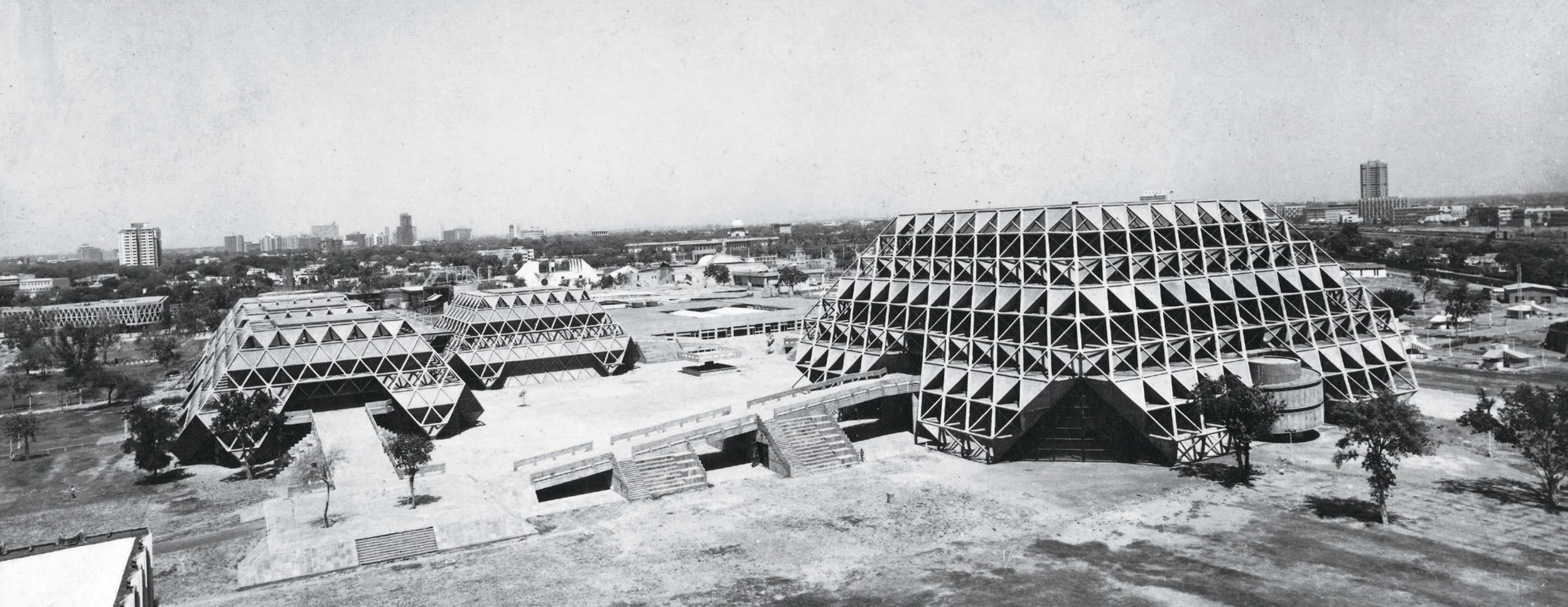


HALL OF NATIONS & HALLS OF INDUSTRIES

NEW DELHI | 1972





This complex of exhibition halls for the 1972 International Trade Fair was planned, designed and constructed in 22 months. Its large-span cast-in-situ concrete space frames were the first of their kind to be built in the world.

The choice of shape and form of the structural system was driven by its potential versatility: it contains an enclosure with a column-free main hall of 6700 sq.m, and four smaller halls adding an additional 7500 sq.m, under its roof structure. After investigating multiple alternatives, such as folded plates and hyperbolic paraboloids, a space frame system with a truncated pyramid as the basic module and overall form was adopted. Steel or pre-cast concrete would have been obvious choices of material for such a space frame, but the constraints of the available construction technology of that time necessitated the use of in-situ concrete.

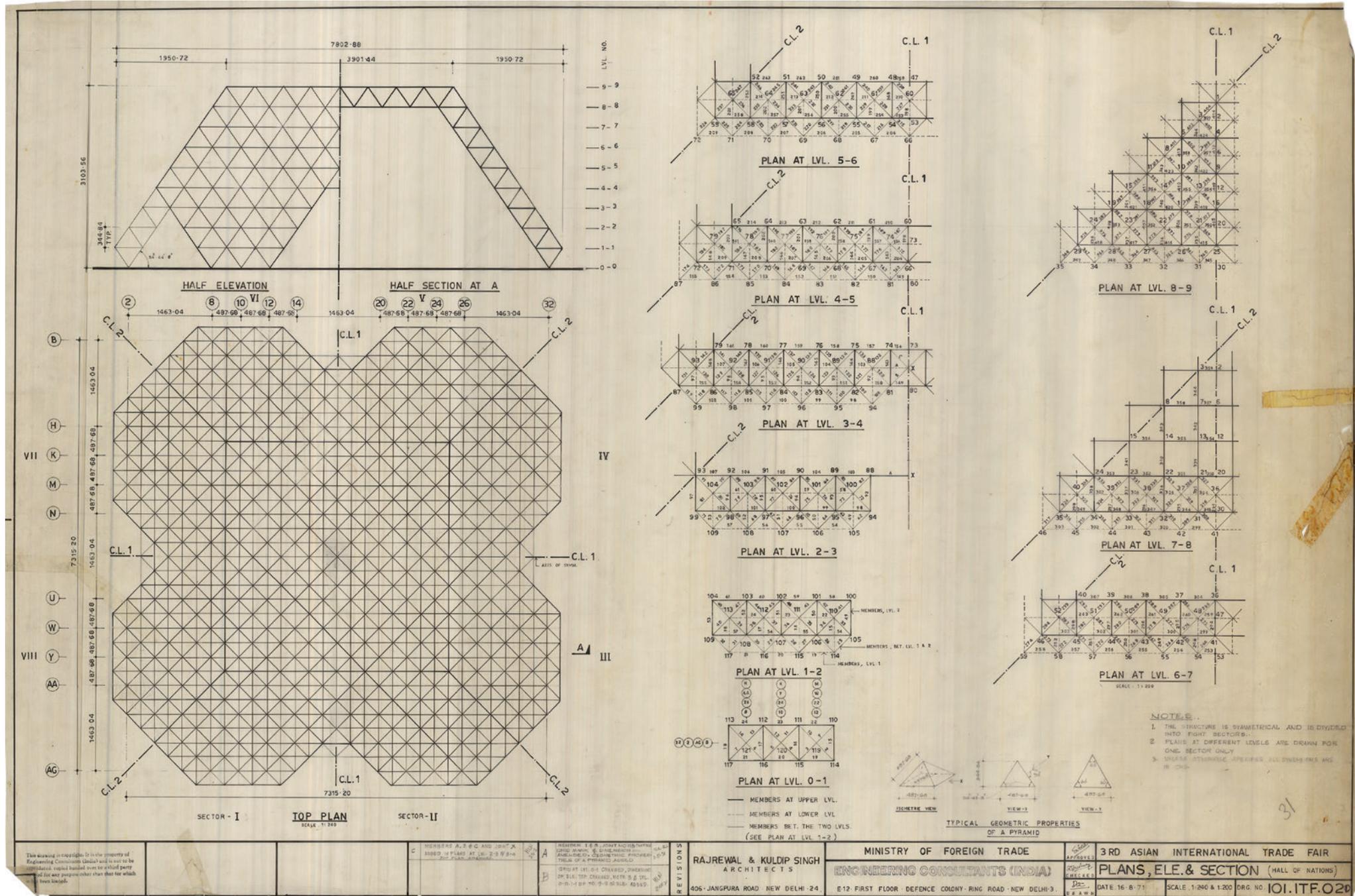
After rigorous investigations into pyramid geometry, the rhombic section developed for all the members of this very large building may well be the secret of its ultimate delicate and light appearance. With chamfered faces of just 25cm in the Hall of

Nations and 23cm in the Halls of Industries, and interface angles drawn from the slopes of its members, the robust rhombus allowed for the in-situ construction of the space frame where as many as nine to twelve members come together at one node. The innovative resolution of the nodes in this way provided the requisite strength at the node to absorb the heavy compressive or tensile forces from the members.

The large truncated pyramids of both structures are composites of smaller unit pyramids. The Hall of Nations consists of units of a 4.9m x 4.9m base and 3.5m height which form the 73m x 73m pyramid, truncated at the height of 30m with a roof span of 39m x 39m. The Halls of Industries are four 18m-high pyramids of 40m x 40m base, with truncated roofs of 22m x 22m, made of units that are 2.6m high and 3.6m x 3.6m at the base. The configuration of both these basic pyramids is such that all members of the square base and the four triangular sides have the same length, finally allowing the same building slope and the angle of this basic unit at $54^{\circ}44'8''$.

Aerial view of the exhibition hall complex with the larger Hall of Nations and four smaller Halls of Industries built for the 1972 International Trade Fair.

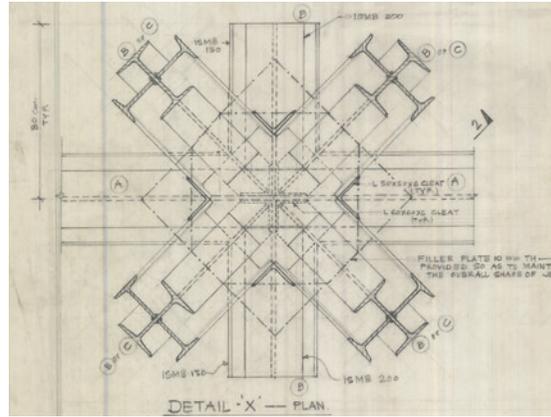
Previous pages: View of the Hall of Nations from the Halls of Industries, visible in profile on both sides of the image.



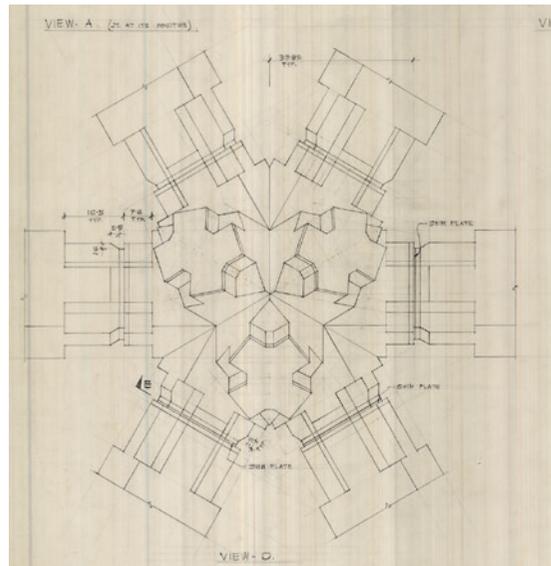
Recent photo of the large interior space of the Hall of Nations diminishing the large trucks parked inside by comparison.

Drawing no. 101.ITF.02D: Plans, Elevation, Section (Hall of Nations): 16 August 1971

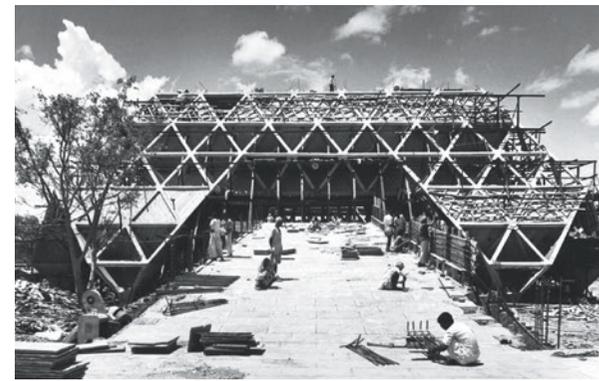
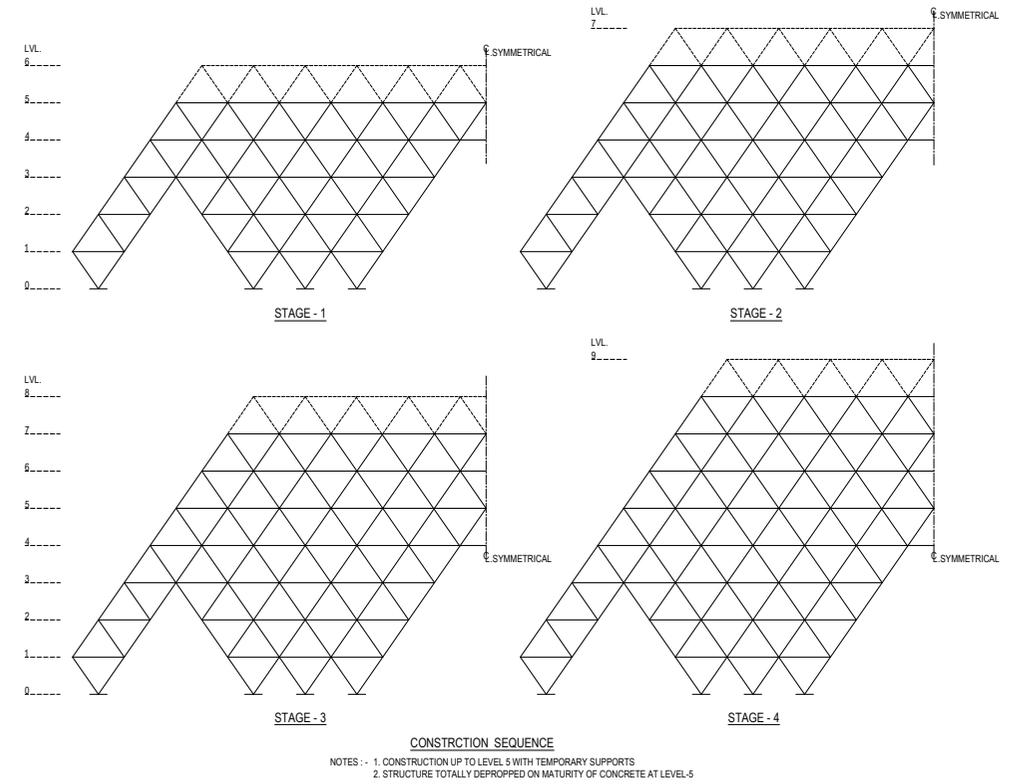
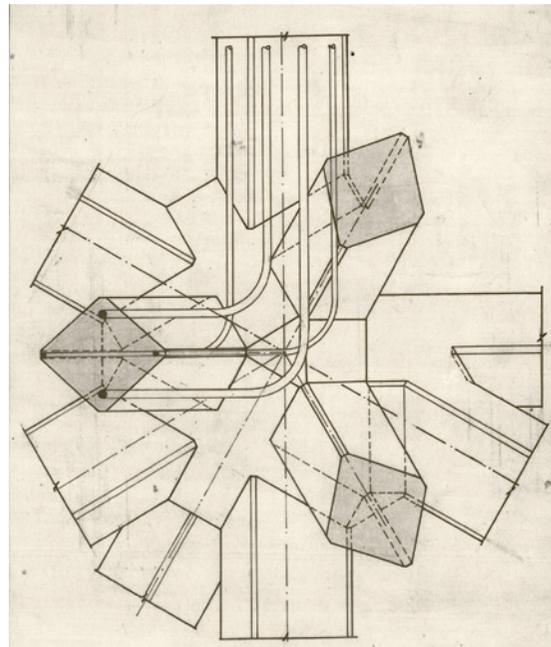
Drawing of plans at all nine levels of the Hall of Nations, with an overall section and elevation and also the geometry of the pyramid used as a basic module. Each plan includes two levels to help explain the pyramidal space frame geometry and how it connects to create the truncated pyramid form. The simplicity and clarity of the pyramidal geometry is carried through consistently in plans, sections and elevations. The structure blooms out of twenty-four nodes at the ground level, six nodes at each face of the square plan.

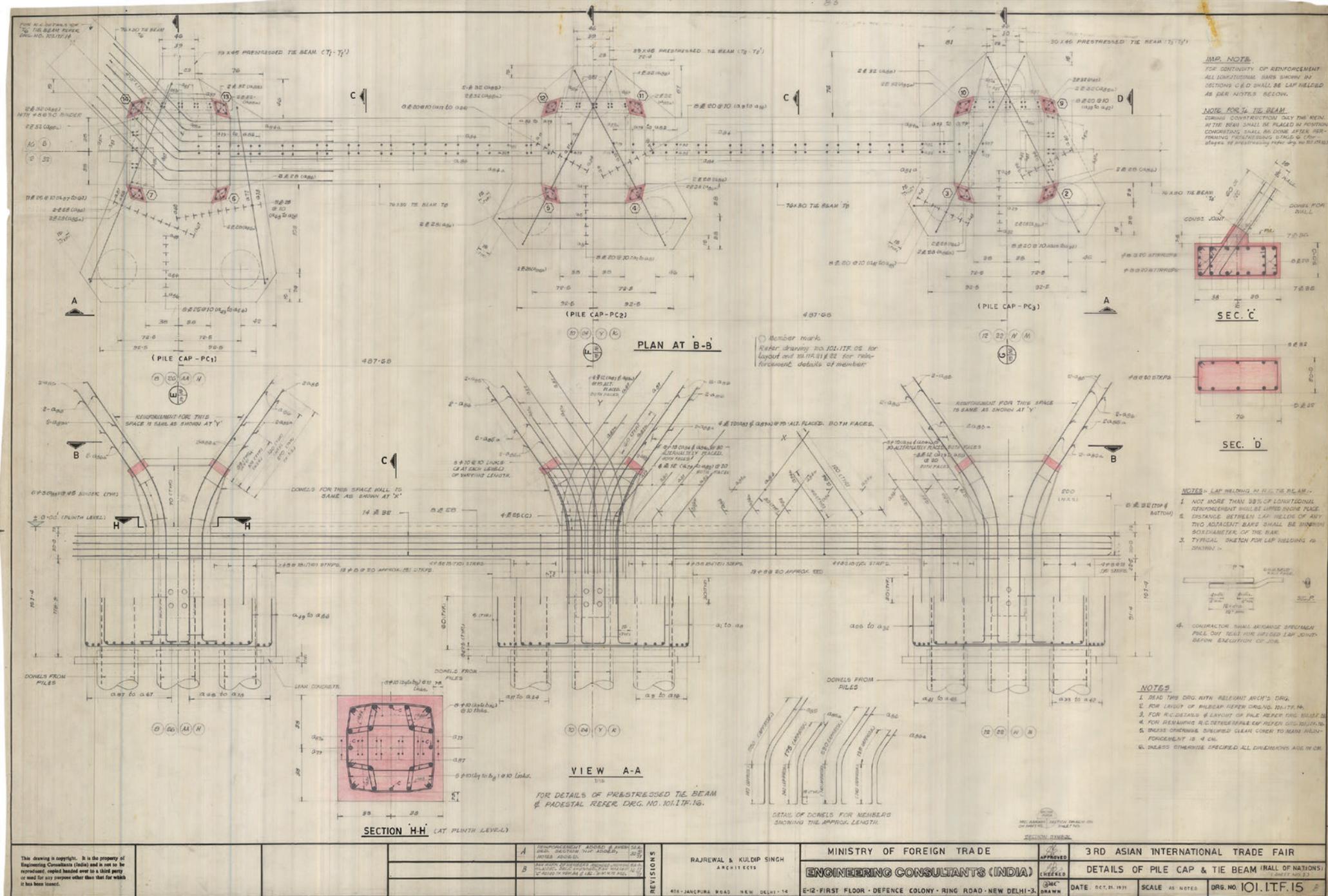


Left, top to bottom: Drawings of a typical joint in steel, precast concrete and in-situ concrete. A complete set of construction documents was developed for each of these material options and finally the cast-in-situ was adopted.



Below and opposite: Construction sequence: drawing and photos. Raj's careful conceptualisation of the stages of construction helped reduce efforts and costs as the entire structure was not supported with scaffolding till the roof. Based on extensive analysis, a detailed construction sequence was established. A system of scaffolding would support the structure till level 5, one level above all the desired openings in the lower levels. After level 5, the structure itself supports additional construction load, freeing the ground space. With each successive level, four different configurations of structure were envisaged and analysed for all possible loading conditions before the final building was completed. During construction, however, despite simultaneous construction on all sides, the rate of progress was not the same; one side was up to the sixth level and another to the fourth. This was a new structure not envisaged or analysed before. At this stage, after more analytical work, the scaffolding was removed as the structure was found to be self-supporting.





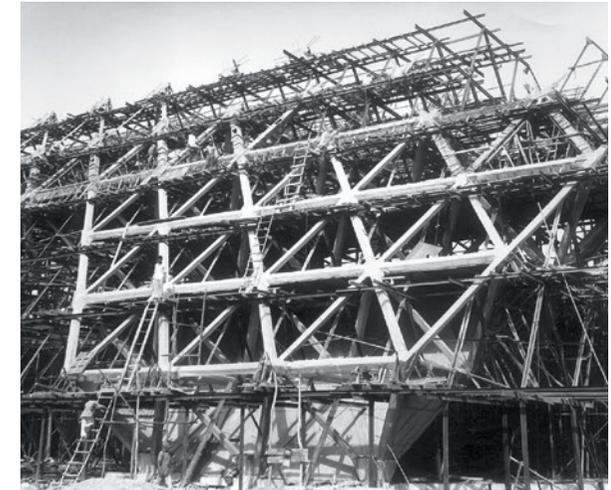
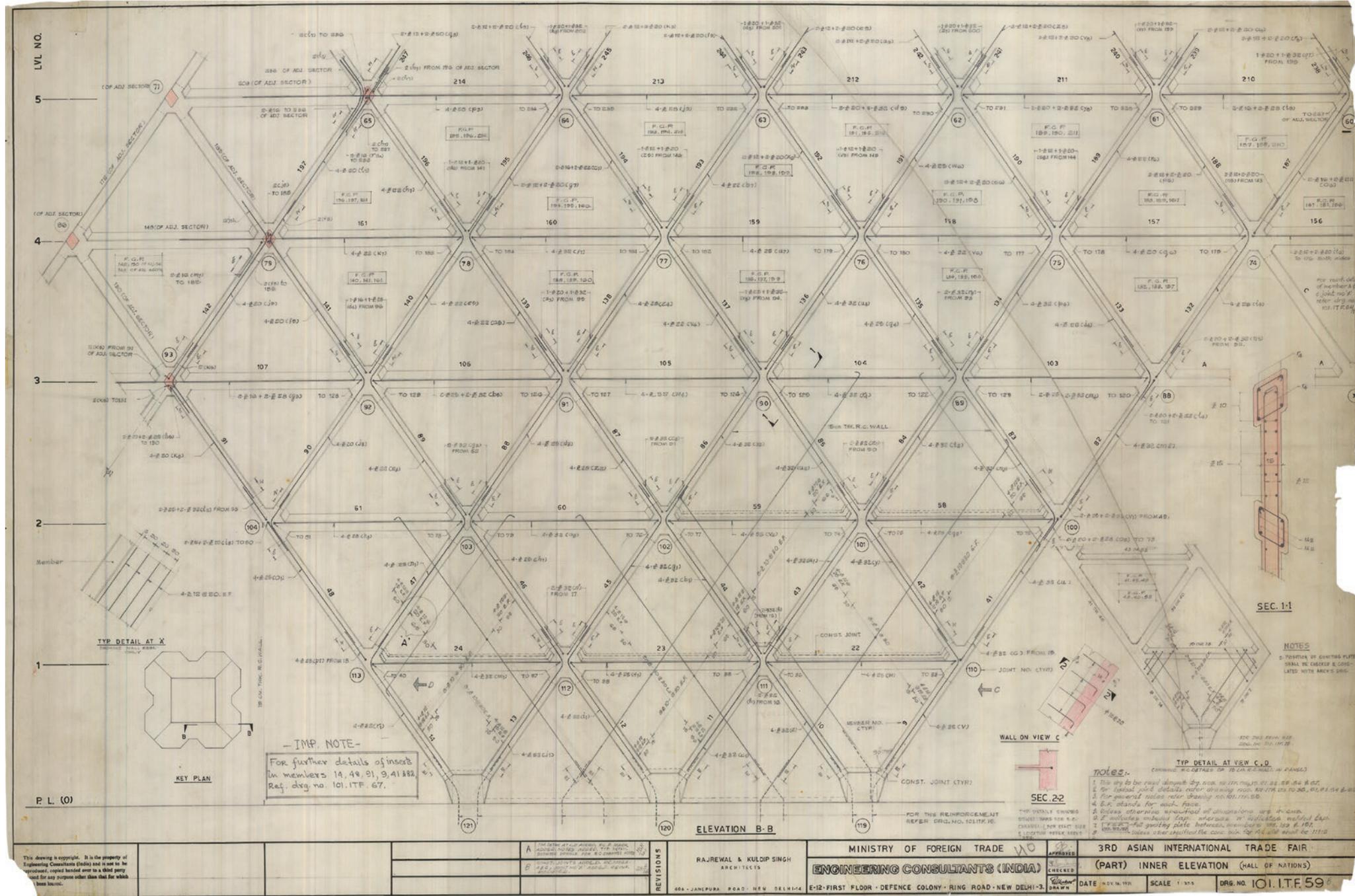
Drawing no. 101.ITF.15B: Details of Pile Cap and Tie Beam (Hall of Nations): 21 October 1971

The Hall of Nations was supported on in-situ-driven piles tied together with grade beams in two directions. First, along the six springing points in one face of the pyramid, and second, along the other direction connecting the opposite faces of the pyramid. The latter were post-tensioned in stages to cater to the large horizontal forces that developed as the structure went up.

Construction photos of pile caps and the reinforcement being arranged for the space-frame members.

Following pages: Photo capturing the springing point of a set of three nodes emerging from the ground with openings on both sides. The height of the basic pyramid module of the space frame is 3.5m and each member is 4.87m long.



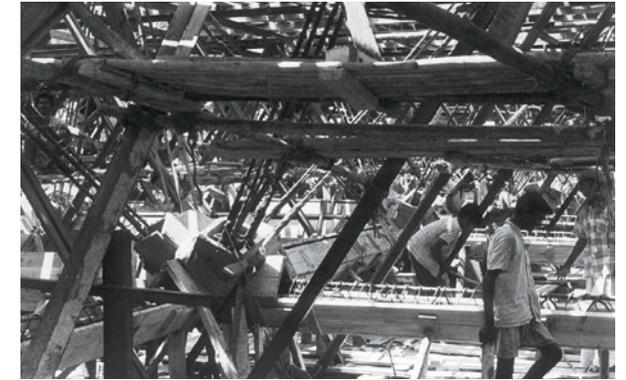
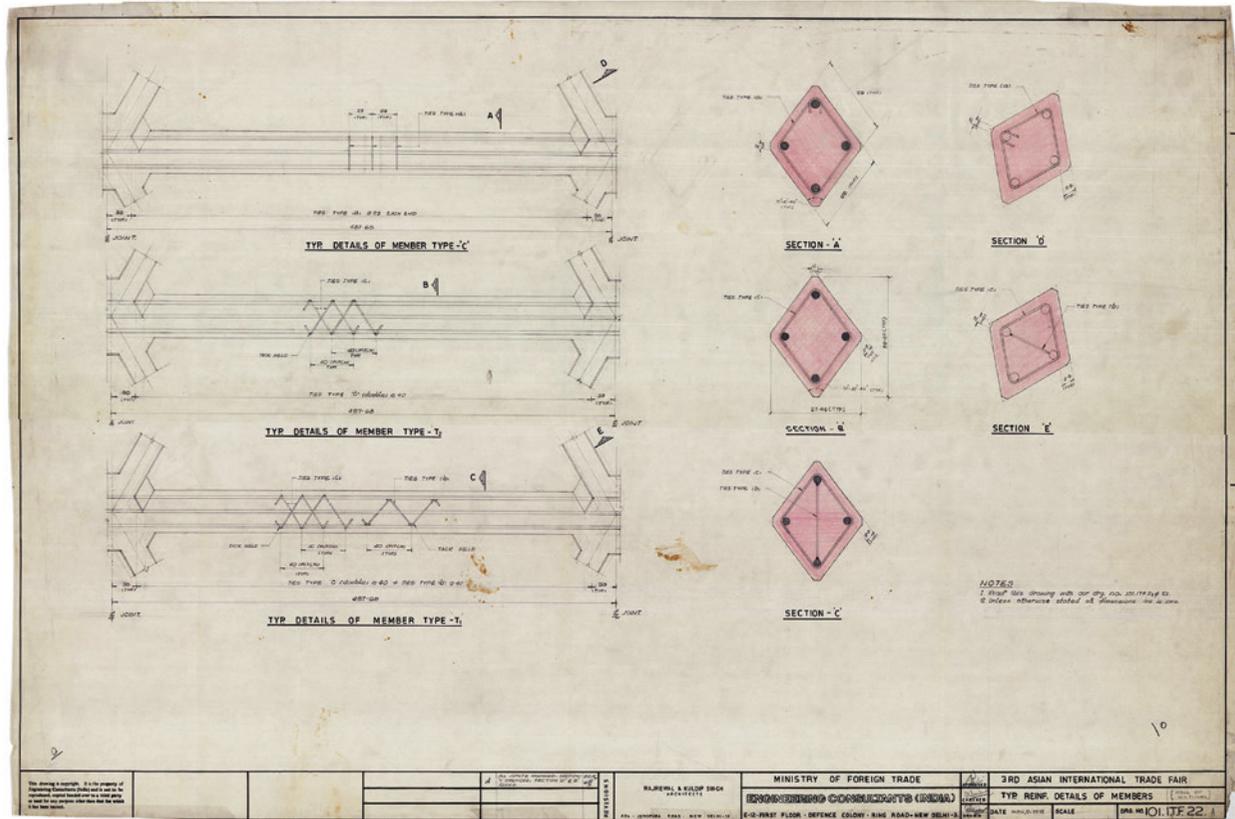


Construction photo of one face of the truncated pyramid form.

Drawing no. 101.I.T.F.59CB: (Part) Inner Elevation (Hall of Nations): 16 November 1971

A typical elevational module emerging from three nodes that sprouts into three inverted pyramids. The three inverted pyramids form the base that multiplies three dimensionally to create an elevational module that forms half of each face of the truncated pyramid. The geometry accommodates the triangular openings formed naturally on each side and corners of the elevational module.



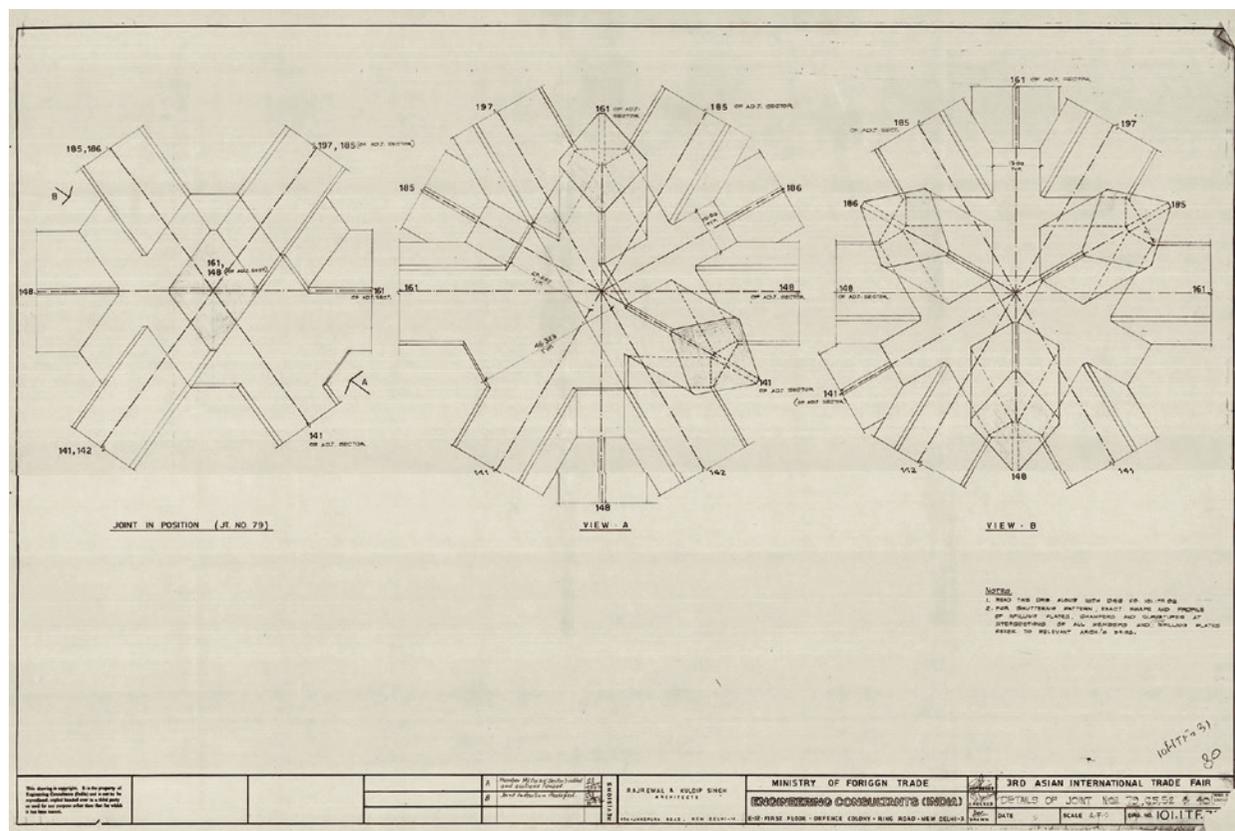


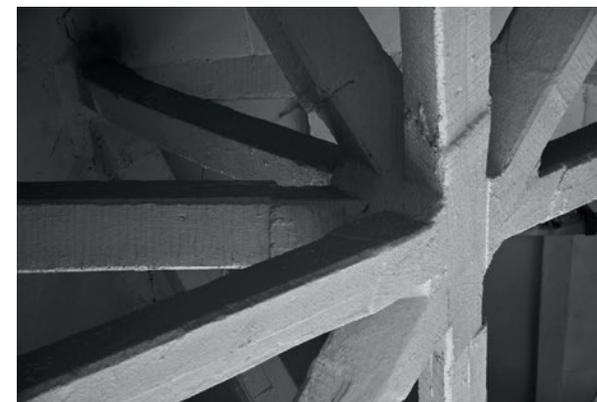
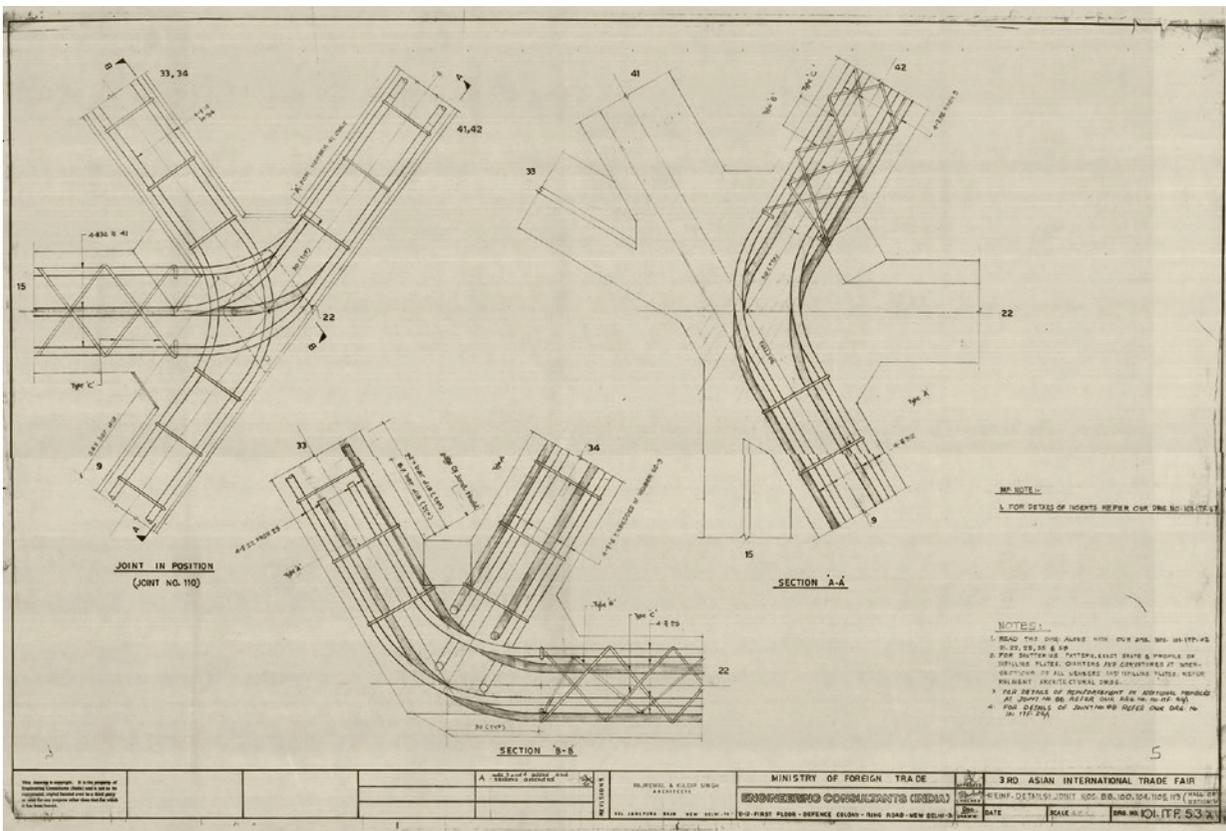
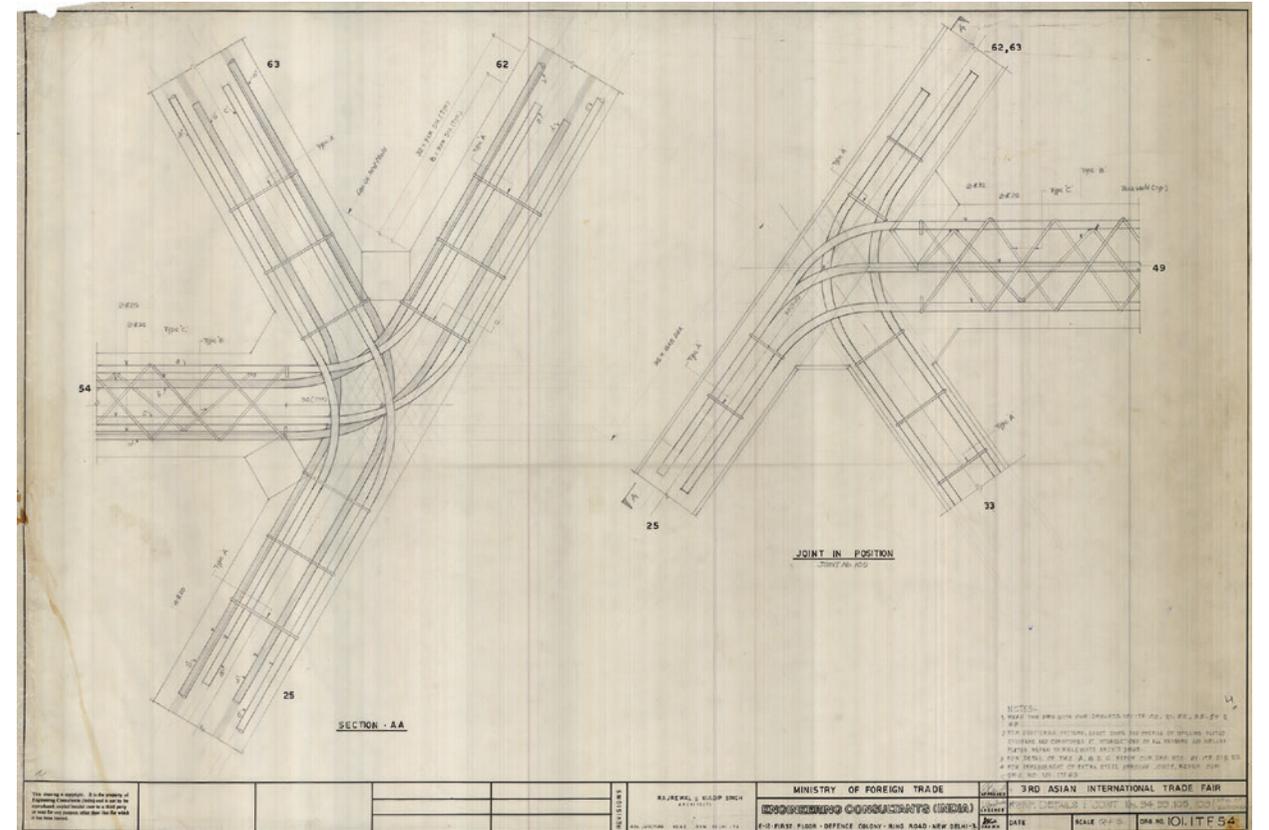
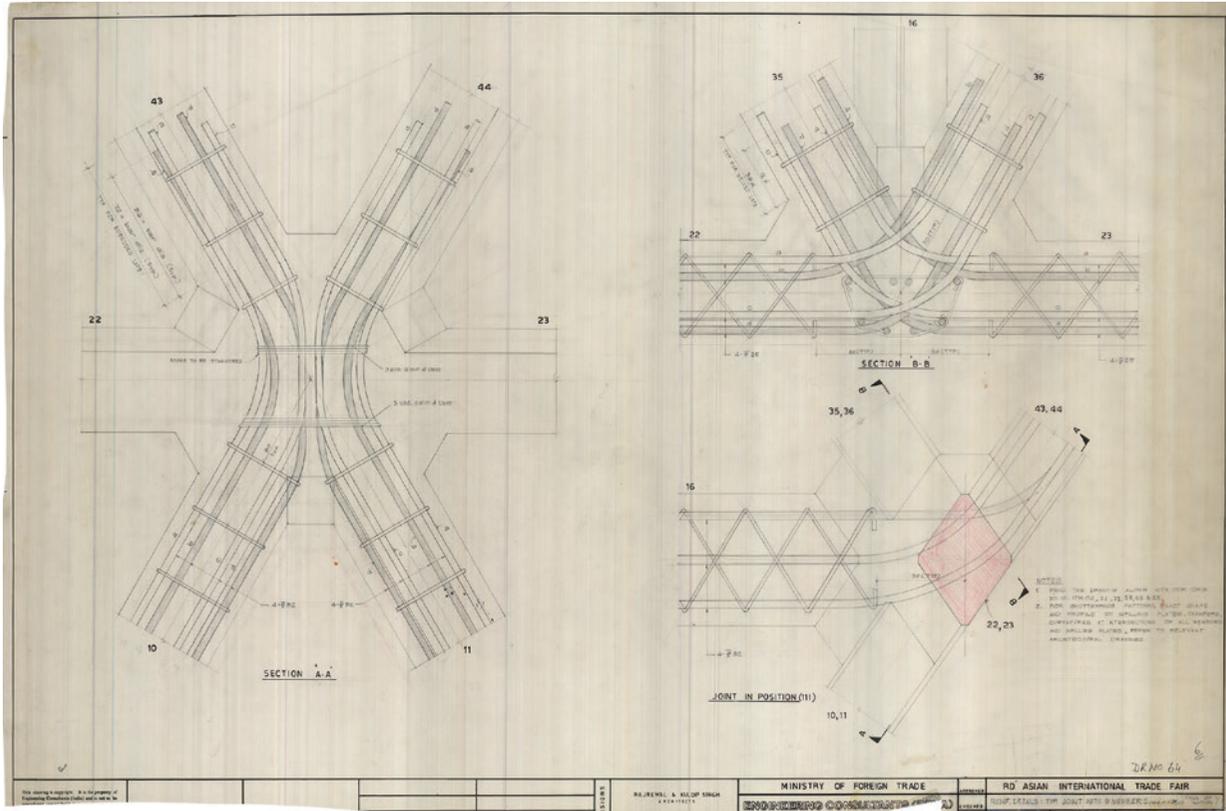
Construction photos of the rhombic members and the nodes.

Drawing no. 101.ITF.22.A: Typical Reinforcement Details of Members (Hall of Nations); 5 November 1971

This drawing brings forth another detail responsible for the slenderness of this gigantic concrete space frame: Type T1 and T2 are members in tension with double spiral ties to counter and contain the micro-cracking of the concrete. Type C are members in compression with straight ties.

Drawing no. 101.ITF.31: Detail of Joints Nos. 79, 65, 52 & 40 (Hall of Nations) Drawing of an eleven-member node visualising the complex intersections of the members with three views.





Above: Drawing no. 101.ITF.54: Reinf. Details; Joint Nos. 94, 99, 105 & 109 (Hall of Nations)

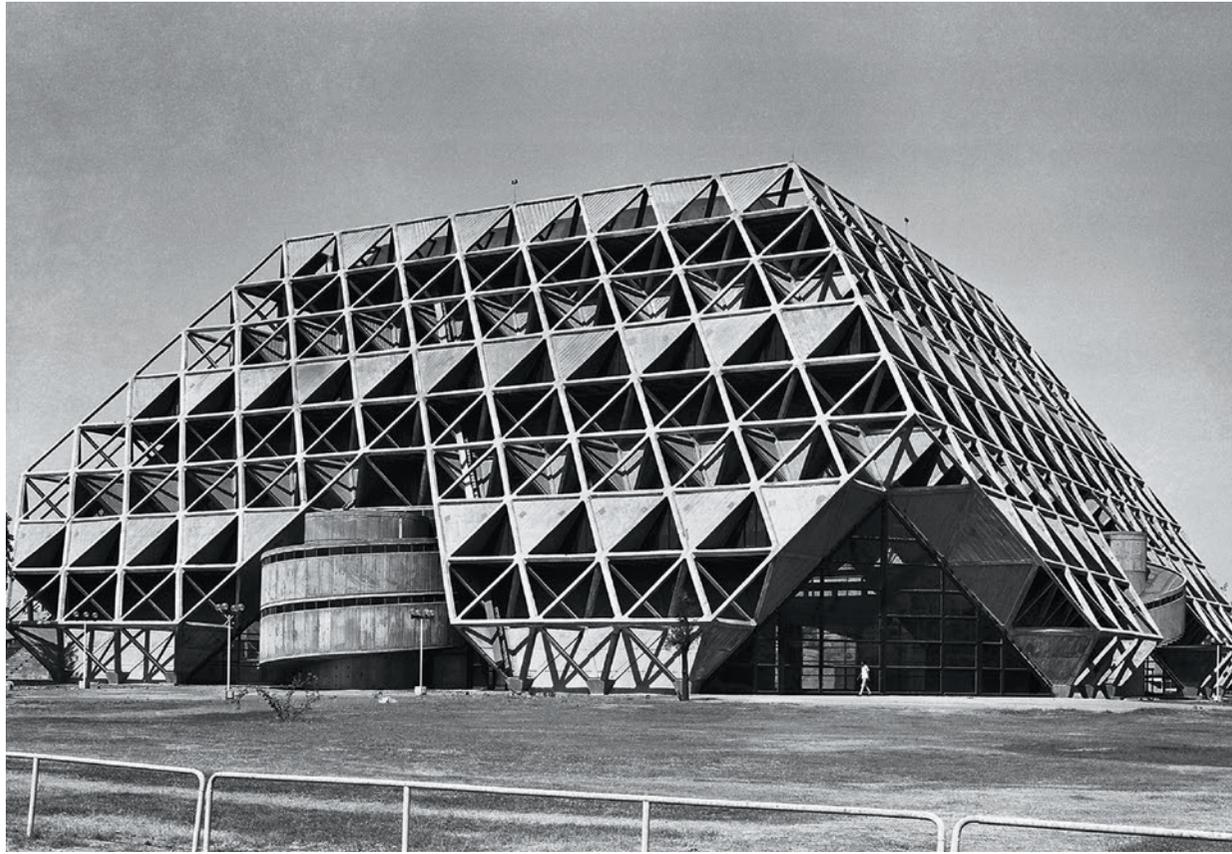
Opposite, top and bottom: Drawing no. 101.ITF.64: Reinf. Details; Typical Joint with Nine Members—Inner Face (Hall of Nations)

Drawing no. 101.ITF.53A: Reinf. Details; Joint Nos. 88, 100, 104, 110 & 113 (Hall of Nations)

Details of configurations of lapping and anchorage of reinforcement bars at different nodes. Detailing involved resolution of the congestion of bars at any given joint. On average, nine members met at a node, with four bars per member—an estimated 36 bars would pass each node, some in compression and some in tension. This congestion was artfully reduced by a system of lapping bars from the four lower members with bars of the four upper members accounting for 16 bars and finally, only 20 bars passed through a node.

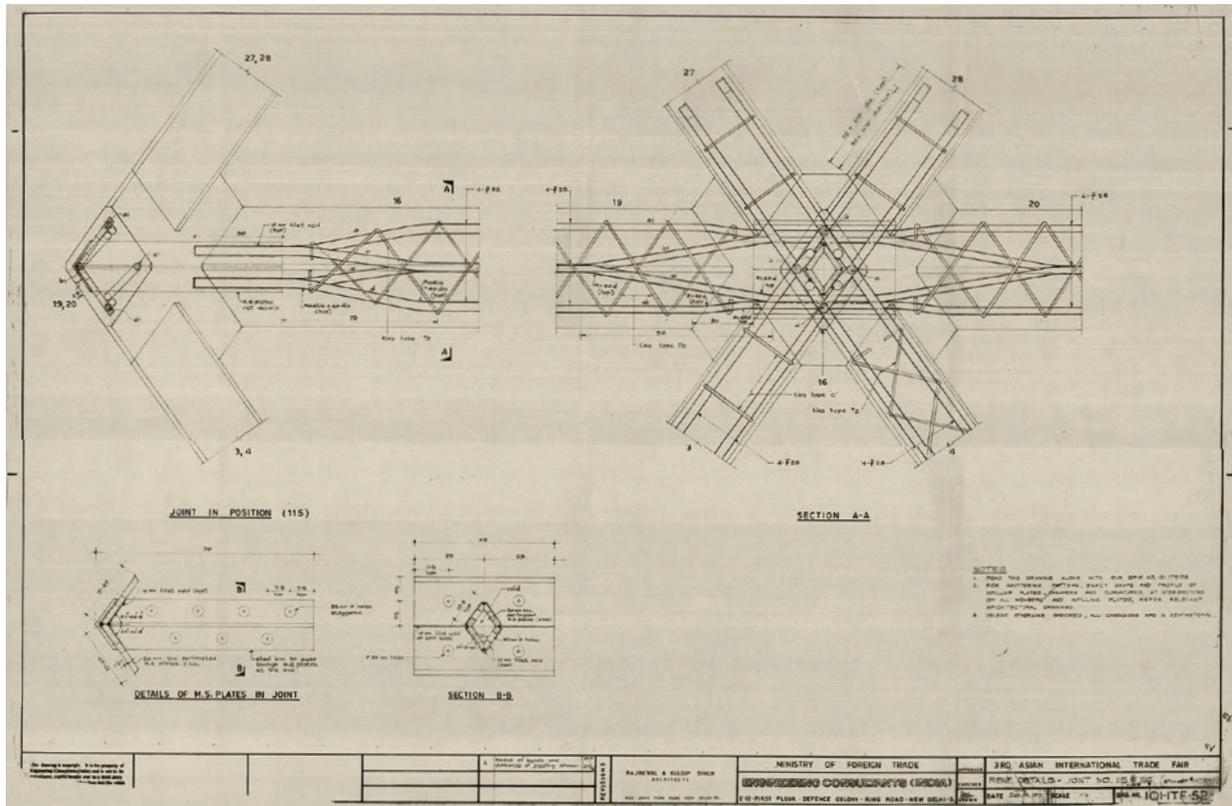
The nodes were constructed by lap-welding members with straight-length bars to short-length curved and bent bars placed in the joint. The sequence was to cast the straight length of a member from joint to joint, place in position partially pre-assembled formwork of the joints along with placed-in-position short-length curved bars. These bars were welded with straight bars of members, formwork of the members up to the next joint was erected and then the next member and joint concreted. (See construction photos, previous page)

Photo of a node with more than nine members.



Bird's-eye view of the entire complex.

Opposite: External view of the Hall of Nations.
 Drawing no. 101.ITF.52: Reinf. Details; Joint Nos. 115, 116 (Hall of Nations);
 6 December 1971



An eleven-member node.



External view of the Halls of Industries.

Internal view of the Hall of Nations.

