The Design and Construction of Putrajaya International Convention Centre

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1. INTRODUCTION

The Putrajaya Convention Centre is located in Precinct 5 of the Federal Administration Centre of Putrajaya. It is situated on the top of 'Puncak Selatan' and has a commanding view of the Boulevard. The Putrajaya Convention Centre was completed in April 2003 at a cost of approximately RM600 million.

The Putrajaya Convention Centre has a total area of 135,000 m^2 inclusive of basement carparks and multi-level convention facilities at higher levels. The Plenary Hall is on the 1st Floor and surrounded by a ring of galleries, both VVIP and VIP lounges, a viewing deck and a conference hall. The Head of States Hall is located on the ground floor, surrounded by VVIP meeting rooms and lounges. The lower ground mezzanine floor has meeting rooms, a reception area, administration and maintenance office. On the lower ground floor, there are meeting rooms, a restaurant and a column-free banquet hall that can host a 2,600 seated silver service dinner.

Perunding Mahir Bersatu Sdn. Bhd. is the concept engineer for the Putrajaya Convention Centre and was subsequently assigned to be the Checking Engineer for Putrajaya Holdings Sdn. Bhd.

Upon the completion of the tender exercise, IJM Corporation Sdn. Bhd. (IJM) was awarded the 'Design and Build' for Putrajaya Convention Centre. Sinclair Knight Merz Engineering Sdn. Bhd. (SKM) was then appointed by IJM as the contractor's consulting engineer.

2. CLIENT REQUIREMENT / BUDGET

Putrajaya Holding Sdn. Bhd., the Employer of this project was given a task to complete this project in time for the 11th Organisation of Islamic Conference (OIC) in October 2003. This commitment to host this conference resulted in a 22 months design and build contract.

The brief from the Employer required not only a state-of-the art world class conference centre, but also an icon building, which can be a landmark for the country. Being sited on top of the highest hill is the Federal Administration Centre of Putrajaya, so nothing less than an icon building justifies its position.

The stunning Putrajaya Convention Centre - A spectacular iconic structure for Malaysia

The brief also required a 2,800 numbers of uninterrupted view seating at the plenary hall, a 70m column-free banquet hall below the plenary hall and a Head of State conference hall in between. This offered a challenge to the Structural Engineer and the Contractor.

How to achieve client's requirement and budget

With thorough understanding of the client's brief and needs, the team applied its local knowledge, tailored solutions and a highly skilled team with leading expertise in long-span roofing structure, to deliver the project. The team conceptualised using the radial arms together with compression ring beam and grillage beams to create a 70m "column-free" banquet hall. The long span geometrically complex roof structure over the Plenary Hall was conceptualised as a "Spine Truss" spanning across the North-South direction.

Working together with the architect Hijjas Kasturi, Perunding Mahir Bersatu Sdn. Bhd. produced the conceptual design and drawings with poundage for tender. Prior to the tender, the quantity surveyor worked out the preliminary estimated cost plan of the buildings for our client Putrajaya Holdings Sdn. Bhd.

Seven (7) tenderers were pre-qualified and a competitive bid was held. Finally, IJM won and the tendered sum was close to the estimated budgetary cost submitted earlier by Putrajaya independent quantity surveyor. The client Putrajaya Holdings Sdn. Bhd. was satisfied that the column-free Banquet Hall, uninterrupted view of the Plenary Hall and budgetary cost met their requirement.

3. SIGNIFICANCE OF THE PROJECT TO THE COMMUNITY

The Malaysia Government recognised the impact that the hosting of major events can have on export earnings. By

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hosting and attracting major events like Organisation of Islamic Congress (OIC) in Malaysia which attracted tourists and their important tourist dollars.

Besides tourism, this major project is very significant to the Malaysia Government, as an Islamic country taking the leading role. It generates close cooperation, bilateral trades and smart partnerships especially within the Islamic world. Some of the Malaysia companies have gone offshore and are working in the Middle East countries and Sudan.

On the local front, this mega project delivered within 22 months to meet OIC deadline, proved the ability of Malaysian consultants and contractors to deliver "fast track" mega projects. Economically, it activated the construction industries and created employment for the local industries.

The completed Putrajaya Convention Centre did become an icon building as promised and the 10th OIC was successfully held. This project has made the country proud not only because the Putrajaya Convention Centre has achieved state-of-the-art world class standard and also it was completed with high quality within a record-breaking time of 22 months.

The completion of the Putrajaya Convention Centre on time and on budget has in a way made known to the rest of the world the capabilities of the Malaysian construction industry as a whole. The design by the Architect was stunning and has offered a lot of challenges to the structural engineer and the construction team, which were overcome professionally and skilfully.

The completed Putrajaya Convention Centre is a world class venue hosting major conferences, exhibitions, meetings and banquet. Its position has also made this monument a tourist attraction. Visitors can get a commanding view of the boulevard and the lake.

4. ENGINEERING ASPECT

4.1 FOUNDATION

The main building is supported by three series of radiating circular columns, of which the diameter of the concentric rings are 70m, 100m and 130m, respectively.

The platform level of the main building is at RL +60.0m and the building is founded on hard material (decomposed shale) except at a small portion at the outer ring where the ground is filled. A raft foundation bearing on hard material was designed to support the building and at the filled ground, bore piles were used. This final position of the main building was determined after a value engineering exercise was carried out by the concept engineer, Perunding Mahir Bersatu Sdn. Bhd. The main building was shifted so that most parts of the foundation is sited on hard material.

The raft foundation is shaped like a 'doughnut' and the thickness varies from 1.50m to 2.25m. The outer diameter is 108.0m and the inner diameter is 58.4m. The inner space is a non-suspended slab. The shape adopted is most efficient to resist the ring tension force from the outward push of the rake column.

The analysis of the raft was carried out using the finite element analysis. (Typical results and reinforcement detail, in stress diagrams are shown in Figure 1 and 2).

As the tension ring forces are also circular, the reinforcement is also aligned in a circular pattern. This was achieved by rolling the bar to the required diameter.

The total volume of concrete for the main raft is 12,800m^3 and casting was

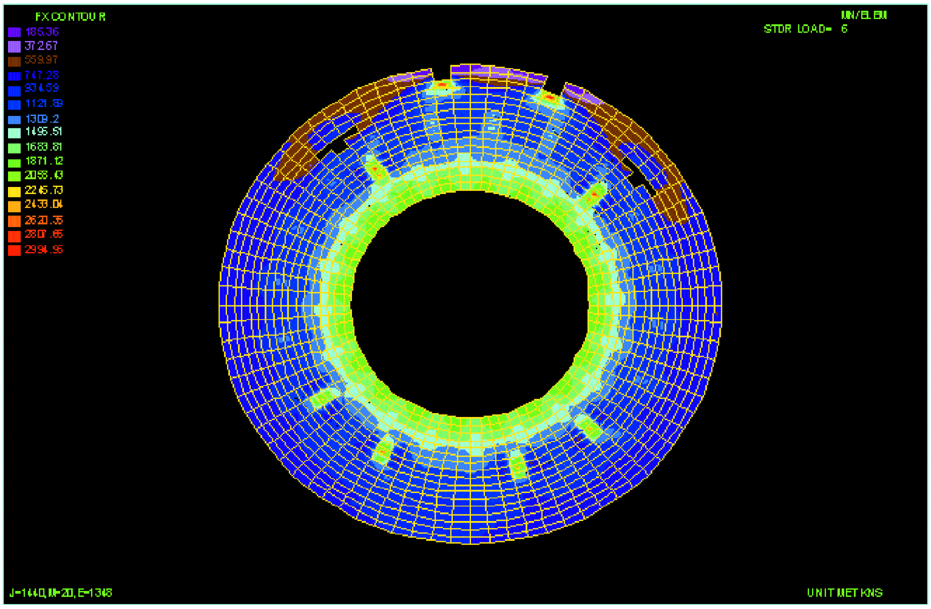

Figure 1: Raft – Hoop Tension – kM/m^2

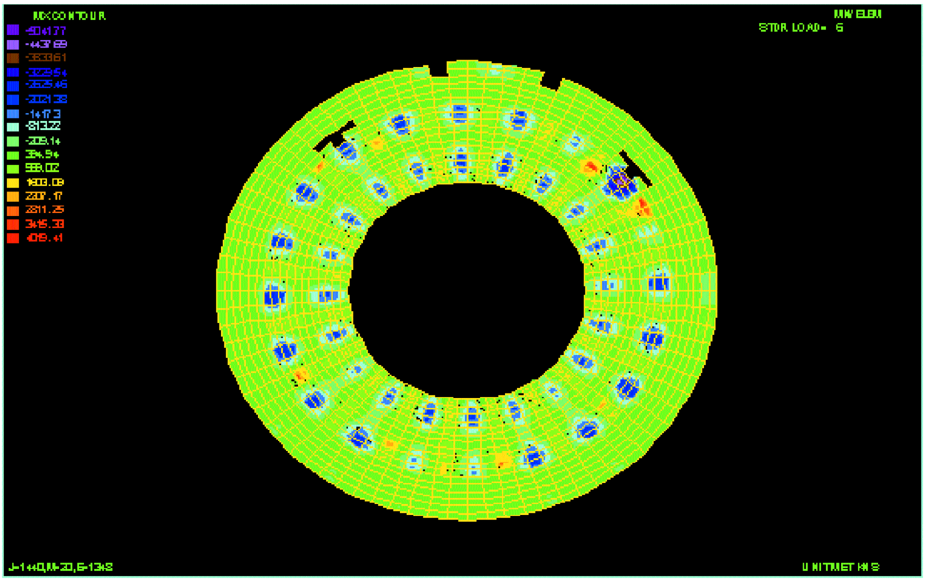

Figure 2: Raft – Circumferential Bending Moment – kNm/m

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Putrajaya Convention Centre construction - Night View

divided into 8 segments. Each casting was completed in about 12 to 18 hours. Thermal insulation using polystyrene sheets and sand bedding was provided after casting.

4.2 STRUCTURAL SYSTEM

The main building consists of 6 levels of functioning space: -

(a) Lower ground (on the raft, housing the Banquet Hall);
(b) Ground Floor (Head of States Hall);
(c) 1^{st} Floor (main entrance to the Plenary Hall and meeting rooms);
(d) 2^{nd} Floor (Plenary Hall and meeting rooms);
(e) 3^{rd} Floor (Plenary Hall, meeting rooms and viewing decks); and
(f) 4^{th} Floor (Mechanical rooms).

The shape of the building is circular hence the structural grid is also circular on plan. The inner ring is 70m in diameter, the middle ring is 100m and the outer ring is 130m. The inner 2 rows of columns (Ring A and B) were 2.0m in diameter and the outer most row (Ring C) consists $900mm^2$ columns.

The lower ground floor housed the column-free Banquet Hall. The span between the column is 70m and above the Banquet Hall is the Head of States hall and the Plenary Hall. To support the loadings from the Plenary Hall, an innovative radiating portal frame (F1 frame) was developed (Figure 3). The F1 frame is part of the inner most row column (Ring A). The horizontal member of the F1 frame reached out 20m towards the centre. The depth of the horizontal member was 3.9m. All the horizontal member of the F1 frame stop at the compressing ring beam. Within the compression ring beam (900 x 2700) was a system of grillage beams 250 x 2000mm (30m diameter)

The analysis of the F1 frame was carried out using finite elements. The design criteria was not only for strength but also the dynamics acceptance criteria, this will be elaborated in the section below.

Above the ground floor the structural system consisted of composite columns, structural steel frame and reinforced concrete composite slab with shear connectors. The steel beam was on a radial and circumferential arrangement. The majority of the beams were constructed of Grade 43 steel built-up sections (using plate thickness up to 40mm) and UB steel beams of up to 388kg/m, acting compositely with the concrete floor slab.

The outer most row column (Ring C) stopped at the ground floor and the inner row column (Ring A and B) continued to the roof at 15° inclination outward from first floor onwards. The columns were composite columns with steel plate with thickness from 20mm to 40mm infilled with concrete.

The design for structural continuity at the column had created a challenge. An innovative design was carried out on the column node using the STRAND 7 program. A typical beam to column connection modelling is shown in Figure 4. To achieve a rigid connection between the radiating beam, the steel column was fabricated into two halves and the radiating beam slotted in between and welded. (Refer to Figure 5).

Each of these column nodes weighed approximately 10 ton and were fabricated off site. A 200T capacity crawler crane was used to erect the nodes.

For the erection of the steel member, one unit of 150T and 200T capacity crawler cranes and four tower cranes with 2.5T tiploads were used. Erection of beam was done in such a way to form a square closed loop for stability of the structure.

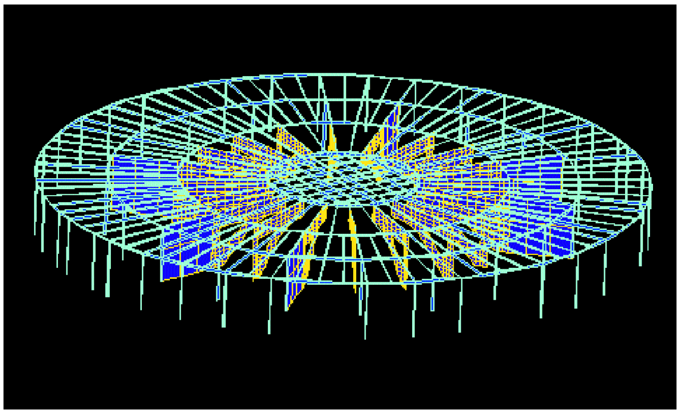


Figure 3: F1 Frame - Ground floor

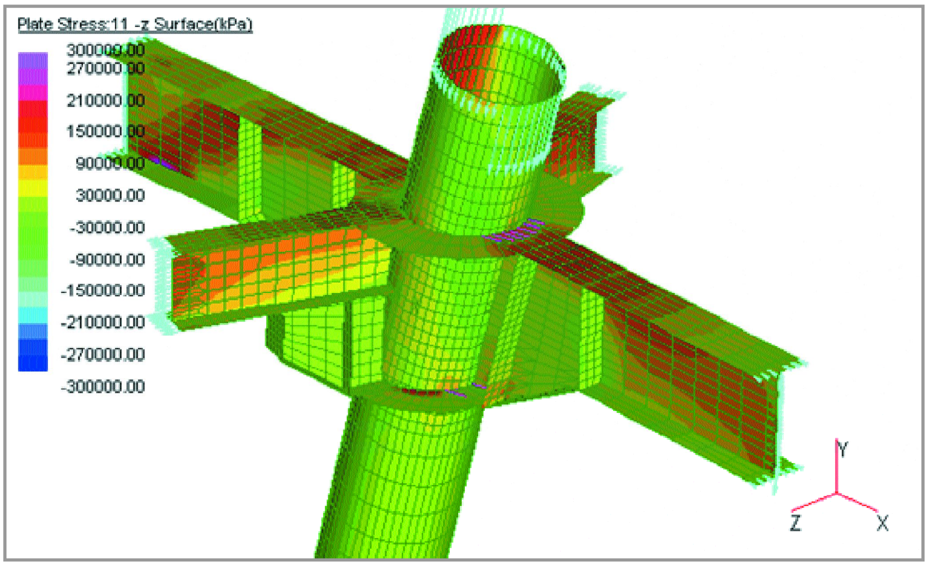


Figure 4: Column Node

Figure 5: Plate Girder welded into half of Column Steel Node

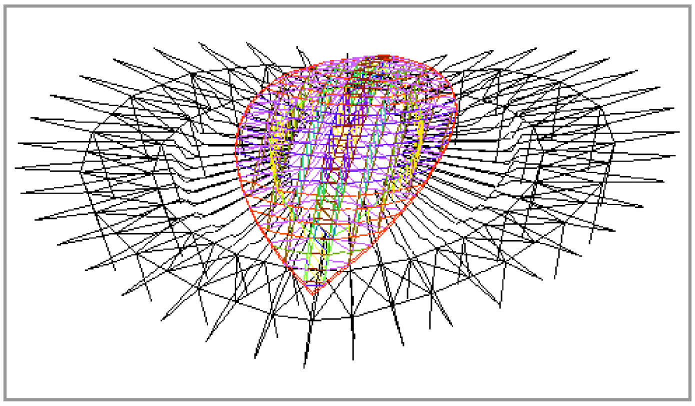


Figure 6: Roof Truss – Wire Frame

The Plenary Hall was formed using built-up steel beam raked and shaped in two (2) directions. Precast planks with structural topping were used to form the seats.

4.2.1 ROOF

The roof structure is unique with its complicated geometry and long span. The shape of the roof resembles a '*pending*' which is a buckle worn in Malay weddings. The spine truss spanned 90m and had a depth varying from 3.60m to 7.50m. This spine truss supported the centre roof, inner roof and part of the outer roof (refer to Figure 6).

The spine was supported by 'Crab Claw's at either end. Each 'Crab Claw' transfered the load to four columns. The roof structure was modelled using the finite element program STRAND 7. The model was 3-dimensional representing the entire roof including the 'Crab Claw' support.

Sufficient access elements were provided for easy maintenance of the building and services, considering clear span and height.

The fabrication and erection of the roof truss was most challenging as it involved extensive welding and tight distortion control. A high degree of accuracy in fabrication was required such that the individual components were aligned properly during erection. In order to catch up with the tight construction schedule, the fabricator had to produce 300 tons of steel per week.

The most challenging in the erection process was the erection of the spine truss. The spine truss was analysed in stages to represent the sequences of erection supported by temporary towers. The temporary towers were 55 m. (Refer to Figure 7).

4.2.2 DESIGN FOR DYNAMICS

One of the most challenging technical aspect of the project was the harmonics of the building. In recent years vibrations due to human activities have created serviceability issues in health clubs, gymnasiums, stadiums and even office buildings. These vibrations are annoying to the users.

Three factors have given rise to these problems: -

(a) increased human activities such as aerobics and audience participation;
(b) decreased natural frequency because of increased floor spans and design which has been pushed towards the limit;
(c) decreased damping and mass in building construction.

In this project (a) and (b) were the prevailing factors.

The F1 frame which supported the plenary hall was checked for dynamics acceptance. The audience in the plenary hall must feel comfortable during all events. The span of the F1 frame which is 70m and being the support for the entire plenary hall loadings had indeed created a challenge to the design team.

4.2.2.1 DESIGN METHODOLOGY FOR DYNAMICS BEHAVIOUR

The structure was first tuned to achieve a natural frequency of 5Hz, thereafter a detail analysis using the STRAND7 program was carried out to determine the accelerations. The results were checked against the National Building Code (NBC) of Canada for compliance. The NBC has set a limit of 4% to 7% g for the expected usage i.e. rhythmic activities. (The acceptance criteria are shown in Table 1). After a series of iteration the design team was able to contain the accelerations within the limits.

In the modelling of the structure the following assumptions were made: -

(i) The mode of vibration of concern was the vertical components.
(ii) The floor vibration was induced primarily by human traffic.
(iii) The forcing frequency was between 1.5 and 3.0Hz.
(iv) The maximum dynamic load was 0.375kPa. (Refer to Table 2)
(v) Damping 10%.

5. CONSTRUCTION METHODOLOGY

The foundation system for Putrajaya Convention Centre was a reinforced concrete raft foundation. The thickness of

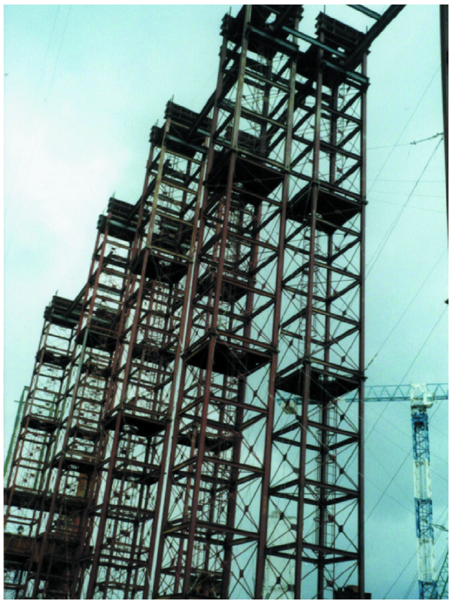


Figure 7: View of Temporary Steel Support for Spine Roof Erection

Table 1: Acceptance criteria

Occupancies affected by the vibration	Acceleration limit, percent gravity
Office and Residential	0.4 to 0.7
Dining, Dancing, Weight Lifting	1.5 to 2.5
Aerobics, rhythmic activities only	4 to 7
Mixed use occupancies housing aerobics	2

Table 2: Design parameters for rhytmic events

Activity	Forcing frequency f_f	Weight of participation wβ psf	Dynamic load factor α	Dynamic load αwβ psf
Dancing	1.5 - 3.0	12.5 (27ft²/couple)	0.5	6.25
Lively concert or sports event	1.5 - 3.0	31.3 (5ft²/couple)	0.25	7.83
Aerobics				
- 1st Harmonic	2 - 2.75	4.2 (42ft²/person)	1.5	6.30
- 2nd Harmonic	4 - 5.50	4.2 (42ft²/person)	0.6	2.52
- 3rd Harmonic	6 - 8.25	4.2 (42ft²/person)	0.1	0.42

the raft foundation varied from 2.50m to 1.50m. The total volume of the concrete raft foundation was approximately 12,800m³ and the casting of the raft foundation was divided into eight sectors. The concreting pour of each sector of the raft was approximately 1,500m³ and was casted within 16 to 18 hours continuously, commencing in the late evening till early the next morning.

The column from basement up to ground floor was constructed in concrete. The ground floor structural system consists of conventional reinforced concrete frame, compression ring beam, grillage beams and slabs which were casted in situ.

From the ground floor up to the roof, the columns raking at 15% angle were made up of composite circular steel sections infilled with concrete. The column diameter of 1,400mm was rolled from steel plates of thickness varying from 20mm to 40mm. Shear connections of 19mm and 100mm long were provided throughout the length of the column. At the beam-to-column junction, some of the plate girder beams were punched through the column to create a rigid moment connections. The roof structure was unique with complicated geometry and long span. Fabrication of the truss connections especially the "Crab Claw" end frame support for the central roof was most challenging as it involved extensive welding and right distortion control.

6. SIGNIFICANCE OF ENGINEERING SOLUTION

The significance of some of the engineering solutions was to meet the requirement of a 70m column-free banquet hall supporting the Head of State Hall and a Plenary Hall of 2800 seating capacity.

In summary, the significance of engineering solution are as follows: -

1. The team devised a sculptural system of radial arms together with the compression ring beams and grillage beams.
2. The relocation of the raft foundation of the building along the main boulevard axis by 60m, so as to be founded on rock, demonstrated the utility of value engineering.
3. The long span geometrically complex roof structure over the plenary hall was conceptualised as a "Spine Truss" spanning across the North-South axis, supported by "crab claws" at either ends.
4. The rigid moment connection between the plate girder beam and column node was an innovative engineering solution.

With the concept developed, the complex mega building was then simplified with the load path clearly defined and analysed to provide sound engineering to a major project.

7. CONCLUSION

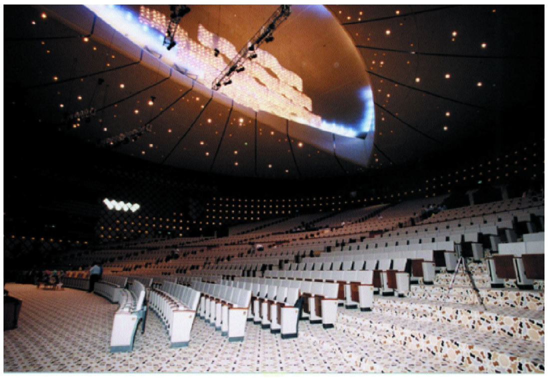
The completed Putrajaya Convention Centre is not just a landmark but an icon building in the Federal Administration Centre of Putrajaya.

The teams of engineers, architect, project managers and contractor have been delighted with the way in which the ideas that the team developed have been transformed on site at Putrajaya.

The completion of Putrajaya Convention Centre on time and on budget has not only made the Malaysian Government proud but has also shown that local contractors and engineers are able to deliver a mega project within twenty-two months.

It has become a masterpiece, a marvel of engineering and the pride and glory of the Malaysian engineering sector. ■

Internal pictures of Putrajaya Convention Centre - Head of State Hall



Internal pictures of Putrajaya Convention Centre - The 2800 Seat Plenary Hall