CHAPTER - IV

ENGINEERING

Architecture, being the art and science of building, is dealt with in this section in its engineering aspects, which may be broadly summed under the umbrella title "Technique". Other aspects of Architecture covered by the word "Art" include: Use or the Utility aspect, which covers Architectural Types like Domestic Architecture, Religious Architecture, Recreational Architecture, etc.; Expression or the Aesthetic Aspect, which covers such elements of Architecture as Space, Structure, Form, and Time; and Philosophic Postulates as are customarily dealt with under Theory of Architecture covering issues like Functionalism, Tradition, Modernity, and so forth.

"Techniques", in simple terms, are Materials and Methods. Methods cover various forms of Building Construction by which structures are formed from particular materials. These methods are influenced not only by the availability and character of materials but also by the total technological development of society, for Architecture depends on an organised labour force as well as on the existence of the tools and skills necessary to secure, manufacture, transport, and work durable Materials.

Techniques are discussed here in terms of the characteristics of building materials and the methods by which they are put together in the making of Architecture. In this special sense, Building Construction is quite simply the sensible assembly of different Materials, viz., stone, and brick.

MATERIALS

Stone: In most areas where stone is available, it has been favoured over other Materials for the construction of
monumental architecture. Its advantages are durability, adaptability to sculptural treatment, and the fact that it can be used in modest structures in its natural (i.e., untreated) state. But it is difficult to quarry, transport, and cut, and its weakness in tension (ability to resist pulling force) limits its use for beams, lintels, and floor supports (all these are horizontal members of Structure).

**Brick:** Brick compares favourably with stone as a building material for its fire- and weather-resisting qualities and for the ease of production, transportation, and laying. The size of bricks is limited by the need for efficient drying, firing, and handling, but shapes, along with the Methods of brick-laying, have varied widely throughout history. Special shapes can be produced by moulding (by hand or by machine) to meet particular building (Structure) or Expressive (Aesthetic) requirements. For example, wedge-shaped bricks are sometimes employed in Arch-construction, and bricks with rounded faces in columns (vertical members of Structure). Bricks may be used in construction only in conjunction with mortar (the material that holds two building units such as bricks or stones together) since the unit is too small and too light to be stabilised by its own weight.

**METHODS**

**Wall:** The two types of wall are load-bearing, which supports the weight of floors and roofs, and non-bearing, which at most supports its own weight.

**Load-Bearing Wall:** The load-bearing wall of masonry is thickened in proportion to the forces it has to resist: its own load, the load of floor, roofs, persons etc., that may cause it to crack or buckle. Its thickness often can be reduced at the top, because loads accumulate towards the base; in high buildings
interior or exterior setbacks at the floor-level of upper storeys do this. Walls that must resist lateral forces are thickened either along the whole length or at particular points where the force is concentrated. The latter method is called buttressing. The type of support for floors and roofs determines the placement of walls. The commonest support is the beam, which must be jointed to walls at both ends; consequently, its maximum permissible length establishes the distance between load-bearing walls. All floors and coverings are most easily supported on straight, parallel walls except the dome.

**Post-and-Lintei:** The simplest illustration of load and support in construction is the post-and-lintel system, in which two upright members (posts, columns, piers) hold up a third member (lintel, beam, girder, rafter) laid horizontally across their top surfaces. Also called the Trabeate System, this is the basis for the evolution of all openings. But, in its pure form, the post-and-lintel is seen only in colonnades and in framed structures, since the posts of doors, windows, ceilings and roofs are part of the wall.

The historical significance of the post-and-lintel system has been brought out in the Encyclopaedia Britannica as under:-

From prehistoric time to Roman Empire the post-and-lintel system was the root of architectural design. The interiors of Egyptian temples and the exteriors of Greek temples are delineated by columns covered by stone lintels. The Greeks opened their interior spaces by substituting wooden beams for stone, since the wood required fewer supports. The development of the arch and vault challenged the system but could not
diminish its importance either in masonry construction or in wood framing, by its nature dependent on posts and beams.

**Arch:** The arch may be called a curved lintel. Early masonry builders could span only narrow openings because of the necessary shortness and weight of monolithic stone lintels. With the invention of the arch, two problems were solved: (1) wide opening could be spanned with small light blocks, in bricks as well as stone, which were easy to transport and to handle; and (2) the arch was bent upwards to resist and to conduct into supports the loads that tended to bend the lintel downwards. Because the arch is curved, its upper edge has a greater circumference than its lower, so that each of its blocks must be cut in wedge-shapes that press firmly against the whole surface of neighboring blocks and conduct loads uniformly. This form creates problems of equilibrium that do not exist in lintels.

**Vault:** The evolution of the vault begins with the discovery of the arch, because the basic “barrel” form, which appeared first in ancient Egypt and the Near East, is nothing more than an arch deep enough to cover a three-dimensional space. In other words, an arch may be called a series of arches joined together to form a continuous whole. Since the barrel vault exerts thrust as the arch does, it must be buttressed along its entire length by heavy walls in which openings must be limited in size and number. This is a disadvantage, since it inhibits light and ventilation.

**Dome:** Domes appeared first on round huts and tombs in the ancient Near East, India, and the Mediterranean region but only as solid mounds or in techniques adaptable only to the smallest buildings. They became technically significant with the

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introduction of the large-scale masonry hemisphere by the Romans. Domes like vaults, evolved from the arch, for in their simplest form they may be thought of as a continuous series of arches, with the same centre. Therefore the dome exerts thrusts all around its perimeter, and the earliest monumental examples required heavy walls. Since the walls permitted few openings and had to be round or polygonal to give continuous support, early domes were difficult to incorporate into complex structures, especially when adjacent spaces were vaulted.

THE INDIAN SCENARIO

In India, the technique of the art of building, i.e., in terms of Materials and Methods, evolved, as elsewhere in the world, from wood to brick to stone to dressed stone. Of particular interest to the aim of this study is the understanding of brick masonry as it was developed in its application especially to religious (or to non-secular) architecture in this country. As would be expected the use of brick masonry flourished principally in the great alluvial plains of the country where good clay was easily obtainable, but the theory of the availability of material should be not pressed too far. Much depends on the human element, and the preference of a people, under certain conditions, for the particular type of construction, which would best suit their purpose. As an illustration of this choice of material, immense buildings almost entirely composed of brick were constructed during the early mediaeval period at Mathura and Benaras, although the extensive sandstone quarries of Rupbas and Chunar were readily accessible.

According to Percy Brown:-

"Brickwork, if properly prepared, and other things being equal, has durable qualities little inferior to those of stone masonry,"
besides it has the advantage of being composed of small units, the flexibility of which gives greater constructional possibilities. On the other hand the use of such small elements adds to the difficulty of bridging spaces, as in the case of roofs, doorways, and all openings. The Indian builder endeavored to overcome this disability by resorting to very large bricks, some of the earlier examples being over twenty inches long, several times larger than the modern article. There was a tendency to reduce the size as time went on, so that within limits it may be said that, the larger the brick the earlier its date. But the builder soon found that even by employing exceptionally large bricks, spaces could not be readily spanned so that it became the practice to introduce beams of wood over the doorways and windows, many of the earlier brick buildings thus containing a moderate amount of timber. Later, when the properties of the stone for such a purpose began to be recognized, instead of wooden supports, lintels of stone were used, and a phase then ensued when brick building with stone dressing found favour. It does not, however, follow that in every locality the two phases of brick with wood, and brick within stone, were in the above sequence. In certain parts this order may, for various reasons have been reversed, but as a whole, constructional evolution in the art of building progressed generally on these lines.

\[1\] BROWN, op. cit., pp. 49-50.
The difficulty of bridging over spaces in brick buildings was overcome by the Indian builder's practice of inserting lintels of wood or stone. Another method was of corbelling i.e., oversailing the courses of brick until they met. It was serviceable but not particularly scientific form of arch found even as early as in the Indus Valley civilisation of 3000 BC. The next logical step of a people committed to brick construction would have been, in ordinary circumstances, some method of placing these brick-units in juxtaposition, so that they would act as supports to one another, either on the principle of the true arch, or even in the form of the arch itself. This step, however, was never taken, the accepted explanation being that the Indian builder, from the beginning, mistrusted the stability of such a structural expedient, because, in his own words "the arch never sleeps". That he consistently adhered to this inhibition is proved by the fact that, with one or two relatively unimportant exception, the true arch is never found in any indigenous building in India, not appearing in the country until it was introduced by the invading Muslims in the 13th century.
STRUCTURE SYSTEM AND CONSTRUCTION

The Structure System adopted in the Golden Temple is a combination of *trabeate* (ie post-and-lintel, slab) and *arcuate* (arch, vault, dome) systems, with more of the latter type predominant. The main dome, which is the crowning feature of the sanctuary, roofs an independent room at the second floor. It seems logical to assume that it has been used mainly as a symbolic device. The sky-vault itself has been called *gumbad-e-bedar* (Persian term for doorless dome) which is believed to be God's own gesture of grace and protection. An umbrella (*chhatri* in Hindi), by the same token, has allusions to a kind of "domed place", and is also a symbol of protection. Le Corbusier has used the parasol (inverted umbrella) roof for his design of the High Court in Chandigarh, with the suggestion that a Court of Law, being a dispenser of justice, provides protection to the lowly and weak from the oppression of the high and mighty.

The construction of the Golden Temple is brick masonry in lime mortar. The building unit called Nanak Shahi [ie belonging to the reign of Guru Nanak Dev (1469-1539 AD), the Founder of the Sikh Faith] brick is actually a kiln-burnt clay tile of 147.3mm length, 97.4mm width and 28.7mm height (or thickness). From the construction of late-16th-century historical monuments in north-west India it appears to be a unique type of masonry such as may be called lime concrete reinforced with Nanak Shahi bricks. This assumption flows from the fact that the mortar joint is as thick as the brick itself or even more. At any rate, since the sanctuary is a bearing-wall structure, the building is predominantly in compression. Hence the thickness of the walls is as much as 2'-2" (660 mm). Nanak
Shahi brick has produced the following results in laboratory tests: water absorption is 13.2%; and compressive strength is 985.7 kg/cm². The maximum absorption of 20% and average compressive strength of not less than 100 kg/cm² have been prescribed under IS: 1077-1992. The report further reveals that "the submitted sample of Nanak Shahi brick does not have smooth rectangular faces with sharp corners. The brick though uniform in colour is having lots of cracks and flaws. No nodule of free lime was visible". In my view, irregular or rough faces are an advantage in that they provide a better bond with mortar. Uniform colour shows that the brick was properly burnt. Absence of free lime nodules testifies to the quality of brick clay. Seen in this light the concluding statement of the lab-test report "The submitted sample of Nanakshahi brick meets the IS requirements w.r.t. water absorption and compressive strength (emphasis added) but fails in dimension test and general quality" is a testimony of the constructional rightness of the building unit. Since the walls have been lime-plastered, failure of Nanakshahi bricks in "dimension test and general quality" is of no consequence. What is more is that the present building dating from 1776 AD (when it was last rebuilt) has successfully stood the test of time for well over two centuries!

Since cornices and other projections had to be built the construction was based on the system of corbelling. The corbel is a block of stone, often elaborately carved or moulded, projecting from a wall, supporting the beams of a roof, floor, vault or other feature. In modern brick masonry, corbelling is a successive projection of 2 1/4" of bricks course-wise using bricks of a standard size of 9" × 4 1/2" × 3". Though the resulting overhang is restricted in dimension as a free-end projection (up to 2'-0" or so) it may be broadly called a cantilever in brickwork without the use of mild steel bars reinforcement which is so
LAMP-POST (3'0"X3'0")
HAR-KI-PAURI
NO. OF STEPS= 19
TREAD=10"
RISER (1)=4"
RISER=8"
WALL BUILT OF NANAK SHAH BRICKS (28.7MM X 97.4MM X 147.3MM)
VAULTS ARE HEMISPHERICAL OR SEGMENTAL AS THEIR SPANS VARY

GROUND FLOOR PLAN

SRI HARMANDAR SAHIB, AMRITSAR:
A Study of Architecture, Engineering, and Aesthetics
PLATE NO V
SRI HARMANDAR SAHIB, AMRITSAR:
A Study of Architecture, Engineering, and Aesthetics

PLATE NO VI
GOLDEN TEMPLE: conceptual plan

SKETCH V
NO. OF STEPS* 19
TREAD* 1'0"
RISER (1)* 4"
RISER* 8"

7 DOMELETS

SECOND FLOOR PLAN

SRI HARMANDAR SAHIB, AMRITSAR:
A Study of Architecture, Engineering, and Aesthetics
PLATE NO VII
SRI HARMANDAR SAHIB, AMRITSAR:
A Study of Architecture, Engineering, and Aesthetics
PLATE NO X
indispensable in rcc (reinforced cement concrete) construction. Compared to a corbelled brickwork projection (which may be continuous along the entire length of a load-bearing wall or a bracket i.e., a projecting support), a cantilever, in non-technical terms, is a large bracket for supporting cornices, balconies, and even stairs. In the case of stone masonry, a bracket is invariably a triangular device cut and carved out of a stone slab and fitted in the thickness of the wall perpendicular to its plane. The seat of the Mughal emperor Akbar the Great in diwan-e-khas (hall of private audience) at Fatehpur Sikri is a central red sandstone free-standing column from which several brackets jut out so as to create a round platform at the level of the first floor. The point of this elaboration is that, though no scientific backup existed then, the Indian builders during the mediaeval period had definitely developed highly rational structural devices even with the use of simple construction methods.
The Pool of Nectar, which measures 490'-0"x510'-0" at the level of the parkarma floor, was developed from a natural water pond which existed near the spot where dukh-bhanjani ber (Zizyphus jujube; literally, the Annulier of Sorrows) has been preserved. The water of this pond, before the launching of the project, was reputed to have miraculous curative powers. Hence the name dukh-bhanjani ber. Amrit-Sarovar is a kachcha basin 18-feet deep with retaining walls on all four sides whose inmost points at the floor of the pond make an angle of about 60 degrees so that the sarovar measures 470'-0"x490'-0" at the base. The top of the retaining wall/embankment has a 75-inch wide border around the tank raised from the floor of the parkarma by 4 inches. The footings of the retaining walls are irregularly shaped steps, both in risers and treads. Thus the first drop is 13¾" and meets a 21" tread followed successively by riser/tread dimensions as : 15"/24", 8½"/22¾", 13¾", 12"/24½", 13"/50½", 5"/17", 46½"/21½", 18"/26", 18"/22", 40½" riser culminating in cyma reversa moulding which drops by 12" to negotiate the kachcha basin of Amrit-Sarovar. A 41"-high railing of precast trellised panels set in bold balusters has been fixed at the edge of the 50½"-wide tread. This is the ultimate limit to which the devotees can descend for a holy dip in the Pool of Nectar. Evidently, the uppermost footing of the retaining walls serve as steps for going down into the sacred tank. Enclosures called ponas have been built at strategic spots, notably, the one near dukh-bhanjani ber as "bath-rooms" for the exclusive use of the womenfolk and girls. The male devotees take bath in the open with their underwears on without removing their turbans and the prescribed symbols of baptisation.
The *Amrit-Sarovar* receives its water supply from Upper Bari Doab (UBD) canal via a desiltation station through a network of *hanslies* (underground water-channels) which have ventilators/markers at regular intervals until they reach the distribution and control station from where water is diverted to the five pools: *Amrit-Sarovar, Kaulsar* (these two water-bodies are interconnected), *Santokhsar, Bibeksar, and Ramsar*. The Pool of Nectar was desilted by voluntary labour performed by the devotees, called *kar sewa*: 1923, 1973, 1980, with the latest one that took place in March 2004.
WATERSUPPLY AND (RAINWATER) DISPOSAL SYSTEMS
(Ref. : Plate No XIII and XIV)

♦ Water is supplied to the Amrit-Sarovar from Upper Bari Doab (UBD) Canal passing near the District Forest Office at a distance of about five kilometres from the pool by a network of hanslis (underground channels).

♦ Part of the watersupply comes from the tubewells installed in the Golden Temple complex.

♦ There is no fixed schedule for emptying the Sacred Pool. However, floating material, if any, in the sarovar is daily removed by sewadars (servers). In the past, the pool had been emptied/cleared at 15-20 years intervals.

♦ Rainwater or waste water (after floor-washing) from the parkarma is disposed of into a drain which has been built around the sarovar. Earlier, this water was discharged into the city sewer, but now it has been diverted to the recharging wells. Water from the Holy Shrine goes into the sarovar.

♦ The Sacred Pool has a kachcha bottom. Fresh water is added, as and when required, to replenish the water in the sarovar.

♦ Causeway as passage to the Holy Shrine has marble flooring laid on the structural slab, which is supported on a vaulted substructure constructed in Nanak Shahi bricks.

3 PWD, Public Health (RWS) South: The Mall, Patiala.
According to the observation of Public Health engineers in charge of the watersupply and disposal systems of the Golden Temple, the Sacred Pool is free from the problem of frogs. "At shallow depth, the pool is pucca, so frogs are not likely to be seen. Being a pool only, marine creatures cannot breed."

A state-of-the-art water treatment and filtration plant was installed in 2004, courtesy Tut brothers, US-based Sikh devotees. The project cost the donors three crore rupees. The incoming water goes to the filtration plant directly, and enters the sarovar after cleansing. A computerised sensor keeps quality check on the watersupply. Fresh oxygen is continually added to the sarovar water by means of 14-inch aeration ducts pumps installed along the sarovar bank. Water is recycled six-hourly to the filtration plant by five 50hp pumps which have a capacity of pumping 25,000 litres of water per minute. The Amrit-Sarovar requires two lakh litres of water everyday.