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Some Indian Examples of Large Span Building Structures

Quelques exemples de structures à grande portée en Inde

Beispiele einiger weitgespannter Tragwerksbauten in Indien

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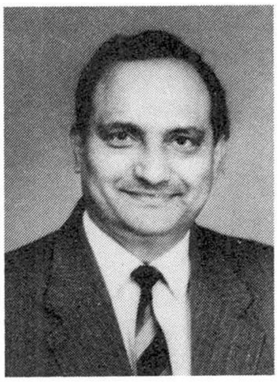

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SUMMARY

This paper deals with some large span building structures which have been constructed in India. The report details the application of precast and prestressed structures using 'A' frames, asymmetrical 'A' frames, and parabolic arch-shaped concrete spans. The use of shells, folded plates and ribbed slabs made of concrete as roof elements for large span structures is also described.

RÉSUMÉ

Ce rapport traite de quelques bâtiments à grande portée construits en Inde. Le rapport décrit l'application de structures préfabriquées et précontraintes utilisant des cadres 'A', des cadres 'A' asymétriques et paraboliques en forme d'arc. L'utilisation de coques, plats ondulés et travées à nervure en béton comme éléments de toiture à grande portée est également décrite.

ZUSAMMENFASSUNG

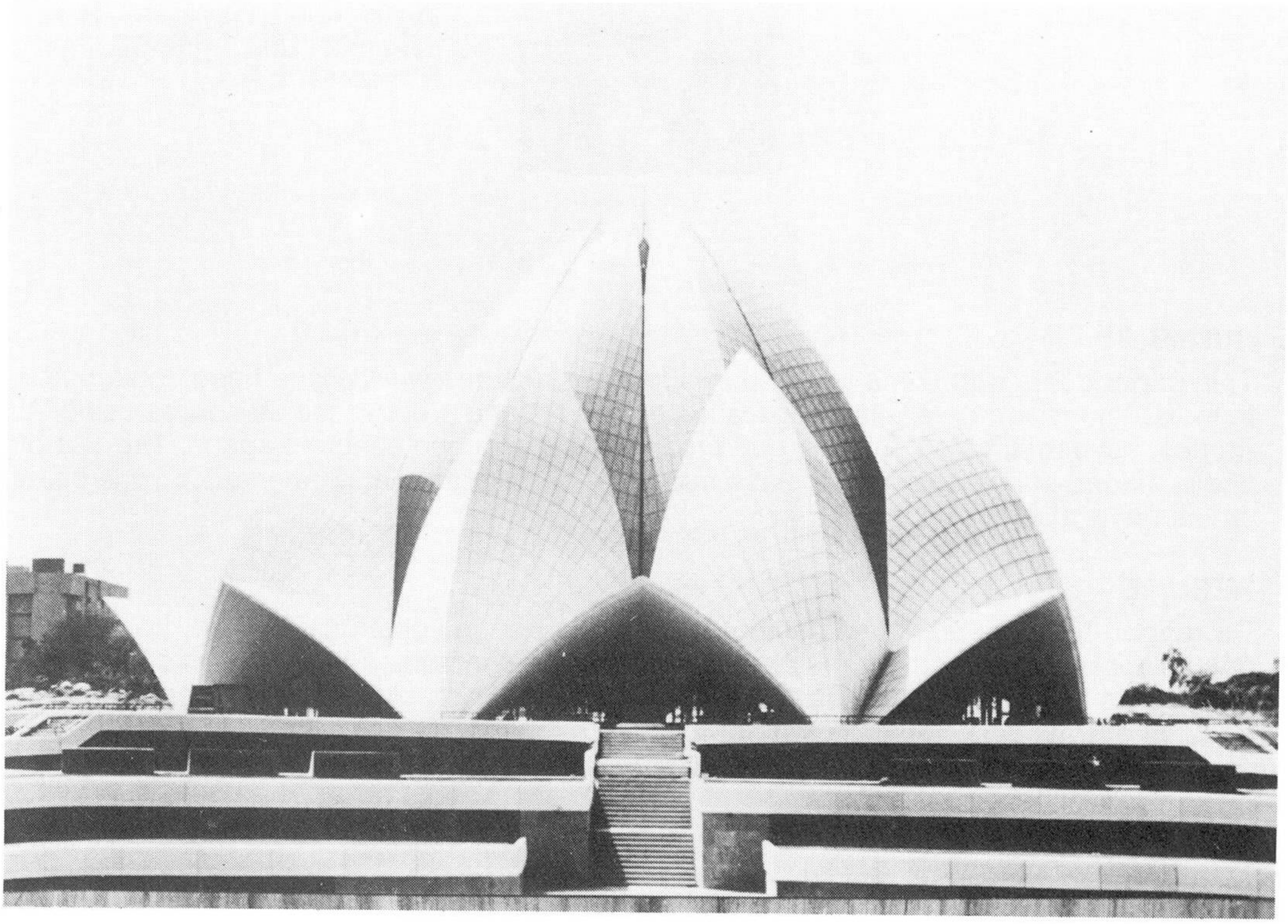
Dieser Bericht behandelt einige weitgespannte Tragwerksbauten, die in Indien realisiert wurden. Der Bericht schildet die Anwendung von vorfabrizierten und vorgespannten Tragwerkselementen, wobei 'A'-Module, asymetrischen 'A'-Module und hohlbogenförmigen Fertigbetonelemente benutzt wurden. Der Einsatz von Schalen-, gewellten Platten- und gerillten Balkenelementen aus Fertigbeton für die Bedachung wird ebenfalls beschrieben.

1. HOUSE OF WORSHIP - LOTUS TEMPLE

The temples of Bahai faith are well known for their architectural splendour and the Mother Temple constructed in Delhi is only a continuation of this rich tradition.

The temple complex, consists of the main house of worship, the ancillary block which houses the reception centre, the library and the administrative building as well as the toilet block. The temple proper comprises a basement to accommodate the electrical and plumbing services and a lotus shaped superstructure to house the assembly area.

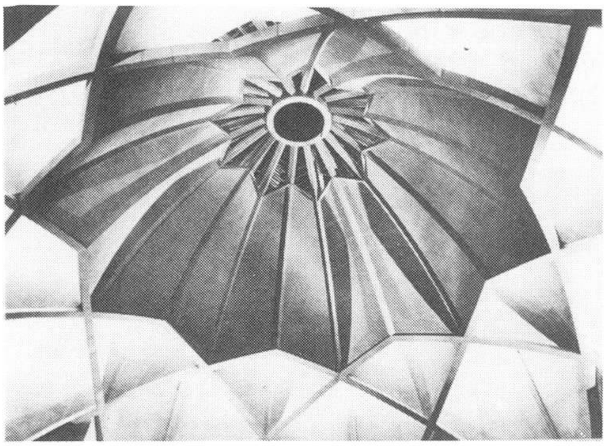
All around the lotus are walkways with beautiful, curved balustrades, bridges and stairs which surround the nine pools representing the floating leaves of the lotus. Apart from serving an obvious aesthetic function, the pools also help in the ventilation process of the building (Fig. 1)



The lotus, as seen from outside, has three sets of leaves or petals, all of which are made out of thin concrete shells. The outermost set of nine petals, called the 'entrance leaves', open outwards and form the nine entrances all around the outer annular hall. The next set of nine petals called the 'outer leaves' point inwards. The entrance and outer leaves together cover the outer hall. The third set of nine petals, called the 'inner leaves', appear to be partly closed. Only the tips open out, somewhat like a partly opened bud. This portion, which rises above the rest, forms the main structure housing the central hall. Near the top where the leaves separate out, nine radial beams provide the necessary lateral support. Since the lotus is open at the top, a glass and steel roof at the level of the radial beams provides protection from rain and facilitates entry of natural light into the auditorium.

Below the entrance leaves and outer leaves rise nine massive arches in a ring, through each one of which is a row of steps leading into the main hall.

The inner leaves enclose the interior dome, a canopy made of criss crossing ribs and shells of intricate pattern. When viewed from inside, each layer of shells and ribs, as they rise, disappears behind the next lower layer. 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 effect of temperature changes and wind (Fig. 2)



1.1 Materials:

The petals of the lotus are in white concrete using specially graded dolomite aggregates form the Alwar mines near Delhi and white silica sand from Jaipur. The white cement used is imported from Korea. The reinforcement used in white concrete, as well as the binding wire for it, is entirely galvanised so as to prevent the long-term effect of rusting of reinforcement on the white colour of concrete. Specially designed steel spacers were used, to keep the reinforcement in place. No plastering painting or any other type of surface finish was done. A lightly bush-hammered, exposed concrete surface, with the pattern of formwork joints form the final finished surface of the interior of the temple.

On the exterior, the petals are clad with white marble panels fixed to the concrete surface with specially designed stainless steel brackets. The marble has been quarried from the Mount Pentilikon mines of Greece and thereafter sent to Italy, where each panel was cut to the required size and shape before transporting them to the site in Delhi. The flooring inside the temple in white marble and the finish of the walkways and stairs of the outer podium is in red sandstone.

The Bahai temple in New Delhi is one of the most complex project undertaken and is also probably one of the most outstanding contemporary structures in the world.

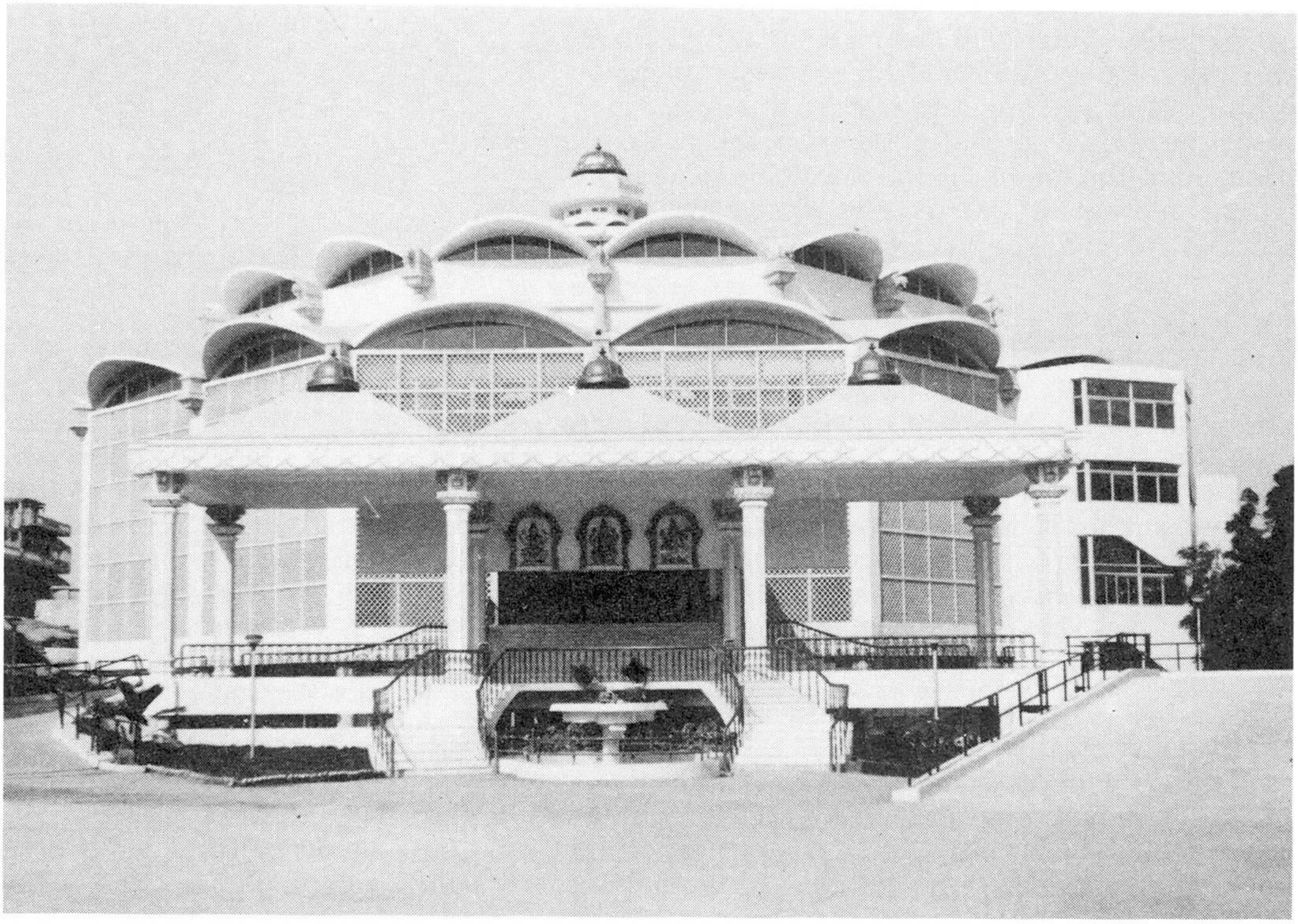
2. MULTIPURPOSE AUDITORIUM - HYDERABAD

2.1 Sri Sathya Sai Nigamagamam

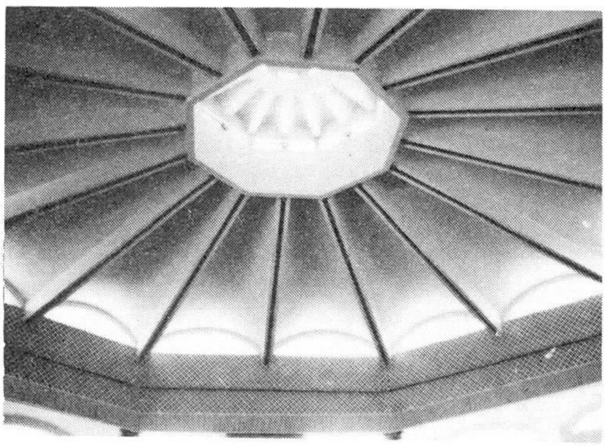
The Sri Sathya Sai Nigamagamam, a modern Kalyanamandapam (marriage hall) cum multipurpose auditorium was built for Sri Sathya Sai Central Trust at Hyderabad.

The auditorium and balcony, arranged in an octagonal shape, has a seating capacity of 1500.

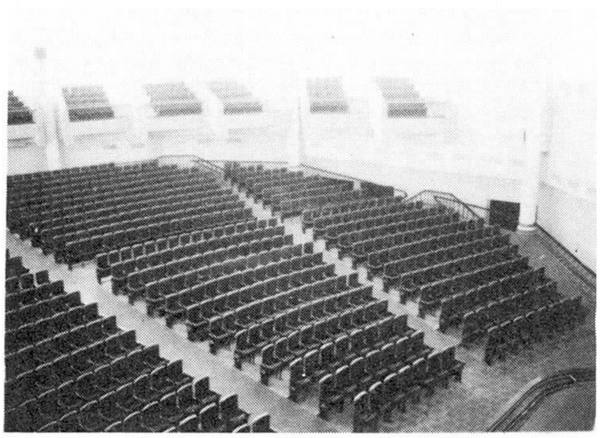
An interesting design feature of the auditorium roof is that it consists of an octagonal concrete compression ring having a height of 3 m. rising to a height of 16.5 m above the auditorium floor level and connected with sixteen concrete beams spanning between columns/circumferential beams and compression ring. An octagonal dome and 16 upper curved shells form the roof of the auditorium. Sixteen lower curved shells form the balcony roof (Fig. 3).



The dining hall roof consists of an interesting grid slab pattern of radial beams and intermediate circumferential beams. The site being located on a rocky terrain, heating of rock using firewood for excavation without disturbing the adjacent structures was resorted to. Single hold drill blast at a time for rock excavation was also done (Fig. 4)



A central scaffolding tower and sixteen radial beam towers were simultaneously erected for stability. Concreting was completed in sequence, taking up compression ring, radial beams and curved shells one after another. The whole staging was deshuttered only after completion of sixteen shells. The air volume



covered within the auditorium / balcony was 1.5 lakh cu.ft. (Fig. 5)

The multipurpose auditorium consists of centrally air cooled dining hall, auditorium and balconies. The main auditorium has an annexe block consisting of kitchen, marriage party rooms and green rooms, plant room and electrical sub-station buildings to cater to air cooling and power requirement of the auditorium.

3. AIR HANGAR FOR INDIAN AIRLINES, BOMBAY

The new Engineering Complex of Indian Airlines at Santacruz, Bombay, has a unique hangar which is being extended to accommodate additional aircraft. The unique 62 m long cantilever folded plate roof of the hangar is considered a world record for such a structure. There was a requirement for expanding the hangar laterally for housing more aircraft. Hence the cantilever scheme was chosen for the roof so that no side supports which hinder free lateral expansion are required. The unobstructed column free space available for the aircraft is 12,000 sq.m in the existing hangar and a further area of 8,000 sq.m is now being added within the full area where six A-300 aircraft are planned to be housed.

3.1. Roof Structure:

The new roof structure will measure 152 m x 60 m in plan, symmetrically divided by an expansion joint located at half the width. The 152 m length consists of two cantilevered hangar roofs of 62.3 m each and a central 27.4 m length over the Engine Hospital Building. The roof system is a continuous multiple folded plate system. The transverse section of the fold consists of 8 modules of 7.62 m width each having a corrugated plate arrangement with horizontal top and bottom plates between webs inclined at 45°.

The cantilevered roof is supported by prestressed concrete suspension ties. The main columns supporting the load at the roof structure are located on the flanks of the central Engine Hospital building and are extended upwards above the roof as concrete pylons. At the lower flange level there is a clear discontinuity in the pylon with the entire roof system sup-ported on reinforced neoprene bearings resting over the top surface of the lower columns. This support system permits free movement of the roof structure under temperature, creep and shrinkage movements. At the upper flange level, a "Freyssinet" type concrete hinge is provided in the pylon to permit free rotations in the longitudinal plane.

Two main transverse diaphragms are provided. The main "forward diaphragm" is located at the front end of the suspension ties near the tip of the cantilever where the ties are anchored. The main "rear diaphragm" is located at the rear end of the ties at the foot of the pylon where the back-ties are anchored. Additional transverse diaphragms spaced at about 9 m centres help in retention of geometrical shape and for carrying transverse wind loads.

3.2 Construction of the roof:

The construction of the thin folded plate elements of the cantilever structure poses a considerable challenge for construction. The sequence of construction is essentially as follows:

- Construction of P.C.C/R.C.C base of flooring
- Erection of staging and shuttering for the folded plate for four folds.
- Casting of roof in the central and cantilevering portions in a sequence specified by designer.
- Casting of pylons and ties
- Prestressing the ties
- Decentering
- Shifting staging to next four folds and repeating above steps.
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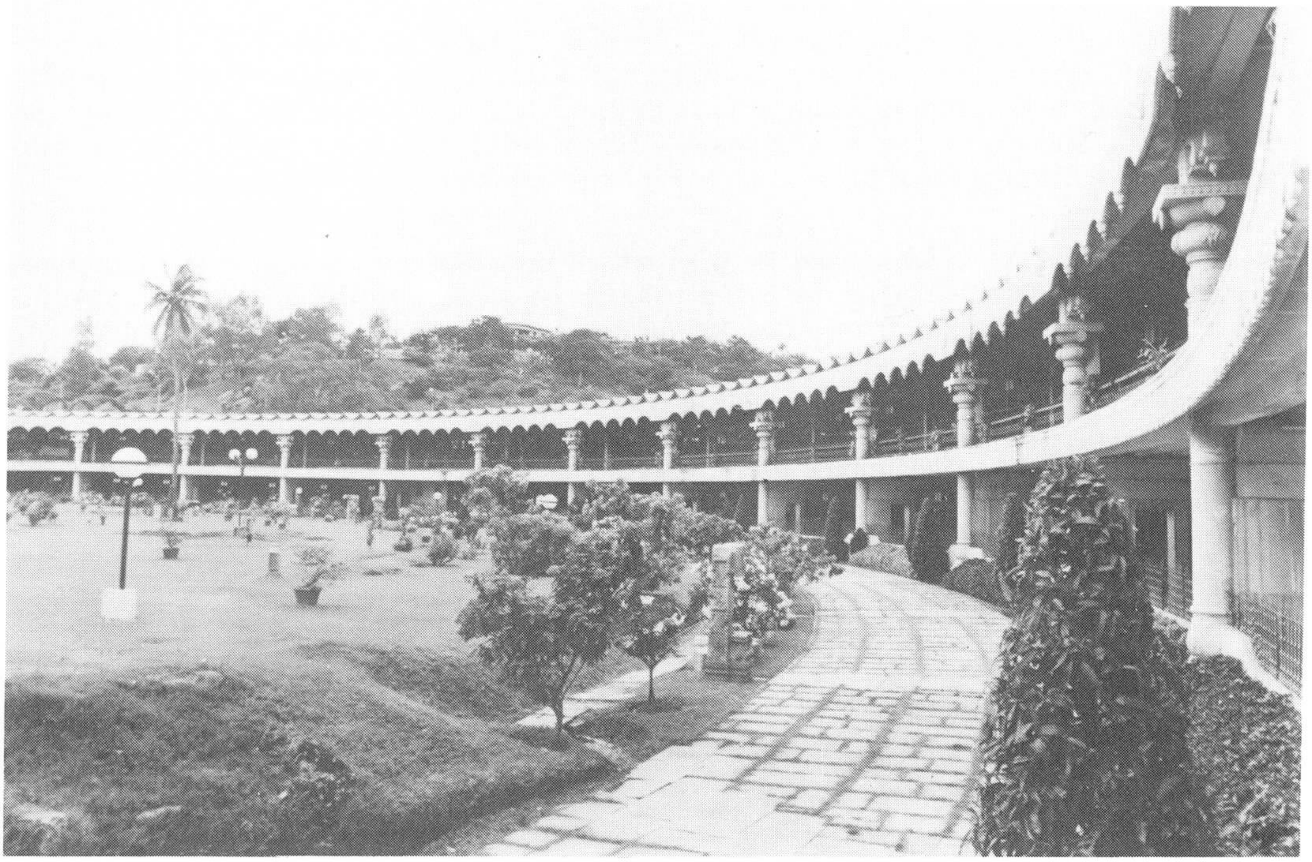
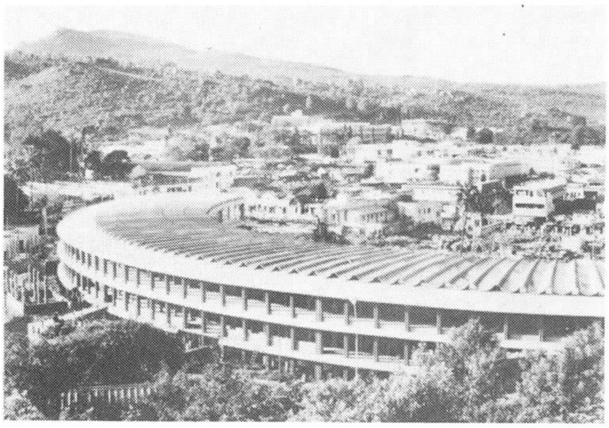
4. MODERN QUEUE COMPLEX AT TIRUMALA:

The complex is meant for devotees waiting to have a darshan of Lord Venkateswara at Tirupati. It comprises seventeen compartments and is like a semi-circular stadium with a bottom and an upper gallery (Fig. 6)

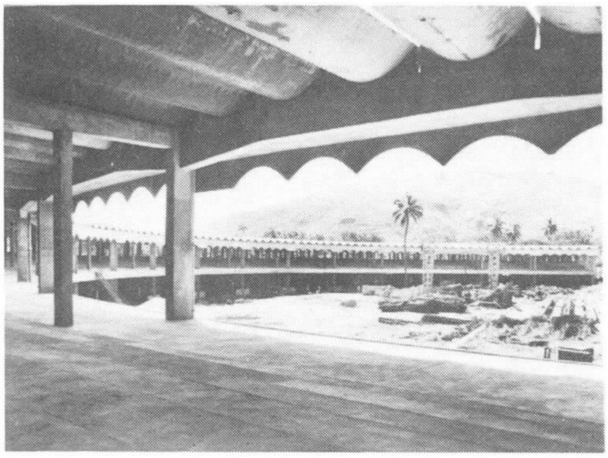


Each compartment contains a reading room, canteen and other facilities for devotees. The upper gallery is made of 323 pre- cast pre-stressed concrete channels and roof consisting of 206 pre-cast reinforced concrete Hyperbolic Paraboloid shells. To facilitate natural lighting, gaps have been left between the roof shells, which are covered with translucent fibre reinforced plastic (FRP) materials. The prestressed channel shaped gallery units are varying in length from 12m to 15m with a width of 915 mm and a depth of 700 mm. High tensile wires of 7 mm dia were used and pretensioning and steam curing was adopted



The pre-stressed channels are supported on brackets projecting from the RCC core walls, in a step-like fashion and form the upper gallery. The gallery steps are finished with marble. The lower gallery is formed by filling with earth and topping with PCC. Cut-outs in the core walls serve as passage for connecting the different compartments. (Fig. 7)

Each of the seventeen compartments can accommodate 400 persons (Fig. 8)



5. ASTHANA MANDAPAM, TIRUPATI:

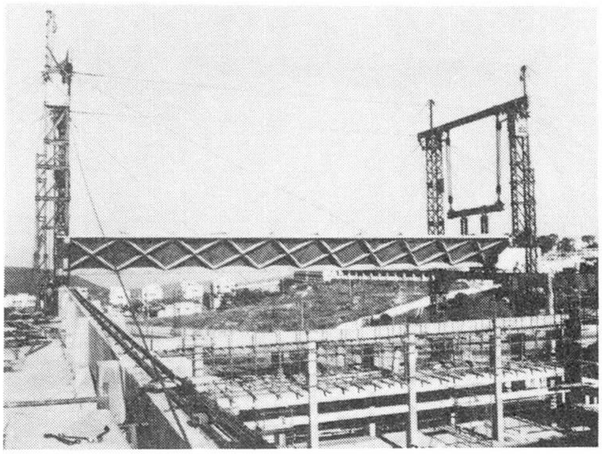
For cultural and religious programmes to take place a complex which has a seating capacity of over 1,500 has been built at Tirupati for Tirumala Tirupati Devasthanams (TTD).

The exclusive feature of this building is a column-free area of 1,700 m^2 achieved by a unique roofing system in precast, prestressed concrete, consisting of nine folded plate elements, each of 30 m span, 6.3 m wide and 60 t in weight. This element is cast on the ground in a timber mould and then erected / placed in position by means of a sophisticated erection scheme.

5.1 Casting:

The mould consisting of timber and plywood has got slab panels which can be lowered after casting, facilitating easy demoulding, refixing and avoiding friction

Prestressing was done by post-tensioning two cables, one of 21 m length comprising six 12.7 mm strands and another of 30 m length consisting of six strands using Gifford-Udall system. Each strand was given a force of 15T(Fig. 9)



5.2 Erection:

Each element was lifted by using four 10 t capacity winches with wire ropes suspended from pulleys hanging from atop the gallow beam. The supporting system comprised four derricks, two of which were on the main columns. Once it was lifted and placed on the trolleys over decking beams, one leg of the smaller derrick on each side was removed so that hauling was done on the rails provided on the beam. The hauling was done by using a chain pulley block and once it was positioned, the unit was again jacked up and placed back in position after removing the rails. The folded plate were waterproofed using two layer tarfelt treatment. (Fig. 10)

5.3 Special features:

The diamond patterned ribs on the bottom of the 'V' type folded plate unit offer a beautiful look when seen from the ground. The economy of this type of roof can be seen from the fact that the slab is only 40 mm thick. Casting being on the ground, the cumbersome scaffolding and staging work was eliminated as the roof is at 10.06 m above the ground level.

6. PRECAST, PRESTRESSED CONCRETE LARGE SPAN BUILDING STRUCTURES

There are many examples of structures built in India in structural steel, cast-in-situ concrete and precast concrete. Some of these structures built in Precast Concrete are described hereunder:

6.1 Storage Structures with Sheet Roofing over "A" Frames

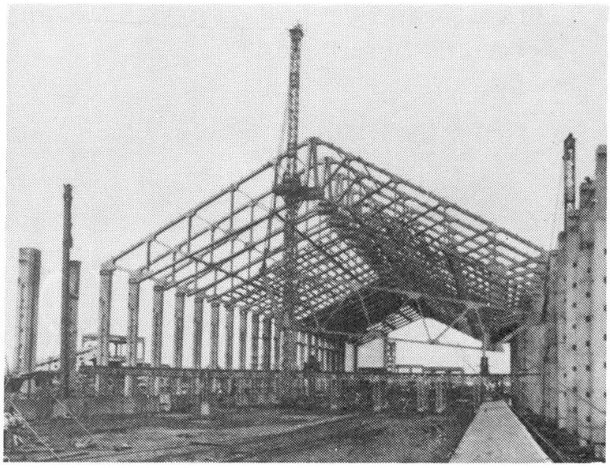
For fertilizer plants in Goa and Tuticorin Precast concrete "A" frames proved to be an economical solution. "A" frames of nearly 40m span were cast in three pieces with two inclined legs and one triangular piece welded together with in situ concrete grouting at a point near the point of contraflexure. Structurally efficient "I" sections were advantageously utilised for the "A" frames to reduce weight for handling. The purlins supporting asbestos sheet roofing with particle board consisted of precast concrete trussed or angle shaped purlins with a thickness of 5 cm. The maximum weight of each element does not exceed 20 tons.

The cross members of the "A" frame besides reducing bending moments in the frame also support the conveyor system as well as walkway slabs. While the conveyor supporting beams are of precast concrete in pairs, walkway slabs are in the form of a ribbed slab with a flange thickness of 4 cm. Compared to structural steel conveyor supporting system and chequered plate walkway platforms, these precast concrete elements proved to be much more economical and durable for the corrosive atmosphere inside fertiliser storage structures.

For storage structure in a cement plant at Satna, unsymmetrical "A" frames were used to match the location of the feed in conveyor. In all other respects it is similar to symmetrical "A" frame storage structure constructed in Goa and Tuticorin (Fig. 11)

6.2 Storage Structure with sheet roofing over trusses:

In the 48m span storage structure for Larsen & Toubro's Cement Plant at Awarpur, the trusses were cast in two pieces outside the building on one side parallel to column grid. The bottom chord of each truss was prestressed at ground level. A specially designed gantry on wheels was used to tilt the trusses and shift the same to the respective places of erection. From the gantry the trusses which were in vertical position after tilting, were hauled inside the building above the conveyor level using two sets of gantries. Three derricks two at the column grid and one at the centre with a platform to receive both the trusses were used for hoisting. After hoisting to the required height, the trusses were made to rest on hydraulic jacks placed over the central derrick and aligned. Two short cables of 3m length were introduced in the sheathing already left in the trusses at the upper end of the lower chord. The central joint was grouted with epoxy and the cables were stressed and grouted. Central jack was released and the truss was made to span 48 m as a single piece. The roof purlins and bracing beams were erected using derricks. An average erection cycle of 10 days per bay was achieved (Fig. 12)



6.3 Storage Structures with Concrete Roof:

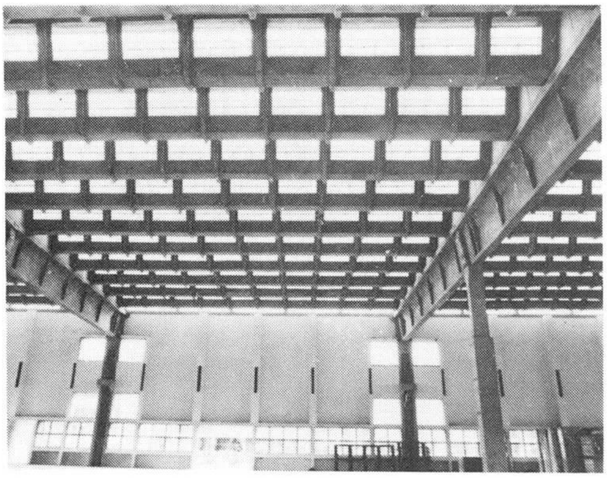
The 55m span 250m long silo at Jagdishpur uses a catenary arch as the main structural system and is 250 m long. The roofing system consists of precast "I" shaped arch units cast in three pieces and channel slabs of 1.5 m width and 8m length. The foundation is a continuous raft with pedestal to support the arches spaced at 8m centre to centre. The beams supporting the conveyor and the walkway slabs are supported on frames suspended from arch units. The entire structure above ground level is in precast concrete. The arches were cast inside the silo area in three pieces, each approximately 30m long and weighing about 20t using a specially designed timber mould supported on steel frames to facilitate vertical casting. The units were picked up sequentially by crawler cranes and made to rest on hydraulic jacks supported on special trestles moving on rails. After alignment, the units were connected by welding and grouting. After assembly, the jacks were released and the arch was made to span 55m as a single unit. The suspender frames were also erected using the same trestle. The roof slabs and beams supporting the conveyor and the walkway slabs were erected by a crawler crane. An average erection cycle of 5 days per bay was achieved (Fig. 13)

6.4 Shells, Folded Plates and Ribbed Slabs as Roof Elements:

Hyperbolic Paraboloid (HP) shells, barrel shells, folded plates and ribbed slabs, both reinforced and prestressed have been advantageously utilised as roof elements for many large span applications in India.

At Larsen & Toubro's hydraulic excavator factory in Bangalore, precast prestressed HP shells 20m in length and 2.5m in width have been used as roof elements together with prestressed concrete roof trusses and lattice type prestressed concrete gantry girders forming a 20m square grid. HP shells were 5 cm thick at the bottom most point and 10 cm at the edges with diaphragms at the end. The weight of each element was 9 tons.

Totally 32 Nos. prestressing cables of 7 mm size arranged in a criss crossing fashion formed the reinforcement in the HP shell. This apart a welded mesh of 10 gauge. 3.25 mm dia at 150mm centres formed the non prestressed reinforcement. These shells were cast in a concrete mould with top surface of the mould having welded mesh and chicken mesh reinforcement in high strength concrete. The top surface was rubbed with carborundum stone and finished with bees wax to give a smooth surface for casting. The end beams of the mould were made in reinforced concrete to support the cross beams transferring the force. These beams help closure of the space by an insulated hood to facilitate steam curing. In a 24 hour cycle of production two HP shell elements were achieved with two moulds. For vibrating the concrete the steel leveller running on the rails on the longitudinal beams of the moulds was used to achieve accuracy in vibrating the concrete during casting (Fig. 14)



For the building of Motor industries company Limited (MICO) at Bangalore 20m span, 3.31m wide folded plate elements were used for the roof. The folded plate has openings for northlight glazing on the one side. This is, one of the largest RCC Folded Plate shells in India. The large depth and small thickness of plate made it economical also. The folded plate has a shell thickness of only 4 cm and the webs of the folded plate were inclined to an angle of 60^{o} to horizontal. The steep inclination warranted shutters not only at the bottom but at top also.

An unique mould was designed and fabricated which had the facility for tilting up/lowering the soffit shutter of the webs. The webs were cast in the horizontal position first. The placing of concrete was very simply accomplished by using skips and gantries and the concrete vibration was carried out using screed vibraters. Two hours after concreting, the entire length of web (22m x 2m size) was tilted to its final inclined position. The reinforcement in the valley was tied next and the concreting completed by casting the valley. Steam curing was resorted to, to attain early strength. The soffit shutters of the webs were lowered and the folded plate removed. The tilting-up and lowering operations were carried out by hydraulic rams specially designed for this purpose. Even though a 36 hour cycle for production of one precast folded plate has been achieved, for operational convenience a 48 hour cycle was adopted. The element weighs only 14.5 tons (Fig. 15)

From the considerations of economy of materials which are relatively more expensive than labour in India and quality, durability, and speed of construction, innovative use of precast prestressed concrete has proved to be extremely successful in India for large span building structures.

CONCLUSION :

The innovative techniques and methods used for large span building structures above coupled with structural design concepts and speed has resulted in construction of elegant and economical structures. This has benefited the world of concrete to a large extent. The varieties of uses to which concrete has been put to for building of large span building structures in India are unique and the adaptations done are economical and pioneering in nature.