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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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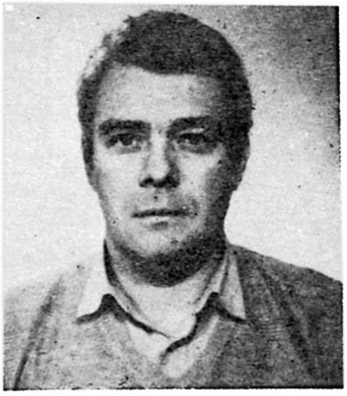


Dušan Arbajter, born 1945, received his civil engineering degree at the University of Belgrade, YU. He worked as a civil engineer on site later on as a designer. He was involved in large projects with design and erection of heavy assembly structures. Presently he is assistant general manager for design,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

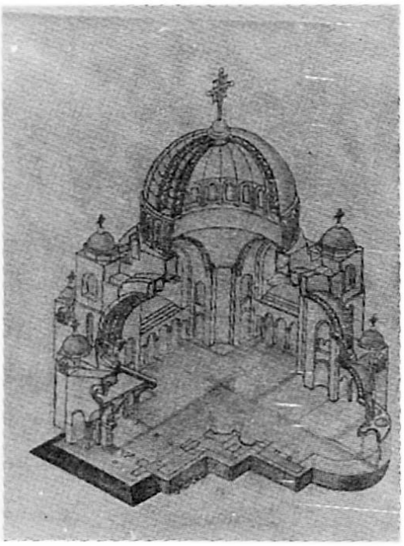


Figure 1.

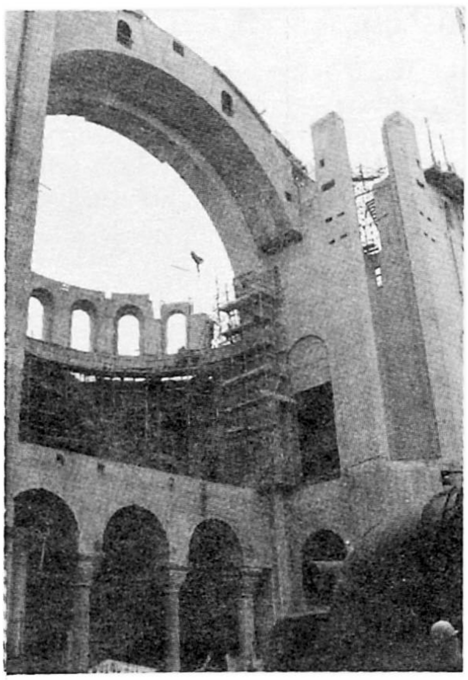
Figure 2.

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

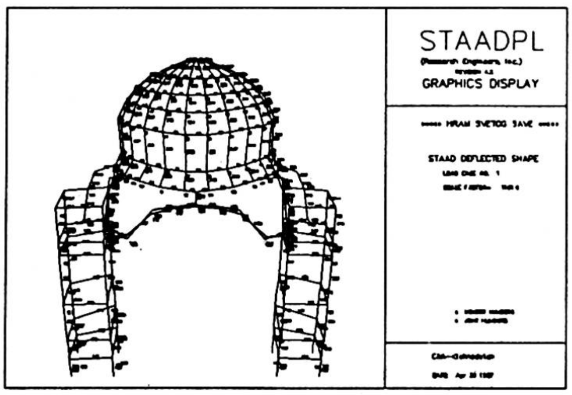
foundations, the existing part and the new structure of the forthcoming stages of construction was achieved with reinforced concrete columns and tie-beams.
Expansion joints of the wing sections were carried out along the line of intersection between the semi-domes and the main arches, and vertically 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

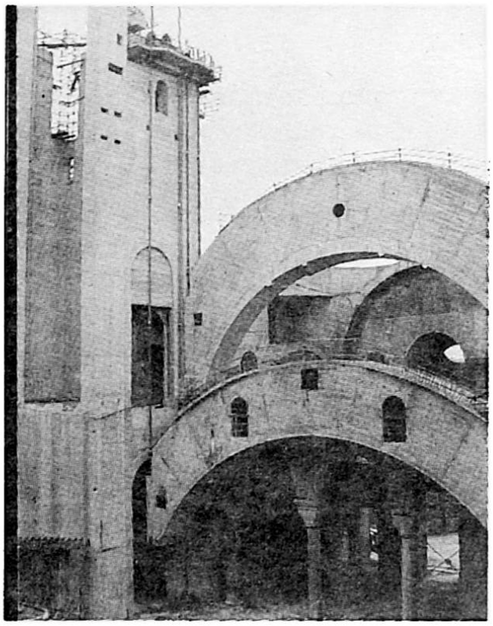
Structural analysis of building structure is made according to new JUS codes, standards of Yugoslavia and appropriate codes. After the building is splitted in to the five parts, calculation is made concerning the wings as one model and central part as another. Separate parts of structure which belongs 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.

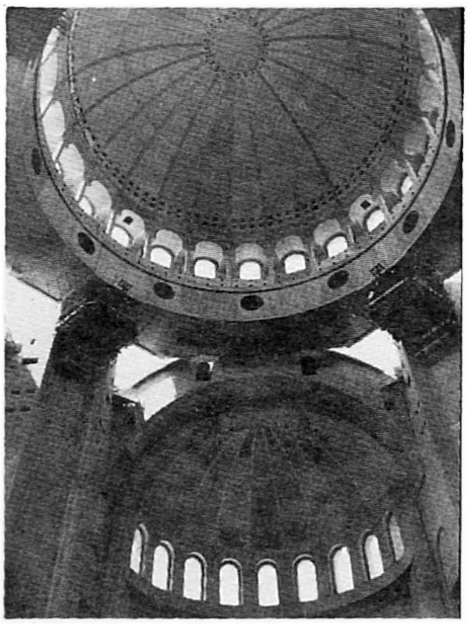


Figure 5.

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-

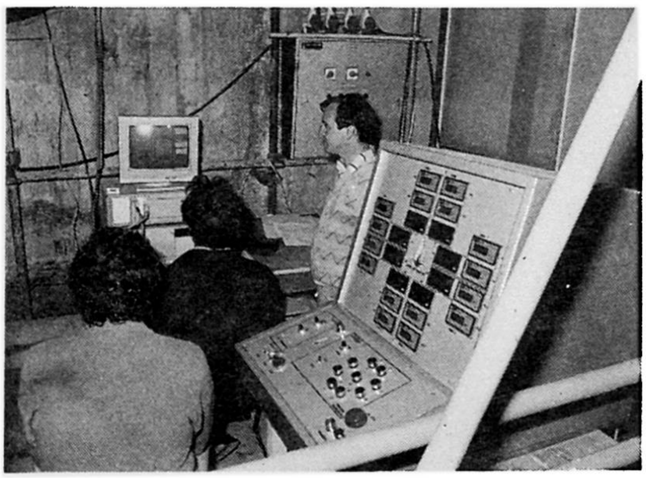


Figure 6.

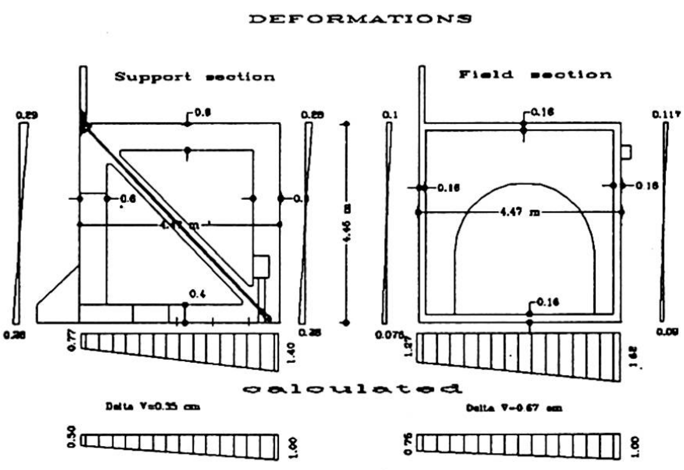
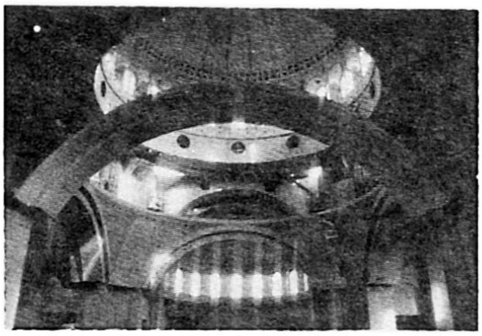


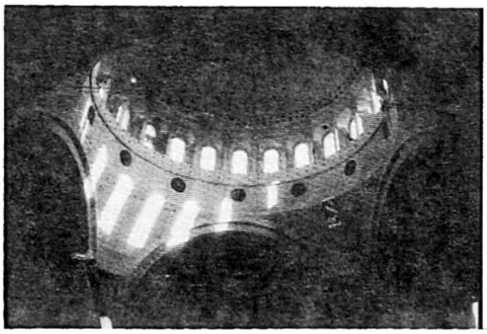
Figure 7.

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.

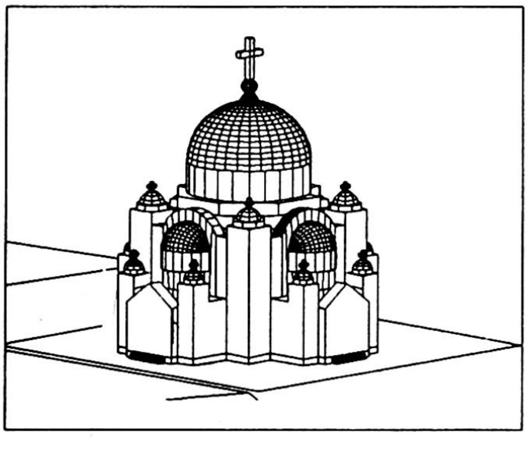
PENDENTIVE

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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