Structural Analysis, Material Optimization, and Seismic Safety of Sabhamandap Vault: A Case Study

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Abstract

The Sabhamandap Vault at part of thereport, stands as an architectural and engineering marvel. This study focuses on the structural analysis, material specifications, and seismic safety of the vault. Finite Element Analysis (FEA) was conducted to evaluate structural stability under gravity, wind, and seismic loads. Key materials such as lime, bricks, stone, and surkhi were analyzed for their performance and compliance with IS standards. Seismic safety was assessed using Finite Element Thrust Line Analysis (FETLA) to ensure resilience under earthquake conditions. The study highlights critical design parameters, provides an in-depth analysis of structural behavior, and proposes measures to optimize material usage and structural safety.

Introduction

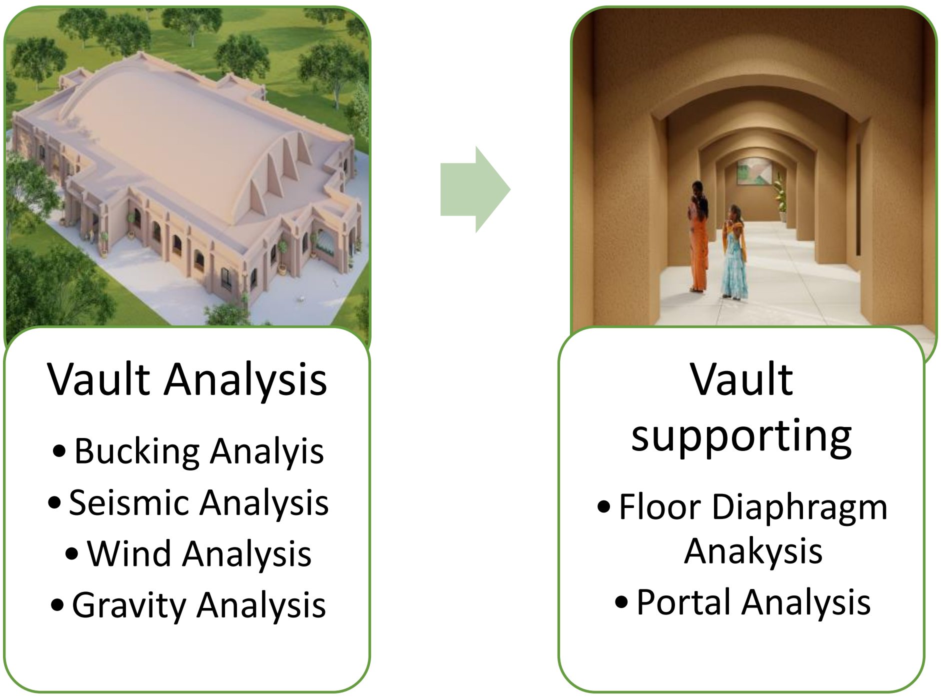
The Sabhamandap Vault serves as a key cultural and architectural landmark. Designed with intricate geometry and supported by traditional materials, the vault faces structural challenges due to its asymmetrical design and varying load conditions. With rising concerns over seismic vulnerability and material sustainability, this study emphasizes the integration of modern engineering techniques, such as FEA and FETLA, with traditional construction practices. The primary objectives include analyzing the vault's stability under gravity, wind, and seismic loads, evaluating material properties, identifying critical structural vulnerabilities, and ensuring compliance with structural safety codes.

Figure 1: External Rendered View of the Sabhamandap Vault

Particular	Quantity	Remark
Type of vault profile	Catetornry Vault	
Thickness of Vault	300 mm	
Span of vault	20.30 m	
Rise of Vault	5,000 mm	
Density of Material	1895 kg/cum F	Data from site Engineer
Type of support	Pinned	
Em (Youngs Modulus)	550 Fm = 1.65 E 9 N/m	NBC (Vol I) Clause 10.3.4.2 & Annex B (B2), page 64=

2. Structural Analysis

Finite Element Analysis (FEA) was employed to evaluate the vault's performance under various load conditions, including gravity, wind, and seismic forces. The vault's asymmetrical geometry incorporates three distinct radii (17.24m, 11.71m, and 16.21m), with a rise of 5m and a thickness of 0.3m.



- **Gravity Load Analysis**: The vault demonstrated complete compression stresses under gravity loads, with vertical and horizontal reactions recorded at 65.28 kN/m and 61.90 kN/m, respectively. Compression forces were uniformly distributed across the structure, reducing the risk of localized failure.

- **Wind Load Analysis**: Under wind pressure calculated as per IS 875-2015 Part III, the vault remained in compression, ensuring stability without tensile stress development. Wind loads were distributed evenly across the surface, avoiding stress concentrations.
- **Buckling Analysis:** A buckling analysis was performed to ensure stability under compression. Results revealed sufficient safety margins, with the structure showing resilience against potential buckling failures.
- **Seismic Load Analysis:** Seismic analysis was performed using IS 1893:2016 Part I, revealing tensile stress of 0.46 N/mm². Through iterative FETLA simulations, the thrust line remained within the vault profile, indicating structural resilience.

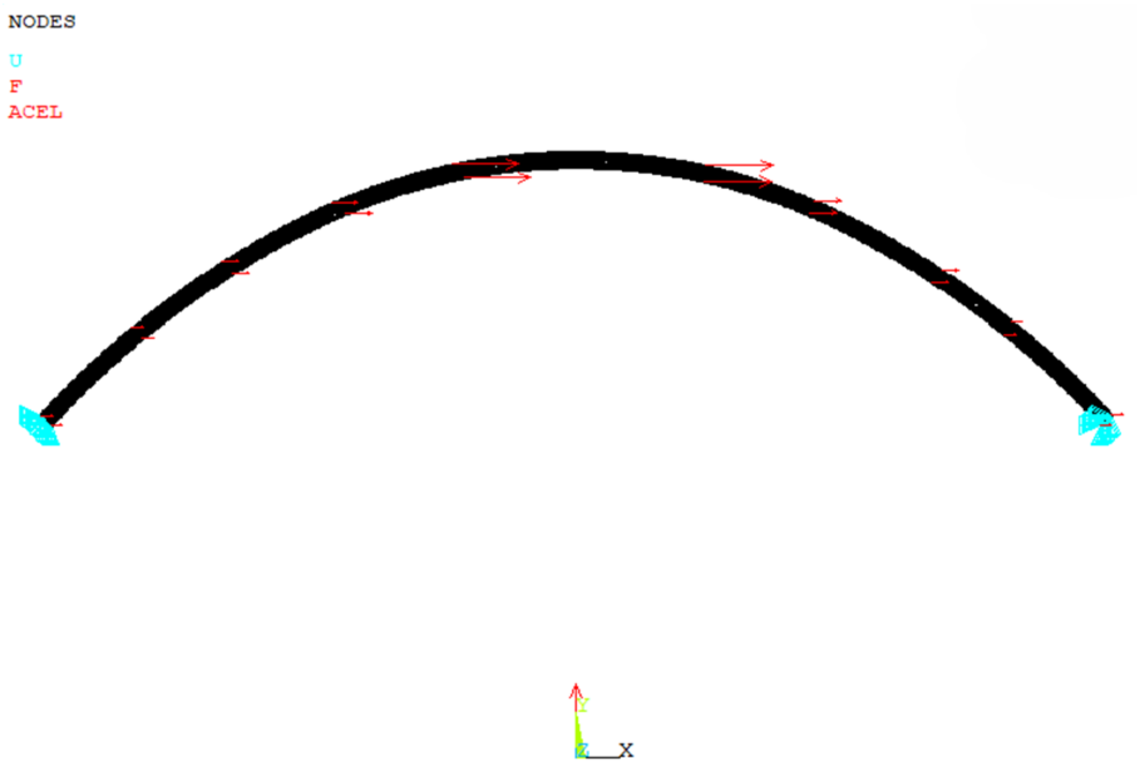


Figure 2: Finite Element Model of the Vault under Seismic Load Analysis

3. Material Specifications

The vault utilizes traditional materials with proven durability and strength characteristics:

- **Lime**: Hydraulic lime (Class A, IS 712:1984) ensures long-term durability and binding strength.
- **Bricks:** Common burnt clay bricks (First and Second Class, IS 1077:1992) provide structural support with water absorption limited to 20%.
- **Stone:** Hammer-dressed stones (IS 1121:1974) offer compressive strength and weather resistance.
- **Surkhi:** Finely ground red brick powder (IS 1344-1981) enhances lime mortar performance.
- **Steel Reinforcements:** Tie rods and RCC bands were strategically placed to counteract tensile stresses and improve overall integrity. These materials were selected based on availability, environmental impact, and compliance with relevant IS codes.

4. Seismic Safety

Seismic analysis of the vault followed the Equivalent Static Method as per IS 1893:2016 Part I. The structure was divided into five mass levels for accurate seismic weight calculations**.**

- **Design Base Shear:** 17.27 kN
- **Mass Distribution**: Mass levels were strategically divided to ensure precise weight distribution across nodes.
- **Thrust Line Analysis:** Iterative Finite Element Thrust Line Analysis (FETLA) confirmed the thrust line remained within the vault section, validating structural stability. Minor tensile stresses were observed but remained within allowable limits.
- **Dynamic Response:** The vault exhibited a fundamental natural period of 0.1391s, ensuring adequate energy dissipation during seismic events.
- **Safety Measures:** Addition of tie rods, RCC bands, and improved mortar quality were recommended to enhance seismic resilience. Additionally, closing weak wall junctions improved lateral load resistance.

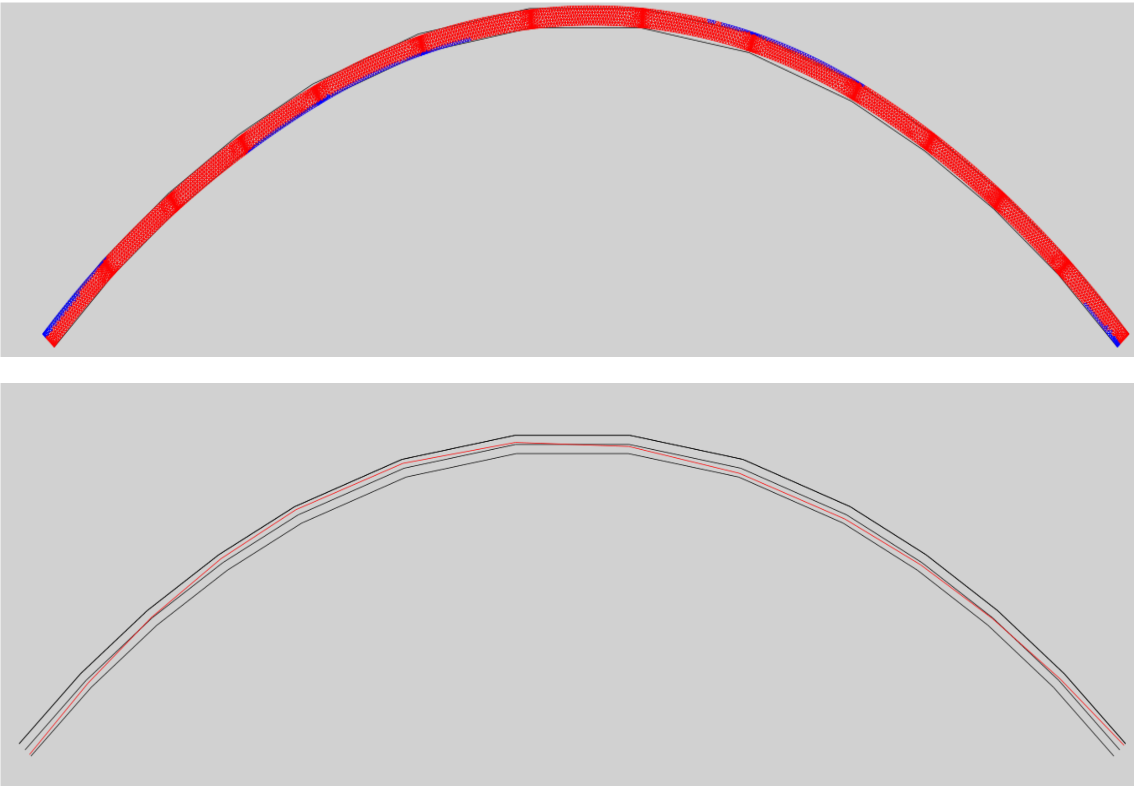


Figure 3: Thrust Line Analysis Showing Stability under Seismic Loads

5. Recommendations for Structural Improvement

- Enhanced quality control in brick masonry and lime mortar application.
- Installation of additional tie rods in areas with observed tensile stresses.
- Improved seismic detailing to reduce stress concentrations.
- Regular structural inspections and maintenance plans.

6. Conclusion The structural analysis revealed that the Sabhamandap Vault remains stable under gravity, wind, and seismic loads. Material selection aligned with IS standards ensured durability and performance.

FETLA validated the seismic resilience of the vault despite minor tensile stresses. Buckling analysis provided additional confidence in structural stability. This study underscores the importance of integrating advanced structural analysis techniques with traditional construction materials to ensure long-term safety and sustainability. Recommendations provided aim to further enhance structural integrity and resilience.

7. References

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