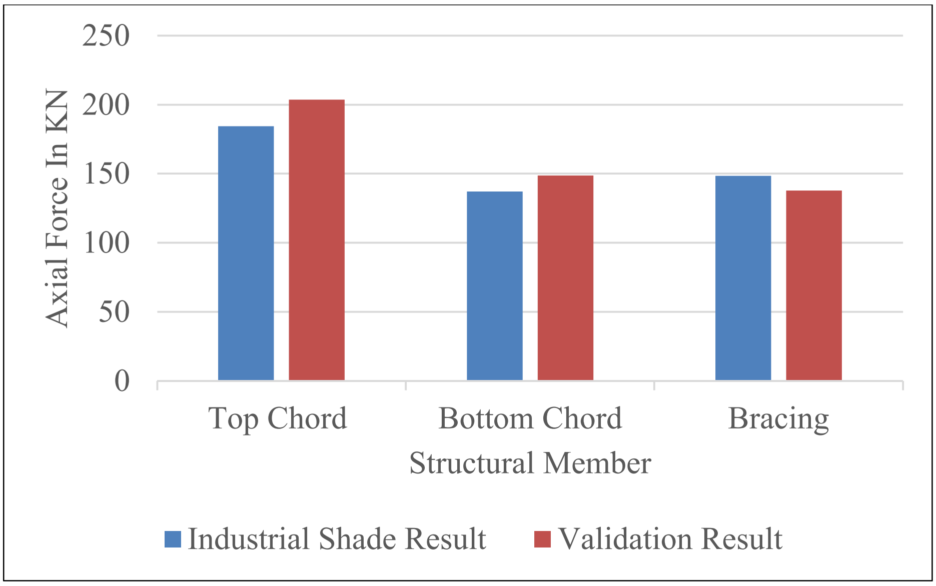


Figure 3.7: Axial Force

4.2 Results for Maximum nodal displacements

Results of behaviour of different geometries of barrel vault truss and results of various span to height ratios of DLBV are presented

Maximum nodal displacements

The results of maximum nodal deflection for top chord member of DLBV is Obtained in STAAD. Pro software following table 4.1 shows Maximum nodal displacement

Table 4.1: Maximum nodal displacement

Member. No	TYPE 1	TYPE 2	TYPE 3	TYPE 4
1	0.7874	1.6002	1.905	1.6764
2	1.5494	2.5654	3.175	2.8702
3	4.9276	11.4554	12.6238	12.6746
4	6.9596	13.2842	15.0622	15.0114
5	11.0998	23.4696	27.0002	27.178
6	13.0302	25.8064	29.3624	29.7688
7	16.256	33.6042	38.3794	38.481
8	16.8148	34.0868	39.2176	39.2684
9	18.2118	37.2618	42.6466	42.5704
10	16.8148	34.0868	39.2176	39.2684
11	16.256	33.6042	38.3794	38.481
12	13.0302	25.8064	29.3624	29.7688
13	11.0998	23.4696	27.0002	27.1781
14	6.9596	13.2842	15.0622	15.0114
15	4.9276	11.4554	12.6238	12.6746
16	1.5494	2.5654	3.175	2.8702
17	0.7874	1.6002	1.905	1.6764
AVG	9.4742	19.35331	22.1234	22.14282
TOTAL AVG	18.27343			
MAX.N. D %	…..	51.04	57.17	57.21

Following figure 1 shows M1 span to height ratio 0.25 Maximum nodal displacement

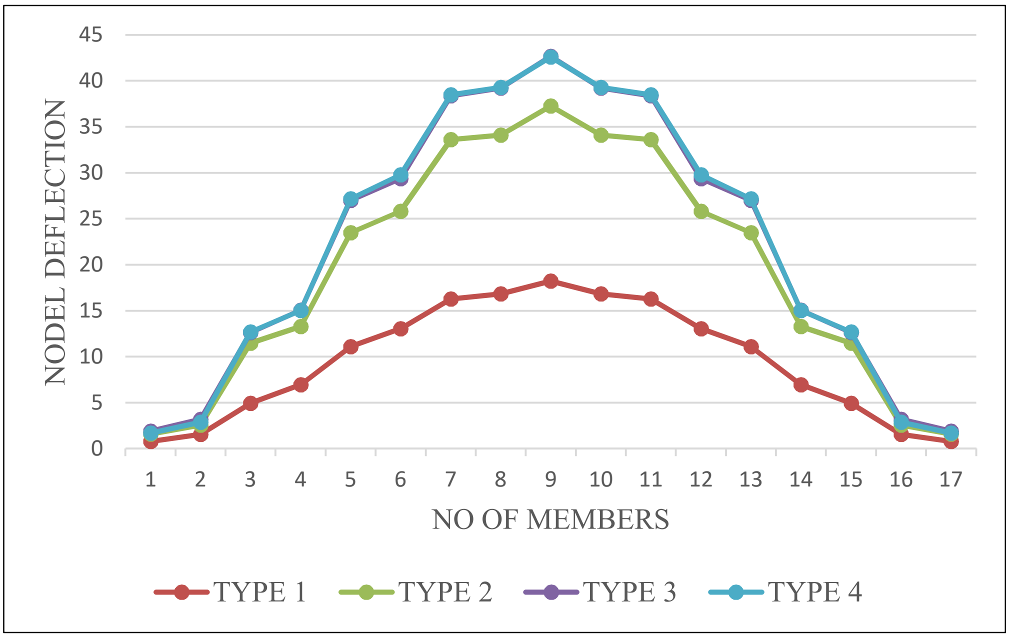


Figure 4.1: Maximum nodal displacement

4.2 Maximum axial forces

The results of maximum axial forces for top chord member, bottom chord member & bracing of DLBV is Obtained in STAAD. Pro software following table shows Maximum axial forces

Table 4.4: Maximum axial forces of top chord

	Type 1	Type 2	Type 3	Type 4
Member. No	Top chord	Top Chord	Top Chord	Top Chord
1	21.892	76.478	118.305	185.47
2	6.847	41.995	84.964	150.187
3	92.112	93.995	145.848	187.494
4	66.869	86.389	115.405	155.436
5	57.969	121.415	181.651	210.642
6	67.463	105.524	159.637	187.553
7	96.711	148.276	207.069	230.995
8	89.009	140.389	194.538	217.883

9	92.525	157.394	209.95	232.522
10	94.02	159.883	207.452	229.96
11	96.475	147.828	186.897	210.229
12	105.061	160.583	194.544	218.33
13	110.5	122.539	142.213	170.016
14	125.623	145.002	159.61	188.426
15	112.248	166.728	189.431	198.785
16	122.848	163.875	199.808	205.699
17	6.847	41.995	84.964	150.187
18	21.892	76.478	118.305	185.47
AVG	77.05061111	119.8203333	161.1439444	195.2935556
TOTAL AVG	138.3271111			
Max.A.F (%)	....	35.69	52.18	60.54

Following figure 4.4 shows M1 span to height ratio 0.25 Maximum axial forces of top chord

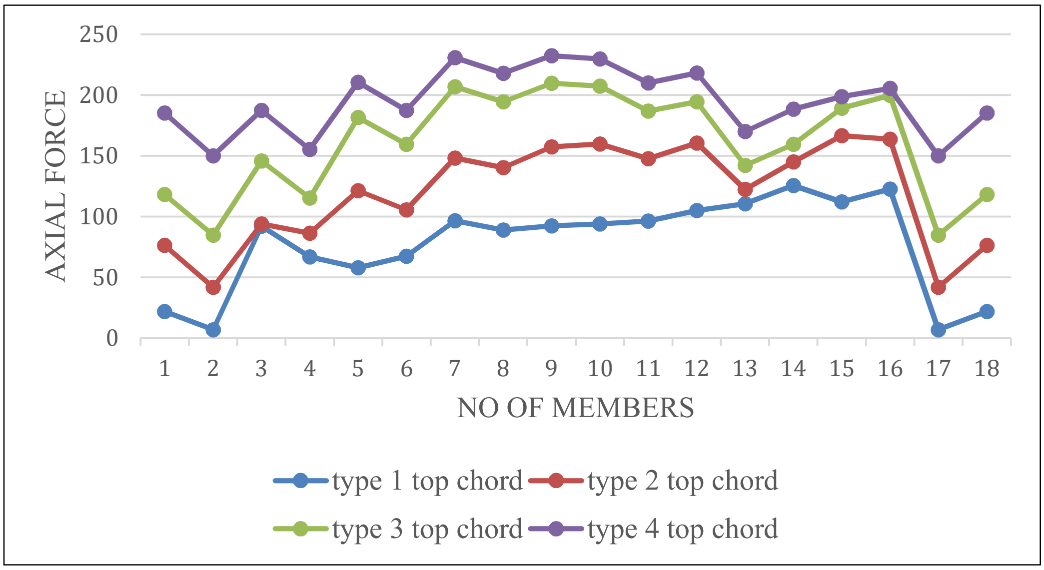


Figure 4.4: Maximum axial forces of top chord

5. Conclusion

This study has shown that the Square-on-Square double-layer braced barrel vault is the most structurally efficient configuration among the geometries investigated. A span-to-height ratio of 0.33 delivers the optimal trade-off between stiffness and material economy. The results provide actionable knowledge for engineers and project managers tasked with delivering long-span structures in industrial, sports, and commercial applications. Beyond technical insights, the findings contribute to strategic decision-making by offering a design pathway that reduces cost while maintaining safety and performance. Future work may involve exploring dynamic and seismic responses, validating through experimental testing, and investigating advanced construction materials.

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