

set of nine petals, called the 'inner leaves',
contractors responsible for constructing the Temple. appear to be
partly closed. Only the tips open out,
The temple complex, as seen from the layout, consists somewhat like a partly
opened bud. This portion, which
of the main house of worship; the ancillary block which rises above the
rest, forms the main structure housing the
houses the reception centre, the library and the central hall. Near
the top where the leaves separate out,
nine radial beams provide the necessary lateral support.

Geometry

Since the lotus is open at the top, a glass and steel roof
The beautiful concept of the lotus, as conceived by the
at the level of the radial beams provides protection from
architect, had to be converted into definable geometrical
rain and facilitates the entry of natural light into the
shapes such as spheres, cylinders, toroids and cones.
auditorium.

These shapes were translated into equations, which were
Below the entrance leaves and outer leaves, nine
then used as a basis for structural analysis and
massive arches rise in a ring. A row of steps through
engineering drawings. The resultant geometry was so
each arch lead into the main hall (see Fig. 1).
complex that it took the designers over two and a half
years to complete the detailed drawings of the temple.

Fig 1. Top view of entrance and outer leaves An attempt is made below to
describe this complex
geometry in simple terms (see Fig. 2).

Entrance leaves and outer leaves.

The shell surfaces on both sides of the ridge of the
entrance and outer leaves are formed out of spheres of
different radii, with their centres located at different
points inside the building. There is one set of spheres for
the entrance leaves, some of which define the inner

Fig 2. Section through entrance leaf and interior dome
(Plan and section at crown of dome also shown)

1. Entrance leaf
2. Outer leaf
3. Interior dome shell
4. Arch
5. Interior dome rib

The inner leaves enclose the interior dome in a
canopy made of crisscrossing ribs and shells of intricate
pattern. When viewed from inside, each layer of ribs and

shells disappears as it rises, behind the next, lower layer (see section on p. 29). Some of the ribs converge radially and meet at a central hub. The radial beams emanating from the inner leaves described earlier meet at the centre of the building and rest on this hub. A neoprene pad is provided between the radial beams and the top of the interior dome to allow lateral movement caused by the effects of temperature changes and wind.

surfaces, and others which define the outer surfaces of arches, thus forming an intricate pattern. of adjacent
the shells. The diameters of the spheres have been fixed Other radial
ribs rise from each of these intersections and all meet at the
to satisfy the structural consideration of varying shell
centre of the dome.
thickness. Similarly, for the outer leaves, another set of
Up to a certain height, the space between the ribs is
spheres defines the inner and outer surfaces of the shells.
covered by two layers of 60mm-thick shells. The intricate
However, for the outer leaves, the shell is uniformly 133
pattern of the interior dome is illustrated in section on
mm thick towards the bottom, and increases to 255 mm
page 29.
up to the tip, beyond the glazing line.

The entrance leaf is 18.2m wide at the entrance and

Setting out

rises 7.8m above the podium level. The outer leaf is
The setting out of the surface geometry posed a difficult
15.4m wide and rises up to 22.5m above the podium.
task. Unlike conventional structures for which the
The inner leaves. elements are
defined by dimensions and levels, here the
Each corrugation of the inner leaf, comprising a cusp shape, size,
thickness, and other details were indicated
(ridge) and a re-entrant (valley), is made up of two in the drawings
only by levels, radii, and equations.
toroidal surfaces. A toroid is generated when a circle of These
parameters, therefore, had to be converted into a
a certain radius, 'r', is rotated around the centre of a set of
dimensions in terms of length, breadth, height,
circle of much larger radius, 'R'. A cycle tube is a typical and thickness,
easily understood by a site engineer or a
toroid. The shaded portion of the toroid is a part of the carpentry
foreman. To achieve this, a system of
inner leaf shell. coordinates
along x, y and z axes for every 40 degrees.
segment of the temple was worked out with the help of

The inner leaves rise to an elevation of 34.3m above a computer. The problem was then further simplified by the inner podium. At the lowest level each shell has a working out from these co-ordinates levels and distances maximum width of 14m. It is uniformly 200mm thick.

The arch.

Fig

3. Station points for setting out of arch, entrance, outer and inner leaves

All around the central hall are nine splendid arches placed at angular intervals of 40 degrees. The shape of these arches is formed by a number of plane, conical and cylindrical surfaces. The intersection of these surfaces provides interesting contours and greatly enhances the beauty of the arches. The nine arches bear almost the entire load of the superstructure (see Fig. 2 and 4).

The interior dome.

Three ribs spring from the crown of each arch. While the central one (the dome rib) rises radially towards the central hub, the other two (the base ribs) move away from the central rib and intersect with similar base ribs which a carpenter or a reinforcement fitter could easily Fig 5. Setting out of surface

comprehend and then arrive at the surfaces and

z ~yel

boundaries. Eighteen reference stations were established plum~T

B

outside the building for setting out the arches, entrance,

Stepped template

outer and inner leaves (see Fig. 3).

bob I

First, 18 radial lines were established from the centre of the building (see Fig. 4). Along these lines, using inclined and vertical distances, end points A and B for surface (1) were established. By using a set of curved templates, each of varying curvature, surface (1) between y

these lines was developed. From this surface the other surfaces of the arch were set out by using stepped templates with respect to surface (1).

Sequences of construction

The stations shown in Fig. 3 were used to set out the inner podium were constructed

cusps, re-entrance and edge lines for the entrance, outer first.

Thereafter, for casting the arches and shells, the

and inner leaves. For example, to arrive at curve AB, structure was divided into convenient parts, taking into consideration point A with coordinates XA, YA, ZA was defined with shells cast that when deshuttered, the portion of the shells cast respect to O. AB was then established by a second shells cast would be self-supporting until the remaining shells were completed. The structure was divided as follows: theodolite and the curve AB determined by a stepped template. Accurately made curved templates of required radii were then used to develop the surface between these boundaries (see Fig. 5). Arch.

All 9 arches were cast one after the other in two lifts

Fig 4. Setting out of arch until the circle was completed. The deshuttering of the soffit of each arch was taken up after the adjacent arches had attained specified strength (see Fig. 8).

Inner leaf, radial beams and central hub.

After the completion of all the arches, the structural steel staging for the inner leaf was erected. Three shells, 120 deg. apart, were taken up at a time and cast in two Building lifts, one after the other, up to the radial beam level,

R ensuring always that the difference in height between

the shells cast was not more than one lift (see Fig. 6).

The process was repeated until all 9 segments were cast.

\ Theodolite Casting of the

central hub was taken up as an

independent activity, and after all the shells were cast,

they were connected to the hub by casting the radial outer

leaves and followed by the intermediate entrance leaf. In

beams. After sufficient curing, the inner leaf along with this manner the remaining leaves were deshuttered

the radial beams were dewedged, leaving the central hub as and when the concrete attained strength

supported. The remaining portion of the inner leaf was and the

leaves adjacent to the shell to be deshuttered

then taken up (see Fig. 7). were cast.

Fig 6. Sequence of construction of entrance leaf, outer leaf

Staging and formwork

and inner leaf

Deflection was an important consideration in the design

of the formwork. The maximum deflection was limited

to 3mm over a distance of 1m (including errors in

fabrication and erection).

The following aspects were considered in arriving at the general arrangement of the staging supporting the inner leaf and interior dome formwork:

a. The concreting of the shells should be taken up 3 at a time, 120 deg. apart, so that the lateral loads on the staging supporting the formwork were reduced as far as possible.

b. Construction joints were to be avoided as far as possible so that the exposed concrete surface did not show any lines other than the architectural pattern.

After de-wedging of inner leaf, the steel staging was modified and two folds of shells of the interior dome located above 24.8m level so that they did not show taken up one after another. For each fold, three shells, the floor level. All other shells were to be cast 120 deg. apart, were taken up at a time and cast one after single continuous pour.

another. For each shell the boundary ribs were taken up staging should support the radial and base ribs first and then the shell cast in one single lift. The process without interfering with the structural steel was repeated until all the shells were completed.

members. After deshuttering of inner leaf, the structure should be able to support the formwork of Entrance and outer leaves.

the inner layers of shells of the interior dome with The construction of the entrance and outer leaves was minimum modification.

taken up as a parallel activity with the casting of the inner leaves and interior dome. Two entrance leaves and the above considerations, a space frame one intermediate outer leaf were taken up first. of 9 radial cusp frames and 9 re-entrant Thereafter, the outer and entrance leaves were cast with circumferential and diagonal members alternately, the outer leaf first and then the adjacent following the profile of ribs and shells, was entrance leaves. Deshuttering was started with a pair of most suitable (see Fig. 7).

Fig 7, Inner leaf and radial beams delihulterrd deflections due to slippage of joints would be avoided and with central hub supported on staging fabrication and erection would be comparatively easier.

The inner surfaces of all the shells have a uniform, bush-hammered, exposed concrete surface with

architectural patterns. For the inner leaves, these patterns were formed out of radial and venical planes intersecting the surface of the torus. For the outer and interior leaves, and the interior dome, the patterns were formed out of longitudes and latitudes of spheres. The form work was designed in a manner that timber joists support the panels instead of the regular pattern of the structural steel supporting members of the space frame (see Fig. 8). Full-scale mockups of the bottom surface of each of the shells were first made at ground level and the architectural patterns marked on this surface. The frame

Various alternatives were considered for the steel of each form panel was fabricated according to staging. Standard pipe scaffolding was found to be calculated dimensions and cross-checked with unsuitable, considering that the slippage of members at measurements from the mockup. The formwork pattern joints would be uncertain and it would be difficult to is seen in the photograph on page 70.

compute and control the deflection, particularly due to The inner formwork for every petal was fully fixed lateral loads. Structural steel framework with bolted joints from bottom to top and aligned accurately. After the form work was found to be unsatisfactory, considering that a very form work was approved, the sheathing joints were sealed with putty made out of epoxy resin and plaster of Paris.

structural work would be required to match the bolt holes and a protective coating was applied over the plywood surface, at junctions of members meeting at different inclinations. In the case of the interior dome shells, sheathing was lined by fiber-reinforced plastic sheets in all three planes. Structural steel framework with welded joints was considered to be most suitable because plastic sheets and the joints sealed with epoxy resin. After this, the location of each reinforcement bar was marked on the formwork along latitudes and longitudes and the bars placed over these markings. To avoid impressions of cold joints on the inner surface, the casting of petals of the inner leaf was carried out in three lifts, some of them 14m high. To facilitate placement of concrete and simultaneous compaction in each pour, the outer form work was placed one row of panels at a time, and as the level of concrete rose, the next row of panels was fixed. These panels, therefore, had to be fixed in position and aligned

View showing newly concreted main arches accurately in the shortest possible time.

- | | |
|--|------------|
| II. Self-weight of structural steel members. | 12. |
| Longitudinal member | |
| III. Live load 2000 N/m ² of plan area. | 13. Wedges |

For the inner leaf, various combinations of the above loads

Based on the above loads, a computer analysis for all were considered for the following conditions (see Fig. 4):

possible combinations was carried out using SAP N program. One cusp frame and one re-entrant frame along Stage I Concrete from top of arch to +24.8m level with inter-connecting bracings were considered as a unit.

Stage II Concrete from +24.8m to +38m level

Stage TII Concrete from +38.8m to the top

A computer model indicating the loads due to one of the combinations of loading for Stage II is shown in Fig. 10.

The combination of loads considered were:

Similar loading conditions were considered for the entrance and outer leaves as also the shells of the

1. Self-weight of space frame (symmetrical)
2. Dead load of shutter interior dome, the only difference being that all the
3. Live load + dead load of concrete Stage I (unsymmetrical) shells were cast in a single pour.
4. Live load + dead load of concrete Stage I (symmetrical)
5. Live load + dead load of concrete Stage II (unsymmetrical)
6. Live load + dead load of concrete Stage II (symmetrical)

Reinforcement

7. Live load + dead load of concrete Stage TII (unsymmetrical)
8. Live load + dead load of concrete Stage TII (symmetrical)

The reinforcement used in the white concrete shells as

9. Wind load for full height (unsymmetrical) well as the binding wires was entirely galvanized so as to prevent the long-term effect of rusting of reinforcement on the white concrete. Since galvanized

Fig 10. Computer diagram of nodal loads for inner leaf

reinforcement for concrete is seldom used in this country, several tests were carried out to ensure that the mechanical properties of reinforcement did not become

5.45 adversely affected due to galvanizing. Sandblasting was

11 3.61 carried out to reduce pickling time with a view to

15.83 778

/ avoiding hydrogen embrittlement. The bottom formwork

18.52

for one shell for each of the leaves was first erected and aligned. The edge lines and surfaces of this formwork were then used as a mockUp to decide the length and

from the Alwar mines near Delhi and white silica sand from Jaipur. Based on the sequence of construction envisaged, the maximum temperature of concrete at assumptions made in the design of the formwork, the time of placing was limited to 30 deg. C. During the procedures developed from mockups, and the tests summer months, when the ambient temperature was as high as 45 deg. C, the temperature of the concrete was criteria of acceptance were established. Checking of controlled by adding a measured quantity of ice and by workmanship was done at each stage to produce the the precooling of aggregates in air-cooled aggregate required quality and accuracy and also to ensure that storage bins. To avoid cold joints due to stoppage of there was no deviation from the conditions of loading work during heavy rains, as also to protect rain water assumed in the design of the formwork. A full-fledged entering the forms, the entire concreting area was concrete laboratory carried out mix designs for different covered by tarpaulins.

grades of concrete and exercised strict control on the After removal of the outer forms, the surface of the quality of concrete.

concrete was covered with hessian and cured for 28 days by keeping it wet continuously by a sprinkler arrangement fixed at the top of the shells.

Marble cladding

The outer surface of the shells, as also the inner surface of the arches, are cladded with white marble panels fixed to Trials and mockups the concrete surface with specially designed stainless steel

The shells of the interior dome were initially 50mm thick brackets and anchors. 10,000 sq.m. of marble was quarried and proposed to be cast by in-situ guniting. Full-scale from the Mount Pentilekon mines of Greece and thereafter mockups were used to study the problems of working sent to Italy, where each panel was cut to the required size and shape to suit the geometry and architectural pattern space available between the shells, the working before transporting them to the site in Delhi.

conditions for guniting operations would be difficult. As After waterproofing of the top surface of each shell, an alternative, the shells were therefore proposed to be timber templates of the same size as the marble panels were used to define the location of the bottom-most rows

that the marble fixing could be carried out without any of marble panels first. The geometry of the cusp re-entrant hindrance from the supports of the staging.

and edge lines was then accurately checked with respect

It may be interesting to note that all the marble work to these panels, and the marble pieces were fixed in was carried out by carpenters who learned the skill of position from bottom towards top and cusp towards re-marble fixing within a few weeks, and were able to entrants and edges. Edge holes were drilled at ground complete the work, to the required accuracy, two months level for each marble panel before the panels were placed ahead of the scheduled completion time.

in position. Holes were drilled in the concrete to accommodate the anchor fasteners of the stainless steel

Project management

brackets to suit the holes in the marble, after each panel The complexity of the structure, and the very high was aligned. After fixing of the brackets, the area around standards of workmanship expected to be achieved, the bracket hole was sealed with a special waterproofing demanded a dynamic construction management with a compound (see Fig. 11).

high degree of innovativeness, team spirit and quality

Fig II . Marble ftx in g deta ils consciousness on the part of staff and workmen.

Anticipating problems in advance and solving them through trials and mockups was an essential part of site planning. Further, great emphasis was laid on the completion of the project within the stipulated time and cost. Resources were planned and physical progress

1.Stainless steel bracket monitored through constant review of PERT/CPM

2.Stainl ess steel anchor fastene r

3.Waterp roof resin networks.

4.Marble panel

5.Mo ulded rubber cordon with silico n sealant

6. Sili con sea la nt

7. 8 to IO mm joints between pane ls

8. Concrete shell

9. Curved surface

The alignment of the panels was adjusted at each layer so that the surface geometry and pattern lines were maintained. The pieces near edge, re-entrant and cusp lines were cut to suit the boundary lines. Gaps 8 to 10

mm wide at the joints were filled with moulded rubber
cordon, and the top of the joints, as also the holes in the
marble, sealed with silicon sealant. The entire marble
surface was, lastly, washed with a solution of 30%
muriatic acid mixed in water, to remove dirt and stains.
A specially designed structural steel framework was
provided to accommodate access and working platforms.
The platforms were free from the surface of the shells so

a. house of worship

h. ancillary building

c. public utilities

d. parking

e. main gate

a.- i. pool

j. outer podium

k. bridges

l. entrance

nl. inner haJJ

Ullder COLLstructioll

Oh lotus in the heart!

Growing up from the soil

Of mother India.

Drawing deep springs

Up from the depths of Asia,

Rising a mighty fountain

Of mystic power unseen

Felt, almost heard,

As it overflows

From petals clasped in prayer

To carry the voices

Of the singers praising God

To be scattered far and wide

By the scattering angels-

Armfuls of prayer they carry

Like pan nie rs of invisible flowers

Scattering the Words of God

Scattering His Glorious Words

Up to the snow clad Himalayas

Down to the lapping edge of t he seas

A rain of perfume

A rain of blessing

It seeps into every crevice

Showers every jungle

Spatters the deserts' sands

Passes above every meadow "

Blows into every cavel

The scattering angels

Rank on rank, tile on file,
Deploying the promise
Of their Lord the Almighty.

Madame Ru~!yyih RabMni
The Shrine of the Bab, Martyr-Herald of the Baha'i Faith, on the slopes of
Mount Carmel. Haifa, Israel.

The Shrine of the Bab is one of the holiest places of pilgrimage for the
followers of the Baha'i religion.

The monumental terraced gardens surrounding it are commonly known as -Hanging
Gardens of Mount

Carmel-, and were designed by Fariburz Sahba, the architect of the Baha'i
Houses of Worship in India,

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INTERNATIONAL RECOGNITION

The Bab's House of Worship in New Delhi. India has been recognized as
one of the masterpieces of World Heritage.
The Ministry of Culture, Government of India, awarding the
following:

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Received the award from the American Religious and
Architectural Association of America and the American Institute
of Architects, Washington, D.C. in 1987

•

Received the award from the Institution of Structural Engineers of the United
Kingdom in 1987

•

The Professional Outdoor Lighting Design Award - Special Achievement
from the Illuminating Engineering Society of North America
in 1988

•

Recognition from the Architectural Record as one of the
most beautiful buildings of the world in 1990

•

The Global Art Award 2000 award for "promoting global unity and harmony
for people of all religions", religious architecture and
sculpture, an unsurpassed by any other architectural
achievement worldwide