

ENGINEERING AND ARCHITECTURE IN ANCIENT
AND MEDIEVAL INDIA

THE achievements of Indian people in the field of engineering began in the proto-historic times, from the third millennium B.C. or even earlier. The ancient Indian civilization like those of Iran, Iraq, Mesopotamia, and Egypt showed skill in the construction of buildings and granaries, in town-planning, and in the provision of civic amenities like community baths and other sanitary conveniences.

The earliest evidence of the technical skill of the ancient Indian lies perhaps in the numerous tools he carved out of stone in the course of his struggle for existence. A long period of trial and error requiring power of observation and the application of what was observed in his natural surroundings must have intervened between this period of the fashioning of crude pebble tools and the development of the hand-axe. The early palaeolithic age was followed by the middle palaeolithic age when he made tools on fine-grained flakes, which were smaller in size and included scrapers, points, awls or borers, blades, etc. These tools, archaeologists think, might have been used for dressing animal skins and barks of trees, smoothing the shafts of spears, cutting, chopping, etc. They may be classified into two groups—core and flake—according to the way in which they were made. Core tools were made by chipping or flaking away a stone until the desired shape was obtained. Flake tools were made, however, by detaching a large piece from a stone and then working it into the requisite shape. A third classification put forward by some archaeologists is the chopper-chopping tool group; these tools were made from pebbles by knocking off a portion to make the cutting edge. The new stone age (c. 400 B.C.) saw the growth of what is called the small stone microlithic industries of India. At Langhnaj in Gujarat have been discovered pottery and tools as well as sandstone slabs, flattened on one side and used for grinding. The next stage in the growth of man's skill in India is termed the neolithic revolution when he started settling down, making tools from bones of animals he hunted. Excavations at Burzahom near Srinagar have revealed that the earliest inhabitants 'of this valley lived in circular or oval pits dug into the *Karewa* soil. Evidence of post-holes along the edge of the pits indicated a timber superstructure covered over by a thatched roof. The pit-dwellers provided landing steps to reach down the floor of their house, where stone hearth and small-sized storage pits were met with. In the succeeding period, red ochre was found used as a colour-

ing material for the floor'.¹ Such pit-dwellings have also been found at Nāgārjunakoṇḍa in the Krishna valley.

CIVIL WORKS OF INDUS VALLEY PERIOD

Remains of the Indus valley civilization (fourth-third millennium B.C.) unearthed at Mohenjo-daro and Harappa now in Pakistan, Lothal in Gujarat, and Kalibangan in Rajasthan amply testify to the well-developed technical skill of ancient Indians. Mohenjo-daro in Sind and Harappa in the Punjab are deemed to have been the capital cities of the Indus valley. Each of the towns was approximately three miles in circuit. The dwellers of Mohenjo-daro were among the world's pioneers in city construction. The largest buildings unearthed in Mohenjo-daro measure 73·76m. × 34·13m. Road alignments were from east to west and from north to south, each crossing the other almost at right angles in a chessboard pattern. The width of the roads varied from 10·05 m. to 5·48 m., depending on the requirements of traffic. There is evidence of attempts to pave the roads at some places.

The houses unearthed are commodious and well built, indicating the civil engineering skill of the people. The bricks were well burnt and of various proportions, namely, 27·94 cm. × 13·33 cm. or 13·97 cm. × 5·71 to 6·98 cm. The bricks were cast in open moulds by the open stack method with wood fuel to burn them. Although the Indus valley people acquired considerable mastery over brick-making they have left us no evidence of decorative brick work. Most of the houses had more than one floor, although the number of rooms on the first floor was presumably limited. Nevertheless, the technique of load distribution must have been mastered by them. The houses were closely built. The average middle class dwelling was about 9·14 m. × 8·22 m., consisting of four or five living rooms. These houses were constructed with due provision for sanitary amenities. A typical house included a central courtyard; a well-room; a paved bath; a sewer pipe protected by brick work which ran beneath the floor into the public drain in the street, providing drainage from the courtyard; and a pipe running vertically in a wall to carry sewage from the upper floor. The use of a pulley wheel for drawing water from the wells was known as may be inferred from certain depictions in terracotta.

Among the ancient remains found in the Indus valley are two remarkable structures, viz. the Great Bath situated in the citadel mound at Mohenjo-daro and the Great Granary at Harappa. The overall dimension of the Great Bath is 54·86 m. × 32·91 m., while the swimming pool, situated in the centre of a quadrangle with verandahs on all sides, measures 11·88 m. × 7·01 m. The massive outer walls of the building are 2·13 m. to 2·43 m. thick

¹M. N. Deshpande, 'Archaeological Sources for the Reconstruction of the History of Sciences of India', *Indian Journal of History of Science* (May 1971), p. 5.

at the base with a batter on the outside. There are at either end of the swimming pool a raised platform and a flight of steps with another platform at the base of each flight of steps. The pool is lined with finely dressed brick laid in gypsum mortar with an inch of damp-proof course of bitumen. From an analysis of samples of bitumen at Mohenjo-daro, Forbes has determined that the cement contained in it was a kind of refined rock asphalt.² The Great Granary at Harappa consists of a series of parallel walls, each 15.9 m. long standing in two sections divided by a passage 7.01 m. broad. The building thus comprises two similar blocks, together measuring 51.51 m. \times 41.14 m. The walls are about 2.74 m. thick. In each block there are six halls alternating regularly with five corridors. Each of the halls is partitioned into four narrow divisions by three equidistant, full-length walls terminating in broader piers at the ends. The piers are made of burnt brick, while the partition walls are of mixed construction.

The remains of Lothal, nearly 3.2 km. in circumference, remind one of Mohenjo-daro in miniature. The town was more or less designed after the patterns of Mohenjo-daro and Harappa with streets constructed at right angles. An important feature was a thick mud wall, reinforced with burnt bricks on its northern periphery, which served as a defence against floods. The blocks of the town were raised on mud bricks to further provide a degree of security against floods. There is evidence of civic amenities like brick-built wells, underground sewers, cesspools, and brick-paved baths. Among the important structures are a dock with a wharf and a warehouse. The dock is a testimony to the engineering skill of its builders and was, according to Rao, 'the first ever venture made by man to build an artificial basin for sluicing ships at high tide'.³ In its conception and engineering it surpasses the Roman and Phoenician docks of later times.⁴ Its embankment walls measure 212.4 m. on the west, 36.4 m. on the north, 209.3 m. on the east, and 34.7 m. on the south. The basin and walls are lined with burnt bricks. It was built off the main stream in order to reduce the likelihood of silting and flooding, and incorporated a water-locking device and a spillway to ensure floatation of ships during low tide. Ships would enter the dock at high tide. The inner walls were made perfectly vertical so that cargo could be loaded and unloaded directly between the ships and the wharf. The wharf, measuring 260 m. ran along the western wall of the dock. From the wharf goods could be taken to the warehouse adjacent to it. The warehouse had a floor area of 1,930 sq. m., larger than the granaries of Mohenjo-daro and Harappa. The structure stood on a 4-metre high platform on which were raised sixty-four blocks of mud bricks,

²R. J. Forbes, *Bitumen and Petroleum in Antiquity* (Leiden, 1936), pp. 29, 38, 42, and 58.

³S. R. Rao, *Lothal and the Indus Civilization* (Asia Publishing House, Bombay, 1973), p. 56.

⁴*Ibid.*, p. 70.

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each block 3.6 m. square and 1 m. high. The blocks were interspersed with 1-metre wide passages to allow ventilation and easy access to the goods. On top of the blocks a superstructure of timber was raised.

Archaeologists have found in Kalibangan ruins of a town and a fortified citadel on an artificial platform of mud and mud-bricks six to seven metres high. Though smaller than Mohenjo-daro, Harappa, and Lothal, Kalibangan was a well-planned town with houses built in oblong blocks flanking the arterial streets, running in cardinal directions. Lack of street drains suggests that the sanitation of Kalibangan was not as rigorously maintained as in the other Harappa towns and cities. There were, however, private baths, soakage jars, and drains. Excavations reveal evidence of the use of copper axes, which 'clearly shows the beginning of metallurgy as early as 2450 B.C.'⁵

The Indus valley people thus achieved considerable proficiency in engineering and technical skill, as shown by their use of building materials and their construction of roads, drains, etc. A system of weights and measures was in vogue. Weights found at Mohenjo-daro and Lothal are normally of cut and polished cubes of chert. Finds of graduated scales made of shell at Mohenjo-daro, of bronze rod at Harappa, and of ivory at Lothal indicate their knowledge of practical geometry and land surveying. The average distance between the successive divisions of the scales is 6.70 mm., 9.34 mm., and 1.70 mm. respectively. Terracotta plumb-bobs and an instrument made of shell for measuring angles of 45°, 90°, and 180° were also found at Lothal.

VEDIC PERIOD

Whereas the Indus valley civilization was essentially urban, relying on extensive trade and depending upon organized city life for its existence, the Vedic civilization was primarily pastoral or an agricultural one in which complex urban organization was unknown. It is not surprising, therefore, that highly developed cities like Harappa and Mohenjo-daro did not appear during the Vedic period and that technology was in evidence only to the extent of providing for the necessities of village life.

Vedic texts are replete with words descriptive of dwellings and contrivances which provide an idea of the extent of technological knowledge of the period. The word pura occurs frequently in the *R̥g-Veda* (I. 53.7, 58.8; III. 15.4; etc.) and later Vedic texts and appears to mean a fort or fortification. Hundred-walled forts are also mentioned (I. 166.8; VII. 15.14). The term *mahā-pura* (great fortress) appears in the *Taittirīya Saṁhitā* (VI. 2.3.1), *Aitareya Brāhmaṇa* (I. 23.2), and other texts. The type of material with which the forts were constructed is not clearly indicated. In all probability they were temporary structures, perhaps merely ramparts of earth with ditches and stone

⁵Deshpande, *op. cit.*, p. 6.

PURA - means Fort

walls, or possibly made of wood. In one place (IV. 30.20) the *Rg-Veda* refers to a fort made of stone (*aśmamayī*), but Macdonell and Keith think this may mean sun-dried bricks.⁶

Gṛha or *dama* is used to denote a house. The sides of the house were called *pakṣa* and the door *dvāra*, while the door with its framework was termed *ātā*. Macdonell and Keith, following Zimmer, believe that houses were constructed with wood.⁷ From passages in the *Atharva-Veda* (III. 12; IX. 3), Zimmer has suggested the following possible method of construction. On a good site, four pillars (*upamit*) were set up, against which beams were propped as supports (*pratimit*). The pillars were then joined on top by cross beams (*parimit*). Bamboo (*vaṁśa*) was used as ribbing over a ridge called *viṣūvant*. Finally, the ribs were covered with a kind of thatching. The walls were set up with grass tied in bundles (*palada*) which were bound together.⁸ Some terms like *sadas* (sitting room) and *patnīnām sadana* (wives' room)⁹ suggest that the dwellings were compartmented.

References to private dwellings in *Gṛhyasūtra* texts indicate that spacious houses in the later Vedic period were quite common. Such a house appeared to contain among other things an assembly room and a resting or retiring room, with a latrine detached from the main building. An arrangement of water supply was evidently part of house construction. Ponds, wells, and other reservoirs of water are also mentioned in *Gṛhyasūtra* texts. Some of these were presumably public works meant for general use. There are references to bridges, roads, cross-ways, and squares.

The chariot (*ratha*) was an important piece of military equipment from the beginning of the Vedic age. It generally had two wheels (*cakra*), each consisting of rim (*nemi*), felly (*pradhi*), nave (*nabhya*), and spokes (*ara*), connected by a non-revolving axle (*akṣa*), the end of which (*āṇi*) fit into the nave holes (*kha*). Solid wheels were also sometimes used. The body of the chariot (*kośa*) was attached to the axle and was possibly constructed with wicker work or leather stretched over a light wooden frame. A seat for the warrior was provided. From the axle a pole (*iṣā*) ran perpendicular to the front of the chariot where it was joined to a yoke (*yuga*) which was secured to the necks of the horses, usually numbering two although three or four were common, and sometimes even five. The horses were also tied at the shoulders by means of traces. Reins were attached to bits in the horses' mouths. The chariot consisted also of other minor auxiliary parts. The *Śulvasūtra* of Āpastamba (VI. 5) gives the following dimensions of the chariot: axle, 104 *aṅgulis* (finger-breadths);

⁶A. A. Macdonell and A. B. Keith, *Vedic Index of Names and Subjects*, Vol. I (London, 1912), p. 538.

⁷*Ibid.*, p. 230.

⁸H. Zimmer, *Altindisches Leben*, p. 153.

⁹Macdonell and Keith, *op. cit.*, Vol. I, p. 231.

pole, 188 *āṅgulis*; and yoke, 86 *āṅgulis*. The driver of the chariot (*sārathi*) stood on the right while the warrior (*savyaṣṭhā*) was positioned on the left, either standing or sitting.

Mention of such words as *kulyā* (canal) and *khanitrimā āpaḥ* (water obtained by digging) in the *R̥g-Veda* (III. 45.3 and VII. 49.2 respectively) suggests that some kind of irrigation system which utilized well water was in existence. Water used to be raised by a wheel to which a strap with a pail attached to it was fastened.

POST-VEDIC PERIOD

For evidence of the engineering and technical skills of ancient Indians in the early post-Vedic period we have to depend largely on literary sources. We are told of high walls with watch towers, strong ramparts with buttresses, and gates. A number of towns and cities, called *janapadas*, of considerable importance had developed before the seventh century B.C. Noteworthy among them were Ayodhyā, Vārāṇasī, Campā, Kāmpilya, Kauśāmbī, Mathurā, Mithilā, Rājagṛha, Roruka, Sagala, Sāketa, Śrāvastī, Ujjayinī, and Vaiśālī.¹⁰ An example of a stone wall around a hill fortress before the sixth century B.C. has been unearthed at Girivraja near Rājagṛha—modern Rajgir. But books referring to this earlier period make no mention of stone except for pillars or staircases. Only while describing a fairyland is a palace of stone referred to. The presumption, therefore, is that the superstructures of buildings during this period were all made of wood or brick. Reference may in this connection be made to the ruins of some other ancient cities like Takṣaśilā and Sāñci. Takṣaśilā is mentioned as a flourishing city and centre of learning in Buddhist literature probably compiled at least in the fourth century B.C. Archaeological excavations at the Bhir Mound have revealed several layers, of which the latest and uppermost was quite clearly of the late third or early second century B.C. There does not appear to exist any direct evidence for dating the lowest layers of the ruins. At any rate, the ruins unearthed in the Bhir Mound bear adequate testimony to the kind of house-building technique in vogue at the time. The buildings 'were of rubble masonry, in which kanjur and limestone, finished with a coating of mud-plaster, were used'.¹¹ The remains of a fairly large house, with a courtyard and pillared hall and flanked by narrow, blind alleys have also been excavated in the western part of the Bhir Mound.

City life became more and more organized and by the time of Candragupta Maurya (c. 324-300 B.C.) it had taken a clear shape. There is evidence of the use of wooden piles in preparing the foundations of houses in soft soil

¹⁰T. W. Rhys-Davids, *Buddhist India* (Calcutta, 1959), pp. 17-21, 33.

¹¹*Buddhist Remains in India*, ed. A. C. Sen (Indian Council for Cultural Relations, New Delhi, 1956), p. 67.

during the pre-Maurya period.¹² And wood continued to be an important constituent of house-building during the days of Candragupta. The testimony of contemporary Greek historians shows that a wooden palisade was erected at this time for the fortification of Magadha's capital Pāṭaliputra against floods.¹³ Other types of fortification were also known.¹⁴

Kauṭilya's *Arthaśāstra* affords a glimpse of Indian approach to town planning about this time. Kauṭilya's view of an ideal city is more or less in harmony with the description of Pāṭaliputra given by Megasthenes and other Greek writers. The *Arthaśāstra* devotes one of its chapters (II. 3) to fortifications. Elaborate discussion follows in the next chapter about the construction of royal buildings and houses for different categories of citizens. Roads of various dimensions are prescribed for different purposes. According to Kauṭilya, the *durga* or fortified city is one of the seven constituent elements of the state. The meticulous way in which he deals with the lay-out and organization of forts gives the impression that the science of fortified city-building had already advanced considerably.

The celebrated Chinese pilgrim Fa Hien who visited Magadha during the reign of Candragupta II (c. A.D. 380-413) was struck with wonder at the sight of the royal palace of Aśoka (c. 269-232 B.C.) as also the houses set up by him for dispensing charity and medicine. Fa Hien is on record as having noted that the palace of Aśoka was not a work of men, but of 'spirits which piled up the stones, reared the walls and gates, and executed the elegant carving and inlaid sculpture-work in a way which no human hand of this world could accomplish'.¹⁵ Mention may be made in this connection of the ruins of a hundred-pillared hall discovered by excavations around the site of Mauryan edifices. One of the important innovations of Aśoka was the substitution of stone for wood and brick. Structures and monuments of various types were set up in the country during his reign. The Mauryas introduced rock-cut architecture and the practice of highly polishing the surface of sandstone pillars. The high polish, besides lending splendour, also rendered the surface water-repellant and resistant to actions of weather.

BUDDHIST STŪPAS AND VIHĀRAS

In the construction of religious edifices like *stūpas* and *caitya-grhas* the Buddhists showed their engineering skill. Construction of *stūpas* and *caityas* was

¹² *Indian Archaeology, 1962-63—A Review*, ed. A. Ghosh (Archaeological Survey of India, New Delhi), p. 47.

¹³ *Ancient India as Described by Megasthenes and Arrian*, trans. J. W. McCrindle (Calcutta, 1926), pp. 65-66.

¹⁴ *Kauṭilya's Arthaśāstra*, trans. R. Shamasastri (Mysore, 1961), p. 50.

¹⁵ *The History and Culture of the Indian People: The Age of Imperial Unity* (Bharatiya Vidya Bhavan, Bombay, 1968), p. 86.

an important aspect of Buddhist religious life. The word *stūpa* is derived from the root *stūp*, meaning 'to heap', and suggests the mound shape and method of construction of these edifices, while the word *caitya* is derived from *citi* (altar).¹⁶ Stūpas are pre-Buddhist in origin, being associated with burial mounds. The earliest Buddhist *stūpas* were most probably low mounds consisting of layers of piled-up earthen tumulus which were separated from each other by thinner layers of stone chips and cloddy clay. The proportions of *stūpas* after construction were enlarged in some cases, and a *stūpa* is sometimes seen to have been enlarged several times. For this reason, and because of wreckage and decay, it is not always possible to determine the exact shape and type of construction of the original *stūpa*. The earliest ones were built solid without any interior structural support or fill. Of the earliest dated *stūpas*, those erected by Aśoka were made of bricks and mud mortar. The Śuṅga period saw some innovations in construction like providing a veneer of hammer-dressed stones and in plastering the surface of the dome. Gradually the advantage of filling the core with rubble or other material was recognized. And the outward thrust of the fill material on the facing wall was minimized by dividing the inner space into compartments in the form of boxes or radiating spokes like those of the wheel of a cart. The stone railings and gates of *stūpas* at Barhut and Sāñcī clearly point to the earlier prototypes being made of wood.

The growth of Buddhism also inspired the establishment of monasteries (*vihāras*). The earliest monasteries were probably simple dwellings made of wood, rubble and mud, or other perishable materials. Thus the *vihāra* had a humble beginning with a building having a series of cell-like rooms, set around facing an open space. The early Buddhist cave monasteries were quadrangular in shape, a typical example of which has been found at Nāsik. This comprises a hall about 4.2 metres square with two cells in each of the three sides. The basic pattern for such *vihāras* must have been evolved by the second century B.C. as seen from some of the specimens at Ajantā. The *vihāra* had later a covered *mandapa* (courtyard) in the centre and with the installation of Buddha's image inside the cell in the back wall it became a *caitya*-cum-*vihāra*, serving the purpose of a shrine as well. At Nāgārjunakoṇḍa separate *caitya* halls were provided in the *vihāra* enclosures. The *vihāras* gradually became larger, some of them being double-storeyed.

The *stūpa* structure in its more developed form included a circular passage and a railing around it with gates (*torāṇa*) as seen at Sāñcī (Plate I). Those in the South did not have the *torāṇas* but often had projected platforms (*āyaka*) at the cardinal points on which rested a row of tall cylindrical monolith pillars as at Jaggayyapeta, Amarāvati, etc. The railings of the Amarāvati *stūpa* are made

¹⁶R. Sengupta, 'The Motif on the Facade of the Visvakarma Temple at Ellora', *Museums and Museology : New Horizons* (Agam Kala Prakashan, Delhi, 1980), pp. 223-24.

of marble and the dome also is covered with slabs of the same material. The *stūpa*, a solid hemispherical dome (*aṇḍa*), usually was placed on one or tiered bases and surmounted by a railed pavilion (*harmikā*). Later specimens show more ornate forms, the base-terraces as also the umbrellas being multiplied as at Nālandā (Bihar), Ratnagiri (Orissa), and other places. The outer surface of the basal cylinder (*medhi*) in southern examples, however, received encasing slabs sculptured tastefully as at Amarāvati (Plate II), Nāgārjunakoṇḍa, etc.

Another type of Buddhist structure was the *caitya-grha*, a *stūpa*-cum-sanctuary. Initially, the *stūpa* was the object of worship. Later, an image of Buddha was either placed on it as at Ajantā and Ellorā (Plate III), or worshipped singly as at Nāgārjunakoṇḍa. The *caitya-grha* usually had an apsidal ground plan with the *stūpa* in the apsidal end and a central nave separated from the side aisles by a row of pillars. Unfortunately no structural *caitya-grha* survives, but the rock-cut examples depict them with gabled wooden roofs, initially simple in form, and with wooden pillars arranged with an inward rake to counter the outward thrust of the gabled roof. The latest examples at Ellorā show a logical development into a two-tiered roof with trusses.

The design of a rock-cut *caitya-grha* or *vihāra* was first planned by an architect or master craftsman. In choosing a suitable site he had to take into account such factors as the type of rock and whether it was free of faults, the existence of a suitable ledge from where the cave excavation could be started, and the proximity of spring or river water for drinking and bathing. The actual work must have been preceded by a detailed plan. It was necessary to know the exact position and size of stone blocks to be left standing which would later be carved into the desired shapes. For this precise measurements were necessary. Sketch-books containing patterns of the decorative stone carvings were no doubt essential. Some examples of unfinished caves show that the procedure was to excavate them from the ceiling downwards, thereby minimizing the need for scaffolding. As the rough cutting was being done inside the cave, simultaneously the decorative finish of the cave face would be in progress. This is borne out by some examples of caves which were abandoned before final excavation of the interior, although the face had been completed. Scaffolding was used for carving the capitals on the pillars.

Buddhist temples followed the contemporary architectural styles, as did the Jaina and Brāhmanical. There are a few very early Buddhist temples still standing from which one can get an idea of the type of construction employed in the superstructure. Wood was no doubt employed to a great extent. The earliest Buddhist temple standing, temple No. 17 at Sāñcī, is made of stone. Among the marvels of Buddhist architecture is the tower of the temple at Sārnāth which with its seven clearly marked receding storeys rose to a height of 33.4 m. The pyramidal structure is decorated by mounting

Amatt

a miniature *stūpa* and *harmikā* pinnacle. Similarly imposing is the shrine at Bodh Gaya with its 55-metre temple spire. Superseding the architectural magnificence of both Sārnāth and Bodh Gaya stand the remains of Nālandā, one of the greatest seats of learning in ancient India. The lay-out of the campus with its 33.4-metre high *stūpa* and the colleges and dormitories must have called for elaborate architectural designing and engineering technique. There is evidence of the use of both brick and timber in construction.

TEMPLE ARCHITECTURE

The Gupta period (c. A.D. 300-600) saw the beginnings of systematic construction on the basis of structural principles in temple architecture. The basic elements are a square sanctum (*garbhagrha*) for the image, a small pillared portico (*mukhamandapa*), and sometimes a covered circumambulatory passage (*pradakṣiṇapatha*) around the sanctum. The characteristic of the early temples is a flat roof as found at Sāñci (Plate IV), Tigawa, and Eran (all in Madhya Pradesh); later temples such as are seen at Deogarh (Madhya Pradesh) and Bhitargaon (Uttar Pradesh) show a rudimentary spire (*śikhara*). There was a tendency during this period in stone construction to use stones larger than what the size of the building warranted. This was because the relationship between the strength and stability of construction and the economy of materials was yet to be understood. The stones were usually well cut and finely dressed, but no mortar was used. The stone was usually prepared at the site of the quarry. After the initial block of stone had been removed from the living rock, it was sectioned by making a groove along the desired division and then sinking holes into this groove at intervals. Wooden wedges were then pounded into these holes. On being wetted, the wood expanded, thus breaking the stone along the line of the groove. The blocks were faced first with a large iron chisel and then with a small one. Fragments of carvings found at some quarries suggest that the sculpturing of the stones was also usually done at the quarry site, although sometimes this was done after the stone had been set in its place on the temple itself. All of this entailed accurate measurements. Models to scale were perhaps sometimes employed.

From about the fifth century A.D. brick-built religious structures, both Buddhist and Brāhmaṇical, gradually became common in the alluvial plains. These include Buddhist *caitya* halls, monasteries, and *stūpas* as well as Brāhmaṇical temples. Bricks were easy to procure in the plains, whereas stone was not always readily available. And bricks also afforded the advantage of convenient handling and flexibility in construction technique because of their small size. One difficulty encountered in the use of bricks was the bridging of spaces as in the case of doorways, windows, and other openings. The craftsmen attempted to overcome this problem by using exceptionally

large bricks, some early examples being more than 50 cm. long. But even this was not always sufficient to surmount the difficulty, and so lintels of wood were resorted to. Stone lintels were subsequently found to be preferable to wooden ones. At one period brick structures with stone dressings became a rather common type of construction. Another method of spanning a gap was to oversail the courses of brick until they met. The vaulted roofs of *caityas* were constructed in this manner, a thick coating of plaster being applied over the surface to create the curvilinear shape of a vault. But the next logical step—to develop the arch in which the bricks act as supports to one another—did not take place until after the advent of the Muslims. There occur a few examples of experiments in this direction, the most notable being the entrance to the shrine at Bodh Gaya, although it is possible that this arch was constructed as part of a later restoration.

The post-Gupta period witnessed brisk building activity with experiments in various temple forms. Interesting results of such experimentations are seen at the principal centres at Aihole, Badami, Mahakuteswar, Pattadakal (all in Bijapur district), and Alampur (Mahbubnagar district). At Aihole the Lād-Khān Viṣṇu temple (sixth century), Meguti Jaina temple (seventh century), and Kontguḍi Śiva temple (seventh century) typify the *maṇḍapa* style with the shrine against the back wall of the pillared hall called *maṇḍapa*; its sloping roof in three tiers has a *śikhara* in the centre and is supported by pillars of receding heights. The Durgā temple (eighth century), though its roof is constructed on the same principle, has an apsidal plan in imitation of the Buddhist *caitya-grha*. Similar structures are also to be found at Chejarla (Guntur district) and Ter (Osmanabad district). Subsequent development is observed in the later examples in which components of the sanctum have a northern *śikhara*, a pillared hall carrying a flat roof, and a porch. This is exemplified by the Huccimalliguḍi temple and others, sometimes with a little adjustment of the *śikhara* in both plan and design. Such specimens are found at Alampur (eighth century), Pattadakal (eighth century), Osian (Jodhpur district, ninth century), Roda (Sabar Kanta district, ninth century) (Plate V), Jageswar (Almora district, ninth-tenth century), etc. The South Indian temples of the *vimāna* (lit. well-proportioned) type with a pyramidal *śikhara* made their earliest appearance at Badami in the simple form of the temple known as Mālegiṭṭi-Śivālaya (garland maker's temple). Later variants and developed forms of *vimāna* with *śālās* (miniature oblong shrine with barrel-vault roof), *karna-kūṭas* (miniature square shrine at the corner of the roof), and *nāsikās* (arched opening above the superstructure wall, projecting from the facade) are seen on the Virupākṣa temple (eighth century) at Pattadakal, Shore temple (eighth century) at Mahabalipuram (Plate VI), Kailāsanātha temple (eighth century) at Kanchipuram, Bṛhadīśvara temple (tenth century) at

Arch
Muslims

Vimāna
started
at
Badami

Tanjore, Airāvateśvara temple (twelfth century) at Darasuram, etc. Equally interesting are the Hoysala (twelfth-thirteenth century) temples at Halebid and Belur, famous for their intricately carved sculptured decorations, a kind of which is also seen in some of the Vijayanagara (fourteenth century) temples noted for large-sized *maṇḍapas*. Gateways (*gopuram*) to the temple enclosures constituted another important feature (Plate VII). These were usually capped by a vaulted roof, the later examples soaring high, the oblong size at each storey diminishing with the height. Although there are many examples, the temple-city at Srirangam has tall *gopurams* fixed in the seven concentric enclosure walls around the temple of Raṅganāthasvāmī (Viṣṇu) which is unique.

The vaulted roof was widely distributed and appeared on structural temples in North India from the eighth century. The Vaital-Deul (eighth century) at Bhuvaneshwar, the Teli-kā-Mandir (ninth century) at Gwalior, and Nava-Durgā temple (ninth century) at Jageswar are examples of this type. Though essentially linear in elevation, the North Indian śikharas have some variations. While at Bhuvaneshwar itself the typical Orissan form is represented by the Siddheśvara and Kedāreśvara temples (tenth century), the Rājārāṇī temple (eleventh century) shows an interesting experiment with miniature śikharas clustered around the *janṅhā* (bottom portion of the spire) as in the temples of western and central India including those at Khajuraho. The Liṅgarāja temple (eleventh century) shows the culmination and grandeur of this type of temple (Plate VIII), but the Sūrya temple (thirteenth century) at Konarak (Puri district) in its original form with bold and lively sculptural decorations must have been a magnificent work. At Khajuraho, again, a beginning was made with a plain *śikhara* without any embellishment of the miniature spires (*urū-śṛṅgas*) which became the characteristics of the later examples. The temple components were *ardha-maṇḍapa* (entrance porch), *maṇḍapa* (hall), *antarāla* (vestibule), and *garbhagrha* (sanctum), the entire structure being placed on a high platform and the walls decorated with beautiful carvings (Plate IX). The result of these experiments was the emergence of two broad temple architectural styles one predominating in the North called *nāgara* and the other common in the South called *drāviḍa* or *vimāna*.

The main structural component during the post-Gupta period continued to be stone. One wonders how the big slabs of stone used in the temple structures were transported and set up in position to make the temples. From reliefs carved on temples and from a manuscript describing the building operations of the temple at Konarak one gets an idea of the methods employed in transporting large stones to the construction site and hoisting them into place. They were transported on barges along rivers and streams or pulled by elephants over wooden rollers. They were lifted into place by means of

North - Nāgara
South - Drāviḍa

rope pulleys on scaffolding. Ramps of timber or sand were built on which to haul up exceptionally large stone slabs.

The Jaina temples did not have any distinct form of architecture. In later days the Jains built up a large number of temples in a rather unplanned manner at the sacred hills like Girnar (Junagarh district) and Śatruñjaya (Bhavnagar district). Nonetheless, the Dilwara temple at Mount Abu and the temple of Nemināthā do evoke appreciation, the former especially for its intricately carved sculptures.

The later temples of Bengal are characterized by a simple curved roof, imitating the bamboo-and-thatch constructions of the region. The Vishnupur (Bankura district) temples belong to this type. There are still other popular types of miniature shrines grouped in tiers to form five- or nine-spired (*pañca-* or *nava-ratna*) shrines.

ROCK-CUT ARCHITECTURE

The rock-cut temples, both cut in and out of the rock, mostly followed the contemporary architectural styles. The earliest group of such temples excavated by Aśoka in the Barabar and Nagarjuni hills (Gaya district), depicts the basic forms of rock-cut architecture. Subsequent rock-cut shrines, especially those of the Buddhists in western India at Bhaja Kondhane, Pitalkhora, Ajantā, Junar Karle, and Junagarh, were fashioned in imitation of the earlier wooden constructions. Among the monasteries, the two double-storeyed ones at Ellorā are the largest. Brāhmanical caves are at their best at Badami, Ellorā, Elephanta, and Mahabalipuram with a profusion of beautifully carved-out sculptures. At Mahabalipuram huge granite boulders have been chiselled to various shapes (Plate X).

The Kailāsa temple at Ellorā (c. A.D. 800) stands unparalleled as a monument to the artistry and craftsmanship of Indian rock-cut architecture. Brown describes it as 'the most stupendous single work of art executed in India'.¹⁷ The temple of Kailāsa was executed by cutting away more than fifty million tonnes of rock from the sloping hill by means of hammer and chisel, a process which took some 100 years. The first step was to cut three trenches at right angles into the hill, thereby isolating a massive block of stone over 60 m. long, 30 m. wide, and 30 m. high. Next, this block was carved from the top downwards and hollowed out into the form of the temple with its intricate carvings. In order to highlight the shape of the temple against the grey stone of the mountain surrounding it, the entire edifice was coated with a white gesso, imparting to it a brilliant sheen.

The Jains too carved out retreats in the hills of Udayagiri and Khaṇḍagiri

¹⁷Percy Brown, *Indian Architecture—Buddhist and Hindu Period* (Bombay, 1942), p. 90.

near Bhuvaneshwar in the first century B.C. and shrines later at Ellorā, Badami, and elsewhere.

INDO-ISLAMIC ARCHITECTURE

The Muslims brought with them new building traditions and forms of expression. The flat lintels or corbelled ceilings were replaced by arches or vaults and pyramidal roofs or spires by domes. Sun-shade or *chajja* fixed into and projecting from the wall, kiosks on the roof, tall towers, and half-domed portals are some of the distinctive features of architecture which came into vogue with the Muslims in India. Introduction of the new style was not, however, universal. Muslim architecture with the associated technique and skill flourished while mingling with the prevailing Hindu style which, again, varied from region to region.

In Delhi itself one can see the development of different forms under the five different Muslim dynasties until the Moguls assumed power. The Mamluks or the Slaves (1206-90) had to their credit the Quwwatī-Islām mosque, the imposing Qutb Minār, and the first monumental tomb in India, Sultan Ghuri's tomb. But it is only during the time of the Khaljis (1290-1321) that Indo-Islamic architectural traits, obviously of Seljukian flavour, like the low dome, red sandstone facing with white marble bands, and 'spearhead' fringe on the underside of the true arch are noticed in the Alāi Darwāza in the Qutb complex and Jamā 'at-Khāna Masjid which influenced later constructions. Thus in spite of the plain and austere surface of grey stone introduced by the Tughluq rulers (1320-1413), Ghiyās-ud-dīn's tomb (Plate XI) still retained the red sandstone and marble facing, though vaults over large halls, battered walls, conical domes, etc. mark further innovations. Again, the tomb of Khān-i-Jahān Tilangānī with an octagonal chamber covered by a dome and enclosed by a verandah, each side of which is pierced by three arches, later influenced the tombs of Mu'iz-ud-din Mubārak Shah and Muḥammad Shāh of the Sayyids (1414-51) and that of Sikandar Lodī. The Lodīs (1451-1526) in their turn introduced in the two mosques of Barā Gumbad and Moṭh-kī-masjid new features in dividing the prayer chamber into five bays surmounted by three domes resting on corbelled pendentives and the terminal bays being roofed by low vaults. These features, along with a wall-mosque in a garden enclosure as in Sikandar Lodī's tomb, were further developed in the Mogul period.

The contemporary architectural styles of the Delhi Sultanate were broadly followed in their provincial kingdoms of Gujarat, Bengal, Malwa, Jaunpur, Deccan, Khandesh, and Kashmir. The Gujarat style emerged as the richest and probably the most prolific, the Deccan style being remarkable for its bold conception and variety of forms. If the Jāmi'Masjid at Cambay (1325) represents the earlier work, the Jāmi'Masjid (1423) at Ahmedabad (Plate XII)

with prominent minarets denotes its transitional period. One can see the flowering of this style in such examples as the mosques of Muḥāfiz Khān (1492), Rānī Siprī (1519), and Sīdī Said' (1572), all famous for beautiful workmanship. In the Deccan, the Jāmi'Masjid (1362) at Gulbarga is unique in having a roofed courtyard. The college building of Khwāja Maḥmud Gāwān (1422) at Bidar with its tall bulbous domes, glazed tiles on the walls, etc. is almost entirely Persian in conception, and the royal tombs there with stilted domes are noteworthy. In Bijapur the bulbous dome with the drum concealed behind a row of petals, four-centred arches with low piers, and slender minarets adorn Ibrāhīm-Rouza (Plate XIII), Mihtar Maḥal, etc. But by far the *magnum opus* is the tomb of Muhammad 'Ādil Shāh (1627-57) known as Gol-Gumbad, having the largest dome cubicle in the world and famous for its acoustic property.

The form of the Lodī octagonal pattern was further improved upon and developed in Sher Shāh's tomb (c. 1540) at Sasaram having pillared domes and matching pillared kiosks on the terraces. It rises with a thirty-two sided base for the crowning dome. The Qil'a-i-Kuhna Masjid inside the Purānā-Qil'a at Delhi anticipated the early Mogul mosques and, unlike the plain tombs, was decorated with coloured marble and ornamental designs.

The contribution of the Moguls of Timurid traditions in the history of Indo-Islamic architecture remains unparalleled. Encased with red sandstone or marble, their buildings are remarkable in conception, beauty, and symmetry. Their earlier construction, the Jamāli-Kamali-Masjid, is traditional in concept. Humāyūn's tomb, set in a garden enclosure, has Persian elements like arched alcoves, corridors, and the high double dome. Akbar's buildings at Fatehpur Sikri like the Jāmi'Masjid with the majestic Buland Darwāza (Plate XIV), the unique Dīwān-i-Khās, and the exquisitely carved houses of Turkish Sultanā and Birbal are the results of a happy blending of indigenous and Islamic modes. At Agra the imposing gateway to Akbar's tomb (Plate XV), profusely decorated with inlay works as also seen in the finely carved marble tomb of I'timād-ud-daulāh having four corner minarets, set a new trend which considerably influenced the technique employed in constructing the Tāj Maḥal (Plate XVI). Shāh Jahān's buildings are noted for their foliated arch; dome, bulbous in outline and constricted at the neck—a typical Timurid feature; and greater use of marble. The Moti-Masjid in the Agra Fort; the incomparable and unique Tāj Maḥal with its garden; the largest mosque in India, the Jāmi'Masjid of Delhi; and the Red Fort in Delhi—all testify to his creative zeal and passion for building edifices. The decline is indicated in the Bibi-kā-Maqbara, a replica of the Tāj Maḥal at Aurangabad, while the tomb of Safdar-Jang marks the last phase of Mogul architecture of the pattern set by Humāyūn's tomb.

Mogul
Contributor