Designing a Landmark for the United Arab Emirates

By Martin J. Halford and Paul J. Walters

The instruction from the client was to design not just a hotel, but a signature building—one that would announce, "Welcome to Dubai." The client wanted a dramatic statement with imagery that would immediately conjure up images of the city, in much the same way the Opera House does for Sydney and the Eiffel Tower does for Paris.

Functionally, Burj Al Arab is part of the Jumeirah Beach Resort and is sited on a man-made island 300 m offshore, which includes the "five-star," 600-bedroom Jumeirah Beach Hotel and the Wild Wadi Aquapark.

The building height is 321 m, making it the tallest hotel in the world. The hotel includes, among other amenities, the worlds tallest atrium at 180 m in height, 202 luxury suites laid out in V formation and an average of 158 m^2 standard single room. It has 202 "seven-star" super luxury suites, each two stories high.

Burj Al Arab is an extraordinary building, both internally and externally. The sail profile was chosen to reflect the seafaring heritage of Dubai. The architecture and the structure have been integrated in every way possible so that each complement of the tower takes advantage of the other. Even the steel-framed exoskeleton, the primary function of which is to provide horizontal stability to the structure, acts to please the senses of the viewer. Furthermore, the placing of the tower on a man-made island 300 m offshore not only reinforced the sail concept, but also has the practical benefit of freeing up space on shore for the other parts of the development. Another significant consideration was minimizing the impact of the tower's shadow on the adjacent resort.

Because WS Atkins & Partners served as both the CM and the architect/engineer, the time for the overall program was substantially reduced, with design and construction kept under six years from initial presentation of design concepts, through construction of the island, island substructure, shell, core and hotel.

Building Team

Architecture, Engineering, Construction Management & Landscaping: **WS Atkins & Partners Overseas**

Superstructure Contractor: Joint venture of **Fletcher** of New Zealand, **Murray and Roberts** of South Africa and locally based **Al Habtoor**

Steel Fabricator: **Genrec** (10,000 tonnes)

Island Contractor: **Dutco Balfour Beatty**

The completed building was delivered to the client, fully fitted for operation, in November 1999.

Environment

The environment in Dubai is typical of the coastal regions of the Arabian Gulf in that it is particularly aggressive to steel structures due to the high concentrations of chlorides in the atmosphere with high temperatures and high humidity. The shade temperature in the summer can reach up to 50 °C in conjunction with a humidity that may fluctuate between 35% and 100% in a few hours.

Corrosion Protection

The external structural steelwork was protected with one of two high-grade corrosion protection systems, each with a life to first maintenance in excess of 15 years.

The exposed steel was coated with a system comprised of an aluminum metal spray, a build coat of two pack epoxy micaceous iron oxide and a white gloss finish coat of two pack polyurethane to give a total dry film thickness of 340 microns.

The steelwork concealed beneath the cladding was protected with a high build glass flake epoxy system with a total dry film thickness of 600 microns.

Wind Effects

Situated on the coast at the southern end of the Arabian Gulf, Dubai is regularly subjected to severe weather conditions including strong winds blowing down the Gulf, which are sometimes accompanied, in winter, by violent squalls and thunderstorms.

Based on guidance issued by the UK's Building Research Establishment (BRE), the recommendations of Dubai Municipality and an analysis of 18 years of wind data from nearby Dubai International Airport, a 50 year return period windspeed of 45 meters per second was adopted for the design.

For the conceptual design, wind loading was based upon an extrapolation of the principles embodied in the UK Code of Practice for Wind Loading. However, in view of the size and unique shape of the tower, together with its proximity to the 100 m tall Jumeirah Beach Hotel, wind tunnel testing was undertaken for the detailed design phase.

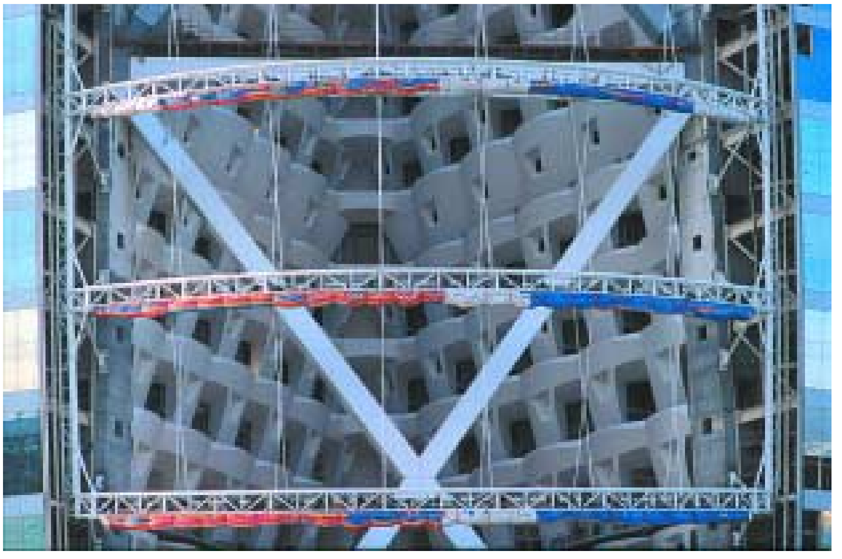
Using 1:300 scale models, BMT Fluid Mechanics Ltd. in the UK undertook a series of two tests.

The first series of tests modeled the Burj Al Arab and the Jumeirah Beach Hotel simultaneously, in order to measure the interaction of one with the other so that the local wind regime could be determined. The tower model was fitted with 200 pressure tapping points, which enabled local pressures for the cladding and curtain walling on the main building façades to be determined. To determine the wind pressures around the various elements of the exoskeleton, probes were used to measure the local wind velocities, later these probes were interpreted using the force coefficients in the UK Wind Loading Code to determine pressures for design.

The second series of tests was carried out using a rigid model of the tower mounted on a force balance. This enabled the static and dynamic components of the structural forces at the base of the building to be measured at about three orthogonal axes that, when combined with the known vibrational characteristics, enabled the displacements and accelerations of the structure to be predicted.

Seismic Considerations

Dubai itself is not situated in an earthquake zone. However, southern Iran, located only 100 miles to the north, is subject to a moderate earth-



quake risk and consequently there is the possibility of tremors in Dubai during a seismic event in Iran.

Thus, the BRE recommend that buildings in the region be designed to resist an earthquake of MM VII intensity, which equates approximately to a Zone 2 earthquake, according to the Uniform Building Code (UBC). This corresponds with the both the requirements of the Dubai Municipality and UBC Zone 2B, therefore a seismic zone factor of Z = 0.20 was adopted for the design.

Structural Analysis

A three dimensional finite element analysis of the entire tower structure was undertaken using the in-house ASAS suite of programs. The walls and floors were modeled as plate elements and the steel-framed exoskeleton was modeled using beam elements.

Response spectrum methods were used to determine the forces and displacements on the structure due to seismic loading and the wind loads were scaled so that the overall shear and bending moment at the base of the building correlated with the results of the force balance tests in the wind tunnel.

A more detailed model of the exoskeleton was used at a later stage in the design process to help with the assessment of risk regarding vortex-shedding induced oscillations of the upper section of the structure.

Island Construction and Substructure

The island is essentially a conventional rockbund with a single layer armour system, lined internally with a geotextile membrane and hydraulically filled with sand dredged from the seabed offshore. The armour system comprises precast concrete "shed" units, manufactured by using white cement above the waterline to improve appearance.

Temporary works were incorporated within the island as it was built to enable the three levels of basement to be constructed within the island. Tubular steel piles were driven into the seabed and incorporated into the perimeter rockbund. Within the rockbund, and just outside the future line of the basement, a high modulus sheet piled wall was constructed and anchored back to the tubular piles. This enabled excavation of the fill within the sheet piled wall to be carried out to a depth of 11 m below pile carpet level.

The building is founded on 250 bored piles, with each pile measuring 1500 mm in diameter. The raft, supported on these piles, is 2.7 m thick reinforced concrete and the basement walls are typically 750 mm thick.

Superstructure

The vertical load bearing element of the superstructure is made of a reinforced concrete honeycomb of walls and floor slabs extending up to a height of 210 m. The accommodation wings extend in a V formation between the main core at their intersection and stair cores towards their extremity. Structural steel with metal deck composite floors are used to frame the end suites, which cantilever beyond the stair cores.

The front elevation of the tower, between the two wings, encloses the atrium and consists of a tensioned membrane made from Teflon coated fiberglass fabric.

The tower's resistance to horizontal loading is provided by a combination of its reinforced concrete structure and exoskeleton. The latter consists of two frames, one external to each accommodation wing, connected at third points up the height of the main concrete core. These are founded on the concrete substructure at ground level, and extend up to a height of 270 m, to support the mast. In combination with the main core, these exoskeleton frames provide lateral stability in the front to back direction.

The rear braced frame comprises three tiers of cross bracing between the stair cores located towards the ends of the accommodation wings. The bracing is attached by large steel embedments into the concrete structure of the stair cores, which provide the chords for the bracing system resisting lateral loads in the side to side direction.

The front and rear legs of the exoskeleton consist of pairs of 3 m deep by 1 m wide plate girders, laced together with I sections, to form a rectangular member approximately

3 m by 6.5 m in plan. These legs were erected in 12 m lengths, by craning in each plate girder section, temporarily bolting them into position, lifting in the lacings and bolting them up and, after final survey and alignment, welded to the plate girder joints in situ.

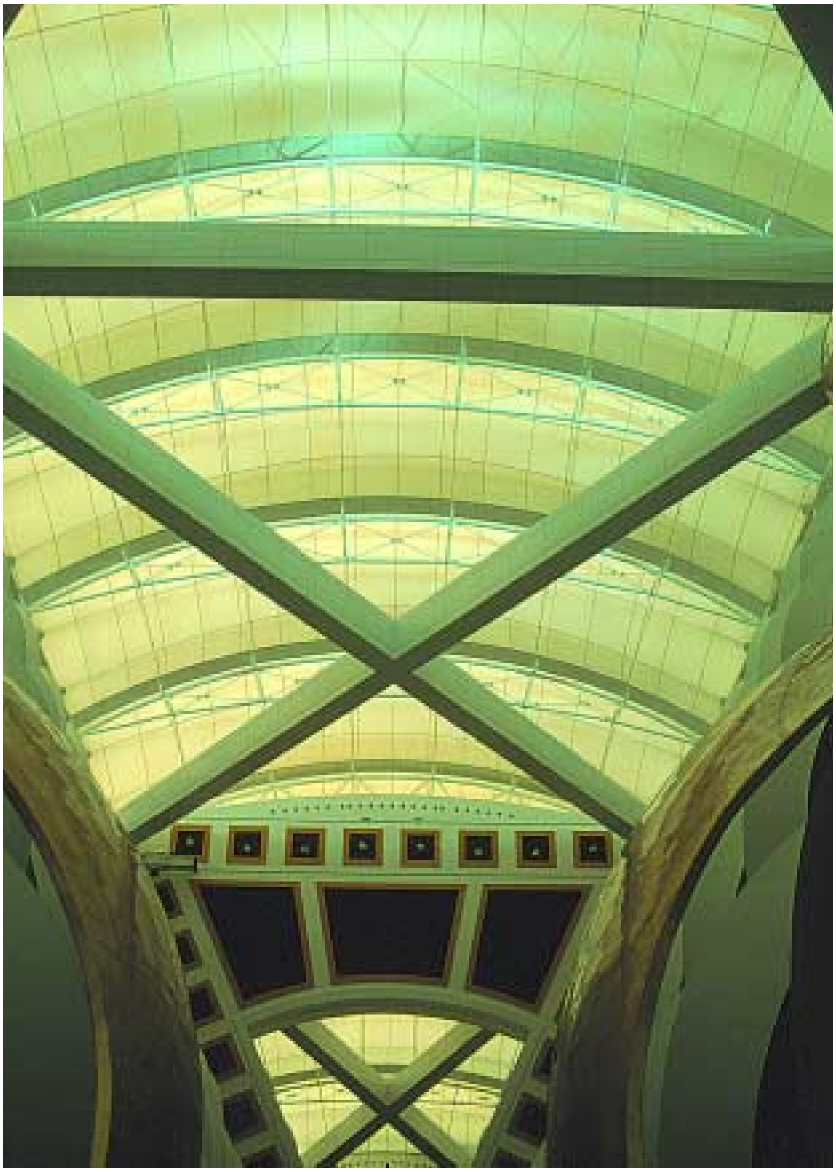
The rear braced frame is comprised of 1.7 m by 2.6 m stiffened box sections, erected in approximately 12 m lengths, temporarily bolted together and then, after final survey and alignment, welded together in situ. Due to the geometry and size of some of these elements, they had to be lifted into position using a tandem crane lift, which required extremely careful planning and coordination on site.

Fabrication and Erection

Three new self-climbing cranes, each with a capacity of 760 tonne metres, were purchased to erect the superstructure. These were positioned one in the main core and one near the end of each accommodation wing, and climbed within the concrete structure on specially fabricated steel grillages. The cranes were carefully selected and sited by the contractor in order to be able to cover the entire building area and to be able to lift the majority of the large, heavy steel elements of the exoskeleton and mast.

The cranes were used to lift custom-made table forms for the main floors, 12 m by 8.5 m on plan and equal to the floor area of one suite. Also, taking full advantage of the high lifting capacity of the cranes, the intermediate mezzanine floors were pre-cast at ground level, adjacent to the building and lifted into place by the cranes.

The majority of the structural steelwork for the tower was fabricated by the contractor in South Africa and transported by ship to Jebel Ali port, about 25 km from the site where a yard was set up to paint the steel. The exceptions to this were the



diagonal elements of the exoskeleton that, due to their design, had to be fully constructed before erection.

Each diagonal was up to 85 m in length with a mass of up to 165 tonnes. Therefore, they were too large to be transported economically by ship and too heavy to be lifted by the luffing cranes. These diagonals were fabricated in Jebel Ali, and then transported by road to the site in one piece using special multi-axled wheeled bogies pulled by heavy tractor units. The diagonals were then lifted and tilted into position on the structure using strand jacks fixed to specially made steel truss cathead structures and then bolted, via temporary embedments, into the concrete structure.

Skyview Restaurant, Helipad and the Mast

Near the top of the tower, there are three structural elements of particular note, the skyview restaurant, the helipad and the mast.

The skyview restaurant is a slender aerofoil shaped structure, which projects dramatically from the face of the building, 190 m above the ground. It offers commanding views over the surrounding coastline and as far as the centre of Dubai, some 15 km away. With a floor plate of over 1000 m^2, it is supported by tapered steel box sections up to 1.7 m deep, cantilevering up to 27 m and anchored into the main concrete core by large steel embedments. These embedments had a mass of up to 40 tonnes.

Due to the large cantilevers involved, careful consideration had to be paid to the erection methodology and presetting of the steelwork to ensure that the completed structure was level under the final dead loading.

Springing from the roof of the tower, with an elevation of 212 m, is the helipad. This is a steel framed structure supported by a 2 m deep box shaped lattice truss. The helipad is anchored at one end into the main concrete core and at the outer end is propped by two 1 m diameter steel circular hollow sections. The helipad is designed to accommodate twin-engine helicopters, up to 7.5 tonnes in mass, for both VIP access and to satisfy Civil Defense requirements as a means of escape in case of fire.

Projecting a further 60 m above the top of the exoskeleton, to a height of 321 m above the level of the island, is the elliptical shaped mast formed from a stiffened steel plate tube, with slip-critical bolted joints between the 12 m long sections. From the outset, it was realized that the mast would be vulnerable to wind induced oscillations and, therefore, a detailed analysis was carried out to determine its natural frequency and susceptibility to vortex shedding and buffeting. The resulting natural frequency of around 1 Hz gives a windspeed typical of that expected on a daily basis in Dubai. The solution was to incorporate three tuned mass dampers into the upper sections of the mast, to dampen out oscillations in each direction of sway. Similar dampers were also required in the upper parts of the rear exoskeleton legs, to control oscillations.

Cladding and Curtain Walling

The main building façades are clad with a modular curtain walling system, with double glazed units in alternate story height bands of light and dark blue, separated by white colored spandrel panels designed to break up the appearance of the large elevations. In order to create a more comfortable and controllable internal environment, the glass is highly reflective and has a low thermal conductivity to reduce the solar and heat gain from the external desert climate.

The cladding to the main core and to the exoskeleton legs and horizontals is comprised of thin resin bonded aluminum panels, powder coated white. Such panels have the advantage over conventional aluminum or stainless steel panels in that they can be stiffened on the rear face to resist high local wind pressures on the tower, yet still appear flat and undistorted on the front face.

Fabric Screen

The desire to give the front elevation of the building the appearance of a sail led to the innovative use of a structural Teflon coated fiberglass fabric as a tensioned membrane façade. Above the glazed entrance, the fabric screen forms the front elevation of the tower, with its appearance resembling that of a huge sail. It is composed of two layers of PTFE coated fiberglass fabric, tensioned between elegant steel bow trusses, which span 50 m between the accommodation wing stair cores at double storey height intervals. These two layers of fabric provide the necessary thermal properties and allow diffuse lighting into the atrium space. The screen is designed such that damage to any one panel of the fabric, between any pair of trusses and or both will not cause a failure of the entire screen.

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