Seminar 1: Creative design as reflected in practical applications

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Seminar 1

Creative Design as Reflected in Practical Applications

Idées créatrices dans le projet et applications pratiques

Kreative Entwürfe und Anwendungsbeispiele

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Future Horizons for Concrete Construction

Perspectives dans la construction en béton

Neue Horizonte im Betonbau

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SUMMARY

The paper reviews significant trends in concrete and discusses these in relation to materials and construction techniques. The importance of education and training at all levels, to spread a better understanding of concrete, is stressed. Future directions are signposted in terms of high performance concrete, better liaison between design and construction and new materials.

RÉSUMÉ

Cette étude analyse les tendances significatives du béton et les examine en fonction des matériaux et des techniques de construction. Elle souligne l'importance de l'éducation et de la formation à tous les niveaux, en vue de propager une meilleure compréhension du béton. Elle indique les voies futures à suivre sous forme de bétons à hautes performances, d'une meilleure liaison entre les projets et les réalisations, ainsi que de nouveaux matériaux.

ZUSAMMENFASSUNG

Der Beitrag diskutiert herausragende Trends im Betonbau, wie sie besonders im Bereich der Werkstoffe und der Verfahrenstechnik zu sehen sind. Ausbildung und Schulung zur Verbreitung besserer Betonkenntnisse sind auf allen Ebenen dringend geboten. Zukunftige Entwicklungen wie Hochleistungsbeton, neuartige Werkstoffe und eine bessere Verbindung der Projektierung mit der Ausführung werden skizziert.

1. INTRODUCTION

Primitive forms of concrete have been used in construction for at least two thousand years. However, the material, which engineers today identify as concrete, dates back only to the middle of the 19th century and began to achieve wide structural application about a hundred years ago. Around the turn of the century a few engineers began to appreciate the exciting potentialities of reinforced concrete and the freedom of design thereby created. Since that time, advances in the design and service performance of concrete structures have depended upon developments not only in the basic material properties of concrete but also in steel (e.g. leading to the practical realisation of prestressed concrete) and in plant and techniques of construction.

My own formative years as an engineer coincided with the emergence in post-war Europe and elsewhere of concrete as the dominant structural and architectural material for the latter half of the 20th century. During the 50's and 60's there was a dazzling succession of notable achievements and applications of concrete in structures. At this time prestressed concrete was making its first great strides en route to becoming the preferred material for medium span bridges; the architectural trend was to employ concrete as the dominant facing material, both inside and outside buildings. Most engineers thought that provided a reasonable job was made of mixing and placing, concrete could do no wrong - it was an adaptable material with a long maintenance-free design life.

Moving into the 70's and 80's, there has been a succession of problems with concrete construction. Most of these problems were avoidable but there is no doubt that they have undermined confidence. This has caused engineers to be much more careful to avoid mistakes and misuse of the material likely to lead to future difficulties in service and has persuaded architects to prefer brick to concrete as a facing material. This paper looks ahead to gauge the likely impact of recent developments in concrete in terms of both the material and the ways in which it is being employed in the construction of buildings and bridges.

Amongst the traditional constituents of concrete - Portland cement, water and aggregates, cement has changed with time to some extent because of trends in the manufacturing process - together perhaps with a perception by cement producers of user demands for higher strength concrete. Such changes have been well documented in the U.K. [1] and are probably representative of the situation in most other countries. However, other more significant trends have also been taking place over the last three decades

- development of cement-replacement materials and superplasticisers
- enhanced interest in the long-term performance of concretes
- greater collaboration between designer and constructor
- application of high strength concrete in practice.

These trends are closely inter-connected and will be discussed under two headings:

A - Materials for Concrete
B - Construction Techniques

2. MATERIALS FOR CONCRETE

2.1 Cement-replacement Materials

Initial moves to replace a proportion of Portland cement in concrete arose principally from a search by industry to find uses for waste materials. Can we use it in concrete? - seems to be an early question which arises for waste products. However, research has shown that three such materials have beneficial effects in concrete.

- Pulverised fuel ash (pfa, often known as fly ash) a waste product from coal-fired power stations has been widely used typically replacing 20-30% of Portland cement, the presence of pfa slows down the early growth of strength of concrete; if properly cured, it will enhance the final strength and decrease the permeability of the concrete.

- Ground granulated blast-furnace slag (ggbs) from iron production has also found extensive application. It can enhance strength but has particular merits in lowering the heat of hydration in large pours and in improving the resistance of concrete to sulphate attack.
- Condensed silica fume (csf) which stems from silicon production is a very fine material (also known as micro-silica) which can, with care, produce very high strength concrete.

These products can be of significant value in concrete structures but all require particular attention in placing and curing. The workability of concrete mixes containing csf poses special difficulties if placing is not carried out expeditiously. Without adequate curing for at least three days [2] the potential long-term strength and durability of concrete which includes pfa, ggbs or csf will not be achievable.

2.2 Superplasticisers

The development of chemical admixtures in order to modify the early behaviour of fresh concrete has long been a feature of the manufacture of concrete elements. Retarders and accelerators have been used when appropriate to modify the setting process. Plasticisers are employed to improve the flow properties and help the placing of concrete in complex shapes, around formwork or in difficult environmental conditions. The advent of superplasticisers [3] which have dramatically enhanced flow properties and workability without sacrifice of strength, has been a great boon in concrete construction. It has led to inherent improvements for in situ concrete and has made more possible the practical use of all the cement-replacement materials described above. Concrete containing a superplasticiser can be pumped for long distances (vertically or horizontally), revolutionising work on confined construction sites.

2.3 Permeable Formwork

Concrete engineers constantly emphasise the importance of the exposed surface region of a structural element. The durability of the element relies upon the ability of this region, 15-20mm thick, to resist the ingress of air, water, chlorides, sulphates and other deleterious substances. Attention has been drawn to methods of improving the surface region and various coatings and surface treatment have been tried, with varying success. The introduction of a proprietary system of permeable formwork, which effectively drains off surplus cement paste and air from the surface, has provided a means of permanently improving the surface region by eliminating blow holes and lowering the porosity and permeability of the formed surface of the concrete. Recent research [4] has shown the effectiveness of this technique and it is to be hoped that widespread use will not be hindered by high cost.

3. CONSTRUCTION TECHNIQUES

Closer collaboration between designer and contractor has led to major improvements in concrete structures and significant advances in the economics and speed of construction.

3.1 Fast Track Construction

There have been major projects in large cities such as Chicago, Hong Kong and London which have concentrated upon 'fast track' concrete construction. For example in London, the Broadgate and Docklands projects have provided opportunities [5]for the application of well-designed combinations of precast and in-situ construction and the first major use in Britain of post-tensioned (bonded and unbonded) concrete floors. Information technology has also played its part; the availability at comparatively low cost of sophisticated software and hardware now permits rapid and accurate analysis and design of complex structural frames. Thereby, over-conservative designs can be eliminated.

3.2 High Performance Concrete

The United States has led the world in the employment of high strength concrete for tall buildings, adopted primarily to reduce the excessively large column dimensions needed for conventional concrete. Thus in the concrete building which is currently the tallest in the world (Fig. 1) - 311 South Wacker Drive in Chicago - it is reported [6] that concrete of 110MPa cylinder strength was used for the base columns and 72MPa higher up the building. Other U.S. buildings have used an even higher specification for a cylinder strength of 130MPa.

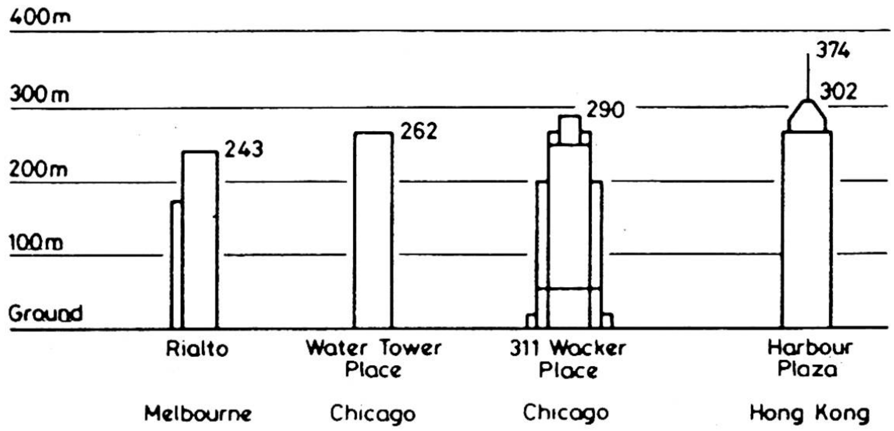

Fig. 1 - Tall buildings of concrete construction [7]

In Hong Kong, 60MPa cube strength concrete (equivalent to about 48MPa cylinder strength) is being used in the 78 storey Harbour Plaza building currently under construction. On completion it will be the tallest reinforced concrete building in the world (Fig. 1). The use of high strength concrete leads to the idea, identified by several authors, [8, 9], of high performance concrete which incorporates three parameters:

- high compressive strength
- high durability
- high deformational (or dimensional) stability.

All three parameters can be of importance for key structures. In tall buildings, high strength should go hand in hand with high deformational stability or stiffness. A high value of modulus of elasticity of concrete will reduce sway and should be included in the specification; however, brittleness can be an undesirable characteristic of some high strength concretes. High durability will also be required in harsh environmental conditions. In North Sea offshore concrete structures for the oil and gas industries, the demand for a concrete possessing a high compressive strength and adequate durability to combat the hostile environment led to the specification not only of a high strength grade but also of maximum values of permeability. This form of specification was repeated even more stringently for the Channel Tunnel. Nevertheless, no simple, rapid test of concrete permeability has been adopted as a standard in Britain or elsewhere; thus permeability monitoring tends to be very limited during the production stages of such projects. This issue needs to be resolved quickly if the specification of permeability is to have any real meaning beyond the stage of mix design.

For concrete bridges all three parameters become essential. For example, match-cast segmental construction, which has proved to be an outstandingly successful technique for multi-span prestressed concrete bridges lends itself to (and benefits from) the use of high performance concrete. Deformational characteristics assume importance - a high modulus of electricity, low creep and low shrinkage are all desirable properties. Strength and durability are also paramount in this form of structure, bearing in mind the very large costs which have been incurred in recent years in maintenance and repair of concrete bridge decks and sub-structures, in the United States and elsewhere.

Within the limited scope of this paper it has only been possible to indicate some general developments in construction techniques illustrated by one or two examples from recent practice. However, the inter-dependence of construction techniques and choice of concrete is clear; advances in construction techniques for concrete are normally only possible when accompanied by improvements in concrete and its properties.

4. WHAT NEXT?

Concrete construction is now at an extremely interesting stage in its evolution. It has suffered in the past from its own apparent advantages, in that it is very simple to make concrete: its constituents are readily available and even unskilled, untrained labourers can make a credible concrete slab or lintel. This low technology approach is still with us, but in many countries the high costs of maintenance, repair or replacement of defective concrete structures are even more persuasive to clients than the voices of the many engineers who have long understood that concrete needs a high-tech approach, with well trained personnel on site. Attitudes are certainly changing, but everywhere, more effective education and training in concrete construction for engineers and concretors are needed to maintain evolutionary progress.

The adoption of high performance concrete for prestige projects is an excellent indicator for the future. It has been adequately demonstrated in the United States [6] that high performance mixes for buildings can be produced consistently by ready mix suppliers and placed successfully on site. The critical importance of extended curing procedures is again stressed here. Sampling and testing including routine taking of cores from the structure are essential; for structures in harsh environments, tests should include the measurement of permeability or diffusion of the concrete. Other major projects such as off-shore structures and bridges are increasingly employing high performance concrete to ensure satisfactory long-term performance.

The closer integration of design and construction with careful review of alternative schemes at the concept design stage, taking due account of speed, cost and ease of construction, is leading to benefits for client, designer, contractor and user. A recent case study [10] on a building in London's Docklands Enterprise Zone has set out the options considered, as well as the chosen solution, which was an interesting in situ concrete building with post-tensioned floors. Publication of case studies of this type is a valuable initiative which could usefully be repeated in other countries. In reports of completed structures, often too little is heard of the rejected solutions and the reasons for the final decisions made. However, the important conclusion to be drawn here is the desirability of close liaison between engineers experienced in both design and construction, architect, building services engineer and client for best use of available technology in concrete.

It is difficult to forecast with any precision the development of new materials. Steel continues to reign supreme as the reinforcing medium for concrete. In terms of corrosion it poses problems and there are various developments of non-corroding polymer materials as possible alternatives to steel. Kevlar has been employed for cables for certain structures; it needs protection from ultra-violet light but is non-corrosive and has a reasonable performance in creep [11]. Other high modulus polymers, produced by extrusion or die-drawing, thereby re-orienting the molecules in one direction, are strong in tension, but have a poor creep performance [12]. However, new possibilities are being examined in research in several countries and in the near future we should see polymer materials used as reinforcement for concrete elements in marine or other environments where concrete structures deteriorate rapidly

Future horizons for concrete encompass better use of established technology, arising from a wider understanding at all levels of concrete as a material. They also include further developments in technology and the use of new materials within concrete and as reinforcement.

REFERENCES

1. CONCRETE SOCIETY, Changes in the Properties of Ordinary Portland Cement and their Effects on Concrete. Technical Report No. 29, 1987.
2. GOWRIPALAN N. et al., Effect of Curing on Durability. Concrete International, Feb. 1990, pp. 47-54.
3. HEWLETT P.C. and EDMEADES R.M., Superplasticised Concrete. Current Practice Sheet 94 & 95, Concrete, April-May 1984.
4. PRICE F. and WIDDOWS S.J., The Effects of Permeable Formwork on the Surface Properties of Concrete. Magazine of Concrete Research 43, 155, June 1991, pp. 93-104.
5. BENNETT D.F.J., Advances in Concrete Construction Technology. British Cement Association, 16 pp., 1989.
6. SHEEHAN T., High Strength Concrete - A Review of U.S. Expertise. Concrete, Nov.-Dec. 1991, pp. 35-37.
7. CUSENS A.R., Concrete Steps to Construction's Future. Structural Engineer 69, 21, 1991, pp. 365-368.
8. MEHTA P.K. and AITCIN P., Principles Underlying Production of High Performance Concrete. Cement, Concrete and Aggregates 12, No. 2, 1990, pp. 70-78.
9. MAHER Y., The French Approach to Using HPC. Concrete International 13, No. 7, July 1991, pp. 28-32.
10. BENNETT D.F.H. and BILLINGHAM A., Exchange Tower. British Cement Association, 13 pp. 1991.
11. CHAMBERS J.J., Long Term Properties of Parafil. Proc. Symposium on Engineering Applications of Parafil ropes (C.J. Burgoyne, Ed.), Imperial College, London, 1988, pp. 21-28.
12. GOWRIPALAN N and CUSENS A.R., Modified Polymer Bar Reinforcement in Concrete Elements. Construction and Building Materials 2, 2, June 1988, pp. 106-111.

Saint Sava Temple – Heavy Building Assembly Application

Temple Saint Sava-Application de la préfabrication lourde

Saint Sava Tempel-Anwendung Schwerer Montagebau-Elemente

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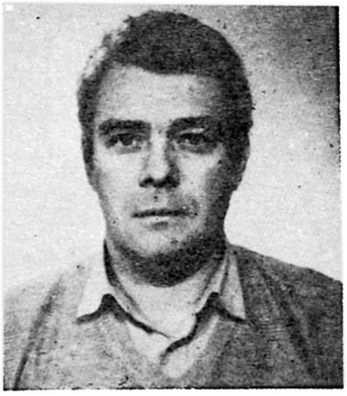


Dušan Arbajter, born 1945, received his civil engineering degree at the University of Belgrade, YU. He worked as a civil engineer on site later on as a designer. He was involved in large projects with design and erection of heavy assembly structures. Presently he is assistant general manager for design, marketing and computer departments, in KMG Trudbanik, Belgrade, YU.

SUMMARY

Saint Sava Temple is a building which was designed and erected applying very advanced design tools and programmes as well as electronic device and equipment. The article presents the methodology of design and calculation of the main dome in all its phases of construction and life This is the first time that such a huge structure was lifted to such a height, without having performed research and checking on the model before. All measured data is presented as reference to those obtained during the design, showing that the design and technology involved were well thought out in advance.

RESUME

Le Temle de Saint Sava représente un ouvrage dont les études et la construction sont basées sur l'application des moyens et des logiciels les plus modernes, ainsi que des appareils électroniques et équipements récents. Le présent exposé présente la méthodologie d'étude et de calcul de la coupole principale, ainsi que de toutes les phases de sa mise en place. C'est une première mondiale, qu'une construction de tel poids soit élevée à une telle hauteur sans essais et vérification préalable sur modèle. Toutes les valeurs mesurées sont — comparées aux calculs, prouvant que les études et la technologie appliquée ont permis d'évaluer à l'avance les valeurs et données réelles.

ZUSAMMENFASSUNG

Sant Sava Temple ist eine Bauanlage, projektiert und montiert unter Anwendung von modernsten heute bekannten Mitteln und Programmen sowie elektronischen Anlagen und Ausrüstungen. In diesem Referat werden das Projektierungs, und Berechnungsverfahren der Hauptkuppel, sowie alle Phasen ihre Hebung und Entstehung dargestellt. Eine so schwere Konstruktion wird dabei zum ersten Mal in der Welt ohne vorherige Untersuchungen und Kontrollen am Modell auf eine solche Höhe gehoben. Alle Messwerte werden parallel mit während des Projektierens erhaltenen Rechenangaben dargestellt. Dadurch wird gezeigt, dass durch das Projekt und die angewandte Technologie schon im voraus die eigentlichen Werte richtig bestimmt wurden.

BUILDING AND DESIGN HISTORY

The building is being constructed on the place where the naturalized Turk Sinan Pasha burnt the remains of St. Sava in 1595. On the eve of World War II, in 1935, the construction of the present day cathedral church began, assuming the size of the largest Orthodox church in the world. Construction was resumed 45 years later, in 1986, according to the original preliminary design of the authors, Arh. Bogdan Nestorović, and Arh. Aleksandar Deroko, both Professors on Belgrade University.

The St. Sava Temple was designed in the Serbian - Byzantine style. The layout is shaped as a cross, sized 91 by 83 meters in plan. The height of the building is 80 meters, including the cross. The building is dominated by a central dome spanning 33 meters, and four semi-domes at the wings. The facade will be clad in marble. The original design project proposed a structure composed of masonry and partly of reinforced concrete.

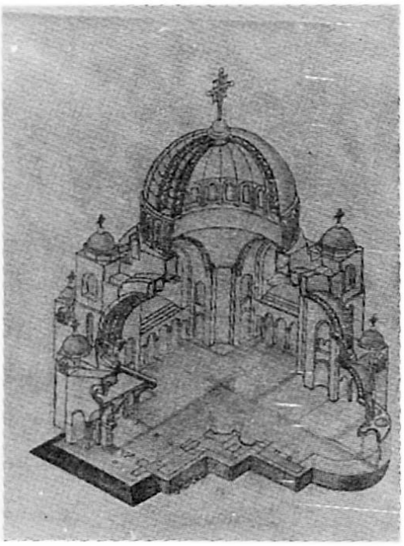


Figure 1.

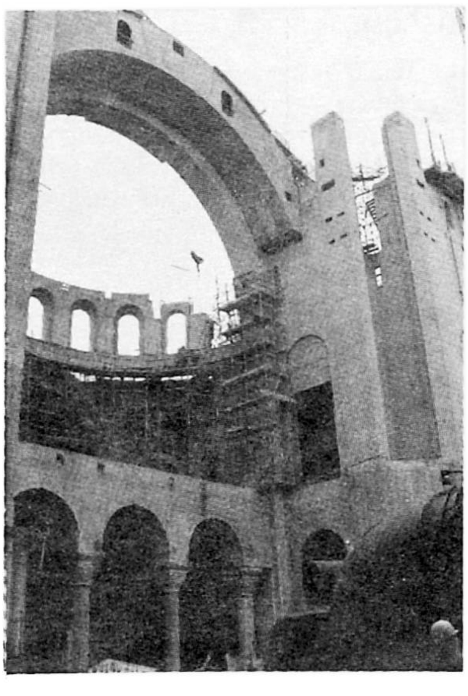
Figure 2.

The as-built state of the foundations was only learned after detailed investigative work. The four central bell towers were founded on 532 "Simplex" piles, 6m in depth, according to some reports. The massive perimeter walls are laid on strip foundations 4m in depth. The quality of the various materials used, i. e. brick, concrete, reinforcement, marble, etc., has been established through investigative work. By carrying out detailed surveys of the existing structure, the as-built outlines of the building were determined, which were to serve as a starting point for further design and construction work.

GENERALLY ABOUT "Saint SAVA" TEMPLE - TECHNOLOGICAL POINT OF VIEW

"St. SAVA" Temple is the greatest sacral building under construction nowadays, one of the greatest Orthodox Temple, the first which is being executed under very high level of assembling of building static system, although it is unusual and unique in building construction assembly practice concerning its geometrical shape (figure 1).

This building, in its essence has the permanent constructing and historical value and it is quite different from any other. Relying on many successful, but indeed, different experience in assembly, KMG "Trudbenik" has devised a constructing technology model of Temple system, providing the maximum parallel works, quality, economy as well as high speed of construction, running before scheduled time, therefore, we can say undoubtedly that it has contributed to significant innovation in building construction of our times.



SEPARATION OF BUILDING - TECHNOLOGICAL PARTS

The original design project proposed a construction combining brick and concrete. For obvious reasons such a structure was kept to the extent in which construction had progressed so far. First of all repairs in the foundation structure had to be carried out, as well as the separation of the wing sections from the central part by way of expansion joints. Tying up of the

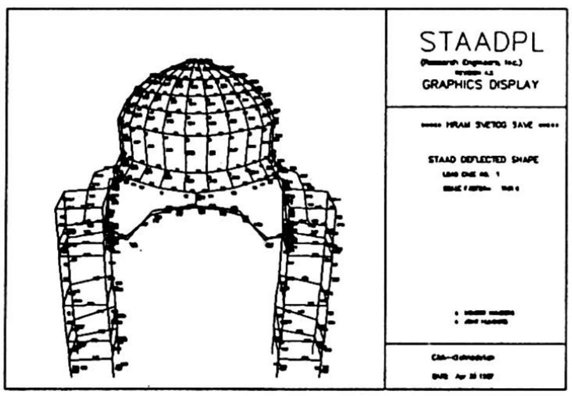
foundations, the existing part and the new structure of the forthcoming stages of construction was achieved with reinforced concrete columns and tie-beams.
Expansion joints of the wing sections were carried out along the line of intersection between the semi-domes and the main arches, and vertically down the bell towers up to the foundations. The continued construction was designed as a fully prefabricated rein- forced concrete element structure. The fact that the building is geometrically extremely complicated from a structural point of view resulted in the breaking down of the elements into precast components outlined with straight lines to the greatest possible extent.
All walls have been designed as hollow boxes which, when assembled into a whole, give the building its massive appearance (picture - right).
All arched shapes of the galleries and vaults have been transformed into assemblies of elements curved in two dimensions which, having been erected, form a three-dimensional shape. The semi-domes and the dome have been linearized by designing a system of arched trusses and two layers of curved decking. The precast parts are bound into a whole by in-situ cast parts of the structure which provide the required safety and long life of the building.
The bell towers were initially started as a combination of brick and concrete columns, and have been continued as a concrete box-structure which provides the greatest possible resistance of the towers with the least possible weight. This part of the building has been completed by applying the sliding shuttering method (slipp-form), whereby the advantages of prefabrication were exploited. The central part of the building Includes four main arches between the bell towers and the central dome with the pendentive underneath (figure 2).

FOUNDATION

It was found that kind and type of foundation chosen by previous design, was not adequate, even for carrying loads imposed from whole building which is according to new design lighter by 30-40%. During the time it was discovered that length of "Simplex" piles bellow the main tower-column is actually about 6m with head laying at level of -10m It was decided that, before the lifting of main dome will start, improvement of main columns to carrying gravity and other loads, have to be done. It was decided to improve the main column foundation by adding (replacing) 13 old piles bellow slab with new one which is 1.4m in diameter, and deep to the -17m level (reaching the rock).

STRUCTURAL ANALYSIS

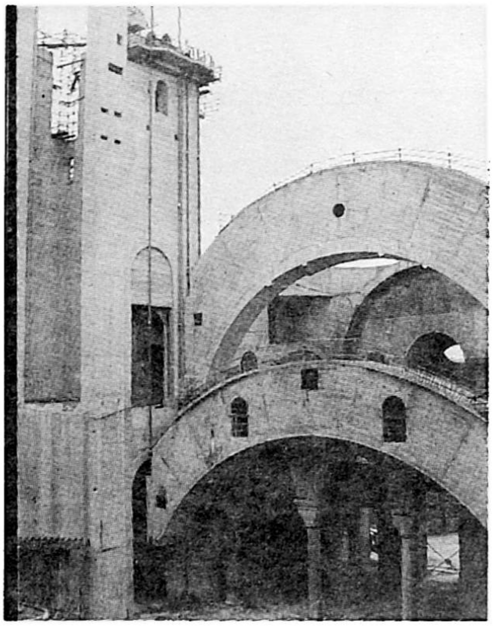
Structural analysis of building structure is made according to new JUS codes, standards of Yugoslavia and appropriate codes. After the building is splitted in to the five parts, calculation is made concerning the wings as one model and central part as another. Separate parts of structure which belongs to prefab group of elements are treated through the calculation as elements which have to be checked against the loads through the transportation and erection time.



Again this elements are checked through his "second life", passing the lifting or pulling phase of erection (elements for arches, main dome and pendentive). Finally all this elements are checked for their "third life" and final life in structure which has to last for next five hundred years as minimum. For a first time dynamic calculation and finding the dynamic characteristics of structure, we used program "TABS" from Berkeley University. Parallel the calculation is made using USA program "STAAD". Dimensioning of all elements are made according to new Yugoslav recommendations which are mainly in accordance with European codes. To prove the static calculation and all of our presumptions, it was made decision to provide all main structures and elements needed for lifting purpose, with measurement instruments during the lifting procedure. All measurement instruments are connected to the computers for purpose to get all data collected for analysis which could be carried out later on. By this way, we are in position to see (in live) directly on computer monitors all relevant data concerning deflection, jack's stroke, leveling of supports, deformations and stresses of main elements .

"CHAINS" AND LIFTING METHOD TECHNOLOGY

The main arch is one of the elements linking the bell towers both physically and in terms of communication. All four pairs of arches were very successfully lifted and fixed into position between January and June 1988, and they are now an integral part of the building. On the outer arches, which belong to the wing sections, the semi-domes have been formed, each consisting of eight curved reinforced concrete trusses covered with curved slab decking.



The assembly of arch assembly-bearers of SEMI-CUPOLA, with weight of 4000 kN/pcs, prefabricated on the ground, presents an innovation from aspect of devised and applied technological lifting equipment (presently known as "chains"). Its very low price, efficiency, duration, lifting force, resisting, remarkable easy operating and, above all, possibility of application for lifting of heavy load on any elevation in building construction and energetics. "Chains", as completely new system were tested against safety factor of overloading between 1.6 and 2.2.

The expansion joint arch rests "hanging" from chains in the lifted position until it's own columns are subsequently cast underneath. It is then released from the chains and, together with the columns, forms a framed system in a "portal" configuration (see picture - left).

Throughout the above mentioned stages of static lives of the main arches we carried out detailed analyses of the arches, both in terms of stresses and deflections. The dimensions of the arches were reduced, optimized, so that the resulting structure is as light as possible for technological purposes, and at the same time strong enough for the life span of the building.

HEAVY ASSEMBLY PUSHING TECHNOLOGY-RAISING OF MAIN DOME

Working out and very heavy building construction assembly of the CENTRAL CUPOLA, weighting 40000 kN, by pushing method, presents characteristic building engineering project, unity in church constructing and Christianity in general. The main gallery, which bears cupola and connects central bell-towers, is prefabricated on the site as a monolith, on gravel embankment, height 120 cm.

Leaving of technological passage for heavy machine resources and transports to the central part of the Temple from South side, makes possible, with special access to the assembly, the execution of the complete structure of the central cupola in one phase, i.e. in continuity, which also has essentially effect on positive course of all work realization. Began on the ground in the beginning of November 1988 and quite completed-assemb-led at the end of February 1989. During execution of concrete works, the method of electrical resistance thermal treatment of fresh concrete in winter period, was applied. The main dome is assembled from 24 curved reinforced concrete trusses with two

Figure 3.

layers of curved decking forming outer skins around either flanges of the trusses (figure 3). The bottom decking is intended for mosaic of church ornaments on the inner surface of the dome. Electro-hydraulic lifting equipment, according to the requests and conditions prescribed by KMG "Trudbenik" were designed and delivered by Hydraulic and Pneumatic equipment and devices factory ".Prva Petoletka" Trstenik, YU.

Figure 4.

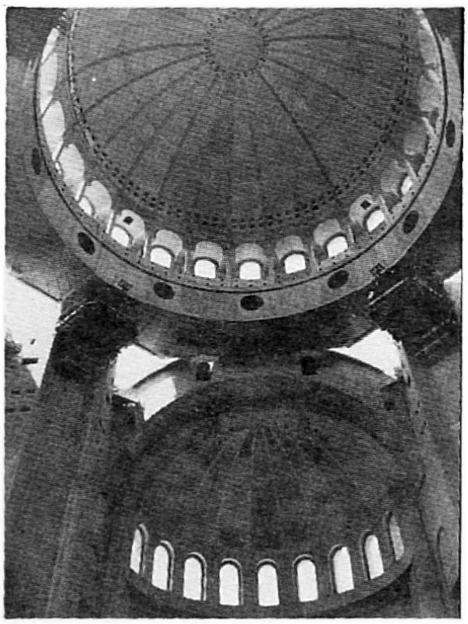


Figure 5.

Assembly-Lifting of the Central Cupola structure, with completely executed copper covering works, and cross, weighting 4000 Mp from the ground up to the designed position on level +40,09m, presents the achieved level of technology for XXI century. The safety speed of lifting of whole 2,50m/day should be possible by devised technology of assembly-pushing by hydraulic integral lifting power of cca 5000 Mp applying proportional serv-valves as well as strike and pressure pickup and electrical devices and by computer leading of unify lifting of cupola on all four reactive supports simultaneously. Vertical stepping of 110mm in one step, was realized by application of reinforced concrete slabs-cribbing (MB-50 MP) in all reactive supports, successively placed under the jacks or cupola by humanized mechanical means which are part of robot engineering resulted as technological achievement of KMG "Trudbenik" and "Prva Petoletka".
Lifting for a first 13m (figure 4) was done with supports passing by the bell-towers, in order to not destroy the r.c. column executed before the second world war. Reaching the proper height, all equipment and support steel (pi shaping) girder are moved in to the slit which is left intentionally during the slip-forming columns. Every day was necessary to cast in situ around the cribbing slabs in order to finalize the column for 2.50 m/day. Column which is assembled of cribbing slabs, placed by means of hydraulic manipulator "robot", are stiff enough for 2.5m therefore the process of pushing cupola is lasted no more then 5 hours each day (figure 5).
Over 280 electronic elastomers were placed allover the cupola and it's elements. All hydraulic components are supplied by measurement instruments to have information about jacks stroke and jack pressure to make possible specially designed computer to take control over the automatic lifting operation. Full independent outside electronic leveling system is attached to computer control to in-

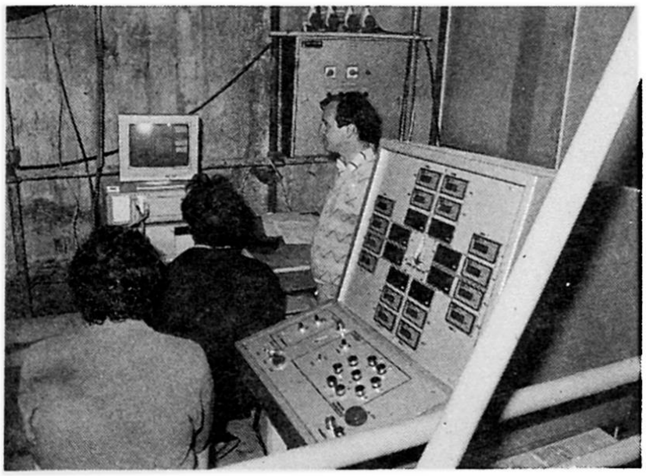


Figure 6.

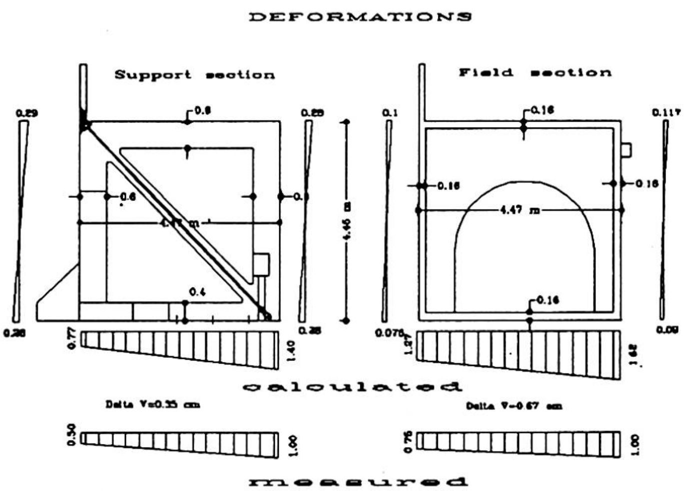
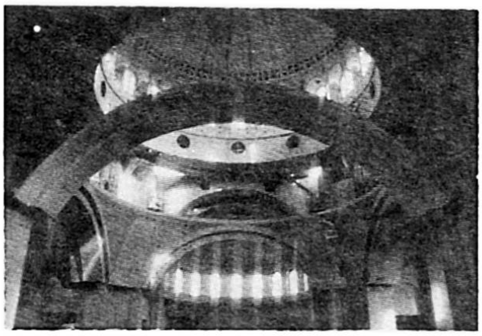


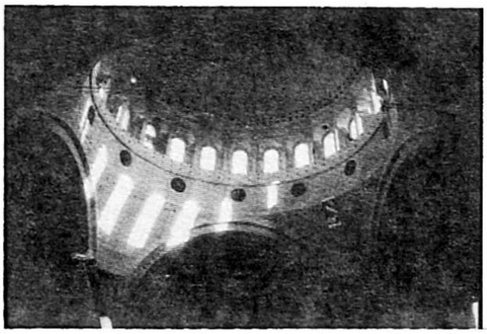
Figure 7.

sure the exact leveling information, which could serve to stop lifting operation in case of misleveling greater then 5mm (figure 6). One of two working PC-AT clones is collecting and monitoring over 24 essential data for performing operation without any mistakes. Graphical presentation is most suitable way for very fast and easy visible recognition for leading engineer to react properly in time.
The last lifting operations were performed on level +39,69m and in the same time, the certain parts of cupola were on +80m, avoiding very risky and complicated assemblies on such big height. Complete covering works by copper sheet on wooden basis and with cross, performed in March and April, while cupola was on the ground.
The results obtained during the lifting operation is shown on diagram (figure 7). It is obvious that stresses and deformations measured and calculated are very fine in conjunction even no any single model in design phase is not used to investigate how dynamic process could interfere structure.

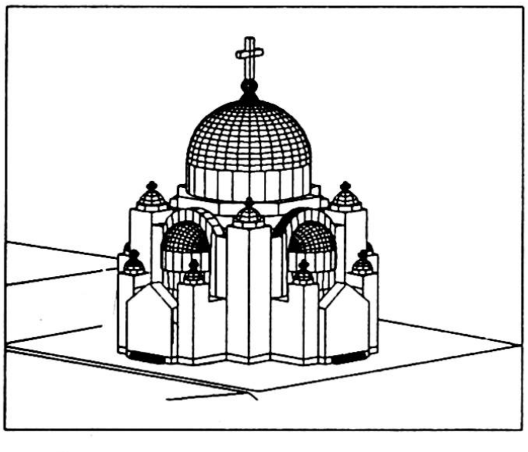
PENDENTIVE

Underneath the main dome, again at ground level +/- 0.0m, the pendentive is assembled. It represents a transitional tie element through which the rectilinear plan of the church hall changes to the circular plan of the main dome. Once the pendentive has been lifted into its position at level +40m, and secured against the main dome, the central part of the church will be rounded off.





Structural connection between pendentive and main dome is to be done by supporting the dome in four position by means of hydraulic jacks capable to produce force of 3000 kN each (total force 12000 kN). These means that pendentive will take care of additional loads coming latter from applied mortar, mosaic and outside marble.
Again, the most efficient lifting technology and equipment called "chains", is used. Pendentive weighted about 1100 Mp, spanning in perpendicular direction 24*24 m, with height of 14m on the ground, lifted on 28m on their position beneath the main cupola.
During the two days at the end of January 1990, pulling of assembly structure of "pendentive" on its position is very successfully done. Total time of pulling was 36 hours, in which we reached speed of erection of 2.0 m/h. "Pendentive" is positioned under the lower ring of "dome" so precisely, reaching the accuracy which is far of prescribed by technology design (tolerance of 5cm.).
After upper part of Saint Sava Temple is completed, waiting for finishing inside and marble with copper covering from outside, the underground part of Temple is in preparation for execution.



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Concrete Cube – Shaped Display Hall

Bâtiment d'exposition cubique en béton armé

Stahlbeton – Ausstellungshalle in Würfelfrom

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SUMMARY

This paper deals with various design and construction aspects of a Display Hall building in Bhopal, having intersecting hollow concrete cubes as its roofing system. The topmost point of the cube is 6 meter above floor level. Structural feasibility analysis, detailed design and specialist construction supervision have been undertaken by the authors.

RESUME

L'article traite de différents aspects du project et de la construction d'un bâtiment d'exposition à Bhopal, caractérisé par des cubes vides en béton formant son système de toiture. Le point le plus élevé du cube est à 6 mètres au-dessus du sol. L'analyse structurale et de faisabilité, le projet détaillé, et la supervision de la construction ont été entrepris par les auteurs.

ZUSAMMENFASSUNG

Der Beitrag behandelt verschiedene Entwurfs-und Baugesichtspunkte einer Ausstellungshalle in Bhopal. Ihr Dachtragsystem besteht aus sich überschneidenden, hohlen Betonwürfeln, deren höchster Punkt 6 Meter über dém Hallenboden liegt. Die Autoren waren mit der Machbarkeitsstudie, Konstruktion und Bauleitung der Spezialarbeiten beschäftigt.

1. INTRODUCTION

The Display Hall located at The Nehru Rose Garden, BHEL Township, Bhopal, India, was built in 1989. The plan of this building as envisaged by its architect is shown in Fig.1. This is generated by combining plans of three intersecting hollow cubes of

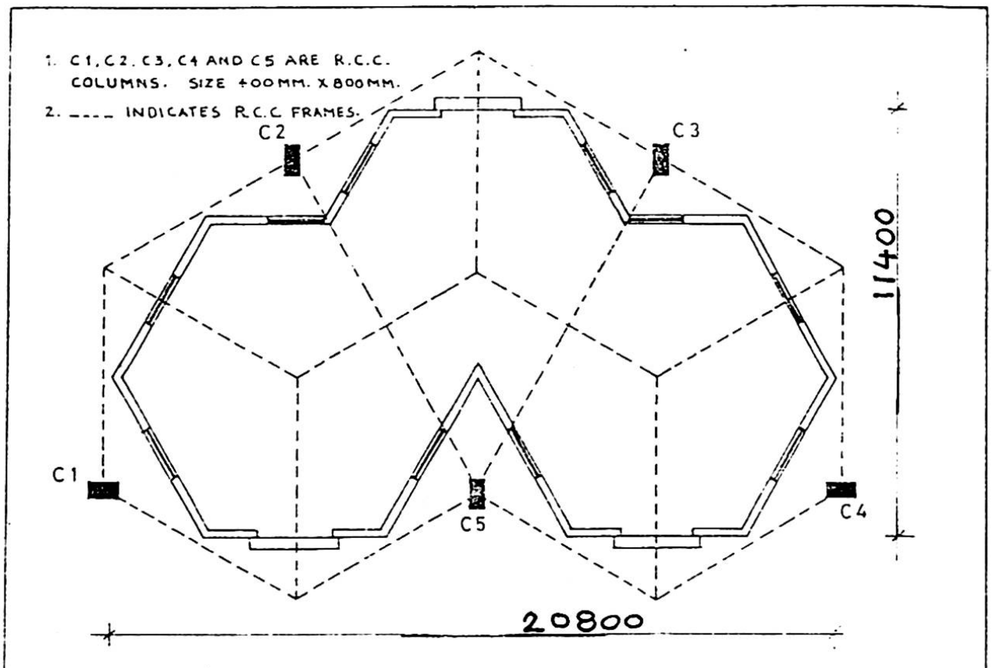

Fig.1 GROUND PLAN AND LOCATION OF COLUMNS DISPLAY HALL, NEHRU ROSE GARDEN BHEL, BHOPAL

reinforced concrete with overall plan dimensions of 11400x20800mm. The entire roof structure rests on five RCC columns, each size 400x800 mm shows as C_1 to C_5 resting on rectangular RCC footings on soft rock with SBC of 25 T/m^2. It is 1500 mm below the ground level. A hinge of size 250x650 mm, length being 500mm is provided at 1000mm above the base of the footing to facilitate hinge action. The topmost point of these intersecting hollow cubes shaped roof is at six meters above hall floor level as seen in Fig.2 & 3. The slopes of roof panels and supporting edge beams are of the order of 55^{o} A cutout on top of each cube provide ingress of natural daylight.

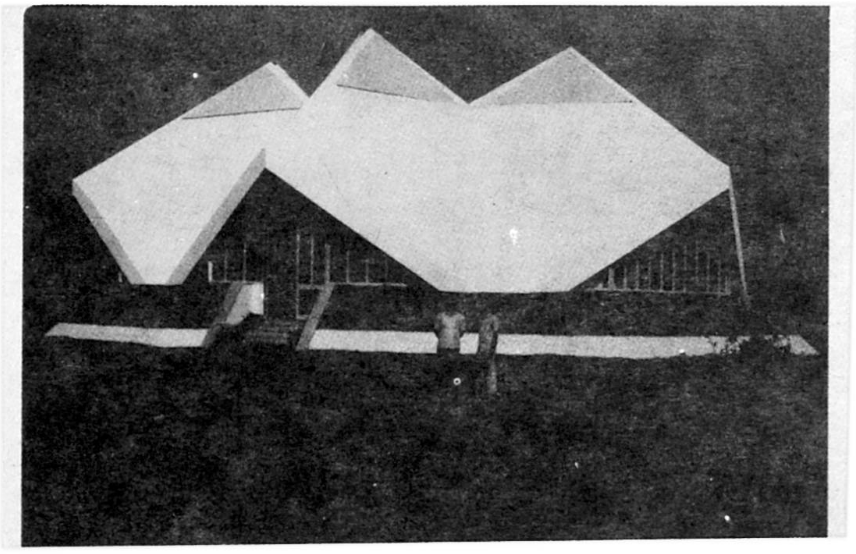

Fig.2 South side Elevation-Display Hall

2. INITIAL DESIGN CONSIDERATION OF STRUCTURAL SYSTEM

The project architects have visualised hollow concrete cohabit cubes consisting of solid slab panels supported on each of its edges by edge beams. These beams in turn rest on space frames as shown by broken line in Fig.1. These inclined slabs have 150mm thickness. These are designed as two-way slabs [1] and suitable reinforcement for restraining torsional effects at each corners is provided. The inclination of roof beams is also of similar order. They also serve forming for the openings for entry and exit of this pavillion as shown in Fig. 4.

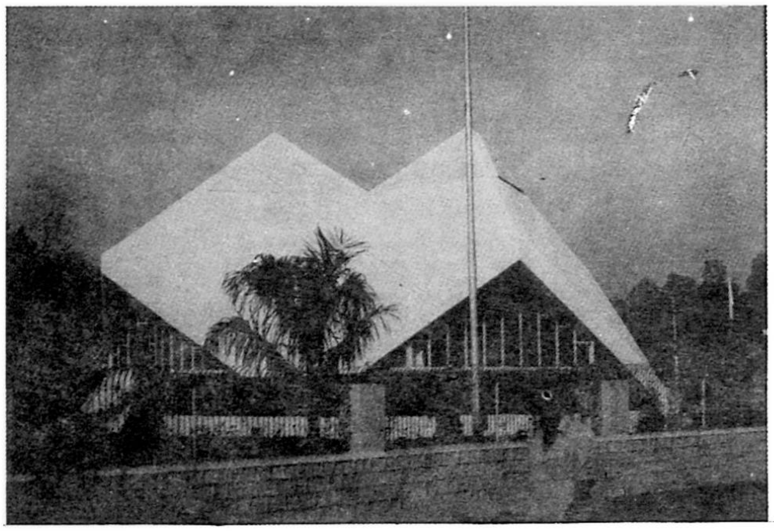

Fig.3 East Side Elevation of Building.

3. FINAL DESIGN CONSIDERATIONS

Some final design considerations in relation to the following elements are given below :

3.1 Composite Tie Beam

Seven steel-concrete composite tie beams were provided at plinth level to take up the horizontal reactions of the space frames at the foundation level in the form of three equilateral triangles. These consist of size 200x300 mm with 4 No ISA 50x50x6 mm suitably laced by 10 mm diameter links. These tie beams are connected to columns through bolted collars made out of 8 mm thich steel plate. The composite beam has to be envisaged to expedite the construction.

Fig.4 Details of Opening South Side, Display Hall Building.

3.2 Inclined Slab Panels and Supporting Space Frame

The type of structure as described above necessiates an integrated Finite Element analysis using the plate and beam elements in space. However due to the paucity of time, intitutive simplified elementwise analysis was undertaken like, roof as an inclined RCC slabs with appropriate edge conditions [2] and RCC space frames [3] supporting the inclined slabs and transferring the load to the foundations [4].

The inclined slabs were 150mm thick reinforced with 8mm diameter bars with 100mm centres bothways, suitably bentup and anchored. The Fig.5 shows details of this arrangement. The inclined roof beam members of the space frames were analysed and designed for combined effects of bending, shear, torsion and direct forces and thus adequately reinforced accordingly [5] M-20 (20 N/mm^2) Grade Concrete was used for roof slabs and supporting beams and columns. High strength deformed Bars Grade 415 were used as steel reinforcement of this structure as shown in Fig.6. below. This imparts adequate waterproofing property and gives enough durability to this structure.

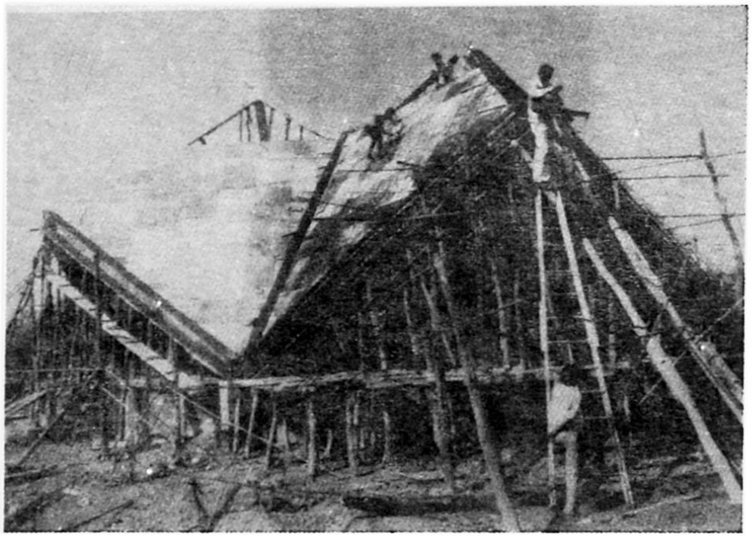

Fig.5 Details of slab reinforcement.

Fig.6 Details of Edge Frame Reinforcement.

4. SOME SIGNIFICANT DETAILS OF CONSTRUCTION PROCEDURE

Some typical and unique features of this type of construction adopted during construction of this Display Hall are discussed and highlighted below.

4.1 Detailing of Beams and Column Junction

The inclined space frames which constitute the most significant part of the structural system are very carefully detailed to ensure proper provision of torsional transverse stirrups, without causing excessive congestion for smooth ingress and compaction of concretemix in the forms to enable adequate compaction of concrete. The Fig.6 shows these details. Similarly the function involving sloping beam, edge beams and vertical columns are given due consideration in reinforcement detailing to achieve proper compaction of concrete. In view of the complex three dimensional geometry of this structrue the laps and anchorages for the reinforcement are carefully detailed [6]. Due care is taken to ensure proper cover to reinforcement in the various structural components of this building.

4.2 Care in Formwork and Usage of Double Shuttering

As the slopes of slabs and beams are steep, of the order of 55^{o}, therefore, extra precaution was needed to ensure correct level of formwork. It was suitabley braced to reduce risk of settlement during concreting operations. Smooth plywood double shuttering was employed to prevent flowing of mix and achieve proper compaction of concrete to resulting in dense and durable concrete mass with smooth surfaces.

5. CONCLUSION

Some of the important conclusions of this discussion are as follows :

- The envisaged form of this display hall incorporates the usual structural efficiency of **Shell Form** to a large extent with the added advantage of simplified formwork was required. The provision of sufficient openings and cutouts at top of cube shaped roof caters for allowing natural daylight, thus reducing energy requirement for lighting and cooling purposes of this building.

- The intitutive simple analysis taking advantage of continuity is in close proximity with the Finite element method of analysis and is less time consuming. It was also incorporating better feeling of behaviour of entire structural system.

- The form adopted for display hall at the Nehru Rose Garden, blended very well with its total environment and described very well the concept of form of a **Rose Bud.**

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REFERENCES

1. Reynolds, Charles,E., Steedman,J.C., Reinforced Concrete Designer's Handbook. 1976, View point Publications, London, U.K.

2. Timoshenko,S., Krieger,S.W., Theory of Plates and Shells, 1985, McGraw Hill Publishing Company, New York, U.S.A.

3. Meek,J.L., Matrix Structural Analysis, 1971, McGraw Hill Publishing Co. Ltd., New York, U.S.A.

4. Jai Krishna, Jain,O.P., Plain and Reinforced Concrete, Volume II, 1987, Nem Chand Bros., Roorkee, INDIA.

5. Indian Standards Institution, New Delhi, SP 16, 1980, Design Aids for Reinforced Cement Concrete.

6. Bureau of Indian Standards, New Delhi, INDIA, SP-34, 1987, Handbook on Concrete Reinforcement and Detailing.

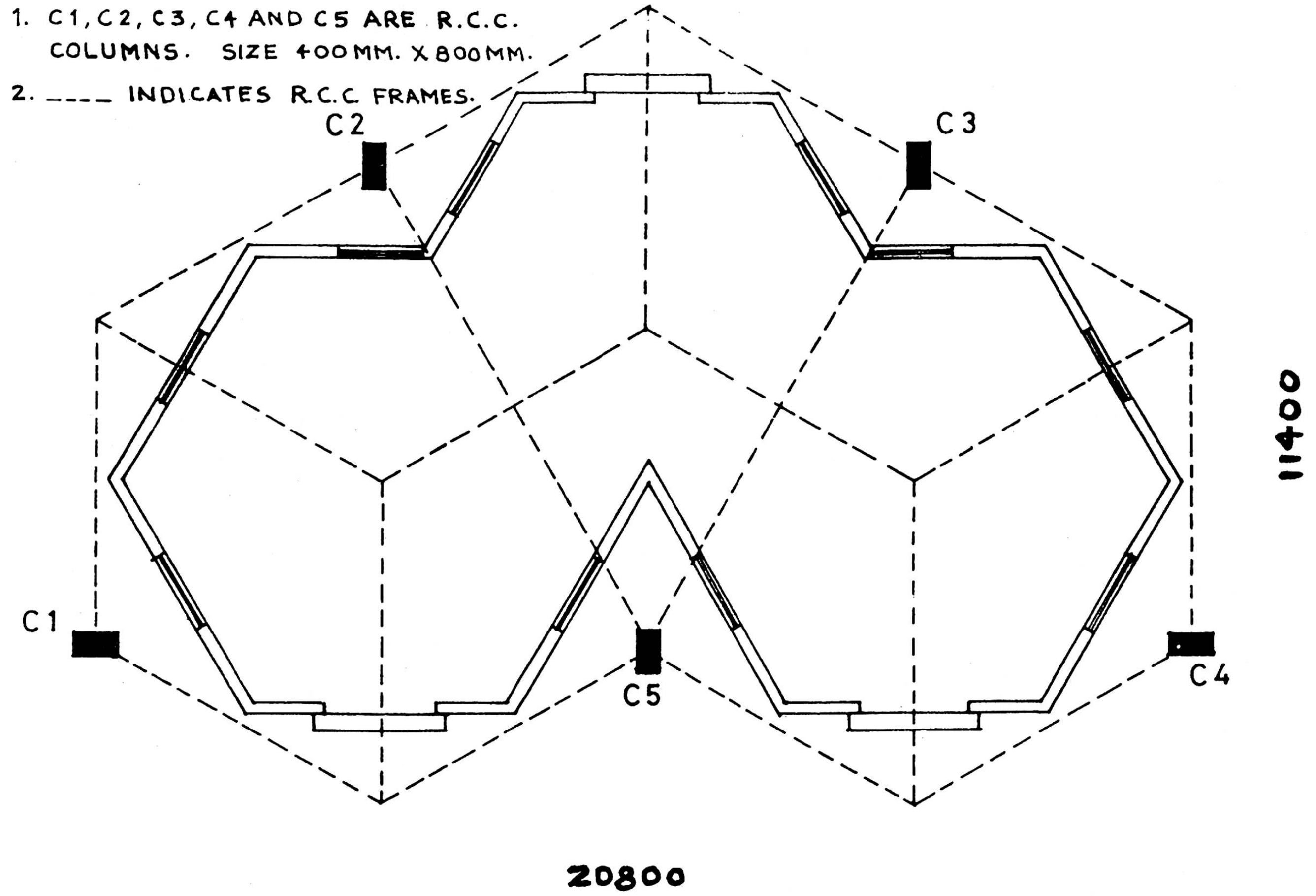

FIG. 1 GROUND PLAN AND LOCATION OF COLUMNS
DISPLAY HALL, NEHRU ROSE GARDEN BHEL, BHOPAL

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