KEY WORDS:
Ek-ratna Temples, Bengal, Bishnupur, Materials, Construction Technology, Form-making

Construction as a Key to Form-making: Laterite Ek-Ratna Temples in Bishnupur, Bengal

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ABSTRACT

The Bishnupur ek-ratna temples have a special status in the history of temple architecture of Bengal. A good number of same type and scale of temples were built over about hundred and fifty years (17^{th}-18^{th} century CE), under the patronage of the same ruling dynasty, thus turning the town into an experiment yard. Out of the eleven significant ek-ratna temples built in Bishnupur during this time, ten were made of laterite. This paper focuses on these laterite ek-ratna temples.

Literature review has revealed that there is hardly any research about the construction technology of these temples. The present article attempts to explore the material, skill, construction techniques and management adopted in the ek-ratna laterite temples of Bishnupur of the 17^{th}-18^{th} century CE. Finally, the paper suggests that the shape, size and mechanical properties of building material (laterite) and the geometry of the temple components were strongly inter-dependent. The master builders derived the temple form by striking a balance between the materials and the geometry, to meet the requirements of function, aesthetics and aspirations.

This research is based on on-site data collection, focusing on the existing temples as primary evidence.

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Introduction

Figure 1: Nandalal – ek-ratna temple in Bishnupur, built in laterite

Bishnupur[1] ratna temples have a special significance in the history of temple architecture of Bengal. Nowhere else in Bengal can one find such a good number of same type and scale of temples built over about hundred and fifty years (17th-18th century CE), under the patronage of the same ruling dynasty (Malla dynasty of Mallabhum), where the entire royal family remained devoted to Vaishnavism[2]. Close observation of the temple forms tends to suggest that there was a continuity of similar type of skills and materials over this period, turning Bishnupur into an experiment yard of temple building.

Bishnupur is widely known as a land of brick and terracotta temples. However, contrary to this popular belief, out of the eleven[3] significant ek-ratna temples that were built in this town during the 17th-18th century CE, ten were made of laterite. This paper focuses on the laterite ek-ratna temples of Bishnupur. A typical ek-ratna temple (Figure 1) consists of a cella surmounted with a pinnacle and surrounded by a veranda, which serve as a sheltered porch as well as a circumambulatory. The temple stands on a raised platform.

Literature review has revealed that there is hardly any research about the construction of these temples. McCutchion (1993), Michell (1983), Santra (1983), Bandyopadhyay (2015), Datta (1975), Sanyal (2012) and Halder et. al. (2011) discuss only a few aspects of construction, which have been referenced in this paper. This paper carries out an in-depth analysis of the material, skill, construction techniques and management adopted in the ek-ratna laterite temple building of Bishnupur of the 17th-18th century CE. The objective is to explore the extent to which these regulated the act of form-making. This research is based on temple dimensions and on-site data collection, treating the temples as primary evidence.

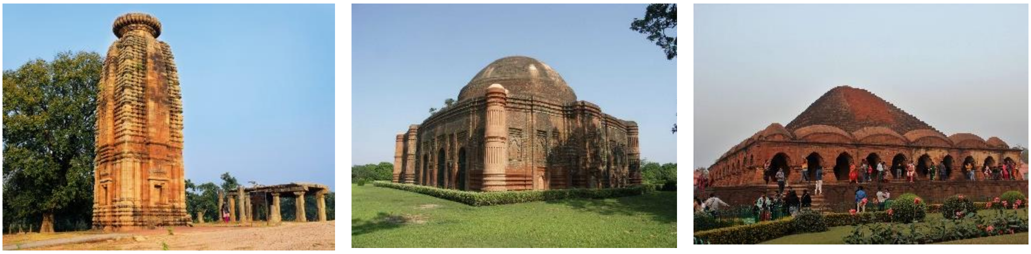

Figure 2: *(a) Rekha tower Jain temple at Banda, Purulia (c. 10th century CE); (b) Lattan mosque at Gaur, Malda (c. 15th century CE); (c) Rashmancha at Bishnupur, Bankura (1600 CE)*

This paper begins with a discussion on the historical context, followed by analysis of skill and materials available and then, the methods and management of construction. Finally, the paper discusses the inter-relation between temple proportions and materials and construction.

Historical Context

In early Hindu period, till the end of 12th century CE (McCutchion, 1993), a number of Hindu and Jain temples were built in West and South Bengal, presently mostly in ruins. They display a distinct Odishan influence, with a Rekha tower and corbel technology of construction **(Figure 2a)**.

During the subsequent Sultanate period (14th- early 16th century CE) (McCutchion, 1993), there is an absence of evidence of temple construction though a number of mosques and tombs **(Figure 2b)** were built using voussoir technology in brick and stone. Initially perhaps, craftsmen had come from Delhi and elsewhere, as people in Bengal did not know voussoir construction techniques. But over time, the Bengali masons learnt this construction method and this became the prevalent technology of the area.

An interesting fusion happened during the following Hindu Revival period (16th – 19th century CE). After a lean period of about two hundred years from the beginning of Islamic rule in Bengal, a boom of temple building began in Bishnupur with the construction of Rashmancha **(Figure 2c)** in 1600 CE by Bir Hambir. who maintained a good relation with Mansingh[4]. The voussoir technology was predominantly used in the temples built in this period (Figure 3a), probably because this was the prevalent technology of the period and the masons and builders were well skilled in it. Lack of opportunity of temple building alongside construction of many Islamic buildings during the Sultanate period with arcuated systems must have made corbelled systems almost non-existent. However, corbel technology was not forgotten, it was used in appropriate places in both temples and mosques **(Figure 3a, 3b)**.

Figure 3: *(a) Voussoir arch and vault in Kalachand temple, Bishnupur, 1656 CE;
(b) Corbelled roof in Bibi Pari's Tomb, Dhaka, Bangladesh, 1684 CE.*

Figure 4(a): *Map of India showing laterite belt*

Figure 4(b): *Map of West Bengal showing location of Bishnupur in the laterite belt*

Materials

This section discusses laterite as the primary building material in Bishnupur – its nature, availability, strength and ways of working with it. It also explores the source and use of lime in this region. **Figure 4a** shows that the laterite belt of Odisha and Jharkhand extends into the Rarh Bengal[5] and Bishnupur lies in this zone **(Figure 4b)**. Hence, most of the

Figure 5: *(a) Map showing location of Bon Birsingha Gram w.r.t. Bishnupur; (b) Laterite at the surface at Kalyanpur village, Sonamukhi block*

temples in this region are made of laterite (locally known as *makra*), while only a few are constructed in brick.

Laterite is formed from sedimentary rocks and occurs naturally in layers. Leaching happens under high temperature and heavy rainfall with alternate wet and dry periods, leaving only insoluble oxides of iron and aluminum in the rock. This results in a low compressive strength of laterite as compared to other stones. In absence of data from Bishnupur, the compressive strength of laterite blocks may be taken as 34 kg/sq.cm., based on IS:3620–1979 (2003). Heyman (Heyman, 1997) refers to Yvon Villareau and states that the nominal masonry stress should be 1/10th of the crushing strength of material. Hence in the present context, the allowable compressive strength of laterite masonry may be assumed to be 3.4 kg/sq.cm.

The next quest was for the source of the laterite stones used by the Malla kings for the construction of ek-ratna temples. While in Bishnupur for site work, the author came to know from the local inhabitants that a very old laterite quarry existed in Bon Birsingha Gram, 19km from the city **(Figure 5a)**. It is not known for certain whether stones from this particular quarry were used in the 17th-18th century temples in Bishnupur. It was reported by the curator of Bangiya Shahitya Parishad, Bishnupur that Archaeological Survey of India had used the stones from this quarry for conservation works in the temples till quite recently. According to some local people, there are several sources of laterite in and around Bishnupur, e.g., Patharmora, Kalyanpur, Sonamukhi – all very close to Bishnupur in Bankura district. Madan Mohanto, a school teacher in Patharmora High School, mentioned that laterite is available at surface in Kalyanpur village **(Figure 5b)**, 20 km from Bishnupur. He recounted stories that he had heard from his grandmother that the Malla kings of Bishnupur owned the Khas jungle of Sonamukhi (27km from Bishnupur) and used to procure laterite blocks from that forest.

Figure 6: *Laterite blocks cut in different shapes and dressed for constructing different parts of the temple.*

The above discussion shows that though laterite is easily available in the vicinity of Bishnupur, there is no authentic information on the source of laterite stone used for the 17^{th}-18^{th} century temple building. The probable quarry could have been one of the places mentioned here or any other nearby place. To get an idea about the convenience of transporting stone blocks to the site, a thought experiment had been conducted, assuming that the source was Bon Birshingha Gram - as it is old, was being used by locals and Archaeological Survey of India till recently and had produced good quality laterite blocks.

When the laterite blocks are procured from the quarry, they are relatively soft (IS:3620–1979, 2003). It may be presumed that the stone blocks would be cut to shape and dressed immediately after reaching the site. The shapes would include perfect wedge-shaped blocks for arches, sculpted blocks for façade, levelled and dressed blocks for walls, decorative blocks for pillars, spherical block for kalasha and disc shaped blocks for amalaka, among others **(Figure 6)**.

In Nandalal temple, the average size of the stone used in wall was 450x225x150 mm and its weight was 27 kg[6]. Some of the stone blocks at the wall base had a dimension of 400x200x100 mm. The proportion of the latter block is very close to that of the laterite blocks used in Odishan temples, which followed Canons of Orissan Architecture (Bose, 1932, p76), which says that *'The (block of) stone should be 4 measures in length, 2 in width and 1 in height. It is auspicious to make it so.'* Perhaps, the dimensions match because both Bishnupur and Odisha are in the same lateritic zone **(Figure 4)**, probably with similar laterite strength.

The walls of some of the temples have lime plaster on the surface, which have weathered away in many places. In Bengal, lime was initially used for floor concreting and subsequently used in mortar and plaster (Datta, 1975). Lime was often obtained here from the snails and sea-shells. Michell (Michell, 1983) mentions that the lime plaster, locally known as *pankha*, was fine and hard; and would be made from snail lime mixed with river sand. It may be mentioned here that the sea-shell is widely available and used in Bengal, e.g. the shell bangle is worn by married women and the conch shell is blown to mark all religious and cultural events.

Skill

Bandyopadhyay (2015) and Santra (1983) mention that the master builders who constructed the Bengal temples were called *sutradhar*, *raj*, or *raj mistiri*. Even today, the mason is called *raj mistiri* in Bengal and the carpenter is called *chhutar* (colloquial version of *sutradhar*). *Sutradahar* literally means the artisan who holds the thread, or the measuring tape. They were experts in the use of wood, stone, clay, painting, metal and ivory. There were 4 categories of *sutradhar*s in Mallabhum (Bishnupur) – *Mandarani* were the brick masons, *Bhaskar* were the sculptors, *Khoripar* made the drawings of temples and did cost estimation and *Astakul* produced the bricks (Saha, 2004). Similar expertise must have been available for laterite construction as well, though the author did not find any documentary evidence in this regard.

These builders worked in teams. Some of the famous teams came from villages like Chetua-Daspur (Medinipur district), Thalia-Raspur (Howrah district), Sonamukhi, Balsi, Bishnupur (Bankura district) and Guskara-Ketugram (Burdwan district) (Bandyopadhyay, 2015). According to Santra, the Bishnupur temples were probably built by the local sutradhars. This is quite possible as Bishnupur and its neighbouring towns were important centres of *sutradhars*, many of whom have been mentioned in the inscriptions of temples built in other districts like Bardhaman and Medinipur (Santra, 1983).

Datta (1975) writes that a team of *sutradhars* would comprise of several families and each family would have its hereditary construction-related expertise[7]. For example, the traditional occupation of the *chunaru* caste in Bengal was to manufacture slaked lime from snail shells[8]. Santra (1983) mentions that sometimes there would be as many as twenty-five artisans working in a team. They would live and work under a leader, who would do the planning and supervision. The teams used to move from place to place in search of jobs. The team leaders would carry several temple designs with them and present them to the patrons for choice and had had knowledge of every aspect of temple design and construction of temples of different scales. This culture of building was passed from one generation to the next through hands-on training and practice at the construction sites (Datta, 1975). This was also learnt from conversations that the author had with Guru Prasad Sutradhar, son of Late Monu Mistiri, one of the traditional temple builders in Bishnupur.

The patrons were mostly the rich Hindu *zamindars*[9] and the royal families, like the Malla kings of Bishnupur and their family members (Santra, 1983). Bandyopadhyay (2015) states that the patrons would select a design according to their aspirations, financial capabilities and available time. They would probably aspire to build as big as possible within their budget. During construction, the patrons would organise the stay and food of the builders.

Construction Methods

The above section narrated the story of materials and skills required for the construction of the laterite ek-ratna temples in Bishnupur. The next section of the paper will discuss the construction techniques of the various components of the ek-ratna temple.

Since it is not possible to understand construction without making the drawings of the buildings, the plans, sections and elevations of seven laterite temples of Bishnupur and its neighbouring area[10] were drawn, based on dimensions taken at site and plan drawings of ASI[11]. **Figure 7** shows the drawings of Nandalal temple, a typical ek-ratna temple of Bishnupur. These drawings have been used to illustrate various construction related issues in the next few sections. The objective was not precise documentation; but to make fairly accurate drawings which would be adequate to explore the construction techniques of the temples. For the ease of analysis and understanding of construction, each ek-ratna temple has been divided into four components viz. the roof, wall, openings and foundation.

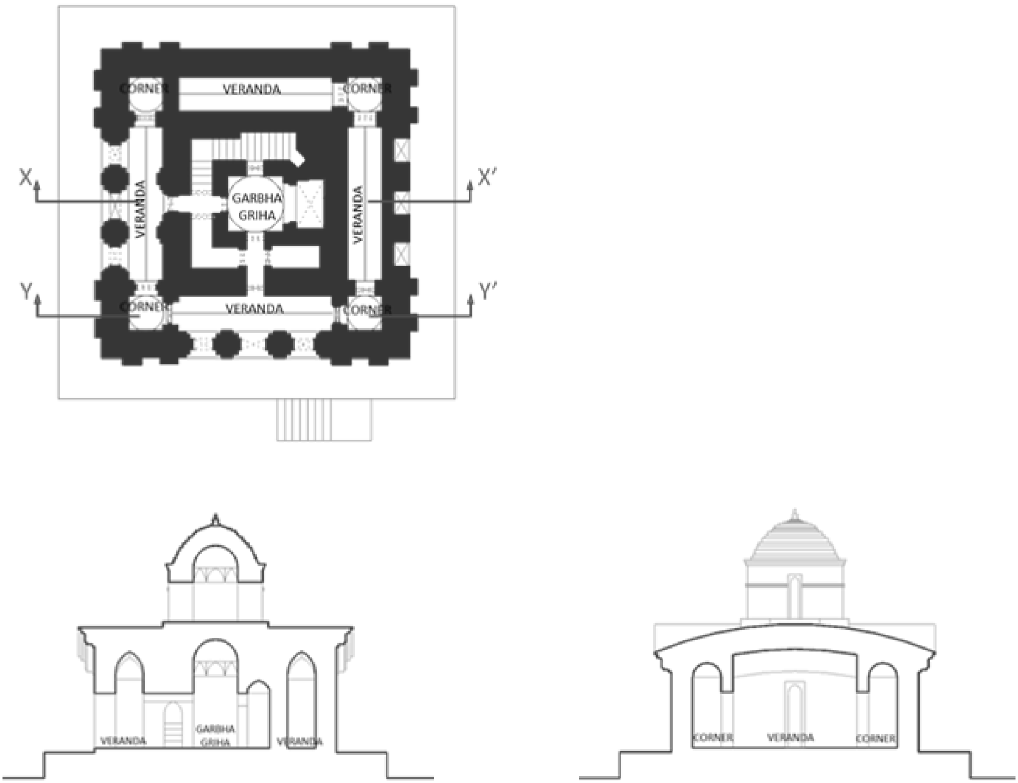

Figure 7: *Drawings of Nandalal temple, Bishnupur, seen anti-clockwise - (a) Plan; (b) Section XX'; (c) Section YY'*

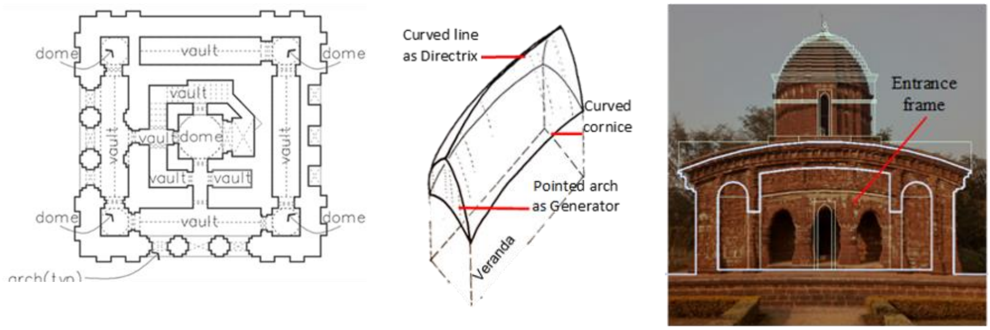

Figure 8: *(a) Spanning systems in Nandalal temple (b) Veranda vault on curved base; (c) Section YY' superimposed on the elevation of the temple*

Roof

A typical ek-ratna temple has a) domes on squinches in garbha griha and pinnacle, b) vaults over the verandas, c) small domes at four corners, d) vault over other ancillary spaces **(Figure 8a)**. The domes were developed as a surface of revolution of a semi-circular arch about the vertical axis. The vault on the veranda was generated by translating an arch (generator) along a curved line (directrix); and, the vault-base was automatically curved **(Figure 8b)**. The main reason for adopting this arrangement was to get the curved cornice, an aesthetic requirement as well as to drain off the rain water.

When Section YY' **(Figure 7c)** was superimposed on the elevation of the temple (**Error! Reference source not found.**c), the inter-relationship between the structural system and the façade geometry was revealed. The figure suggests that the façade elements and the roof of the veranda were complementary to each other – a well-planned action by the master builder bringing in harmony between construction and aesthetics. The figure shows that the top of the entrance frame of the temple marks the vault base, i.e., upon constructing the walls of the temple up to the top of the entrance frame, the roof construction would start. Formwork would be erected at this level for the construction of the veranda vault and the corner domes. The rise of the dome was smaller than that of the vault. This difference in heights was maintained while filling up the top of the domes and vault, giving rise to the curved cornice of ek-ratna Bengal temples.

Among the seven temples surveyed in and around Bishnupur, the maximum span of the dome over the garbha griha is 2829mm (Lalji temple). According to Heyman (1997), the minimum thickness of a hemispherical masonry dome should be 4.2% of the radius, to keep the stresses within safe limit. Therefore, in the present case, the minimum thickness required for dome of Lalji should be 60mm. Considering the laterite block size of 450x225x150mm the actual dome thickness would be at least 150mm and hence, highly safe against the breaking strength of laterite masonry. Since the spans of the domes of the other temples in Bishnupur are less that 2829mm and the minimum dome thickness is 150-225mm, they are all safe.

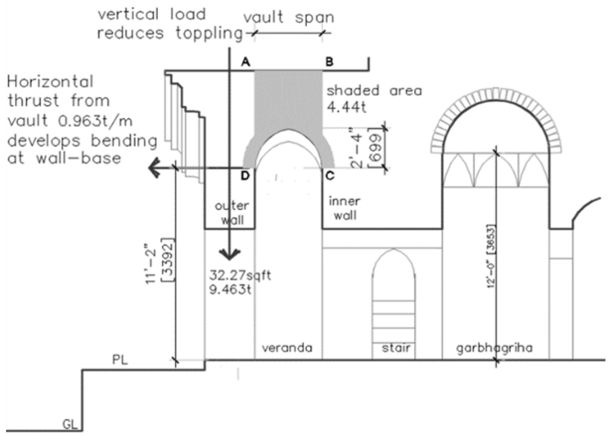

Figure 9: *Horizontal thrust at the base of veranda vault*

The vaulted roof of the veranda spans between its internal and external walls and the question is whether the compressive stress in the vault is within safe limits. Load of the masonry in the portion ABCD, plus the live load on the portion AB **(Figure 9)**, acts on the vault creating axial compression in the generator arch. Heyman (1997: p50). states that *"the barrel vault maybe thought of as a series of parallel arch rings,* and Hejazi (2014, p.130) refers to Heyman and writes that "...the thickness of the arch should be just over 10% of the radius". Considering the maximum width of veranda as 1486mm (Radha Shyam temple), the minimum thickness of arch should be 75mm and the minimum arch thickness provided with the laterite blocks is 150-225mm. Therefore, the vaults in all the ek-ratna temples in Bishnupur are safe in compression.

The load on the vault generates a horizontal thrust of 0.963t/m run at the base of the vault on each side **(Figure 9)**. The effect of the horizontal thrust at the base of walls and pillars is discussed in detail in the section on 'Wall and Pillars' below.

Wall and Pillars

The supporting system of ek-ratna temple consists of the garbha griha wall, veranda wall internal, external wall and pillars **(Figure 10a)**. Section XX' of the Nandalal temple (Figure 7b) reveals that the pinnacle walls are perfectly aligned with the garbha griha walls. As mentioned in the section on 'Materials', the average size of the laterite block used in the wall has been assumed as 450x225x150mm (Nandalal). These blocks were used to construct either dry coursed masonry walls, or two leaves of laterite walls with infill material in between. While laying the stones, the masons must have faced difficulty to adjust the positions of the blocks in order to maintain line, level and plumb, because of the

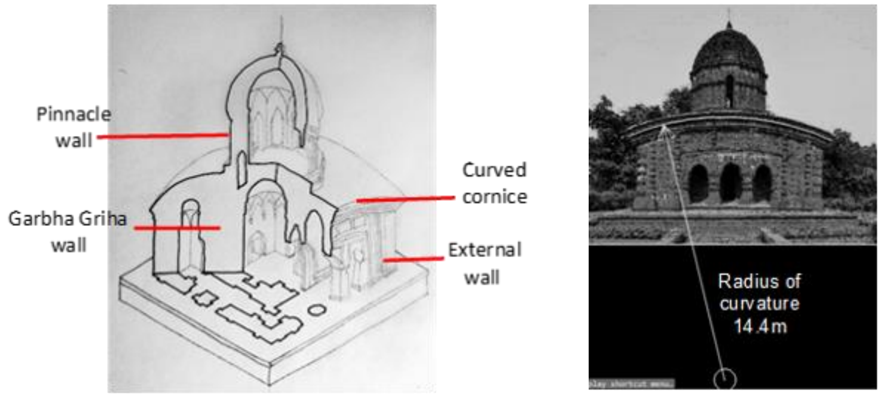

Figure 10: *(a) Supporting systems in Nandalal temple;*
(b) Centre of curvature of the curved cornice of Nandalal temple lies below ground level

weight of the block and inter-block friction. Bishnupur masons probably used a thin layer of lime mortar as lubricant in the bed joints, as was the practice elsewhere (Coulton, 1995).

The curved cornice is the characteristic feature of the Ratna temples of Bengal. There was probably a rule for setting the curvature, which is approximately an arc of a circle with the centre of curvature below the ground level **(Figure 10b)**. It is obvious that the curved geometry of the cornice was not set in-situ, using a peg as the centre and a string as the radius. It is possible that the curvature was first drawn horizontally on the ground with the required radius. The heights were then measured at equidistant points along the base line. These heights would then, perhaps, be marked off on the façade, which would be under construction at that point of time. The curvature of the cornice would be developed by plotting an arc through these points. Alternatively, a long piece of bamboo or a couple of them tied together would be bent to develop the curvature of the cornice. It may be noted that the latter is the prevalent practice in vernacular roof construction in Bengal even today.

Most scholars (Hasan, 2007; McCutchion, 1993; Michell, 1983; Sanyal, 2012) etc. have stated that the curved cornice of Bengal temples is a derivation of Bengal vernacular. While this may be partially true, the curvature could also be due to the need of roof drainage. **Figure 11** shows that there was an attempt to achieve an appropriate climate-responsive roof in the early mosques of the Sultanate period. The curved cornice of ek-ratna temples might have been influenced by these Islamic precedents or directly by the Bengal vernacular.

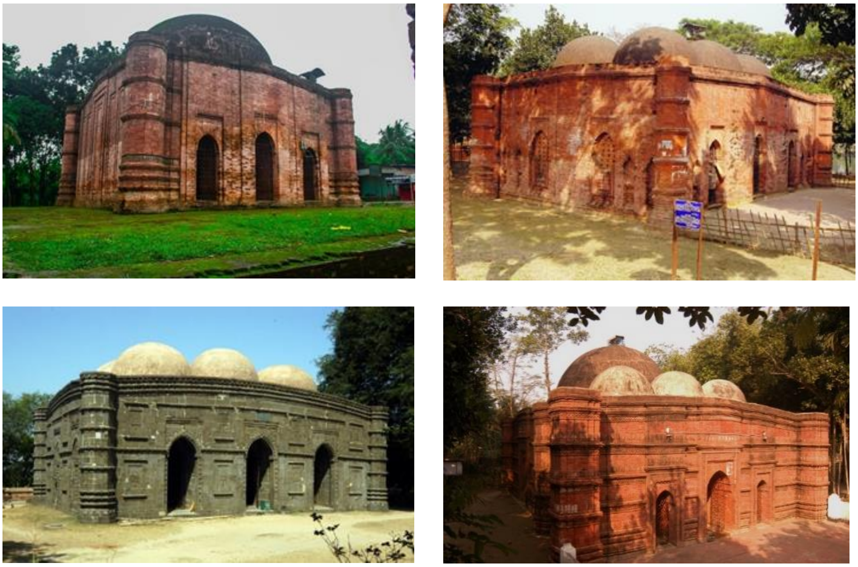

Figure 11: Development of curved cornice of the Bengal roof
Clockwise from top left, (a) Jor Bangla Mosque (1397 CE) Barobazar, Bangladesh;
(b) Golakata Mosque (Early 15th century CE) Barobazar, Bangladesh;
(c) Ghorar Mosque (Early 15th century CE) Barobazar, Bangladesh;
(d) Kusumba Mosque (1558 CE) Naogaon, Bangladesh

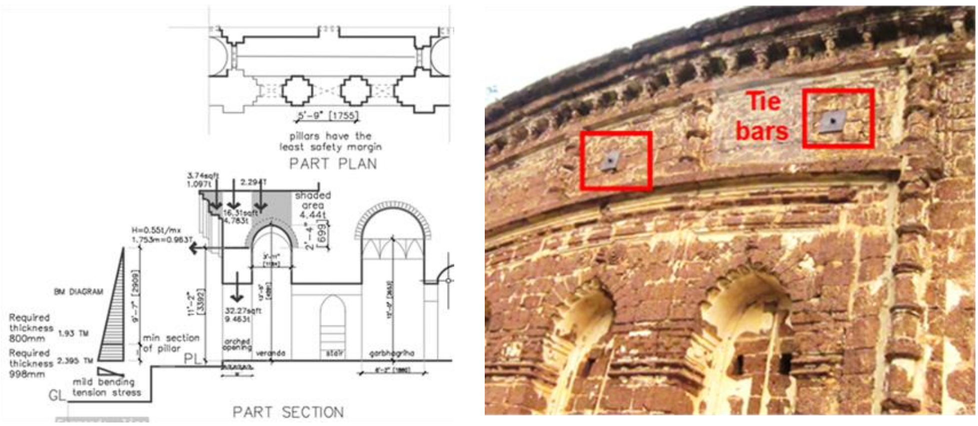

Figure 12: *(a) The pillar may turn about the base, causing a crack at the vault base*
(b) Tie bar in Radha Madhav temple

In ek-ratna temples, the most critical part of the supporting system is the stone pillar as this has the minimum cross-sectional area. Load calculation shows that that there is a horizontal thrust of 0.963 t/m at the base of the veranda vault (section on 'Roof' above), inducing a bending moment of 1.37tm at each pillar base P1 and P2 **(Figure 12a)**. Calculations show that the resultant of the horizontal thrust and the vertical load will just cross the middle-third at the base of the pillar, leading to a minor tension at the inner edge of its base, for which a minor hairline crack may appear. In addition, the turning outward of the pillar about the base may cause the pillar head to move outward, resulting in cracks in the upper part of the wall. This is evident in Radha Madhav temple, where tie bars were inserted at the base of the vault to stop the outward movement **(Figure 12b)**. The rest of the walls are safe from such bending moment as the cross-sectional area is adequate and all inner walls have low level of stress compared to the strength of laterite masonry.

Opening

The geometry of the arched openings in the facades was explored. It was found, by trial-and-error method, that the façade arch is a two-centered arch **(Figure 13)**. The laterite stones were cut in wedge shape, with little projections in each, which gave rise to the foliations when the blocks are put together. The wedge blocks were cut perfectly to shape and the joints between two blocks follow the radial lines. Such perfection in construction of arches was possible only when the template for these arches was laid on the ground, and the blocks were shaped and cut according to the template. These blocks had no mortar between them; the thin white lines are the remnants of surface lime coating. These arches are adequately safe against thrust and bending as the spans are too small.

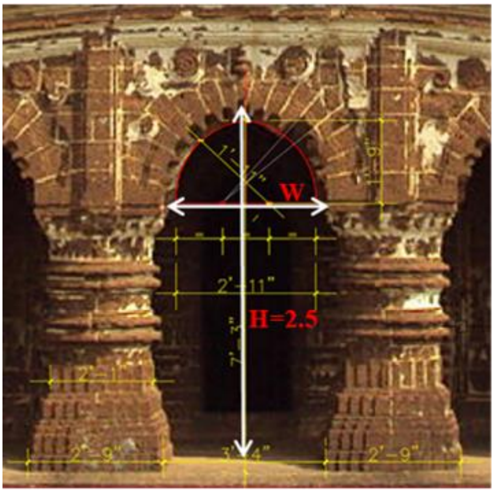

Figure 13: *Geometry of the entrance arch of ek-ratna temples*

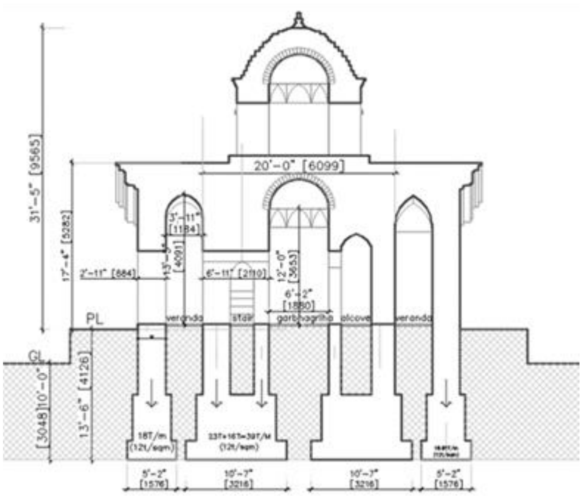

Figure 14: *Nandlal Section: Developed stress at the bottom of the wall and the width of foundation*

Foundation

Books and articles on Bishnupur temples do not provide an insight into the foundation of the ek-ratna temples. It is almost impossible to know the depth and the nature of foundation in historical buildings without excavating and/or carrying out sonography, all of which are expensive, inconvenient and require permission from the appropriate authorities. So, in the absence of hard data, secondary sources were used to deduce the foundation type of ek-ratna temples.

After studying Odishan Shilpashastras (Bose, 1932), Hari Bhakti Vilasa (Sharma, 1911) and writings of scholars like Bandyopadhyay (Bandyopadhyay, 2015), in detail, it was assumed that that the foundation of ek-ratna had a depth of one-third the temple height, as discussed by Bose. This is a reasonable assumption since both the Odisha and Bishnupur temples were built on of the same lateritic belt (section on 'Materials'). Thus, the foundation depth of ek-ratna temples such as Nandalal, whose height is 9.2m, would be about 3m.

To analyze a foundation, it is important to know the SBC[12] of the soil, which will determine the foundation width. This is a specialized area and some of the articles referred to, viz. by Bhadke and Savoikar (2021), Dixit and Patil (2012), helped to determine the SBC at 3m depth to be approximately 12t/sqm.

Based on the drawings of Nandalal, load on the external wall at foundation level is 18t/m run and the required foundation width is 1576mm. In a similar manner, the combined load of internal wall of the veranda and garbha griha wall has been calculated to be 39t/m run, which would require a foundation width of 3216mm **(Figure 14)**. So, widening the wall by two steps would be adequate to keep the developed stress on soil within the SBC.

This is a conservative calculation for determining the foundation width of Nandalal temple. Site selection guidelines and ground improvement techniques have been laid out in the canons of temple construction in great detail, which would lead to an increased SBC of soil and reduced width of foundation.

The overall stability of the temple and safety against horizontal forces were ensured by keeping the centre of gravity of the superstructure close to the base (superstructure weight: pinnacle weight :: 12:1).

Construction Management

Most of the kings of Bishnupur reigned for 10-36 years, which was adequate time to build a few temples. For example, during the thirty years' reign of Raghunath Singha (1626-1656), five significant temples were constructed, viz. Brindaban Chandra (1638), Gokul Chand (1643), Shyam Rai (1643), Keshto Rai (1655), Kalachand (1656), which was an exceptional achievement. Apart from great aspirations, he must have had a peaceful time, adequate money, material and human resource in order to achieve this. The following is an analysis of the quantum of material, human resources and time required for one typical ek-ratna temple, e.g., Nandalal.

Based on the measured drawing and field studies, the calculated number of laterite blocks (average size 450x225x150mm) used in the temple construction (e.g., Nandalal) was 50,241. Assuming Bon Birsingha Gram as the laterite source (section on 'Materials), which is 19km from Bishnupur, bullock carts would probably be used for transporting the stones, as even today, this is the mode of transport in the nearby areas.

Patre (2018) mentions. that a wooden bullock cart with wooden wheels has an average speed of 3 kmph with a payload of 900 kg on rural roads. This load corresponds to 34 laterite blocks, each weighing 27 kg (section on 'Materials'). At 3kmph, this cart would have reached Bishnupur in 6.5 hours, making only one trip a day possible. Hence, 1480 bullock carts would be required to transport the total quantity of stone. Assuming that a caravan of 10 such carts would be travelling together in each trip, then the total number of trips would be 150. Since only one trip is possible in a day, just the transportation of stone blocks to the temple site would take 150 working days. In reality the total duration of transportation would be more than that, considering the holidays, rest time, seasonal condition, etc.

To get an idea of the time taken for constructing a temple, the Orissa Analysis of Rates (Works Department, 2006) has been referred[13]. Based on this and the author's past experience of working with laterite[14] in Odisha, she has assumed two teams of 4 head masons and 8 helpers each, as the main team for construction. A similar estimate has been recorded by the Mandal family[15] of Hadal-Narayanpur, who commissioned twenty-five artisans to construct a few buildings over two and a half years (Santra, 1983). The required time for constructing a temple structure such as Nandalal temple, with 24 workers and without finishes, would be at least 365 working days, i.e., about 1.5 years[16], provided that the construction process was not interrupted.

Apart from these, an additional three months would be required for allowing the laterite to gain strength (IS:3620-1979, 2003). The blocks would have to be stacked on reaching the site, carried from the stack to the cutting yard, where they would be shaped and dressed. Then they would be taken to the construction area and would often have to be hoisted to the level where the construction was going on. A block could be carried safely by one person[17], or lifted safely in a sling by two people. These activities were also time consuming. In addition to this, foundation construction would need time for excavation, compaction, plinth filling and above all, allowing the foundation to settle and get consolidated, which would require at least one rainy reason. Many of these might have been done as parallel activities, if the construction site was efficiently managed.

In the light of this discussion, it appears that a temple would require about 3-4 years to complete its construction. In this type of assessment, there are many assumptions and one may raise a question on the accuracy of the estimated time, materials and skills requirements. In the absence of exact data, this section has carried out the assessment by logical argumentation that gives a fairly good idea on the construction management of temple buildings in Bishnupur.

Construction Management

The author has worked on the dimensional analysis of the ek-ratna temples of Bishnupur in order to decode the proportioning system, which is the matter for another publication. This was based on the dimensions of ten such temples. This paper, examines whether there was an inter-dependence of the proportions of temples and materials and construction techniques adopted.

To begin with, the external wall thickness was considered as the basic module, as it is determined by the strength and stability requirements of a structure during and after construction. The mean dimensions of the temple components **(Figure 15)** were divided by the external wall thickness. The ratios have been rounded off to one decimal place and tabulated in **Table 1 and 2**. These tables clearly indicate that the external wall thickness was the basic module of ek-ratna temples. For example, if the external wall thickness is assumed as ‘x’, then the garbha griha width is 2.5x (Table 2, column 3), veranda width is about 1.5x (Table 2, column 1) and veranda length is about 9.5x (Table 2, column 2), the façade width is about 11.5x (Table 1, column 1) and façade height is about 5x (Table 1, column 3). These numbers will be more accurate when this work is extended to the dimensions of more temples.

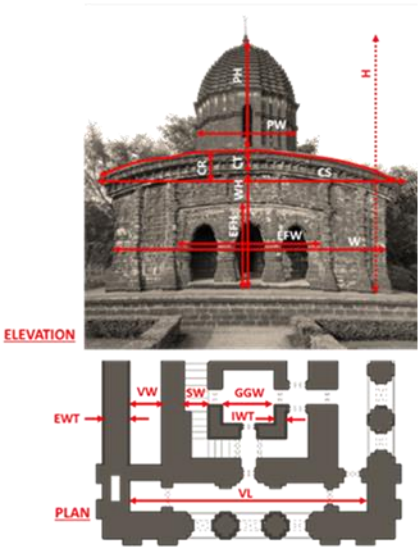

Figure 15: *Parameters for analysis of proportions*

	1	2	3	4	5	6	7	8	9	10
PARAMETER	W: EWT	H: EWT	H: EWT	EFW: EWT	EFH: EWT	CS: EWT	CR: EWT	CT: EWT	PW: EWT	PH: EWT
RATIO	**11.4**	**9.7**	**4.9**	**5.8**	**3.6**	**12.2**	**1.1**	**0.8**	**3.9**	**4.8**

Table 1: *Ratio of average façade dimensions with respect to external wall thickness (ewt) Source: Author*

	1	2	3	5	6	7
PARAMETER	VW: EWT	VL: EWT	GGW: EWT	IWT: EWT	EWT: EWT	SW: EWT
RATIO	**1.4**	**9.4**	**2.5**	**2.2**	**1**	**0.7**

Table 2: *Ratio of average plan dimensions with respect to external wall thickness (ewt) Source: Author*

It must be borne in mind that the external wall thickness is a function of the laterite block size. Another factor that plays an important role in determining the wall thickness is the bending moment created by the vault at wall base, as discussed in the section on 'Wall and Pillars'. Increase in veranda width would have increased the bending moment on the exterior wall demanding higher width to keep the resultant eccentricity within middle third. This suggests that the shape, size and mechanical properties of laterite stone and the geometry of the temple components were strongly inter-dependent. The master builders derived the temple form by striking a balance between the materials and the geometry, to meet the requirements of function, aesthetics and aspirations.

Conclusion

Bishnupur temples stood at the crossroads of religious requirements and technological possibilities, and was the product of the then contemporary knowledge of materials, skills and techniques of form making.

To begin with, this paper discusses the materials used, especially laterite and shell lime. This is followed by a discussion on the skills available and craftsmen's teams. The leader would have a set of standard designs and the patron could choose, based on his aspirations and financial capability.

Construction techniques of the roof, walls, openings and foundation of ek-ratna temples have been discussed. The most striking feature of the ek-ratna temples is the curved cornice, which follows the curvature of the entrance frame. The top of the entrance frame marks the top of the wall and the springing point of the veranda vault and corner domes. The cornice thickness seen on the façade is the thickness of the veranda vault. Thus, construction of some elements of the temple were articulated on the façade.

One of the main reasons for survival of ek-ratna temples was that the developed stress in the roof, opening, supporting and foundation systems were well within the allowable stress. However, the central pillars of the facade were the weakest links in the overall structural system of these temples. Calculations show that the horizontal thrust at the base of the veranda vault would create a minor tension at the inner edge of pillar base. Such small level of tension would not lead to structural failure, though, the turning of the pillar about its base might cause cracks at the vault base. Use of metal ties in Radha Madhav temple confirms this. This knowledge is very important for authentic conservation of the temples.

There is no direct information about the foundation of the ek-ratna temples. So, other researchers' works have been used to deduce the SBC of the soil and the calculations done to ascertain the nature of foundation. It was realised that widening of the walls by two steps was adequate if the foundation was taken deep enough.

A rough estimate shows that a temple construction would have taken 3-4 years. In absence of exact data, this section has carried out the assessment by clearly stating all the assumptions and gives a fairly good idea on the construction management of temple buildings in Bishnupur.

Finally, the paper demonstrates that the overall proportioning of the ek-ratna temple is related to its external wall thickness, which in turn is related to the laterite block dimensions, as well as strength and stability requirements of the temple. ■

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Notes:

[1] Bishnupur is a temple town in Bankura district of West Bengal. This was the capital of the medieval kingdom of Mallabhum, which was ruled by the Malla dynasty. The dynasty was founded by Raghunath, also known as Adi Malla, in 695CE.

[2] Gaudiya Vaishnavism is a bhakti movement which was initiated by Shri Chaitanya in early 16th century CE in Bengal. At the behest of Shri Chaitanya, Rup and Sanatan Goswami went to Vrindavan to establish the philosophical foundation of the Bengal Bhakti movement. This branch of Viaishnavism was known as Braja Mandal.

[3] The eleven significant ek-ratna temples in Bishnupur are Kalachand (1656 CE), Lalji (1658 CE), Murali Mohan (1661 CE), Madan Mohan (1695), three temples of Jora Mandir (1726 CE), Radha Govinda (1729 CE), Radha Madhav (1737 CE), Nandalal (n.d.) and Radha Shyam (1758 CE). Of these, only Madan Mohan was constructed in brick, the rest were in laterite.

[4] Mansingh’s son Jagat Singh was captured by Kotlu Khan, a local chieftain. Bir Hambir came to know of his whereabouts and helped Mansingh to find his son. This incident had been recorded in Akbar Nama Volume III (Beveridge, 1939: P 879). This ensured a cordial relation between the Mughals and Mallas.

[5] The western and south-western part of West Bengal till the river Hooghly is known as Rarh.

[6] Considering the maximum dry density of laterite as 1.8 tons/cum with moisture content of 17.65% (Ojo, G P et. al., 2016, p58), the weight of a laterite block 450x225x150 mm is 27 kg.

[7] The skill is disintegrating because of a lack of patronage and appreciation.

[8] The numbers of *chunarus* dwindled as the shell lime was gradually replaced by limestone-lime and finally with cement. There are only a few hundred *chunaru* families left in Bengal presently (https://en.wikipedia.org/wiki/Chunaru dt. 9.7.21).

[9] Land owners

[10] Kalachand, Lalji, Patpur, Radha Govinda, Radha Madhav, Radha Shyam, Nandalal, all in Bishnupur, Bankura district

[11] ASI →Archaeological Survey of India. Initially, plan drawings were obtained from https://www.asikolkata.in/ bankura.aspx dt 24.2.19 and subsequently, ASI furnished the digital copies of these drawings in April 2021.

[12] Safe Bearing Capacity

[13] It seemed viable to use the Orissa Analysis of Rates (Works Department, 2006), as it has a few items on the laterite wall construction and was drafted in the pre-independence days, after observing the traditional practices and interviewing the masons. It states that 8 people would need about 20 days to excavate the soil and 40 days for dressing and consolidation of the base.

[14] Odisha Health Project, Ministry of Health and Family Welfare, Government of Odisha, 1998

[15] Probably one of the local land owners or businessmen, who would commission constructions in the 17th-18th century CE

[16] There are about 299 working days in a year (365 days – 52 rest days – 24 ekadoshis, i.e. eleventh day of the lunar calendar – 60 rainy days = 299 days). Number of working days have been calculated based on conversation with Guru Prasad Sutradhar, son of Late Monu Mistiri, one of the traditional temple builders in Bishnupur.

[17] Each block weighs 27kg. The rates of an Indian Railways porter are fixed on the basis of the wight that one person can carry and starts from 40kg (source: https://www.irctchelp.in/porter-or-coolie-charges-at-railway/ accessed 5.2.21 07.30am). The same capacity has been assumed here as a minimum weight carrying capacity of construction workers.

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