Innovative Structural Designs –Case Study

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1. Abstract

The Capital Gate, Abu Dhabi.

Structural design is the methodical investigation of the stability, strength and rigidity of structures. The basic objective in structural analysis and design is to produce a structure capable of resisting all applied loads without failure during its intended life. The primary purpose of a structure is to transmit or support loads. The Capital Gate building is an iconic and avant-garde entrance to the city of Abu Dhabi. Leaning at 18 degrees westward, the tower claimed the Guinness Book of World Records title of The Most Inclined Building on Earth which makes it an innovative structural design. At 160 m and 35 stories, it is one of the tallest buildings in the city. The top floor overhangs its base by 33 metres. Capital Gate is a skyscraper in Abu Dhabi adjacent to the Abu Dhabi National Exhibition Centre designed with a striking lean. The owner and developer of Capital Gate is Abu Dhabi National Exhibitions Company. The tower also known as the Leaning Tower of Abu Dhabi is the focal point of the Capital Center. The tower's curvaceous shape draws strongly on the sea and desert – two elements that have great resonance in Abu Dhabi. The building's form is meant to represent a swirling spiral of sand, while the curved canopy, known as the "splash," which runs over the adjoining grandstand and rises on one side of the building, creates a wave-like effect, reflecting the building's proximity to the water and the city's sea-faring heritage.

2. INTRODUCTION

Situated at the edge of Persian Gulf, it is the richest and largest of the seven emirates together called as UNITED ARAB EMIRATES. Sheikh Sultan Bin Tahnoon Al Nahyan wanted an architecturally unique building which would serve as an international symbol for Abu Dhabi. It was strongly felt that the entire development required a signature tower, a cutting-edge structure with a futuristic design, aesthetic splendor and technical excellence to celebrate human achievement and reflect the dynamism of Abu Dhabi. Capital Gate is the result. The architect responsible for the design was Neil Van Der Veen. Having the design ready, Tony Archibold was the project architect responsible for the construction. Mona Vasigh –The structural engineer was responsible for the planning of the core. Les Fairchild – Core Construction Manager. Baskeran–Steel Manufacturer. Craig Rooney-Construction manager wanted to test the glass panels. It was done by Leighton Aurelun - Wind engineer.

3. SHAPE AND LOCATION:

The shape was sought to be looked into the nature of Abu Dhabi and was inspired by the sand dunes and rolling waves. Combining the forces a building that spirals out like a Whirl-wind was designed. The building had to be located next to The Grand Stand built by sheik's late father and the founder of U.A.E. A whole city called the Capital City was built and the Capital Gate was the center of the whole city.

4. DEEP FOUNDATION-PILE

November 2007 - Pile driving starts

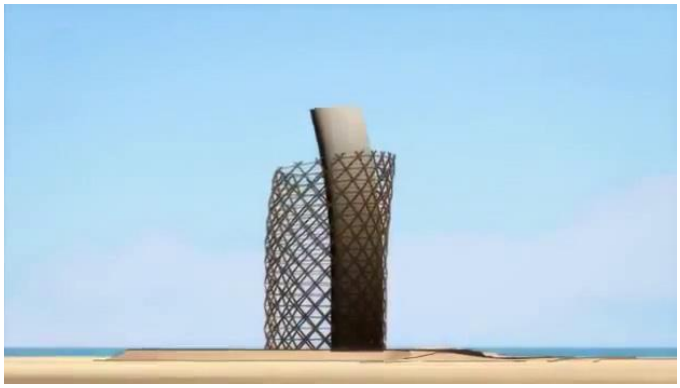
A pile is a column of concrete that extends downward deep into the soil. Pile foundations consist of a number of piles connected by a ring of concrete called a ground beam. This is similar to a strip foundation but not as wide. About 6000 cubic metre of sand was excavated. Over 400 piles were driven into the ground, which was divided into two sets- One for the large weight going down and the other for the large weight coming up as shown in the figure below. The first set is made a little shorter to push the overhang's forces into the ground and the other made a little longer which anchors deeply into the bed-rock to the resist the stretching forces. The piles, which were initially in compression during construction to support the lower floors of the building, are now in tension as the stresses caused by the overhang have been applied.

To evenly distribute the load on the piles, Reinforced Cement Concrete is used.

5. CORE AND ITS CONSTRUCTION

5.1. April 2008 - Core wall construction starts

Normal skyscrapers are built around a thin vertical core to the channel the building weight into the ground. But, the pull of the Capital Gate wants to stretch the core on one side causing the concrete to tear apart. The Capital Gate tower features an innovative construction technique of 'Pre-cambered core', which contains more than 15,000 cubic metres of concrete reinforced with 10,000 tons of steel. The core, deliberately built slightly off centre, has straightened as the building has risen, compressing the concrete and giving it Strength , and moving into (vertical)position as the weight of the floors has been added. The core shift is 350mm. The core grows 4m a week.



5.2. Construction of the Core:

Method - Hydraulic Jack, It is a Hydraulic platform.

A jack is a mechanical device used as a lifting device to lift heavy loads or apply great forces. Jacks employ a hydraulic cylinder to apply very high linear forces. Dense steel reinforcements are used. The core will strengthen as it straightens. In order to take the load effectively Rebar's of steel are used as reinforcements. The steels are raised in the day-time. A mould encloses around the steel to form the shape. It is filled with concrete. Due to the high temperature in the day-time, the rate of heat of hydration fastens (dries too fast) and leads to cracking. Hence, Hot weather concreting is adopted and the concrete is poured in the cool of the night.

5.3. Test for concrete:

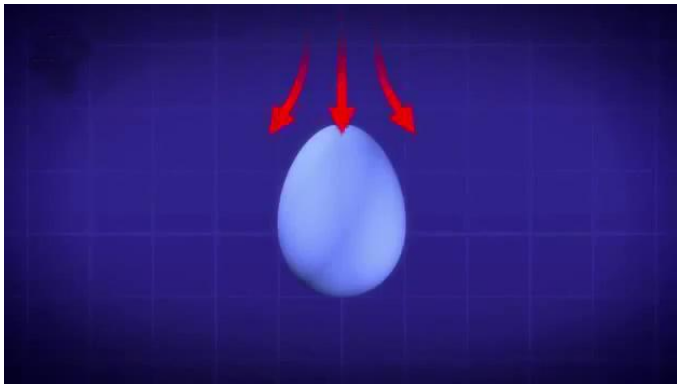
Consistency test: As the core grows larger, concrete needs to be pumped up to long distances. Hence, the consistency of concrete needs to be checked. The consistency of the concrete is tested using a slump cone test. Slump cone reveals consistency of 215mm and is directed O.K to be pumped.

6. TENDONS

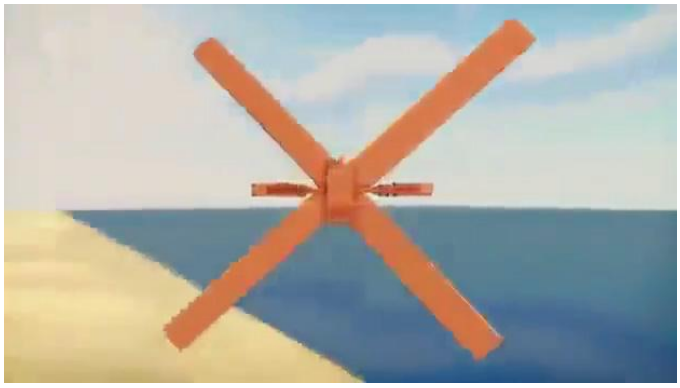
In addition to the core and the Rebar's, Tension forces are needed to be applied at the top to avoid the building from toppling over.146 Steel tendons are forced vertically through the ducts in the concrete. Each Tendon is 20m long and overlapping each other for maximum strength. The weight of the tendons is 120000 tons. A pneumatic jack will climb over each tendon and tension it to the correct stress level. When tendon is stretched, the stress produced will compensate with the pulling force.

7. INNOVATIVE TECHNIQUE INVOLVING DIAGRIDS

7.1. The external frame should be thin to give more floor space and to accommodate windows. Hence a Diagrid is used to channel the forces. It is based on the load distributing property of an egg, which evenly distributes forces throughout its shell.



The Diagrid is especially designed to absorb and channel the forces created by wind and seismic loading, as well as the gradient of Capital Gate. Capital Gate is the Middle East's first building to use a Diagrid. It is a design for constructing large buildings with steel. The external diagrid is composed of hollow square sections 600 x 600 millimeters on a side. They carry floors four meters high. Each diagrid member is a different length, depending on the angle at which it leans. The external diagrid elements are made from welded steel plates, 80 millimeters thick at the bottom floors, and progressively lightening to 40 millimeters at the top floors. The internal diagrid around the atrium is made of round steel profiles 400 millimeters in diameter, which are also hollow. The diagrid connections are nodes located at the floor slab levels where girders frame in. The external diagrid nodes are also designed for the façade panels to frame on the outside. Designers studied these connection details extensively to optimize construction, as well as structural integrity.



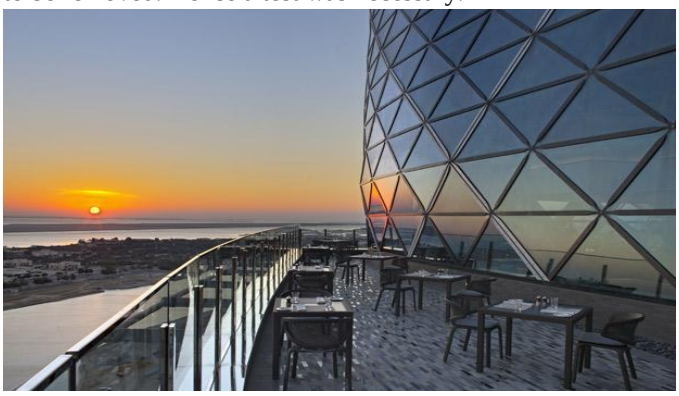
7.2. Manufacture:

The Diagrids are manufactured in the nearing Emirate called Sharjah , 18 Cruciforms are manufactured every week to meet the construction requirements. Each of the Capital Gate's Diagrid is uniquely shaped. A total of 72 Diagrids are used.

240 Steel fabricators crane-lift the Diagrids to some angles. Care was taken to achieve millimetre accuracy in order to prevent the loss in the channelling of the forces.

8. GLAZING

The use of curved glass to cover the building would blow-up the budget. Hence flat glasses must be used. Triangular glass planes are selected, which can pivot in three directions. These planes joint together can cover complex geometric design. Over 26,000 triangle planes are used. These glass panels are stacked over one another starting from the bottom. . To prevent water entry, the glass must be capable of shifting 20mm. Such a scale was never heard of in the skyscraper rule book. Any discrepancy will cause the whole of the glass panel to be removed. Hence a test was necessary.



The test which was carried out in the Dubai Laboratory involved the simulation of worst weather case scenario. A leak was found which was devastating to the whole team. Diamond connects to each other by a two layer bismuth seal. Flexible spongy seal allows the facilitation of movement and keeps the water out. At intervals, drainage tubes were fitted to drain the water out. The clog of one such drainage tube with sand resulted in the leak. Having the cause squared-out the fitting process continued.

9. HANGING RESTAURENT

October 2009 - Attains final height of 160m

The design required a Hanging Restaurant and a Swimming pool at a height of 100m.

9.1. Problems-

The design did not want any visible supports. The weight of the pool water was itself 150 tons.

Hence reinforced support was needed from below. 22 Under-pinning strut was used to carry the weight back into the building and also was built to meet the aesthetic demands.

10. FUNNEL SHAPE

Funnel shaped Capital gate facilitates natural lightening upto half the length of the building. The other advantage lies in the transferring of the load from the diagrid to the core. Hence internal diagrid system is employed to reduce the

weight of the structure. The ground-breaking form of Capital Gate is due not only to its lean, but also to its funnel shape. It widens as it spirals upwards and outwards.

11. HELIPAD

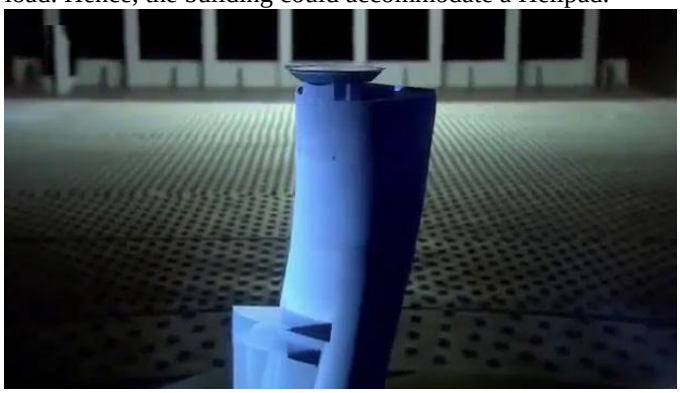
Nearing the completion of the Capital Gate, a message was received from the Sheik's office wanting a helipad.

11.1. Problems –

The core is already strained and cannot take new loads. Formation of a turbulence of wind at the top of the helipad causes Wind Shear at the blades of the helicopter.

11.2. Modal Analysis-

Test results show that huge suction forces are created on the other end, which wants to rip the helipad off its base. Solution- Lowering the helipad to a 2m above the top of the building, dramatically decreased the wind shear as well as the total wind load. Hence, the building could accommodate a Helipad.



December 2009 - Completion of exterior core structure.

12. SPLASH

A splash a steel connects the capitol gate to The Grand Stand. The façade glazing emphasizes the organic elements with diagonals spiralling up along the structural diagrid. This weaving pattern is further broken down with individual panes of glass in a complex mesh wrapping the entire building. The sheer skin is interrupted only by two entrances on the ground floor, the footbridge to the car park, and the terraces at the top of the "splash." The potentially monumental scale of Capital Gate is tempered by this "splash" sun shading on the south façade. This metal mesh screen at the lower half of the tower adds complexity to the overall form as it highlights the different uses of the tower -offices in the lower half and hotel in the upper half. Capital Gate's most visible feature is the "splash," which twists around the building towards the south to shield Capital Gate as much as possible from direct sunlight. The metal mesh eliminates 30% of the sun's heat before it reaches the building, reducing the air conditioning load on the protected floors. It also provides outdoor shade to the main entrance on the ground floor. The upper half of the tower has a double skin façade to reduce the solar heat gain at the hotel levels. This is a modified double façade, which recycles interior air from the guest rooms into the façade cavity. Here it creates an insulating buffer between the hot outside air and the cool inside air. The air is re-used in the room rather than exhausted and replaced with outside air.

INTERIOR FIT-OUT

February 2010 - Interior fit-out commences

13. SPECIFICATIONS

13.1. STRUCTURAL

13.1.1. Design Loads

Office area superimposed Dead Load = 2.4kPa,
Live Load = 5.0kPa Cladding.
Fully unitised facade curtain walling system is made up from 2 storey height diamonds which make up the 'free form' facade comprising double glazed factory sealed triangular glass units and steel section frames.

13.1.2. Dimensional Information

Floor to floor height: 4.00m (4,000mm).
Floor to ceiling height: 2.50–2.75m (2,500–2,750mm).
Ceiling to void average: 0.80m (800mm).
Raised floor height: 0.15m (150mm).
All dimensions are approximate

13.2. ELECTRICAL SERVICES

13.2.1. General

One passenger elevator is backed up by standby generator power, for use in case of emergency. All life safety systems and essential services are backed up by the standby generator and uninterrupted power supply (UPS) to ensure availability of power at all times.

13.2.2. Power Supply

The building is supplied at 11KV.Power is transformed to the operating voltage of 415 volts by five, 1,500KVA transformers installed in the substation.

13.2.3. Power Feed

Office Areas are provided with 63 Amp three phase

power supply for smaller units and 100 Amp three phase power supply for larger units, locally for each office unit with a local Isolator. Each tenant will provide a distribution board as per their load requirements and connect to the local Isolator provided by the Landlord.

13.3. MECHANICAL SERVICES

Fresh air ventilation, fan coil unit (FCU) systems, fresh air handling units (AHUs), smoke extract ventilation system, variable volume air-conditioning system, and chilled water (CW) system are provided. The office areas including basement, ground and mezzanine are served by centralised AHUs (2 Nos.).

13.4. PLUMBING AND DRAINAGE

Sanitary wares, water tanks, domestic water systems, soil/waste/vent and overflows, irrigation system and rainwater system have been included. The concrete water tank is a double compartment type, allocated for domestic water, fire protection system, and irrigation source. The plumbing system consists of metered cold water (CW) network, filter cooled cold water supply (FCCWS) and centralised hot water (HW) distribution system which supplies water at 55°C.

13.5. FIREFIGHTING

Sprinkler installation, external hydrant system, manual fire protection system of fire extinguishing, gas fire suppression system, fire alarms, and fire detectors have been included. All floors are provided with accepted zonal fire sprinkler suppression with individual zonal control valve. Each floor has three fire hose cabinets (FHC) at the common area. All electrical rooms are supplied with either automatic fire extinguishers or foam type fire suppression systems.

13.6. OTHER SERVICES

13.6.1. Fire Alarm and Public Address Evacuation Systems

Smoke detectors have been provided. Smoke detectors are provided with approx. two metres of additional cable for lowering in to the ceilings. Voice evacuation speakers are provided within each office space, for announcements.

Emergency Lighting

Sufficient emergency lights are provided with, together with one wall mounted type exit light for installing above the entrance/exit door for each office space. All the emergency and exit lights are backed up by the central battery system, which is backed up by the standby generator.

13.6.2. Telecommunication

State-of-the-art passive connectivity solutions allow tenants to deploy a full range of telecommunications services from the UAE's leading service providers. Optical fibre connections with up to 10G capacity are available to tenants for connections to service providers.

13.6.3. Security

Security system has been provided with 24 hour physical security presence incorporating CCTV surveillance of the main entrances, elevator lobbies and external areas. Tenants will use security access cards in conjunction with proximity readers to access the security barriers and at each of the main entrance points.

13.6.4. Elevators – Passenger

Three passenger elevators are provided for office floors, serving Ground floor to Level 16. Each elevator is 1,600kg (21 person) capacity. One elevator is backed up by generator power for use in case of mains power failure.

13.6.5. Elevators – Service/Goods

One office floor service elevator of 1,600kg capacity is provided.

13.6.6. Floors

Fully accessible raised access flooring (600 x 600 tiles) with an overall floor depth of 150mm allowing 110mm clear void may be provided.

13.6.7. Walls

Unplastered block and steel columns with cementitious fireproofing to be painted.

Toilet and Pantry

High quality finishes including tiling to floor and walls, ceilings, recessed lighting, ablution facilities and marble vanity tops are provided.

14. PROJECT TIME LINE

September 2007- Enabling works commence
November 2007 - Pile driving starts
April 2008 - Core wall construction starts
February 2009 - Façade commences
May 2009 - Reaches 100m in height
June 2009 – Incline starts to take shape
October 2009 - Attains final height of 160m
December 2009 - Completion of exterior core structure
January 2010 - First phase of splash completed
February 2010 - Interior fit-out commences
March 2010 – Commencement of link bridge
April 2010 – Commencement of atrium roof
2011 – Expected completion of construction
Opening date- 21-Dec-2011

15. CONCLUSION

The Capital Gate was a structural design that could deter any skyscraper rule book. It proved to be a difficult task owing to its extraordinary lean and the need for extremely small external frame, serving both as a load distributer as well as cover from the external harsh environment The building saw the usage of Diagrid systems and world's very first pre-cambered core. Structural designs like Capital Gate could open new doors to more innovative structures. While clearly a unique structure was built using some of the world's most advanced construction techniques, it is believed that the tower's appeal goes far beyond an architectural and engineering marvel. Functionality and purpose have been a

prime focus.

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