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# concrete

Incorporating CONCRETE ENGINEERING International

In-Situ Concrete
Construction Chemicals

# Highest marks for execution

## Forming the Aquatics Centre diving platforms

(Photo: Zaha Hadid and Hufton + Crow.)

Figure 1: Completed dive towers.

(Photo: Zaha Hadid and Hufton + Crow).

# *The Aquatics Centre*

## EAST LONDON

**Alastair Seaton of Cordek describes the planning, design, forming and construction of the six diving platforms at the London Aquatics centre - a focal point of attention during the summer's sporting events.**

There cannot be many people in the country who have not seen images of the iconic Zaha Hadid design for the London Aquatics Centre. The practice summarises the design as 'A concept inspired by the fluid geometry of water in motion, creating spaces and a surrounding environment in sympathy with the river landscape of its park setting. An undulating roof sweeps up from the ground as a wave, enclosing the pools of the Centre with its unifying gesture'.

With that concept it is not surprising that there are very few straight lines in the design, and the dive towers are no exception. The raking towers rise up out of the pool surround in a continually changing profile and then taper gracefully into a slender cantilever over the pool (Figure 1).

## Construction planning

The structural design proved to be a particular challenge for the engineers Arup, as the slender structures have to meet stringent performance criteria defined by the sport's governing body Fédération Internationale de Natation (FINA).

Gordon Mungall, project engineer says "These regulations, along with consideration of construction tolerances, vibration, long-term deflections, creep and shrinkage cracking, were critical in the design and reinforcement detailing carried out by Arup. Reinforcement bars were also provided in 3D digitised format to allow manufacturing of templates by Cordek to position the bars at key positions in the kickers and pours. The only method of providing tolerance to the platform levels was by adjustment to the base kicker level which was finalised following trial erection of all formwork to ensure that the boards could be set at their design level. Following these trials, the kicker forms were set and poured, which ensured that the elegant boards rose to the required level set by the diving competition events."

## Formwork design

Cordek were initially consulted by the Architect to discuss possible formwork solutions for the construction of the towers. Using the architect's 3D digital file a scale model was machined, which proved invaluable in determining the optimum construction joint locations and split lines for the formwork. As four of the six dive platforms share similar geometries a formwork layout was devised that optimised the reuse of the formers while still conforming to the architect's aesthetic requirements (Figure 2). To accurately create the double curvature shape traditional sheet materials such as steel or timber would not have been suitable and therefore glass-reinforced plastic formers were proposed. A fair-faced, as-struck finish with no through ties added to the challenge.

At tender stage, Cordek worked with a number of contractors to develop alternative methods of construction. A precast concrete outer shell option was considered but ultimately the project team, Zaha Hadid, Arup and main contractor Balfour Beatty Civil Engineering (BBCE) settled on an in-situ construction solution proposed by A J Morrisroe. The project programme dictated that the roof would already be in place and the pools constructed before the dive towers could be built and therefore access and craneage would be severely restricted.

The highest tower (10m) was to be constructed in four 2.5m-high pours, the last of which included the 7m-long dive platform.

Due to the complexity of the form, a composite design engineer was employed to complete a detailed finite-element analysis of the proposed formwork layout for each stage of the construction sequence. The formwork design allowed for the full hydrostatic pressure of a superplasticised concrete.

Maximum theoretical deflections were set at 5mm for the form surface, with a further limitation of a flange deflection at the construction joints of only 1mm. These tolerances were achieved by incorporating stiffening ribs into the design to limit surface deflections and by including tie bolts across the top of each pour to control movement at the construction joint.

To achieve the cleanest construction joints it was determined that the first former would be left in place after concreting and that the second former would be bolted on to it. Not only did this have the benefit of doubling up the flange thickness at this point but it also avoided having a lap joint in the complex curves of the formwork. Any movement of the formers at the construction joint would have resulted in a step in the finished surface and unsightly grout loss. To further minimise any deflection of the formers at this position a steel yoke was added into the design which was fitted with screw jacks which could be preloaded at critical locations prior to placing concrete for the second lift (Figure 3). This design process was then repeated for the remaining units.

## Pattern making

After the formwork design principles had been established the pattern making could begin. The 3D model was initially split down the centerline and then divided into manageable-sized sections for machining. Each section of pattern was constructed on a steel and timber frame for rigidity and dimensional stability.

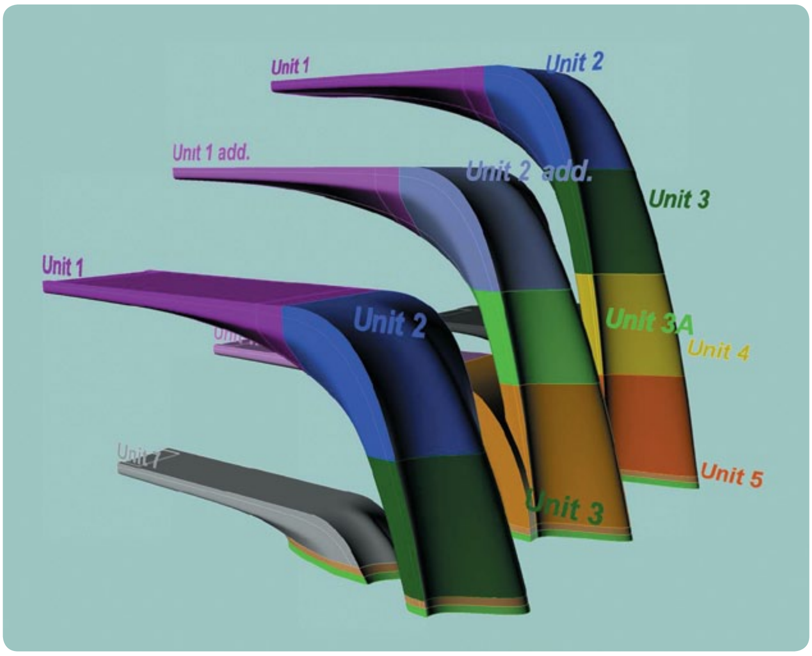


*Figure 2: 3D model showing joint location and reuse of formwork units.*

**"A composite design engineer was employed to complete a detailed finite-element analysis of the proposed formwork layout for each stage of the construction sequence."**

*Figure 3: Part of the finite-element analysis showing theoretical deflections on the surface of the former and at the locations of the yoke screw jacks.*

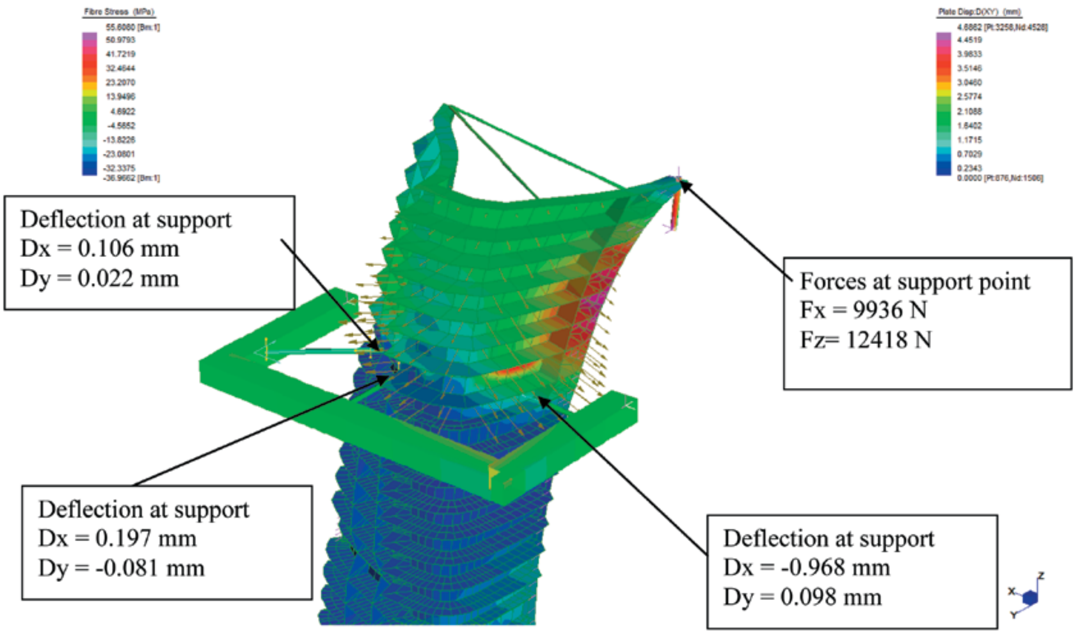


*Figure 4: EPS pattern being routed on Cordek's five-axis CNC router.*

Profiled blocks of expanded polystyrene (EPS) were laminated on to the frames. Using Cordek's largest five-axis CNC router, the EPS core was then machined to 10mm below the final surface level (see Figure 4). High-density polyurethane foam was then spray applied onto the EPS and this was then remachined to 0.5mm below finished surface level. This was followed by a seal coat of resin and a high-build primer.

The completed patterns where then shipped to Production Glassfibre, where they were assembled to form one complete half of the 10m tower (Figure 5). Finally a surface primer was applied which was then sanded and polished to create the finished surface.

## Formwork manufacture

The first phase of the formwork manufacture was to apply a cement-resistant gel coat to the pattern, which would provide the concrete forming surface.

The surface skin of the former was then constructed. The structural analysis determined that in the areas of maximum stress the skin of the former required 17 layers of glass-fibre reinforcement consisting of alternate 600gm/m$^2$ layers of woven and non-woven material. After completion of the skin lamination the

*Figure 5a and b: Complete pattern for left side of the 10m dice tower being finished ready for mould laminating.*

*Figure 6: Formwork units in various stages of construction.*

*Figure 7: Trial assembly of formers for pours one, two and three of the 10m tower.*

18mm ply stiffening ribs and joint flanges were cut and laminated into position with a further 5 layers of glass-fibre mat.

Each lift of formwork consisted of a left half and a right half with bolted flange connections along the centreline. Adjacent sections of formwork were match cast against each other to achieve the tightest joints possible (Figure 6).

The formers were delivered to site where a trial erection enabled AJ Morrisroe to finalise its method statement and to establish level data for the casting of the kicker formers (Figure 7). The largest single section of formwork was 7m long and weighed 1.8 tonnes.

## Achieved

The dive towers were constructed to a very high standard in a restricted space using only a small 10 tonne mobile crane (Figure 8). This was achieved with the full involvement of all parties from the early design stage and with sufficient time in the programme to design, develop and manufacture the formwork.

Sara Klomps project architect for Zaha Hadid says "It was a fantastic experience to work with the structural engineer, contractor and formwork supplier in such tight collaboration and the results confirm that this is the right approach to achieve high-quality architecture" ●


*Figure 8: Dive towers under construction showing 5m board in the foreground, 10m board behnd and the restricted cranage and access.*