

Foundation Stabilization of the Janmabhoomi Temple at Mangarh

Sanjay Gupta, Managing Director

Ravi Sundaram, Director

Cengrs Geotechnica Pvt. Ltd., New Delhi

SYNOPSIS : The Janmabhoomi Temple is planned as an elegant structure in granite stone blocks. The foundation block bearing at 3 m depth is a 5.4 m thick massive platform made of granite masonry. Review of the soil condition revealed that under the design loads, the total and differential settlement may be excessive. To stabilize the foundation system, confinement of the foundation block was done by providing a row of 400 mm diameter closely spaced piles all around the Garba Griha, and in the central Mandap portion. Ground improvement was done in the associated structures (small temples corridor) to strengthen the soils and to restrict settlement.

INTRODUCTION

A grand massive temple is under construction at the birth place of His Holiness Acharya Kripalu Maharaj, a highly respected saint, at Mangarh, Uttar Pradesh. The temple town of Mangarh is near Kunda, off the Lucknow-Allahabad Highway, about 35 km from Allahabad. Photograph of the temple's model is presented on Fig. 1.

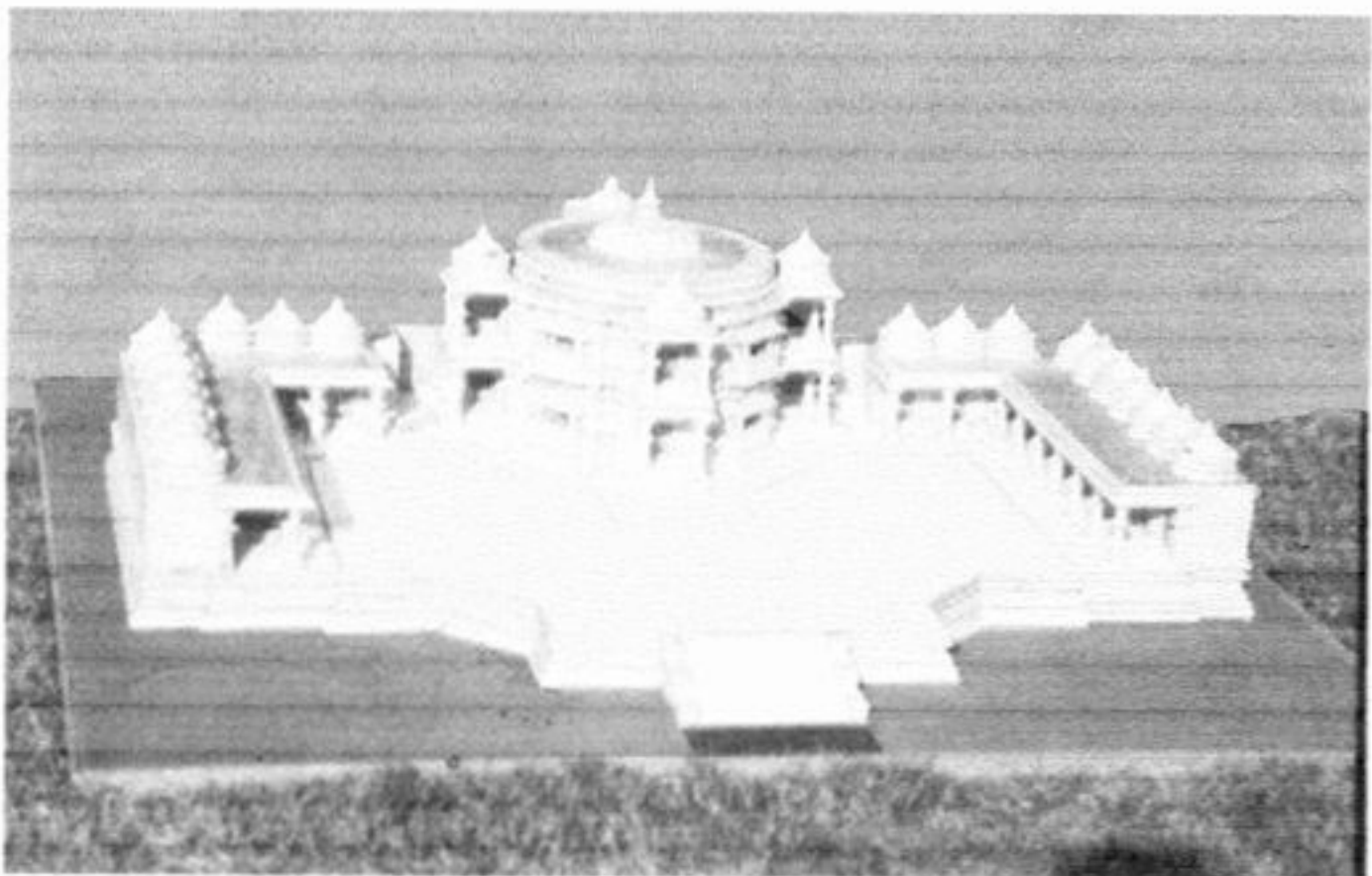


Fig.1 : Photograph of the Model of the Janmabhoomi Temple at Mangarh

ARCHITECTURAL AND STRUCTURAL DETAILS

Concept and Mythology

The temple is being built in traditional Hindu style. Drawing from ancient temple architecture, the construction primarily uses granite masonry. Granite blocks have been used for the foundation and upto the platform level. The super-structure of the temple consists of carved granite pillars and domes. Use of modern construction materials such as reinforced concrete, steel etc., are not permissible.

The philosophy is that steel should not be used in the construction. The reason is the belief that steel will obstruct the divine vibrations between the Devotee and God. It was also felt that steel will rust over a period of time and will destroy the sanctity of the temple. To preserve the temple for a long time, granite is considered as the best option since it does not undergo much degradation with time.

Foundation Block

The foundation block is a massive raft of granite block masonry bearing at a depth of 3 m below the ground surface. The granite masonry platform had been constructed upto 2.4 m above the ground level. Thus, a total 5.4 m thick massive granite structure was constructed.

Super-Structure

On this platform, the main Garba Griha is located at the farthest end with a grand elegant dome over it. The Mandap covers the area in front of the Garba Griha. The main block surrounded by 1.2 m wide peripheral granite stone walls on either side for small temples and corridors.

Loading

Considering the density of granite as 2.85 g/cc, the gross bearing pressure applied by the 5.4 m thick platform (raft) works out as about 15.5 T/m². The net bearing pressure at 3.0 m depth works out as 10.5 T/m² even before construction of the superstructure.

As per the temple planning, the load expected in the main temple area over the Garba Griha is about 25~27 T/m². In the small temple area, the anticipated loading is about 20-21 T/m². Over the platform area beyond the Garba Griha, the loading is expected to be about 15~16 T/m².

The Problem

When the platform had constructed up to +2.4 m level, some cracks were observed in the foundation block. The designers and construction engineers also had an apprehension regarding the soil bearing capacity and whether the soils will safely withstand the varied design loads. In particular, since the loading condition varies across the foundation block, it was felt that differential settlement could be critical. At this stage, the problem was referred to M/s. Cengrs Geotechnica Private Limited to evaluate the problem and to suggest remedial measures.

FORENSIC GEOTECHNICAL ACTIVITY – THE APPROACH

After review of the site conditions and loading data, the forensic geotechnical engineering activity to assess the problem and work out the engineering solution was undertaken in the following steps:

- Evaluation of the soil conditions;
- Prediction of likely foundation behavior;
- Determining the need for foundation strengthening;
- Developing a technical solution that respects the religious sentiments involved; and
- Executing the foundation-strengthening scheme.

Soil Investigation

The first step in evaluating the problem was conducting a geotechnical investigation to assess the site stratigraphy and determining the engineering properties of the soils. Since the platform had already been constructed, the test points were selected close to the foundation block, as per practical feasibility.

The scope of the investigation included the following:

- four boreholes to 15-25 m depth;
- two static cone penetration tests; and
- two plate load tests.

A layout plan showing the locations of the soil investigation points is illustrated on Fig.2.

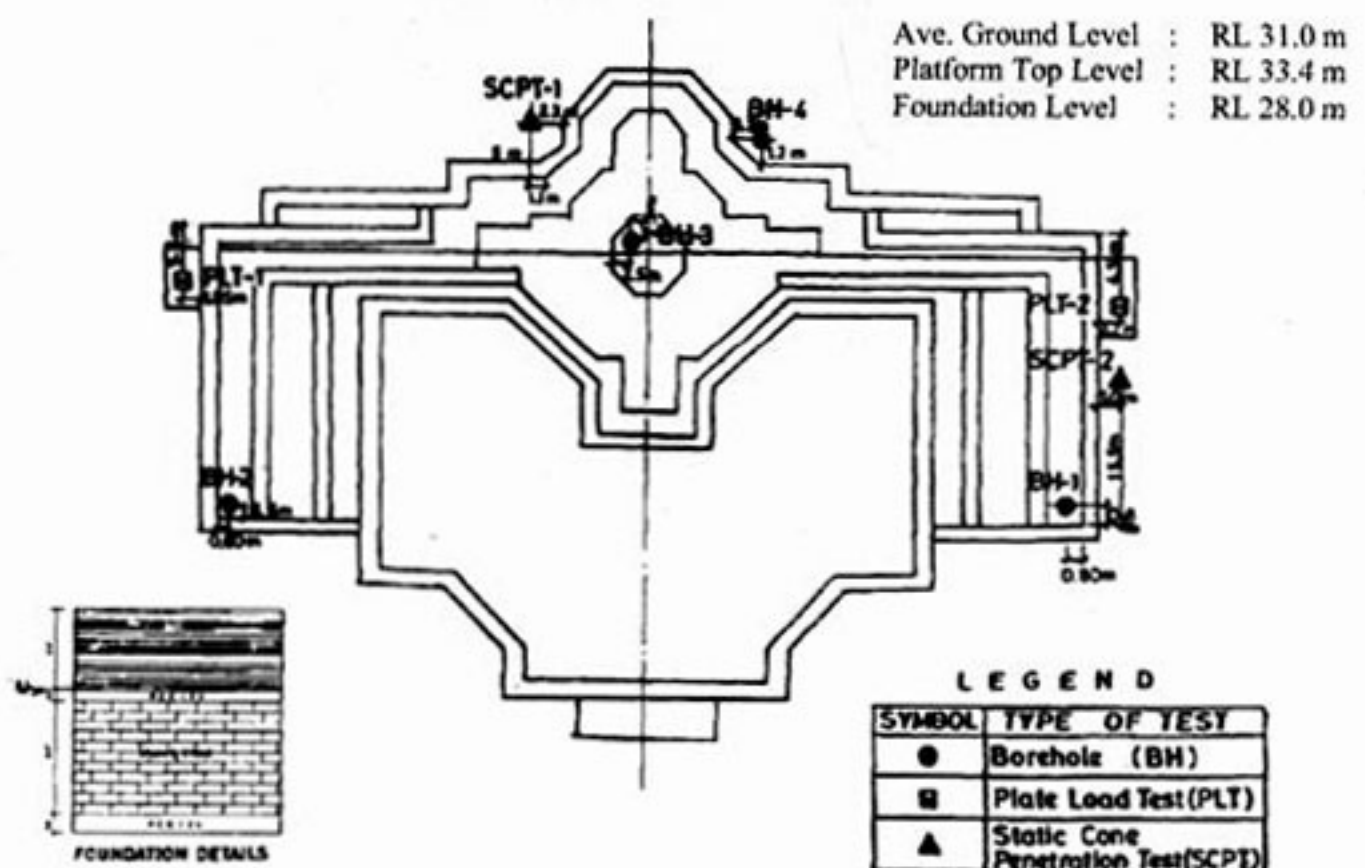


Fig.2 : The Janmabhoomi Temple at Mangarh – Soil Investigation Program

Soil Conditions

The soils at the site are alluvial in nature. Below a surficial fill, that extends to about 1.5-3.0 m depth, the natural soils below foundation level consist primarily of sandy silt and clayey silt of low to medium plasticity to 25.0 m depth. Water table was encountered at about 2.0 m depth (RL 29 m) and is likely to rise up to GL during rains. The stratigraphy at the site is illustrated on Fig.3. The results of the SPT and static cone penetration tests are plotted on Fig.4.

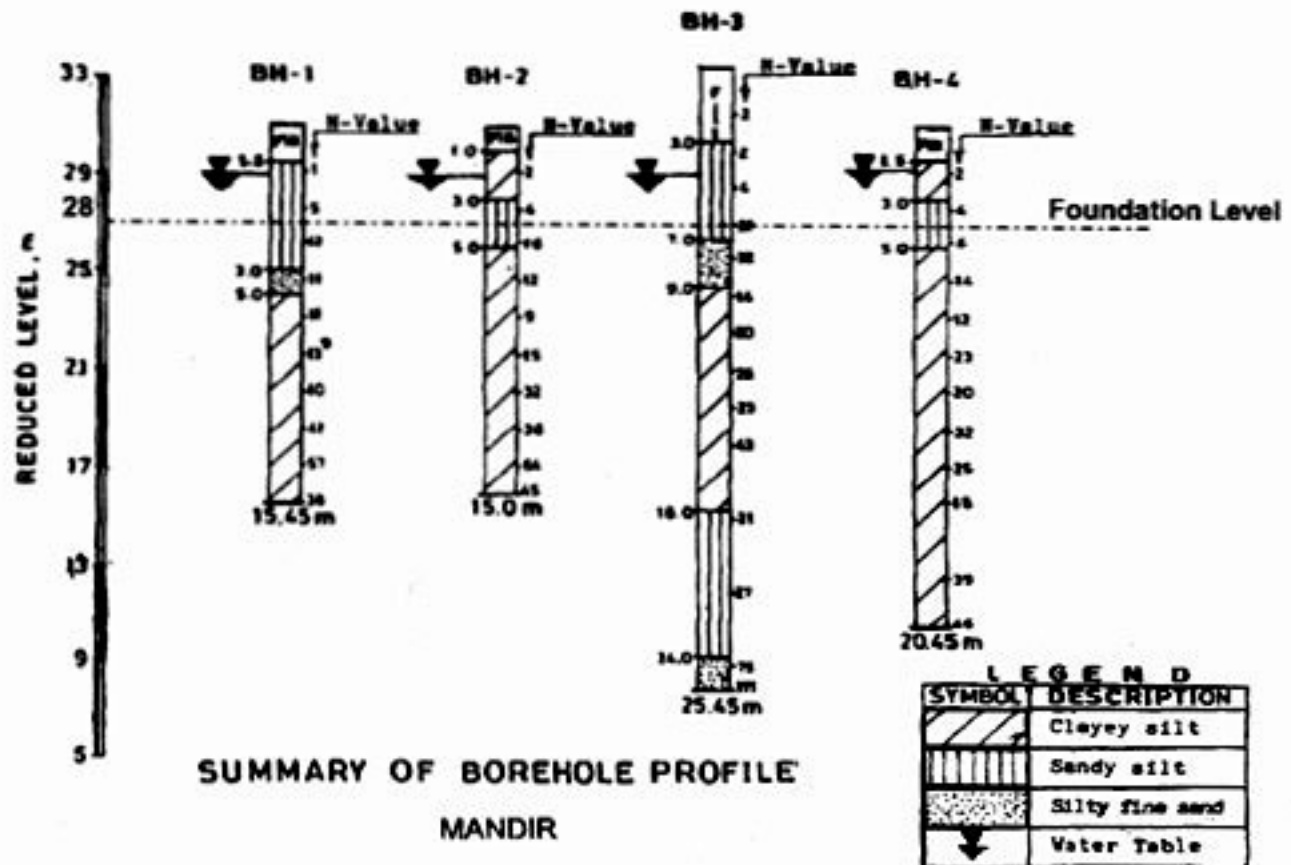


Fig.3 : Site Stratigraphy

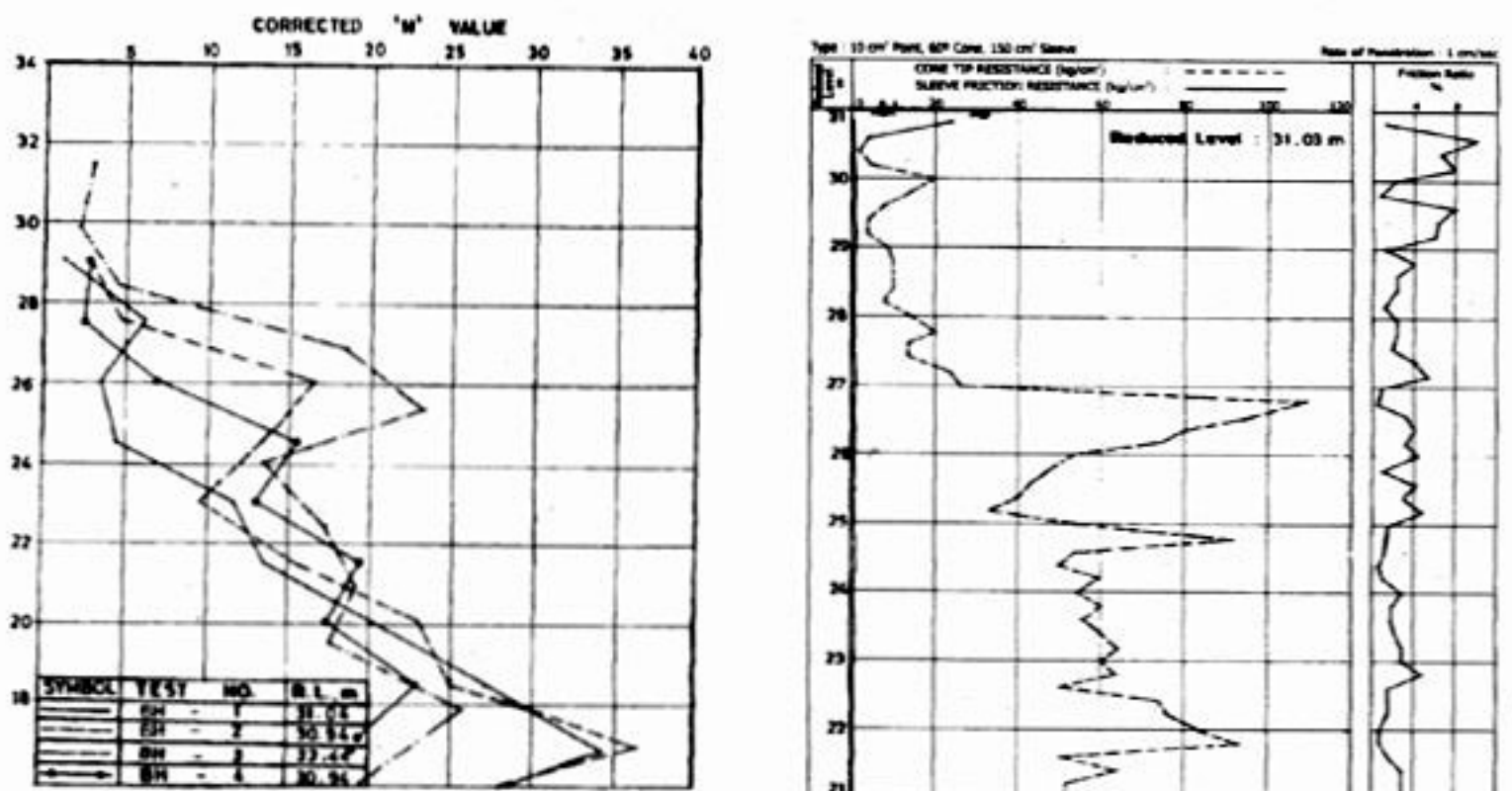


Fig. 4 : SPT and SCPT Data – Janmabhoomi Temple at Mangarh

Geotechnical Considerations

The platform (foundation block) is expected to behave as a massive raft foundation. Considering the size, the authors are of the opinion that total settlement is **not** likely to be a serious problem. However, the granite masonry structure may not be able to withstand any significant differential settlement or tilting. Particularly, the dome of the Garba Griha is expected to be very sensitive to differential settlement.

A settlement analysis of the raft indicates that under a uniform loading of about 25~27 T/m², the total settlement is expected to be on the order of 130~160 mm. At the time the problem had been referred for evaluation, platform had already been in place for about 6-8 months. During this period an estimated 20~30 percent of the total settlement may probably have occurred already.

However, the main matter of concern was that the platform is not uniformly loaded. While the loading in the Garba Griha area is about 25~27 T/m², bearing pressure under the rest of the platform is only about 15~16 T/m². Further, the small temples area which consists of parallel strip footings (granite walls) is relatively less stiff in comparison of the platform block.

In view of this, it was felt that differential settlement is a matter of serious concern. The granite masonry structure is unlikely to be able to withstand the tensile stresses due to differential settlement

ENGINEERING SOLUTION

The engineering solution has to take cognizance of the fact that a massive foundation block has already been constructed. Therefore, limited work space is available for any additional foundation system. The following issues were identified to work out a foundation system that will not only address the geotechnical concerns but also ensure that the temple stands the test of time:

1. Create a confinement for the soils beneath the Garba Griha;
2. Restrict any potential for outward flow of soil;
3. Ensure that the settlement is relatively uniform, thereby minimize the chances of differential settlement/tilt; and
4. Limit potential for upward movement of soil in the Mandap area by plugging it effectively.
5. Reduce the total settlement of the foundations in the small temples area by strengthening of soils.

Certain constraints / limitations specified by the Temple architect has to be respected to maintain the sanctity of the temple structure. These include –

- (i) No steel should touch the temple structure;
- (ii) No steel should be used in the Mandap area;
- (iii) The basic structure, as constructed, cannot be altered; and
- (iv) Avoid use of RCC to the extent possible.

After evaluation of various aspects of several possible solutions, the following strengthening measures were adopted for action

- (1) The confinement of the main temple block was achieved by provision of closely spaced RCC bored piles.
- (2) The Mandap area was plugged by provision of plain concrete piles.
- (3) Improve the soils around the small temples/corridor area by provision of rammed stone columns so as to reduce the total settlement of the strip footings (wall foundations).

The foundation-strengthening scheme is illustrated on Fig.5.

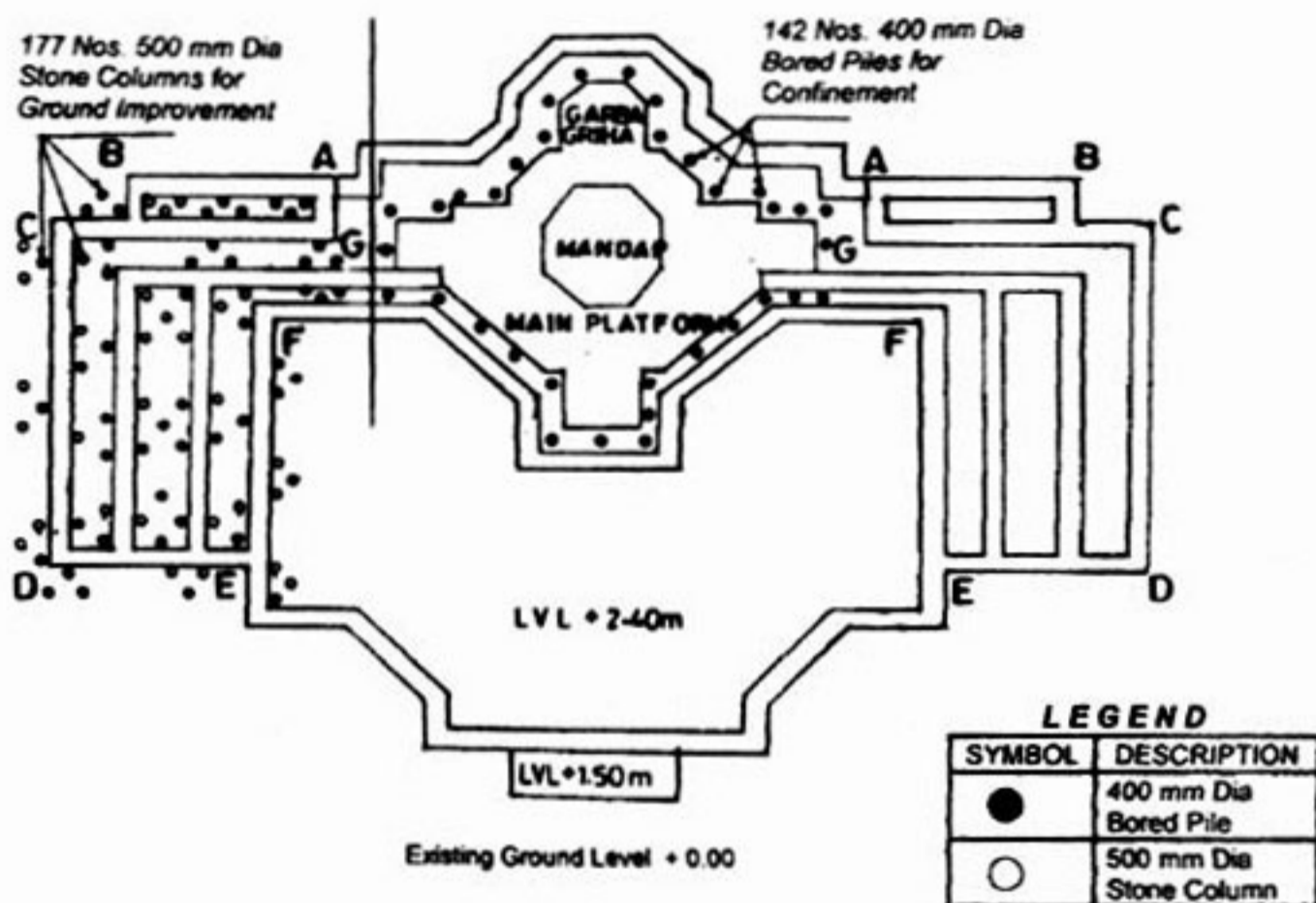


Fig. 5 : Foundation Strengthening

Confinement of Main Temple

In order to ensure that the settlement of the foundation block is uniform, it is necessary to confine the soils beneath it. Confinement serves the following purposes :

- It increases the bearing capacity safety factor against shear failure;
- It alters the pressure distribution beneath the foundation, making it more uniform;
- It restricts lateral soil movement associated with tilting/differential movement; and
- It ensures that the total settlement takes place uniformly, in a more controlled manner.

Confinement was done by provision of closely spaced piles. A total of 142 nos. 400 mm diameter, 12 m long reinforced concrete piles (extending 9 m depth below foundation level) were provided. The cut off level of the piles was 0.7 m below the platform level. The piles were spaced 750 mm centre-to-centre. A tie beam interconnecting the piles was provided. The piles were designed as fixed head to resist the lateral thrust developed due to the confinement effect. The top of the beam was 300 mm below the platform level.

The scheme used is illustrated on Fig.6. The temple authorities were persuaded to permit use of reinforced concrete for the piles. The suggestion was accepted because the steel is coming outside the temple. Also, as a compromise, the RCC beam and stone masonry was separated by an intermediate Shailtex board. The space above the beam was covered by granite slabs, leaving an air gap.

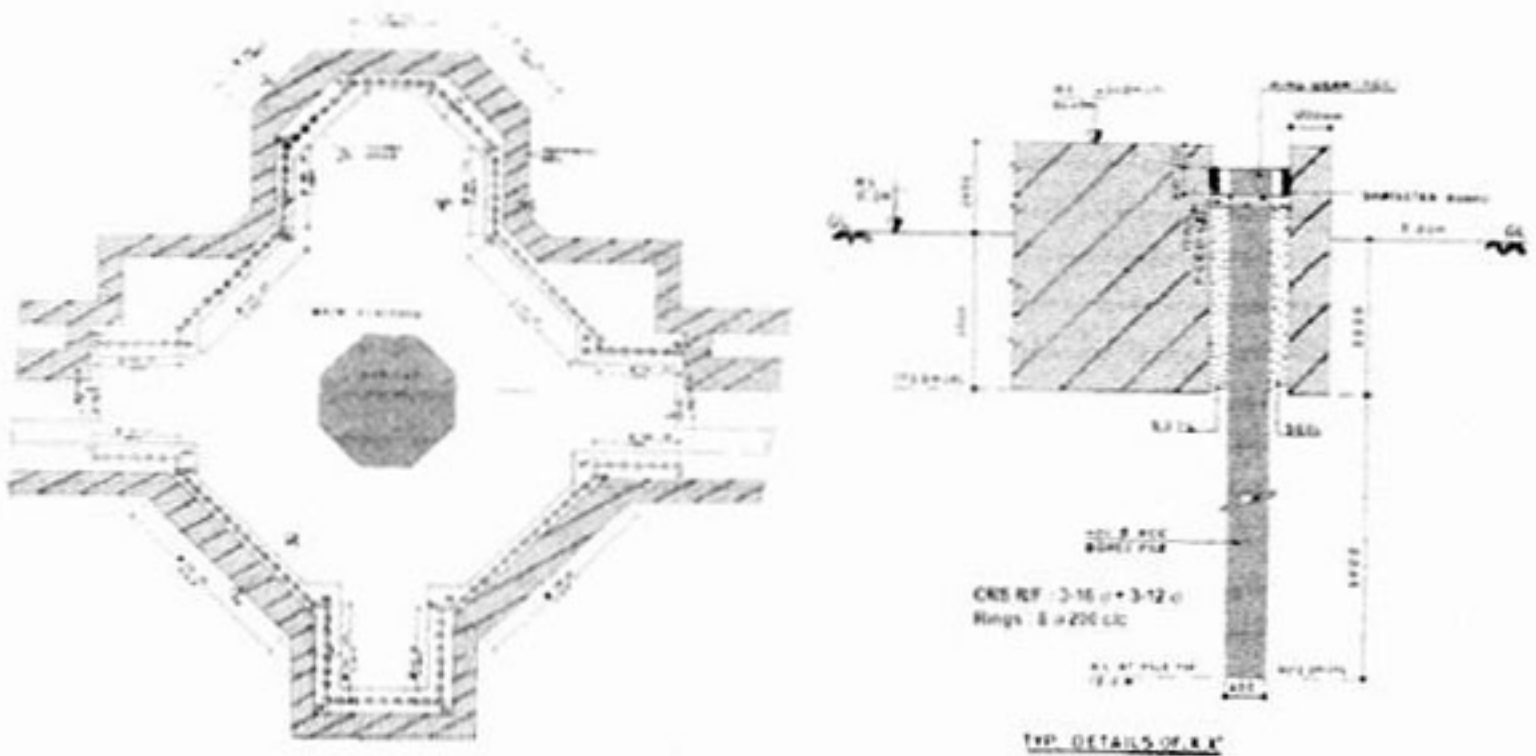


Fig. 6 : Piles for Confinement in the Main Temple Area

Mandap Area

The Mandap area is an octagonal opening in the centre of foundation block of the main Temple. The Mandap will have a big dome over it supported by eight columns. It is an unloaded part of the foundation block; the columns will apply point loads. The concern was that the soil plug in this portion may get squeezed and may move up. Also strengthening this part will make the confinement more effective, thus ensuring a more uniform settlement of the foundation block. However, in this area, use of reinforced concrete was not permitted.

After review of various alternatives, it was decided to install a total of 49 nos. 400 mm diameter plain concrete piles in an octagonal grid pattern. Fig.7 presents the layout of piles in the Mandap area. The pile tip was at 12 m depth below ground level (9 m below foundation level) and the pile top was 1 m below the platform level. Over these piles, a 0.3 m thick plain concrete slab was placed with a Shailtex board to isolate the concrete from the stone masonry.

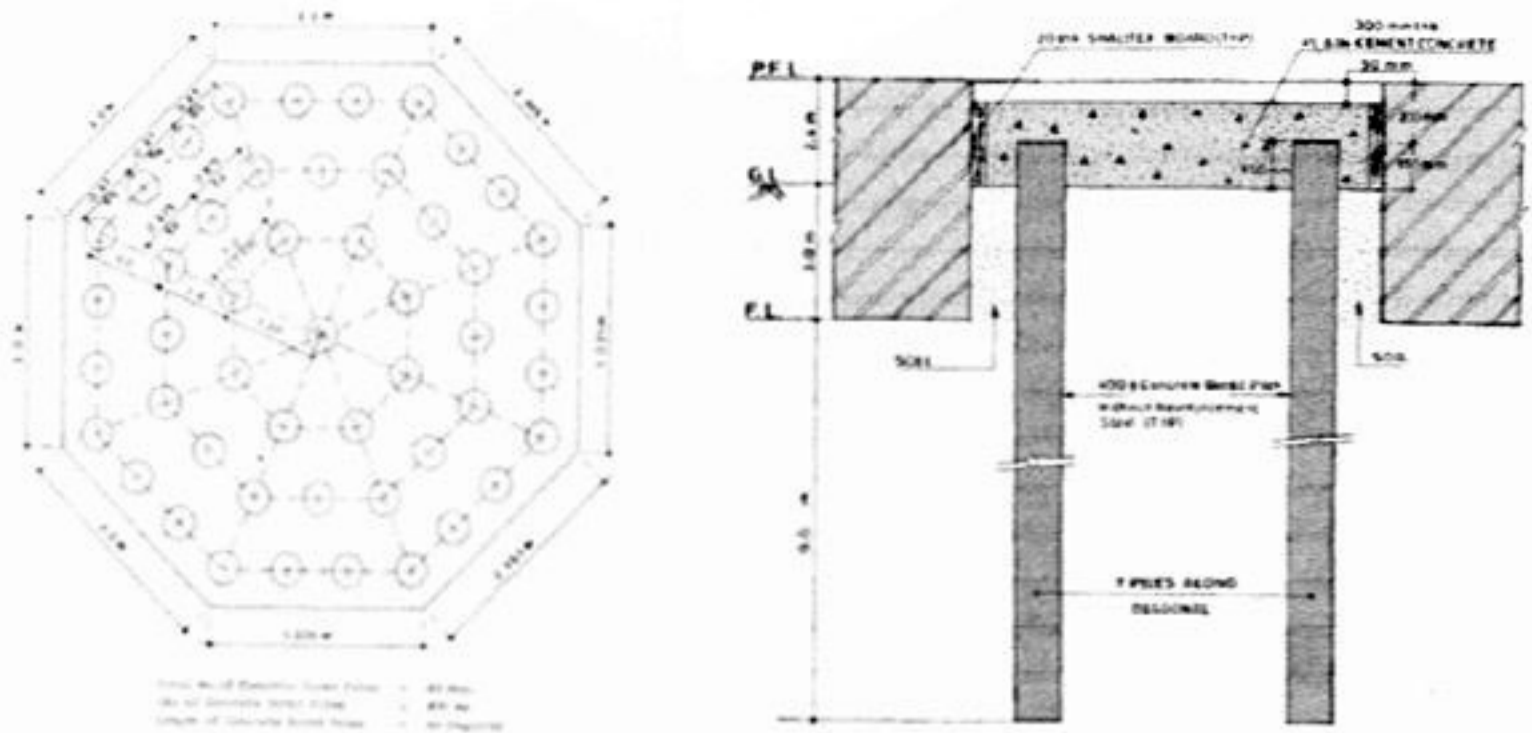


Fig. 7 : Plain Concrete Piles in the Mandap Area

Small Temples / Corridor

This area is planned as a set of vertical walls (that act as strip footings). In this area, the anticipated bearing pressure under the 1.2 m wide strip footing bearing at 3 m depth is about 21 T/m².

Reviewing the soils data, the main concerns were as follows:

- The soils beneath the footing are not strong enough to transmit the loads safely; punching shear failure could occur.
- The soils between the walls above founding level are not properly compacted; it may not contribute effectively to shear resistance of the overburden.
- The settlement of the strip footing under the anticipated loading may be excessive.
- Due to the difference in rigidity/stiffness of the main platform and these wall foundations, differential settlement could occur.

In this area, it was decided to improve the soils by provision of rammed stone columns in order to strengthen the soils and reduce the settlements. The improvement was done by provision of 500 mm diameter rammed stone columns extending to 5 m depth below the foundation level. The stone columns extended 1.5 m above the foundation level in order to compact the backfill also. The stone column layout is illustrated on Fig.8. The ground improvement system achieved the following objectives:

- By providing a composite material with ϕ value in the range of 35-45 degrees, the safe bearing capacity of the soils was increased and the possibility of punching shear failure was eliminated.
- The total settlement of the wall foundations reduced substantially, thereby ensuring a greater compatibility with the main foundation block and that the total and differential settlements were well within the acceptable limits.

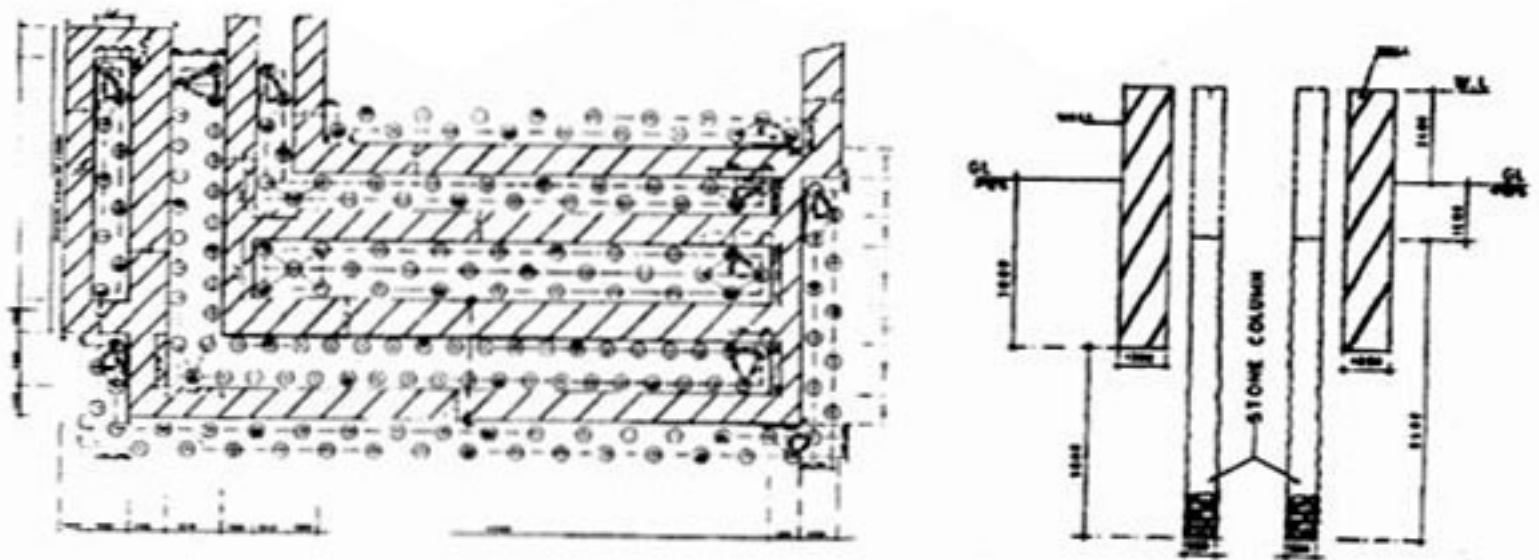


Fig. 8 : Stone Column Layout in the Small Temples Area

CONCLUDING REMARKS

With the foundation stabilization in place, the construction of the super structure has since been taken up. Due to the elaborate carving and on-site placement of the granite blocks in a planned and meticulous manner, the super-structure construction is taking place at a rate somewhat slower than what modern civil engineers are used to. The slower rate of loading is advantageous from a geotechnical point of view since it allows a greater time for pore-water pressure dissipation and equalization of stresses.

The temple is planned to withstand the ravages of time and survive for several centuries. The authors believe that with the settlement pattern engineered in a more controlled and uniform manner, the foundation system is now stable and reliable. The traditional architectural concepts using granite masonry as the principal building material coupled with the dedication and commitment of the temple construction team certainly builds the confidence that the Janmabhoomi Temple of Acharya Kripalu Maharaj will be around for a very long time.