

Seismic Response of Hindu Temple Architecture: Insights from Traditional Planning and Construction Techniques

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Abstract— Hindu temple architecture represents a significant confluence of spiritual, artistic, and scientific principles. This paper investigates the seismic resilience of historic Hindu temples, focusing on planning, geometrical configuration, construction techniques, and traditional knowledge systems such as Vastu Shastra. By analyzing the structural behavior of selected case studies, including the Ramappa Temple, Ekambareshwar Temple, and Sun Temple at Modhera, this study demonstrates how ancient Indian architectural practices offer viable solutions to contemporary seismic design challenges. The research underscores the continued relevance of traditional design philosophies in the context of sustainability and disaster-resilient architecture.

Index Terms—Hindu temple architecture, seismic resilience, Vastu Shastra, symmetry, construction techniques, structural stability.

I. INTRODUCTION

The rich legacy of Indian temple architecture offers timeless examples of structural ingenuity and spiritual expression. Among their many characteristics, the resilience of these temples to natural disasters, especially earthquakes, stands out. Their endurance is rooted in centuries-old planning principles, material wisdom, and construction techniques informed by the Vedic sciences and treatises like the Vastu Shastra and Shilpa Shastra. In contrast to many modern structures, which often succumb to seismic forces, these ancient temples have withstood centuries with minimal damage, suggesting an intrinsic earthquake-resistant design. This paper aims to decode the structural logic and traditional wisdom embedded in Hindu temples and explore their applicability to modern-day architectural practices. Aim of this research paper is to study the seismic resilience of Hindu temples through the lens of planning, proportion, and construction techniques, and propose their relevance for

contemporary architectural practices. Objectives for the research paper are to explore the cosmological and philosophical underpinnings of Hindu temple architecture, to identify seismic design principles embedded in traditional planning and construction, to analyze case studies of temples that have survived seismic events, to assess the applicability of traditional knowledge systems in modern seismic design. The scope of study include focus on stone-constructed temples from pre-14th century India, emphasizing base-to-height ratios, symmetrical layouts, structural geometry, and traditional materials. Study limits temples built primarily using wood or brick, and those reflecting Indo-Islamic synthesis from the post-14th century, fall outside the purview of this study.

II. CONCEPT OF TEMPLE ARCHITECTURE

Between 600 and 800 AD, the fundamental forms and stylistic features of Hindu temple architecture were firmly established. The design and character of these temples were deeply influenced by regional architectural traditions, locally available materials, and the craftsmanship of the time. While the core elements of temple architecture remained consistent across India, the form, scale, and decorative details exhibited significant variation. These distinctive architectural styles evolved in response to broad differences in geography, climate, culture, ethnicity, history, and language between the northern plains and the southern peninsula of the country.

ELEMENTS OF HINDU TEMPLES: -

A. **SIKHARA**: - tower or the spire. It is the pyramidal or tapering portion of the temple which represents the highest mountain peak.

B. **GARBHAGRIHA**: -womb chamber. Innermost chamber of the temple where the image or idol of the deity is placed.

C. PRADAKSHINA PATHA:- It is an ambulatory passageway for circumambulation.

D. MANDAPA:- is the pillared hall in front of the garbhagriha, for the assembly of the devotees. It is used by the devotee to sit, pray, chant, meditate and watch the priests performing the rituals.

E. ANTARALA:- intermediate chamber.

F. ARDHAMANDAPA:- front porch or the main entrance of the temple leading to the mandapa

III. LITERATURE REVIEW

A. Fractal Geometry and Temple Planning Sardar and Kulkarni (2015): explored how fractal geometry and the Vastupurushmandala influence temple layouts. Their research highlights the recursive, self-similar forms used in temple design, which contribute both to aesthetic coherence and structural stability.

B. Seismic Design and Symmetry Gokhale (2004): identified symmetry, grid planning, and interlocking masonry as key elements in enhancing seismic resistance. The use of squares and triangles results in layouts that distribute seismic forces evenly.

C. Climatic and Structural Sensitivity Padmavathi (2016): emphasized the climate-responsive planning of traditional architecture. Her work ties spatial orientation and material usage with thermal and structural performance.

D. Structural Modelling of Gopurams Jetson et al. (2017): provided structural analysis of South Indian gopurams, revealing how tapering forms and lightweight materials in upper stories reduce seismic loads.

E. Sacredness and Structural Hierarchies Sharma and Deshpande (2015): identified how spatial hierarchies—from entrance to the sanctum—support not only spiritual experiences but also structural coherence through progressive mass reduction.

IV. METHODOLOGY

This study employs a qualitative approach that synthesizes historical texts, structural analyses, and case studies. Key sources include ancient manuals (Vastu Shastra, Shilpa Shastra), scholarly articles, and documented earthquake performance of historical temples. Comparative analysis is conducted on the geometric, material, and constructional attributes of selected temples.

V. CASE STUDY

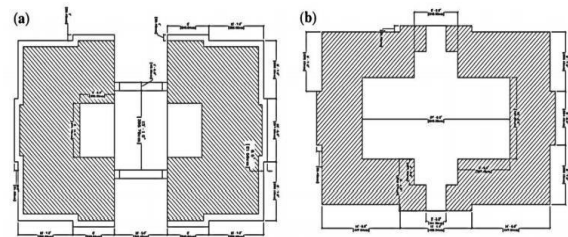
A. EKAMBARESHWAR TEMPLE, KANCHIPURAM:

The temple is regarded as one of the most ancient and revered shrines dedicated to Lord Shiva, believed to have existed well before the 7th century AD. Over the centuries, it has undergone numerous additions and renovations under different dynasties, notably the Pallavas, Cholas, and Vijayanagara rulers. The monumental nine-tiered gopuram, emblematic of Dravidian temple architecture, was modeled on the iconic Rajagopuram of the Ekambareswarar Temple in Kanchipuram. This grand gateway tower, attributed to the reign of Krishna Devaraya of the Vijayanagara Empire in the early 16th century, reflects the culmination of structural and decorative advancements in South Indian temple design.

Planning:

The gopuram is laid out in a rectangular plan, with base dimensions of approximately 25 meters by 18 meters, tapering gradually as it ascends. The vertical hierarchy of tower not only marks the sacred axis of the temple complex but also serves as a visual landmark symbolizing the mythological Mount Meru. The tower rises to a commanding height of 48.4 meters, making it one of the tallest structures of its kind. Despite its imposing scale, the foundation is relatively shallow—no more than 3 meters deep—constructed primarily using random rubble masonry, a traditional technique offering stability through mass and compaction. The entranceways and sub-structures within the gopuram include a series of 16-pillared and 4-pillared mandapas, each rising to heights of 3 meters and 7 meters respectively, which serve both ceremonial and structural functions.

Figure 1 Plan Layout of a Traditional Gopuram: (a) Base Level, (b) Elevated Storeys



Material and Construction:

The base of the gopuram is made using multi-leafstone masonry, consisting of finely dressed granite blocks on the outer surfaces and a rubble-filled core for mass and support. The upper tiers

transition into burnt clay brick masonry, which is lighter and allows for the soaring verticality of the structure without compromising stability. This hybrid technique is typical of Vijayanagara-era gopurams, balancing durability with material economy. In traditional South Indian temple construction, particularly in Dravidian architecture, stone members are not interlocked but rather rely on precise placement and the force of gravity. This method, though seemingly fragile, has allowed many structures to survive centuries of wear and seismic activity.

Wide cornices and sunshades, often carved elaborately, are supported on stone beams and held in place by the mass of parapets or merlons built above them. These features serve both aesthetic and climatic functions, offering protection from monsoon rains and harsh sunlight. Pillar spacing within mandapas typically varies from 2 to 3 meters, designed to create rhythmic, open interiors suitable for ritual gatherings, musical performances, and devotional processions. The extensive use of sculptural relief and iconography on the gopuram, often depicting mythological narratives and divine beings, is not merely ornamental but serves as a medium for religious storytelling and instruction for devotees. Together, these architectural elements reflect a sophisticated understanding of structural engineering, religious symbolism, and artistic expression—hallmarks of South Indian temple architecture during its golden age under the Vijayanagara Empire.

B. RAMAPPA TEMPLE, WARANGAL:

The Ramappa Temple, also known as the Rudreshwara Temple, located in Palampet, Telangana, is a UNESCO World Heritage Site and a testament to the exceptional craftsmanship and structural ingenuity of the Kakatiya dynasty. Constructed in the early 13th century during the reign of Kakatiya ruler Recharla Rudra, a general under King Ganapati Deva, the temple is often referred to as the "Temple of a Thousand Pillars" due to the intricacy and profusion of its sculpted columns. The temple is dedicated to Lord Shiva and exemplifies Kakatiya-style architecture, a distinctive blend of Nagara and Dravidian elements. Over the centuries, the temple has withstood multiple earthquakes, including a major seismic event in the 17th century. Remarkably, the core superstructure and

ceiling remained intact, while only minor displacements were observed in the foundation pillars. This resilience can be attributed to the innovative earthquake-resistant construction techniques employed by the Kakatiyas.

Construction Technology and Structural Innovations:

1. Sandbox Technology in Foundations:

One of the most advanced techniques used in the temple's construction was sandbox technology, an early form of base isolation. For major structural components like sanctum (garbhagriha) and mandapas, foundations were excavated to a depth of approximately 3m. These pits were then filled with clean river sand, which acted as a shock absorber, dispersing energy generated by seismic vibrations.

To enhance the binding capacity and structural cohesion of the sand foundation, a special organic compound mixture was added, including:

- Powdered granite – for bulk and grain size stability.
- Jaggery (unrefined sugar) – acting as a natural binder and microbial growth inhibitor.
- Terminalia chebula (Haritaki) – a medicinal fruit known to strengthen mixtures, often used in traditional Indian construction practices.

This composition not only stabilized the sand layer but also offered resistance to microbial degradation, ensuring long-term durability.

2. Iron Doweling Technique for Superstructure Stability:

To ensure lateral stability and enhance resistance against high-intensity earthquakes, the Kakatiyas employed an interlocking framework system. Small tunnel-like perforations were drilled through the massive stone blocks used in the walls, pillars, ceilings, and roofing slabs. Into these, molten iron was poured, forming continuous iron dowels that hardened upon cooling and functioned like structural pins or tie rods.

This method created an integrated stone skeleton, allowing the temple to behave as a single monolithic unit during seismic motion. The technique resembles modern reinforcement practices where steel rebar is embedded in concrete. The interconnectedness minimized joint failure and prevented dislodgement of stone elements under lateral stress.

3. Use of Lightweight and Porous Floats:

An additional feature of the Ramappa Temple's seismic strategy was the use of lightweight porous

bricks in the superstructure. These bricks, known for their low density and high thermal resistance, reduced the overall dead load of the temple, decreasing the seismic forces acting on the structure. Their placement in the shikhara (tower) and upper mandapas optimized the load distribution and protected the more delicate lower structures.

4. Pillared Mandapas and Load Distribution:

The temple's pillared mandapas feature lathe-turned, intricately carved granite columns, arranged to provide uniform load distribution. axial symmetry and stepped plinth design allow the structure to adjust gradually to ground movement. The placement of pillars also allows flexibility, as they function like energy-dissipating units during seismic activity.



Figure 2 Ramappa temple, Warangal (weekendyaari, 2024)



Figure 3 Mandapa of Ramappa temple (unesco, 2019)

C. SUN TEMPLE, MODHERA – An Architectural And Astronomical Marvel

Constructed in the early 11th century CE under the patronage of King Bhima I of the Solanki dynasty, the Sun Temple at Modhera is one of the finest examples

of Maru-Gurjara architecture and is dedicated to Surya, the solar deity. The temple exemplifies a sophisticated fusion of sacred geometry, solar cosmology, and structural ingenuity, designed in strict accordance with Vastu Shastra and astronomical alignment principles to harness solar energy and maintain balance in form and function (Michell, 2011; Hardy, 2007).

• Plan and Orientation:

The temple complex is aligned precisely east to west, ensuring that during equinoxes and specific solar events, the first rays of the rising sun directly illuminate the garbhagriha (sanctum sanctorum), where the image of Surya was once placed. The axis of the temple serves not just symbolic but also astronomical functions, reflecting the advanced understanding of solar movement by medieval Indian architects. The temple layout follows a tripartite scheme: garbhagriha, the gudha mandapa (main hall), and the sabha mandapa (assembly hall), all placed in perfect axial alignment to facilitate processional and ritual flow (Dhaky, 1996; ASI, n.d.).

• Structural Features:

The entire complex stands on a high plinth that enhances visual dominance and protects against environmental degradation. In front of the temple lies magnificent Surya Kund (stepped tank), a sacred reservoir consisting of more than 100 miniature shrines on its stepped walls, used for ritual ablution before temple entry. From an engineering perspective, the Surya Kund also serves as a passive load stabilizer, balancing earth pressure and possibly absorbing seismic vibrations, a trait found in other earthquake-prone temple sites (Jain-Neubauer, 1981). The plan geometry—square sanctum and cruciform mandapas—creates symmetrical load distribution, enhancing temple's resilience to natural forces such as wind and tremors.

• Material and Construction Technique:

Temple is built using locally sourced yellow sandstone, cut into finely dressed blocks and assembled without mortar through precision interlocking joinery—a hallmark of western Indian temple architecture. This dry-stone technique, along with uniformly distributed sculptural mass, ensures even weight transmission across columns, lintels, and beams. Walls, ceilings, and pillars are richly adorned with iconographic carvings, including depictions of Surya on a chariot drawn by seven horses, celestial

nymphs (apsaras), and scenes from epics like the Ramayana and Mahabharata. This not only enriches the temple artistically but also contributes to the vibrational dispersion of sound and energy through surface texture (Hardy, 2007; Michell, 2011).

• Cultural and Environmental Context:

Situated on the banks of the Pushpavati River, the temple was conceived not only as a space for worship but as a solar observatory and educational center. Festivals like Uttarayan and Equinox Day were celebrated in accordance with the temple's solar orientation. The temple's water tank and elevated plinth also reflect climatic adaptability, serving to manage monsoon runoff and groundwater recharge. Though the central idol of Surya was destroyed during later invasions, the structure remains a vibrant symbol of Gujarat's architectural legacy, spiritual devotion, and scientific advancement.

Table 1 Comparative Analysis of Temple Case Studies

Feature	Ekambareshwar Temple	Ramappa Temple	Sun Temple, Modhera
Period	16th Century	13th Century	11th Century
Location	Kanchipuram, Tamil Nadu	Warangal, Telangana	Modhera, Gujarat
Foundation Type	Rubble masonry	Sandbox technology	Raised plinth with stepped tank
Materials Used	Granite, Clay Bricks	Sandstone, Granite, Iron dowels	Sandstone
Height	48.4 meters (Gopuram)	Varies; multi-pillared mandapas	Medium height structure
Construction Technique	Tapered gopuram, dry masonry	Interlocked stone, doweling	Interlocking joints, no mortar
Seismic Feature	Tapered height, mass gradation	Shock-absorbing foundation	Axis alignment, raised base
Damage History	No major damage recorded	Withstood major earthquake	Stable, no major damage reported

VI. ANALYSIS AND DISCUSSION

The effectiveness of traditional temple architecture against seismic forces lies in its systemic integration of structure, spirituality, and science. Rather than

resisting forces rigidly, these buildings respond dynamically. Their resilience is due to both their material intelligence and planning foresight. Square garbhagrihas, corbelled vaults, and symmetrical mandapas create compact, cohesive forms that vibrate with, rather than against, seismic energy. These elements reflect an advanced understanding of both physical forces and metaphysical symbolism.

VII. CONCLUSION

Hindu temple architecture represents a harmonious blend of aesthetic values, spiritual beliefs, and scientific principles. Their resilience against natural calamities, particularly earthquakes, is rooted in symmetrical planning, proportionate design, and robust construction techniques. These principles, codified in ancient texts like the Vastu Shastra, offer a valuable framework for modern architectural practices aiming for sustainability and seismic safety. Integrating these time-tested methods with contemporary materials and technologies can pave the way for resilient urban infrastructures in seismic zones.

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