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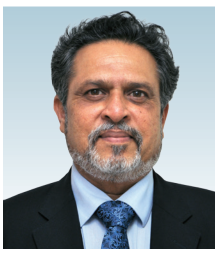
A Home for Lord Ram

CW learns more about the creation of the Ram Janmbhoomi Mandir, the elements incorporated, and the challenges overcome during its construction.

Photo courtesy: L&T

On 22 January 2024, the nation watched in awe as the Ram Janmbhoomi Mandir was inaugurated by Prime Minister Narendra Modi. It was a civilisational moment for the country – and a triumph for those behind its construction.

“Our journey to construct the iconic Ram Janmbhoomi Mandir has been a testament to the perseverance and dedication of our employees and workers, combined with precision engineering and intricate craftsmanship,” says **MV Satish, Whole-Time Director & Senior Executive Vice President (Buildings), Larsen & Toubro (L&T)**. “We have overcome various challenges to realise a timeless symbol of Indian heritage that will last a millennium.”



MV Satish, Whole-Time Director & Senior Executive Vice President (Buildings), Larsen & Toubro (L&T)

The foundation

“We were a part of the structural review team of the Sardar Patel Statue of Unity, the world’s tallest statue,” says **Amit Sharma, Managing Director and CEO, Tata Consulting Engineers (TCE)**. “That iconic project involved a lot of engineering design, timebound work and coordination. We leveraged some of those learnings on this project as well. The

Amit Sharma, Managing Director and CEO, Tata Consulting Engineers (TCE)

teamwork was great on this project with the best people in India working on it, such as L&T, architect CB Sompura, CSIR-CBRI, the IITs, NIIT, TCE, and others."

"After being awarded the design and build contract to construct the Ram Janmbhoomi Mandir, the first task for L&T was land excavation, which commenced in January 2021 and was completed in three months," says Satish. "The next critical task was to lay the foundation. As the structure had to last a millennium, steel or reinforcements could not be used and, hence, the team created a special multilayer foundation."

The first layer was a specialised engineered fill comprising sand, aggregate and a minor amount of cement, designed with the expertise of L&T and IIT Madras. The 6,300-sq-m concrete raft, crafted from high-strength M35 grade plain cement concrete, serves as a robust foundation on

Photo courtesy: Tata Consulting Engineers

The 6,300-sq-m concrete raft serves as a robust foundation on which sits the 6.3-m-high plinth structure made of 23,000 interlocking granite stones.

Project Details

Location: Ayodhya
Construction cost: Rs 18 billion
Year of completion: 2024
Equipment/ technology suppliers:
Solar City lighting Project: Signify India in line with Uttar Pradesh New and Renewable Energy Development Agency (UPNEDA)
40 MW solar plant: NTPC Green

- **CPCBIV+ gensets:** Cummins India
- **Over 100 pumps (for water management, fire safety infrastructure):** Kirloskar Brothers
- **Indoor lighting:** Havells India
- **CPCBIV+ gensets:** Cummins India
- **System integrator for CCTV surveillance with existing control room:** Allied Digital Services
- **Official map for Ayodhya:** Genesys International
- **Inner sanctum (Garbhagriha) door and 118 doors for the temple:** Anuradha Timbers International
- **Indoor lighting:** Havells
- **Integration of CCTV with control room:** Allied Digital Services
- **First gold-plated Kalasam installed in Ayodhya:** Smart Creations

Photo courtesy: L&T

About 58,211 cu ft of Pink Bansi Paharpur sandstone and 46,659 cu ft of the stone ensured adherence to traditional material requirements.

which sits the 6.3-m-high plinth structure, made of 23,000 interlocking granite stones. The erection of the temple columns, beam stones and slab stones commenced in January 2022, with the roof of the ground floor completed by August 2023.

Blending the old and new

"The temple follows the ancient Nagara style of architecture, blending history, tradition, high-tech engineering and construction," says Satish. Standing at 161.75 ft tall, 380 ft long and 249.5 ft wide, the temple is a three-storey marvel, featuring five mandaps – Nritya Mandap, Rang Mandap, Gudh Mandap, Kirtan Mandap and Prarthana Mandap – and the Main Shikara.

So, just how difficult was it for the team to work without modern materials such as steel and concrete and cope with the traditional 5th century Nagara style, using sandstone linked with tongue and groove joints and intricate carvings?

"CB Sompura, the accomplished architect, had devised all this but to convert that into engineering without the use of steel required a lot of new things," responds Sharma. "Analysis was done by CSIR-CBRI (Central Building Research Institute) labs; we studied all the deflections and issues. It was a good marriage of traditional temple architecture with a new approach. A lot of coding standards didn't exist because most civil engineering standards are based on the use of rebar and steel. Thus, there were many interesting observations, iterations and decisions before the final way forward was agreed upon by all the parties."

For his part, **Dr Debdutta Ghosh, Senior Scientist, CSIR-CBRI**, says, "CSIR-CBRI, Roorkee, successfully carried out a detailed comprehensive scientific study of several aspects of the temple at Ayodhya, including a geotechnical analysis, foundation design vetting, 3-D structural analysis and design, opto-mechanical design of the Surya Tilak, and providing construction SOP (standard operating procedure) after periodic site supervision. The multichannel analysis of surface waves (MASW) to identify anomalies, water saturation zones and water tables served as crucial inputs for estimation of seismic design parameters. The structural design was recommended for construction after simulating over 50 computer models and superstructural material; i.e. Bansi Paharpur sandstone has been tested to evaluate the engineering properties and used as input for structural analysis."

Dr Debdutta Ghosh, CBRI

Material medley

Not surprisingly, the construction of the temple necessitated substantial quantities of materials, underscoring the magnitude of the project. Satish lists some of them:

- **Excavation**: Approximately 1,88,000 cu m was excavated
- **Roller compacted concrete (RCC) for backfilling**: 1,32,250 cu m
- **Plain cement concrete raft foundation**: 12,370 cu m
- **Plinth stone with granite blocks**: 19,575 cu m
- **Bansi Paharpur stone superstructure**: The superstructure of the temple, crafted from Bansi Paharpur stone, required approximately 13,450 cu m, contributing to the grandeur and durability of the structure.

"Procurement of all these materials was its own challenge," adds Sharma. "The heavy igneous stone or granite blocks, chosen for their high compressive strength, came from the Karnataka and Telangana region. As transport by road would take too long, the supply chain leveraged Indian Railways. Similarly, the Bansi Paharpur stone came from Rajasthan, as did the marble. Logistics, supply chain planning, getting all the stones in a certain dimension, getting them processed at site, then carving… all these require deep project planning and working with multiple partners. That's what the team did in the past three years."

What's more, there were specific requirements for traditional and sacred materials.

"Traditional and sacred materials are central to the Ram Mandir," affirms Satish. "Carving work for the temple began in 1990 at the Karyashala in Karsevakpur, Ayodhya, using pink Bansi Paharpur sandstone. Approximately 58,211 cu ft of stone was carved based on the old temple design established in 1990. However, with the finalisation of the new temple design in 2021, approximately 46,659 cu ft of stone from the Karyashala was utilised, ensuring adherence to the traditional material requirements."

The challenges

The construction of the Ram Mandir encountered various challenges, including soil complexities owing to limited soil profile details and the presence of structures that needed to be dismantled for which advanced tests were conducted. A thorough drone survey and soil investigations led to the design of a foundation system comprising PCC piles and diaphragm walls.

"Accommodating large machinery was challenging as the entry gate was not tall enough, necessitating its reconstruction," shares Satish. "Enabling facilities were constructed and test piles were cast while awaiting the completion of the batching plant. Based on expert recommendations, open excavation with engineered concrete backfilling was finalised in December 2020. That commenced in January 2021, but encountered several hindrances owing to buried structures and artefacts. To preserve the sanctity of the excavated soil, it was meticulously stored for reuse."

Built to last

One imperative for the entire team was to ensure the longevity of the structure.

Quake resistance was a significant factor where learnings from the past also came into play. "In design engineering consulting, each project adds to the knowledge repository," says Sharma. "For instance, the lessons from the Latur earthquake have helped us with seismic evaluation analysis. But those are standard buildings with civil codes and rebars. Here this is a non-rebar, no steel structure and the thermal stress analysis is very different than what you would do for reinforced concrete cement-related work. That said, all knowledge derived from past projects adds on to doing things for the first time."

"All materials were carefully chosen for their durability, longevity and resilience against environmental factors," says Satish. "A site-specific response spectrum prepared by IIT Madras using soil parameters aided in the analysis of the temple structure's seismic response. Comprehensive 3D Plaxis and Ansys analyses were conducted for settlement calculations and superstructure design, respectively, to maintain structural integrity. Various instruments like settlement-liquid level sensors, surface-mounted vertical strain gauges, tiltmeters, accelerometers and hydraulic sensors are strategically

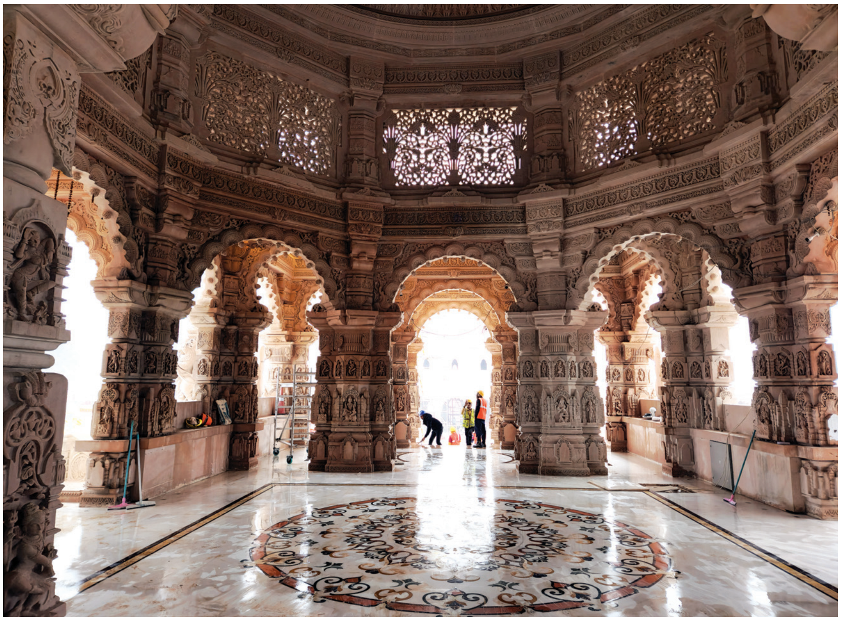


Photo courtesy: Tata Consulting Engineers

Temperature-sensing probes helped monitor concrete temperature, ensuring structural integrity.

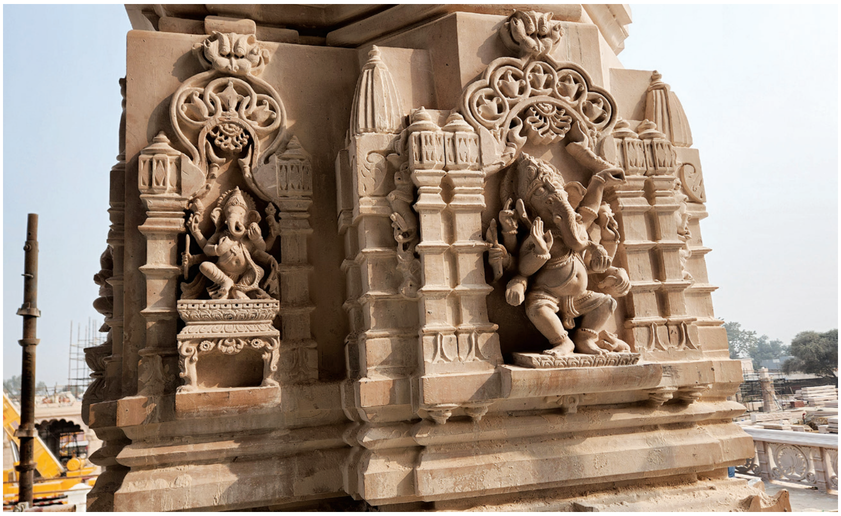


Photo courtesy: Tata Consulting Engineers

Stone carvings of the God of beginnings, Lord Ganesha, are engraved in the interior of the temple.

placed to monitor structural health, measuring factors such as settlement, seismic forces, strain and lateral forces to assess stability over time.

"The selection of material with a lifespan of 1,000 years means the structure is low maintenance," adds Sharma. "When you don't use steel and iron that corrode after 80 to 90 years and cause degradation of stability, that itself enhances the life of any structure. The reason to remove rebar was primarily to give the structure a longer life. The use of natural sandstone, marble, granite for plinth and the raft foundation enhances the life of the structure and reduces operational maintenance. All this will contribute to the structure's longevity."

Innovation at work

Innovative construction practices and cutting-edge technologies were instrumental in the construction of the Ram Mandir.

According to MV Satish, these included:

- **Construction practices**: Granite stones were transported on container trains from Bengaluru and Telangana, facilitated by CONCOR, which ensured efficient logistics. Vacuum lifters and telehandlers optimised the stone-handling processes, enhancing safety and efficiency. Implementation of a QR code system enabled efficient tracking of stones throughout the construction phase.
- **New technologies**: Trimble Connect facilitated a comprehensive understanding of the 3D temple model, which aided construction planning and sequencing. Temperature-sensing probes helped to internally monitor concrete temperature, optimising de-shuttering time and ensuring structural integrity.
- **Best practices**: Tarpaulin sheets for soil slope protection during the monsoons maintained site integrity and minimised erosion risks; passive wheel washer systems prevented soil contamination and maintained cleanliness, while water sprinklers, water chillers and ice-crushing machines optimised concrete curing and reduced concrete temperature. Concreting at night further mitigated concrete temperature, enhancing quality. Shear keys and copper pins/straps ensured robust interconnection of stonework, enhancing structural stability and longevity.

"There are four unique elements of this project," says Sharma. He explains further, "For the foundation, the initial hypothesis was to use stone piles but the geotechnical aspect of this area is such that it is very difficult to get structural integrity with piles. So, all the different teams came up with roller compacted concrete, which was a challenge to excavate all the earth mass below. We created a roller compacted concrete base and on top we created a 1.5-m-thick raft foundation of cement concrete without any rebars. In this second part of the raft foundation, we did a thermal stress analysis so there were no distortions on the raft foundation. And via a lot of iterations, the team arrived at a configuration of 9 m × 9 m pouring at 1.5 m depth of this raft foundation. The third stage was the plinth. Initially it was sandstone but looking at the pressure requirements, the compressive strength of the superstructure above it was changed to granite. Finally, this temple has an interlocking structure at the top with copper pins to increase structural stability but an integrated Finite Element Method (FEM) analysis was also done for both static and dynamic loads. This is Zone 3 so we had to simulate an earthquake of seven on the Richter scale. CBRI-CSIR along with architect CB Sompura did another simulation to see if it would be structurally stable. After our teams reviewed it, we added certain structural elements to give it rigidity. Around the main mandir is the Parkota with six, seven temples around it, and then there is a Kuber Tila. As the name suggests, it was on a slope, leading to challenges in terms of erosion and other slope failure issues. We employed a solution where mud was placed on this slope with a bit of piling to stabilise it."

Further, the project benefited greatly from the use of 4-D modelling. "This project had many first-time elements where every party was discovering things as they went along," says Sharma. "For example, looking at the foundation, there were initial challenges in terms of selection of methodology. Should we use roller compacted concrete or piling or stone piling? Then, we discussed how we would use the raft, the plinth and the whole interlocking structure on the top. In doing that and with multiple parties and interfaces, we had to simulate how this would happen 30, 60, 90 days from now and for the next two years because the timeline was stringent and most projects get challenged because of these interfaces between people, machinery, inventory and materials. 4-D simulation helped us get a good grip on these elements. We predicted requirements and everybody came together as a team to ensure that even 30/60/90 lookahead dates were planned early enough to meet timelines. 4D helps people relate to the project much better. Reading a book is interesting but watching a movie gets a lot of information conveyed without a lot of challenges of communication. 4D helped everyone in that respect."

Safety first

Notably, safety was prioritised for both workers and visitors throughout the construction process of the Ram Mandir. "Comprehensive safety induction training, including the use of virtual reality kits, prepared workers and staff for safety protocols," elaborates Satish. "Separate pedestrian pathways segregated vehicular and machinery movements, reducing the risk of accidents. Safety cautionary boards, directional signage and emergency contact numbers prominently displayed across the temple complex improved safety awareness. PPE was mandatory for all at site, including visitors, VIPs and priests. Short briefings were conducted on access points and safety hazards, and a dedicated site engineer or safety officer accompanied visitors during their visit to ensure adherence to safety protocols."

Green elements

Along with people, the environment was also a priority for the project managers. Satish gives us the highlights of the green measures taken:

- Only a minor amount of cement has been used in the engineered fill (only 60 kg against the usual concrete of 350-400 kg).
- All design mixes have cement replacement ingredients such as fly ash, ground granular blast-furnace slag, etc.
- Manufactured sand (M-Sand) has been used instead of river sand for concrete mixes.
- Curing compound has been used for curing instead of water.
- The temple has been constructed entirely with stonework, which is a natural material for longevity.
- There is a natural ventilation system inside the temple.
- Treated water has been reused for flushing and rainwater recharge pits have been installed.
- Maximum number of existing trees were retained.

Other facilities and amenities

Infrastructure in the city of Ayodhya has improved significantly with enhanced connectivity by air, rail and road. The temple complex includes a sewage treatment plant, water treatment plant, fire service, and an independent electrical substation. A Pilgrims Facility Centre with a capacity of 25,000 offers medical facilities and locker services while dedicated facilities like bathing areas, washrooms, washbasins and open taps cater to pilgrims' needs. The temple is safeguarded against lightning strikes by 200 kilo ampere lightning arresters. Further, as Satish tells us, "A museum showcasing artefacts related to Lord Ram and the Ramayana transforms the temple into a cultural and educational hub, extending its significance beyond religious boundaries."

Milestone project

"This is a very interesting, innovative project that combines our science and knowledge of the past hundreds of years with a modern way of working," concludes Sharma. "There were a lot of unique challenges as well to achieve the structural integrity in such stringent timelines. The solutions that were devised by the team jointly in response to these challenges were the real milestones that will help us in future projects as well."

- R SRINIVASAN | CW |

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