

A photograph of the Capital Gate tower in Abu Dhabi, United Arab Emirates, at dusk. The tower is a tall, curved skyscraper with a distinctive twisted design, featuring a glass facade that reflects the sky. It is situated on a small artificial island, with a bridge connecting it to the mainland. The surrounding area includes other modern buildings and a body of water in the foreground, which reflects the tower and the city lights. The sky is a mix of blue and orange, indicating the time is either dawn or dusk.

ARCH 631

APPLIED ARCHITECTURAL STRUCTURES CASE STUDY

CAPITAL GATE

Abū Dhābi

ADITHYA DEVDAS

HANISHA KAJA

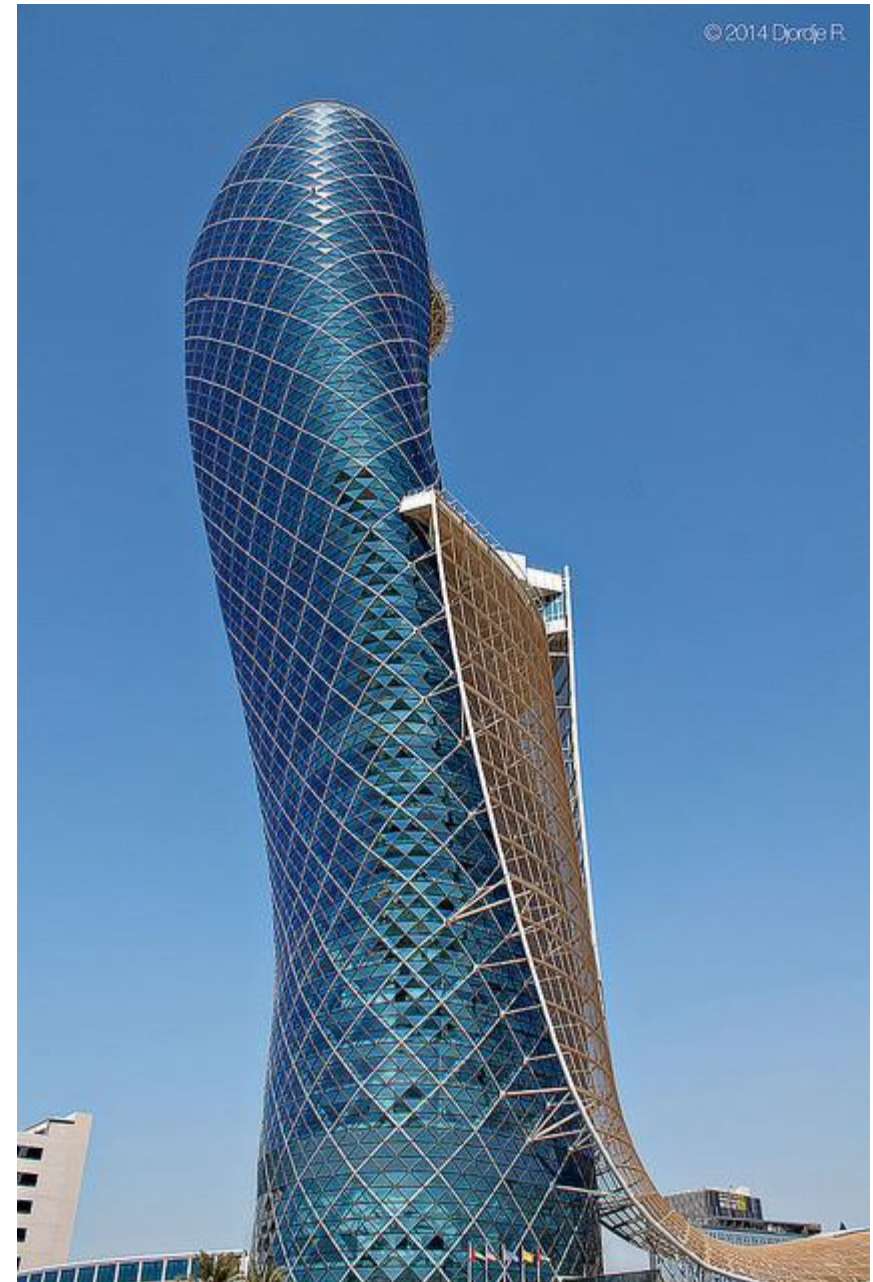
SARAH MATHEWS

RILWAN O. KAMOJU

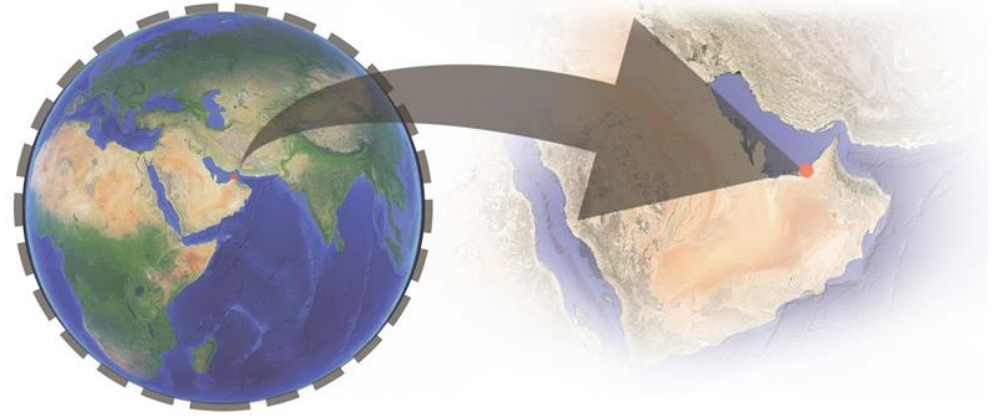
TARUN POTLURI



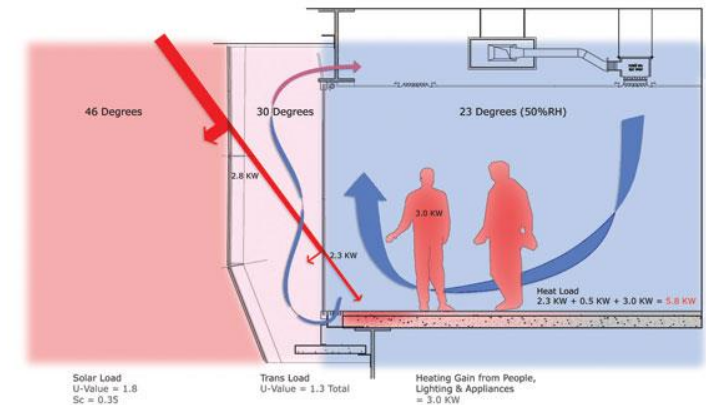
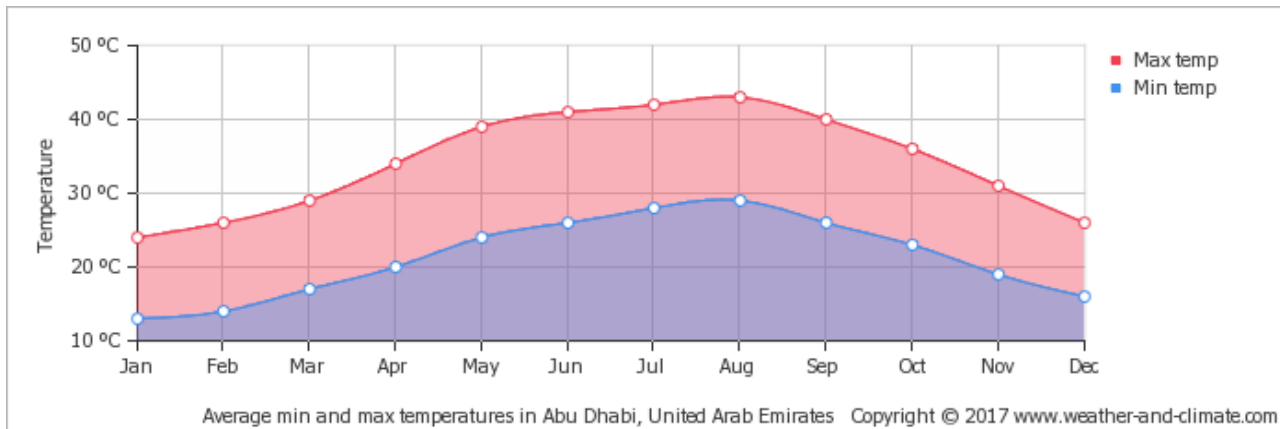
The **Capital Gate** building is located in Abu Dhabi, in the United Arab Emirates and was completed in 2010. The reason for analysing this particular building is because, it is the only building in the world to lean to an astounding 18 degrees and currently holds the Guinness world record for the furthest leaning manmade tower in the world. This building is truly iconic in every way and represents the achievements of mankind in the field of Architecture, Engineering and Construction. The building presents us with the opportunity of understanding the structural challenges and analysing the various systems employed to counter lateral loads. It is not only aesthetically pleasing but also an engineering marvel.



- The Capital Gate building is located in **Abu Dhabi**, which is the second largest city in the United Arab Emirates. This is a t-shaped island which juts into the Persian Gulf.
- The building is an icon in the city, and helps establish the status of Abu Dhabi as a global megacity. The coordinates of the building are 24.4187° N, 54.4347° E.
- In order to create maximum impact, this skyscraper is located next to the Grandstand, a monument of national importance. This is done to link the future of Abu Dhabi with its past.



- The climate of Abu Dhabi is subtropical and arid with high temperature and sunny blue skies.
- The average rainfall is 12cms per year mainly falling during winter season from november to march. The summer's from the month october to may the temperature will be typically above 40°C and during winter the temperature ranges from 13°C to 24°C.
- Air conditioning is considered as a much needed and import necessity for all vehicles and buildings such as hotels, conference and exhibition halls and shopping malls.
- We see that the climate plays a role in the construction of the building as well. When the concrete was poured, it cracked due to the heat. Therefore, to work around this, the concrete had to be poured at night.

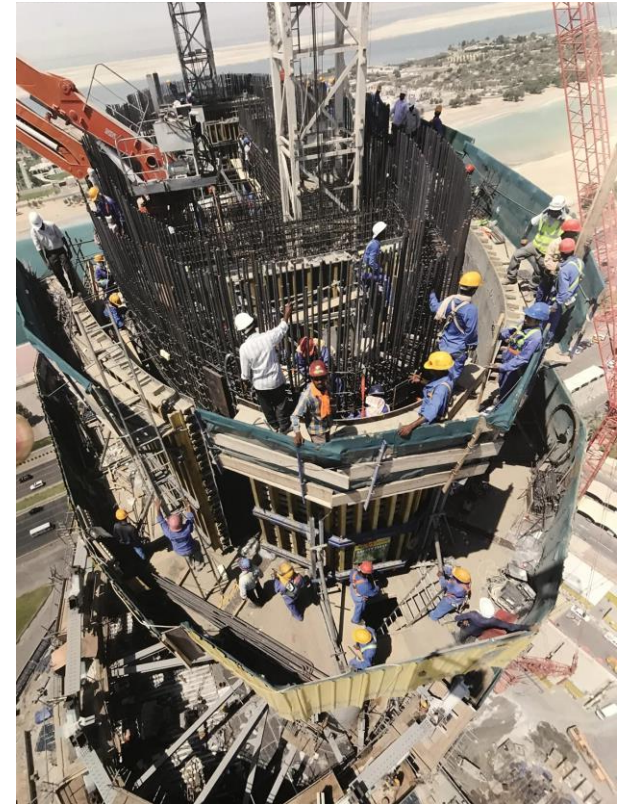


- Generally, low lying sandy deserts dominate the landscape of Abu Dhabi, accompanying the hot desert climate.
- The Capital Gate building is constructed near the seashore.
- The primary soil type seen here is sandy soil which does not have a good bearing capacity.
- Therefore, the foundation for a building of this size must be designed keeping this in mind.
- There is a layer of bedrock beneath which can serve as the anchor/support for the foundation used



In Compliance with Code requirements

- Building height: 160M (high rise)
- Occupancy type : Group A(institutional/public), R1(hotel)
- Occupancy category : (iii) (more than 800 people)
- Reinforced concrete grade : Deflection does not exceed ACI 318
- Steel grade : Deflection does not exceed AISC 360
- Seismic consideration : site class “E” - values determined in accordance to ASCE 7
- Fire safety : SFRM minimum bond strength - 48 Kpa
- wind consideration : 80 percent of design base overturning moments determined in accordance to ASCE 7
- Soil consideration : Lateral soil load (active pressure) - 7.05





- Ever since the building was constructed in the year 2011, it has become the **pride** of Abu Dhabi. A structure, truly one of a kind and the best in its class, it has helped Abu Dhabi retain its name and stature as a global megacity.
- It forms the **focal Point** of the Abu Dhabi National Exhibition Center Complex and the Capital Center Master Redevelopment, along with other 23 towers, that include branded hotels, commercial buildings, residential, service apartment complexes and developments for mixed use.
- Its **location** plays a vital role is one of the many reasons why it is considered iconic. It dominates the waterfront area, overlooking an urban highway and rising above other developments in its immediate vicinity.
- It is the only tower in the world that has this degree of inclination. It inclines at an astounding **18 degrees** and holds the Guinness World record for the furthest leaning manmade tower in the world.



ARCHITECTS: RMJM Architects

LOCATION: Abu Dhabi, United Arab Emirates

COORDINATES: 24.4187° N, 54.4347° E

COMPLETION DATE: 2011

BUILDING USE: Hyatt Hotel, Commercial spaces and mixed use.

HEIGHT: 164 M

FLOORS: 35

BUILT UP AREA: 53,100 SQM

OFFICE AREA: 14,396 SQM

HOTEL AREA: 25,050 SQM

FOOTPRINT: 1,390 SQM

INCLINATION: 18 DEGREES

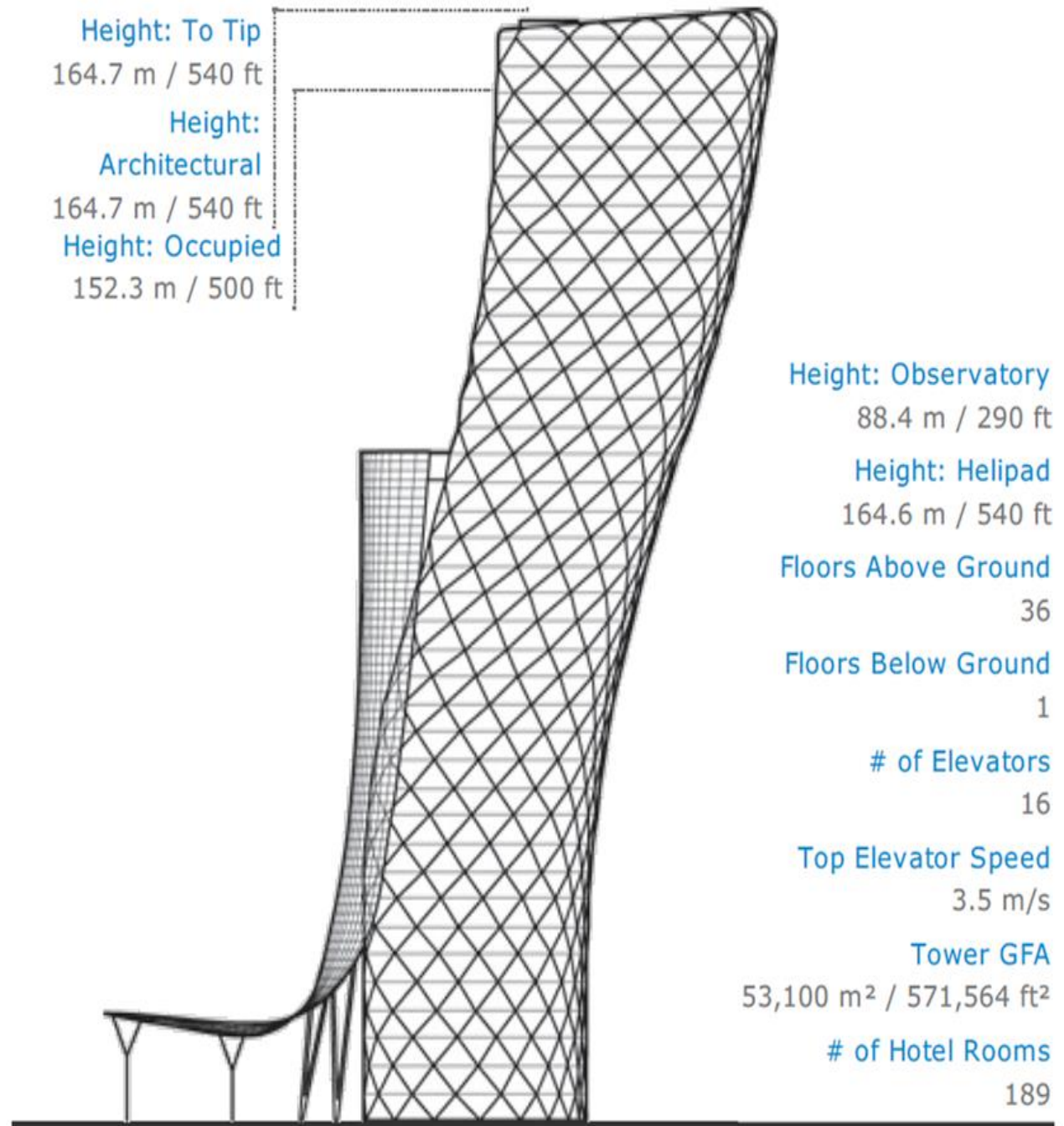
PROJECT MANAGER: Mace Group

CONTRACTOR: AL Habtoor Leighton Group

OWNER: ADNEC (Abu Dhabi Exhibitions Company)

COST: \$231 million

“It is the first building in the world to use a pre-cambered core with a built-in lean of 350 millimeters that has been engineered to straighten with the addition of the upper floors. It is also the first building in the world to use vertical post-tensioning of the core to counter movement and support stresses created by the building’s overhang.”



- The team of architects was selected by the man in charge of the project, His Highness Sultan Bin Tahnoon Al Nahvan.
- He selected the the firm RMJM (Robert Matthew Johnson Marshall) as the concept architects of this project.
- This firm is one of Britain's largest architecture firms, which is based in London and Edinburgh.
- RMJM Architects have a wide portfolio and working on sustainable design, interior design, masterplanning, urban design, historic preservation, and computer visualisation. In terms of sectors, they work in mixed use, education, residential, hospitality and government projects.
- The Mace group was in charge of the project management aspect of the Capital Gate building.
- The contractors who were a part of this project was the Al Habtoor Leighton Group.
- Some of the structural engineers in charge of this project were Mona Vasigh and Irfan Ahmed.



Architect Neil van der Veen



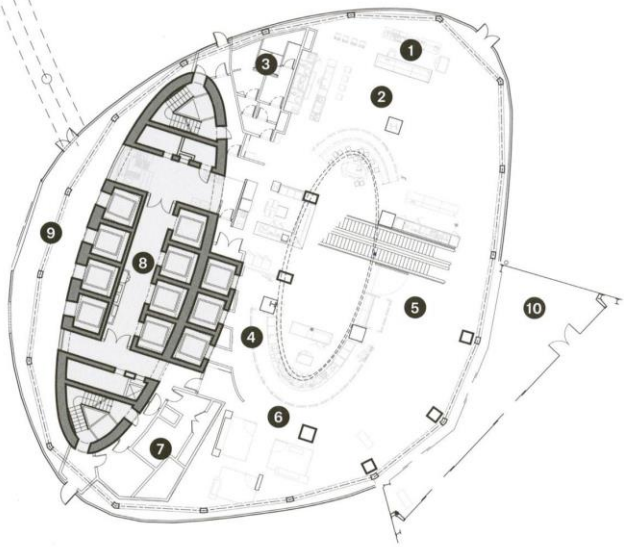
- **Guinness World Record** - The furthest leaning manmade tower with an inclination of 18 degrees.
- Won 'Best Commercial/ Mixed Use Project' at the International property Awards in 2015
- Sustainability Award at the AEO Excellence Awards
- Venue of the Year for ExCeL London at the AEO Excellence Awards,
- Exhibition Venue of the Year at Event Awards,
- Middle East's Leading Exhibition & Convention Centre at World Travel Awards,
- Best Middle East Exhibition for IDEX at Middle East Events Awards,
- Best Meetings & Conference Centre in the Middle East for Al Ain Convention Centre at Business Destinations Travel Awards,
- Best Commercial High Rise Development – Capital Gate at Arabian Property Awards.

Capital gate won around 75 awards since it started in 2011.

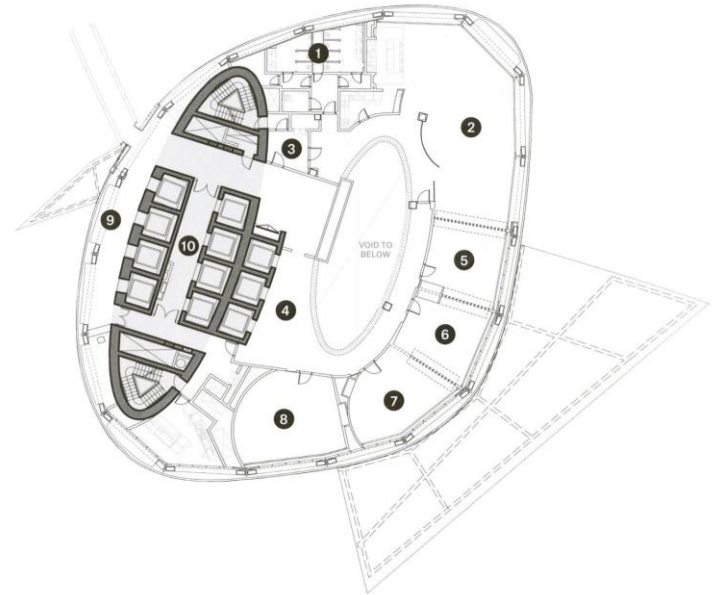




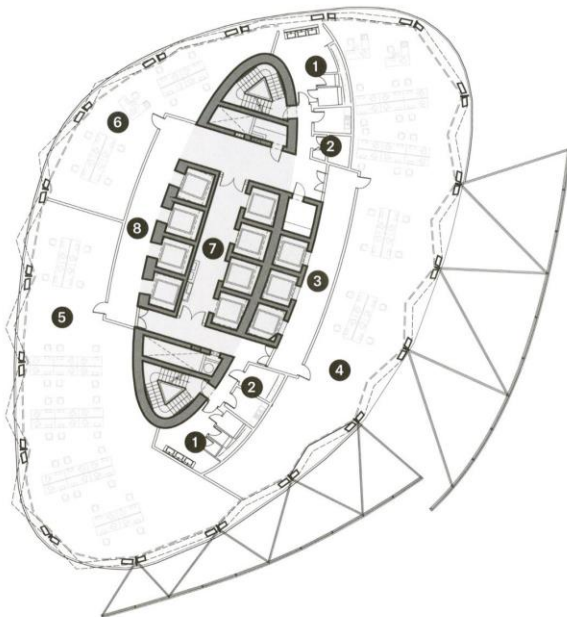
- The **Capital Gate** is an iconic structure on the skyline of the Emirate of Abu Dhabi.
- The tower's curvaceous shape is inspired strongly from two main geological elements, one being **the sea** and the other, **the desert**. These two elements resonate strongly with the essence of Abu Dhabi.
- The main building's form is meant to symbolize a **swirling spiral of sand**, while the curved canopy, known as the "**splash**," is meant to represent the **waves in the sea**. It creates a wave-like effect, reflecting the building's proximity to the water and the city's seafaring heritage.
- The imposing mass, the organic fluidity of its twist, and the idiosyncratic lean of the funnel-shaped tower, combine to embody a specific time, a particular space and a specific volume, reflecting the geography and culture of ABu Dhabi.



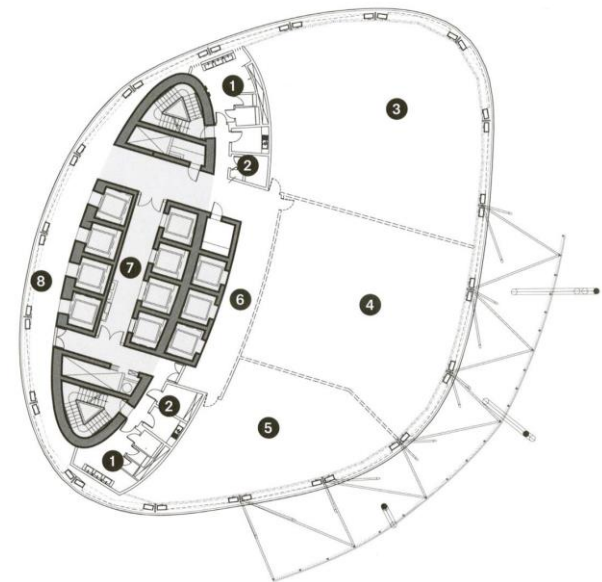
GROUND FLOOR PLAN



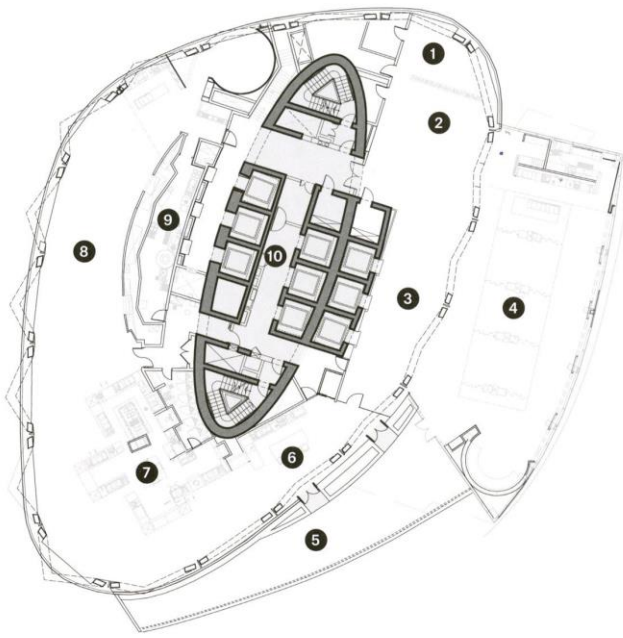
MEZZANINE FLOOR PLAN



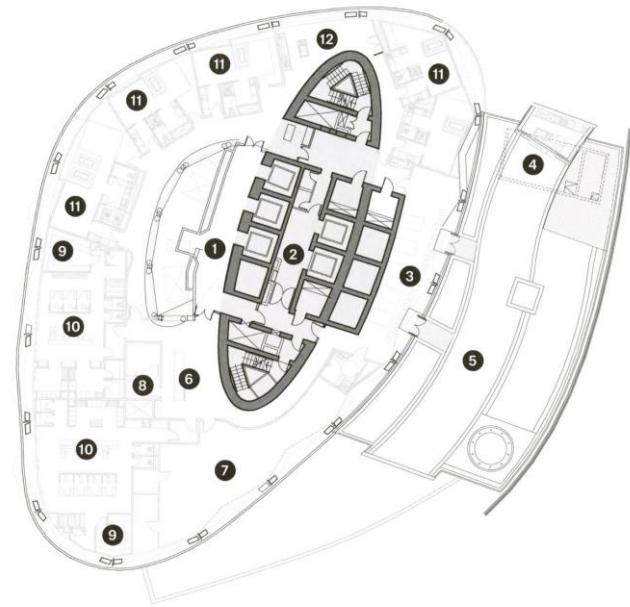
SECOND FLOOR -OFFICES



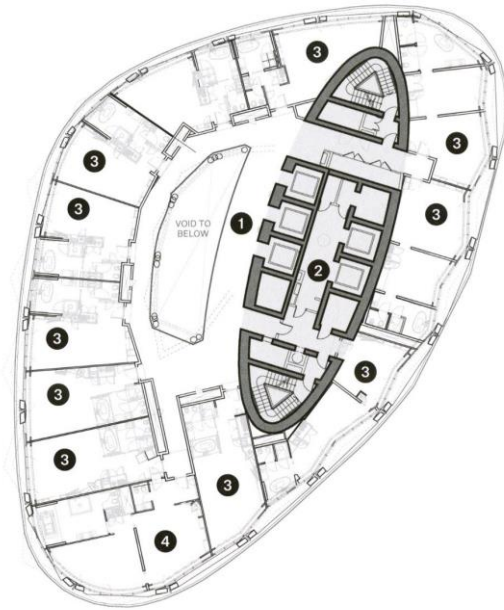
16TH FLOOR -OFFICES



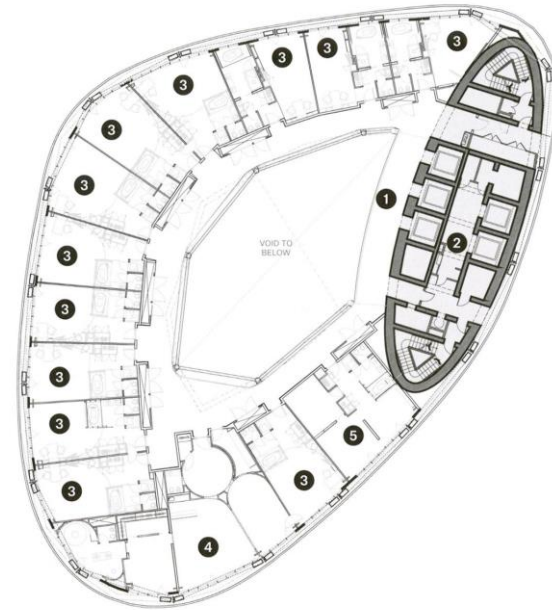
18TH FLOOR -RESTAURANT



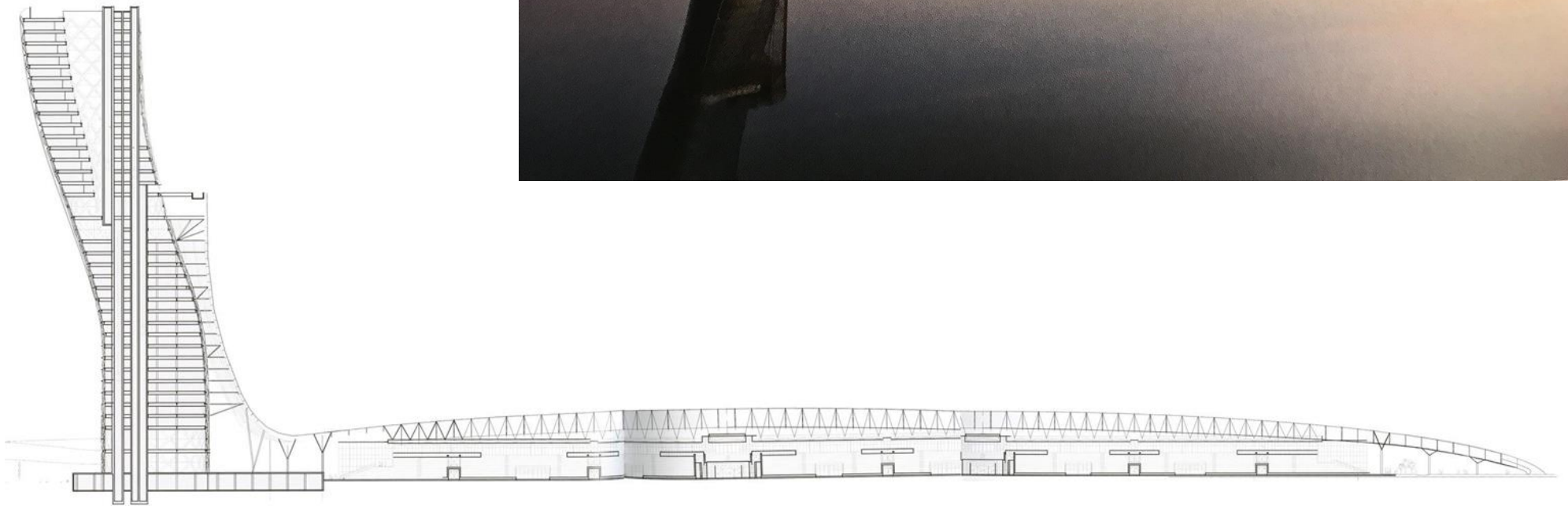
19TH FLOOR AMENITIES



20TH FLOOR -HOTEL

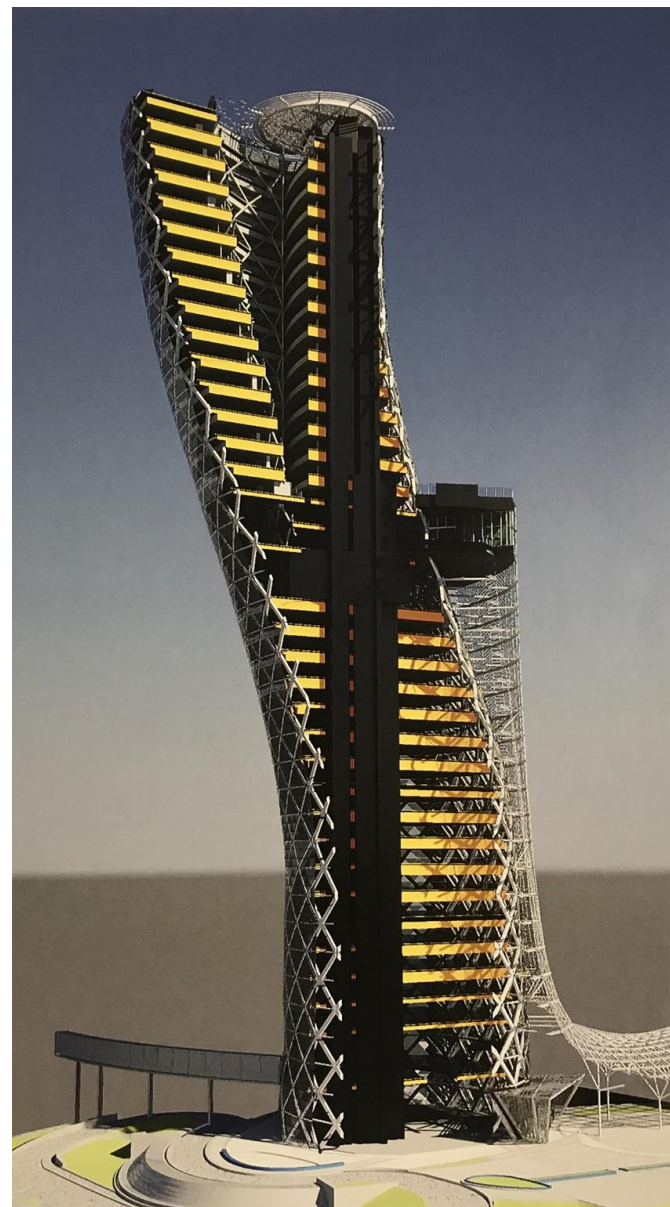
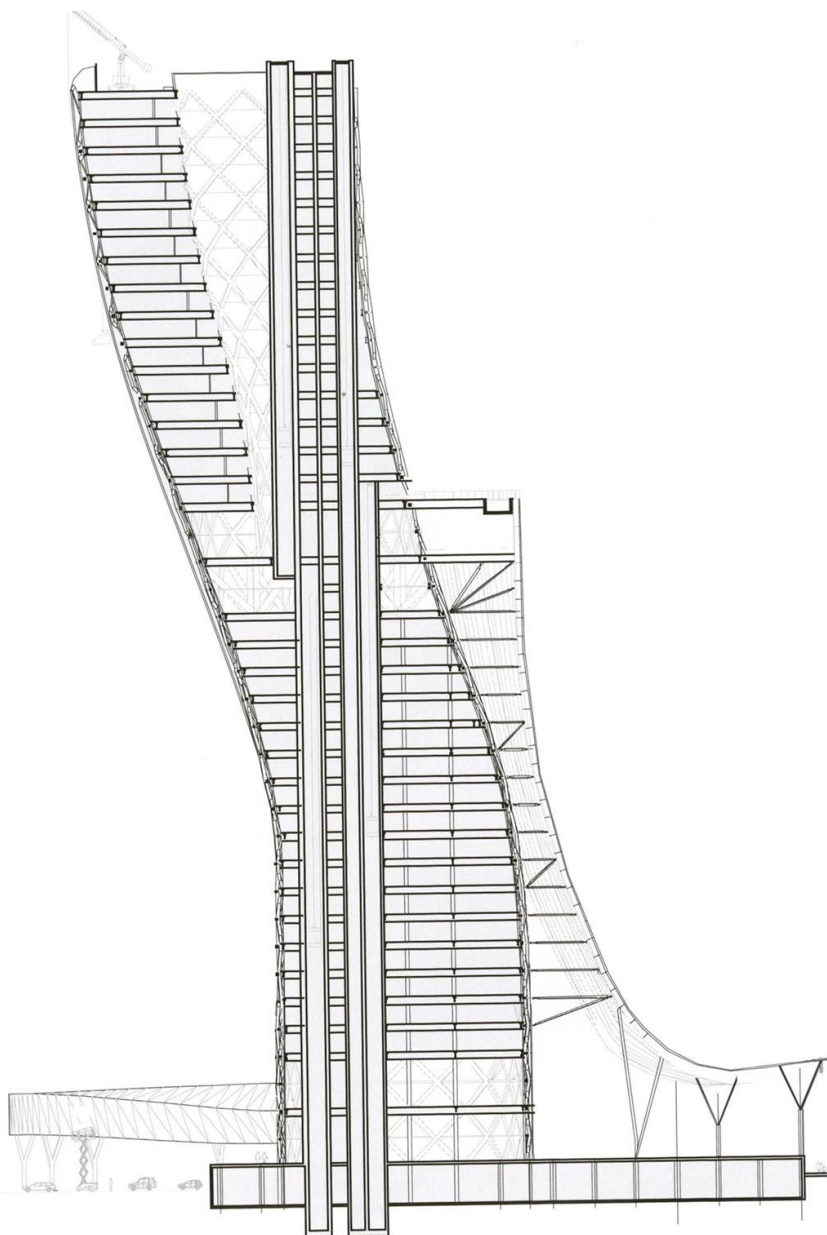


30TH FLOOR -HOTEL



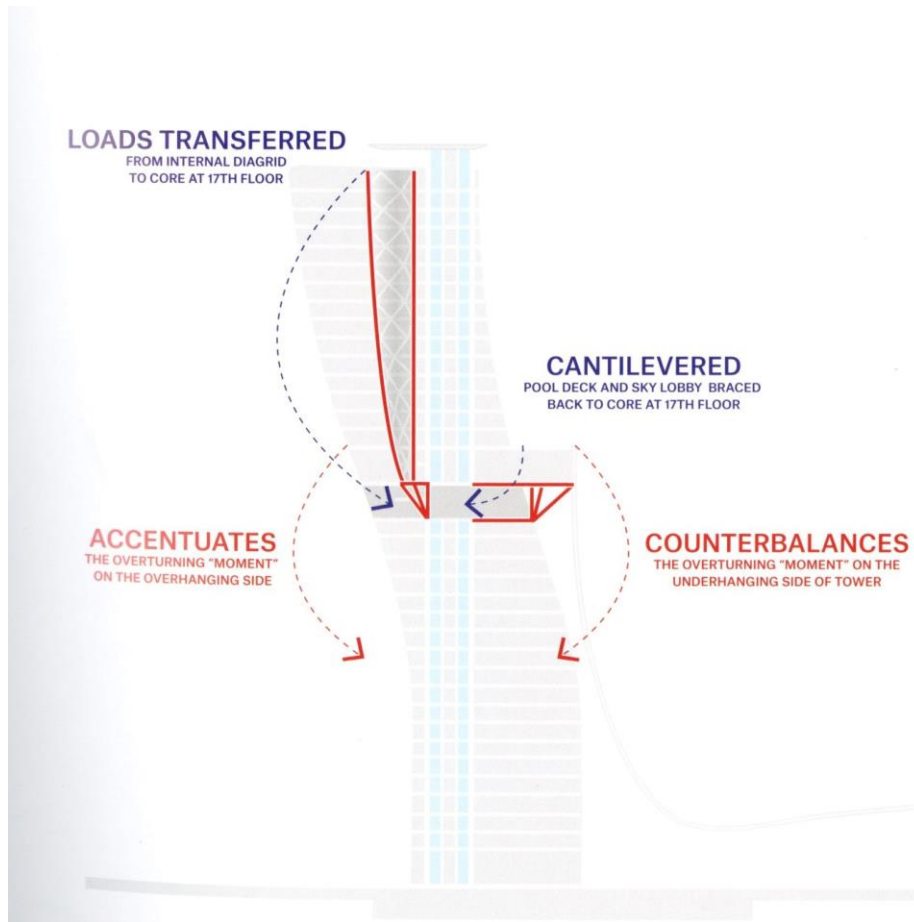
SECTIONAL ELEVATION

Roof level
 Level 34
 Level 33
 Level 32
 Level 31
 Level 30
 Level 29
 Level 28
 Level 27
 Level 26
 Level 25
 Level 24
 Level 23
 Level 22
 Level 21
 Level 20
 Level 19
 Level 18
 Level 17
 Level 16
 Level 15
 Level 14
 Level 13
 Level 12
 Level 11
 Level 10
 Level 09
 Level 08
 Level 07
 Level 06
 Level 05
 Level 04
 Level 03
 Level 02
 Level 01
 Mezzanine level
 Ground level



MAIN STRUCTURE:

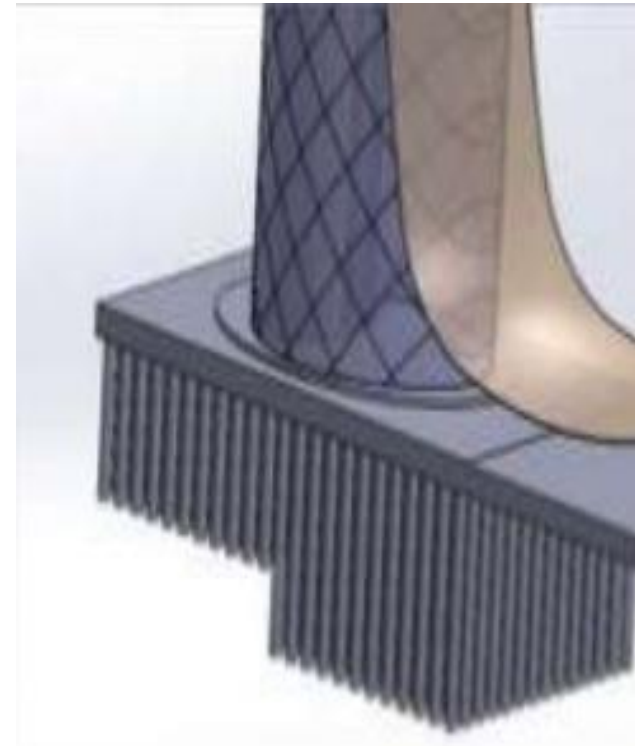
- The structure consists of a post tensioned concrete core surrounded by two steel truss systems (diagrid system).
- External and Internal diagrid system (lateral load resisting system).



- Steel beams support concrete floor & run throughout the diagrid system horizontally at the node intervals.
- Outrigger are horizontal trusses used to connect the building core to the exterior bracing system.

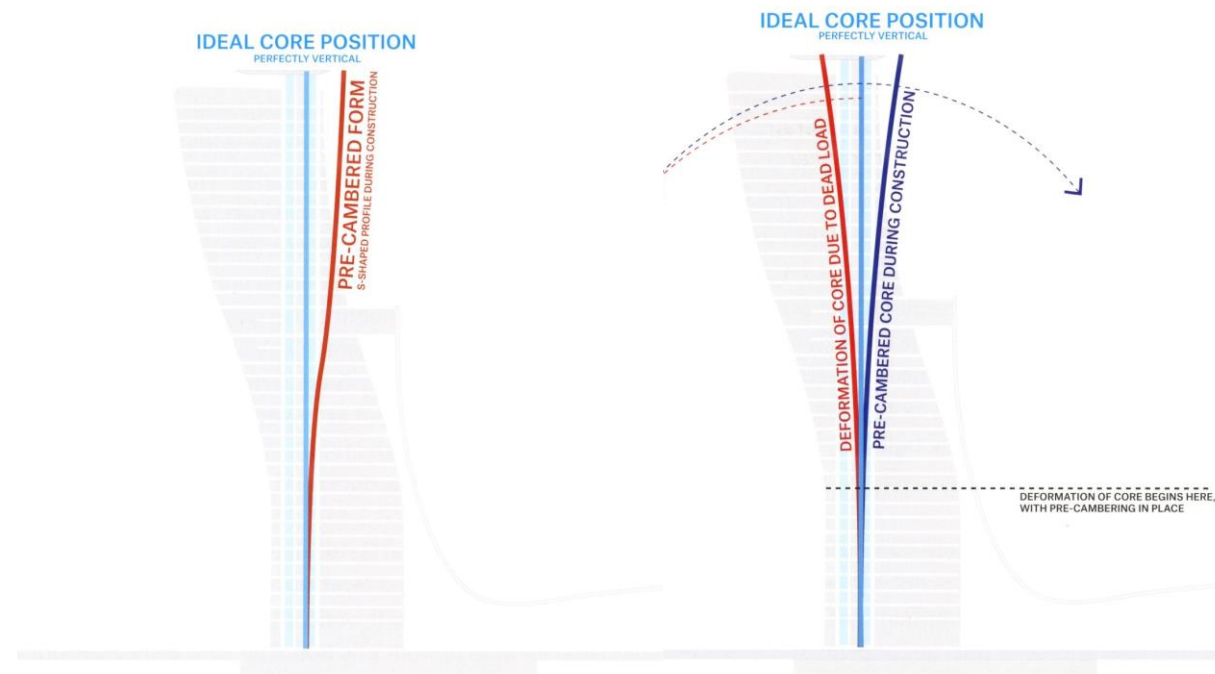
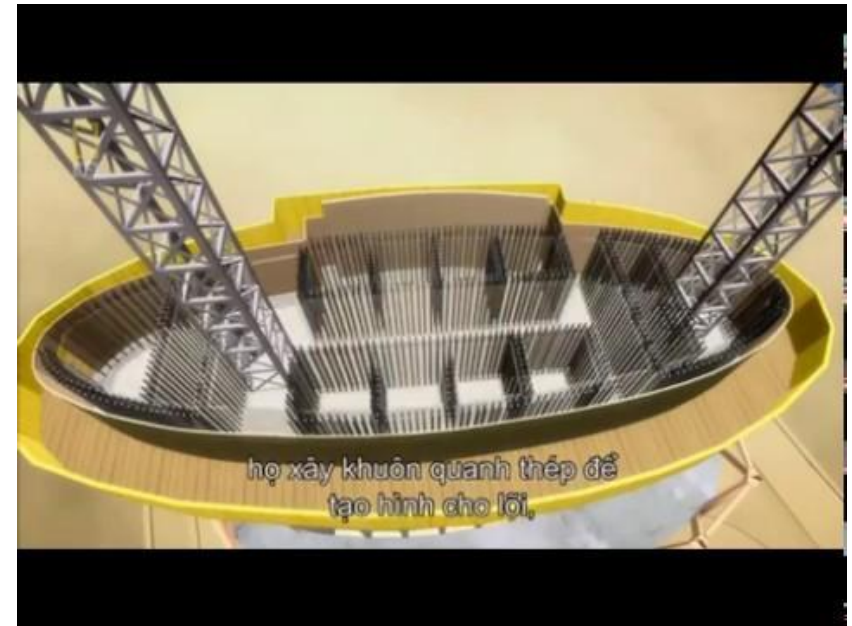
FOUNDATION:

- The foundation system used was a deep foundation.
- The foundation consists of a 2m deep 7000 cubic meter reinforced concrete rectangular raft footing supported on 490 concrete piles of 1 meter diameter.
- Half of the piles are under compression and run to a depth of about 20 meters.
- The other half of the piles run to a depth of about 30 meters to the bed rock and anchor tightly to the soil and are in tension due to the massive eccentric overhang of the building.



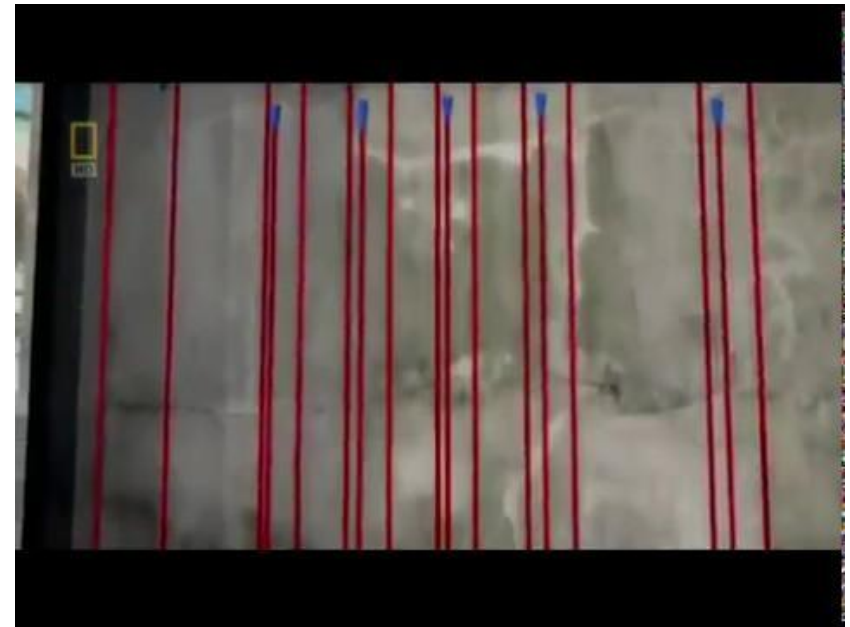
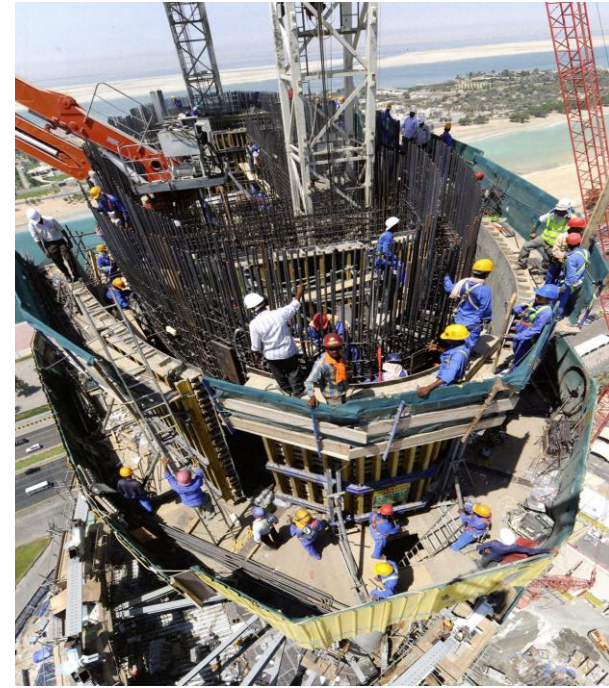
THE CORE:

- The core was pre cambered meaning it was initially tilted away from the overhang of the building and was straightened by the dead load of the building.
- The core was built using the technique called jump forming.
- The concreting was done at night to avoid the extreme day heat which may cause the concrete to dry and crack.



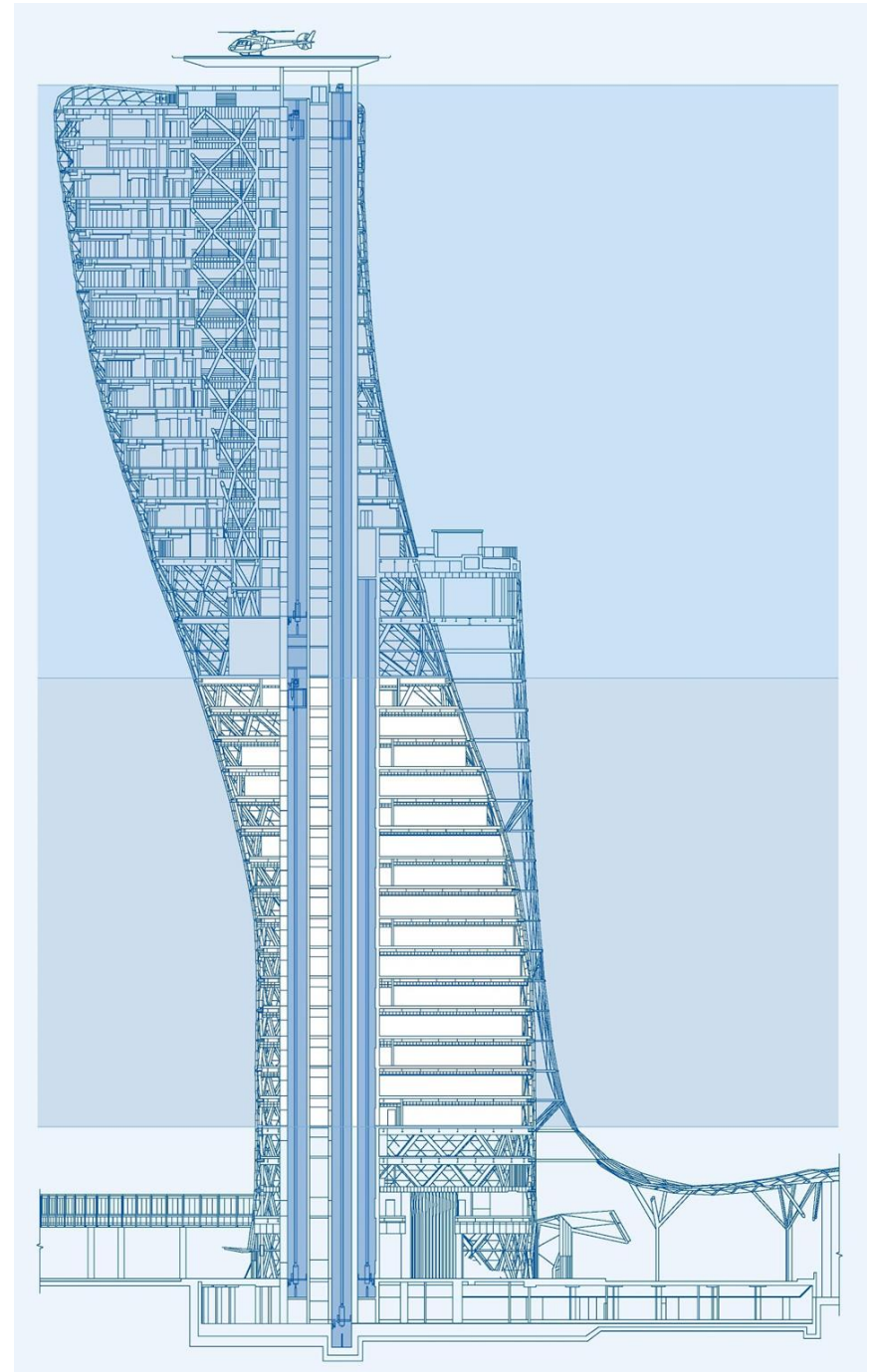
THE CORE:

- Slump tests were carried out on every batch of concrete.
- The core was post tensioned.
- A total of 146 tendons were incorporated into the core through ducts.
- Each 20 meters long tendons spans 5 floors and overlaps at each ends. .
- Pneumatic jack was used to stretch each tendon at a time.



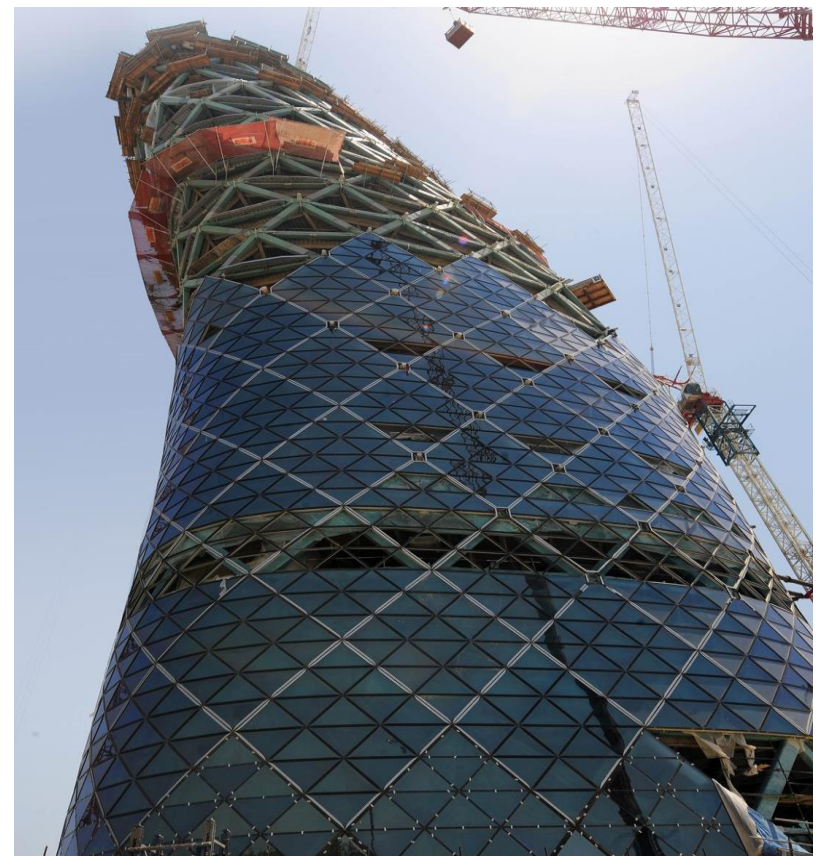
FLOOR SYSTEM:

- A composite floor system is used, spanning from the main core to internal and external diagrids.
- Floor beams are connected to the concrete core via embedment plates already casted in the core walls.
- From level 1 to level 10, the floor plates are stacked directly over one another, and then begins to stagger over each other at 800-1400mm and then back to 900mm in line with the lean of the building, between level 10 through 27.
- The remaining floors, between levels 27 and 34, shift between 900mm - 300mm.



THE FACADE:

- The facade consists of the steel diagonal framing system(diagrid), and diamond shaped glass modules.
- The Diagrid was made up of steel cross sections called cruciforms.
- The external diagrid consists of 720 of such cruciforms.
- Each cruciform has different curvature, length and thickness.
- The interlocking part of the cruciform is called the diagrid node, and an horizontal tie beam connect all nodes together horizontally through the circumference of the building, the give a strong bracing system.
- The external cruciforms were made up of 600×600 mm hollow sections, and the thickness of the sections ranged from 80 mm at the bottom to 40 mm at the top of the tower.



THE FACADE CONT'D:

- Each diamond shaped glass modules are made up of 18 triangular panels connected to each other by hinge joints forming a diamond shaped panel measuring 8×8 meters, spanning 2 floors vertically.
- There are 26,000 triangular glass panels called c240.
- The diamond modules were connected to each other by a two layer seal which made it waterproof and also allowed it to move by 20mm causing a change in shape.



INTERNAL DIAGRID:

- The internal diagrid cruciforms were made with 80 mm diameter hollow circular sections.
- the top 18 floors houses an atrium which reduces the eccentric weight of the building.
- The internal diagrid support the weight of the 18 floors and is shaped like a funnel.
- The internal diagrid is connected to the core by 8 pin jointed structural members on the 18th floor also known as mechanical floor.



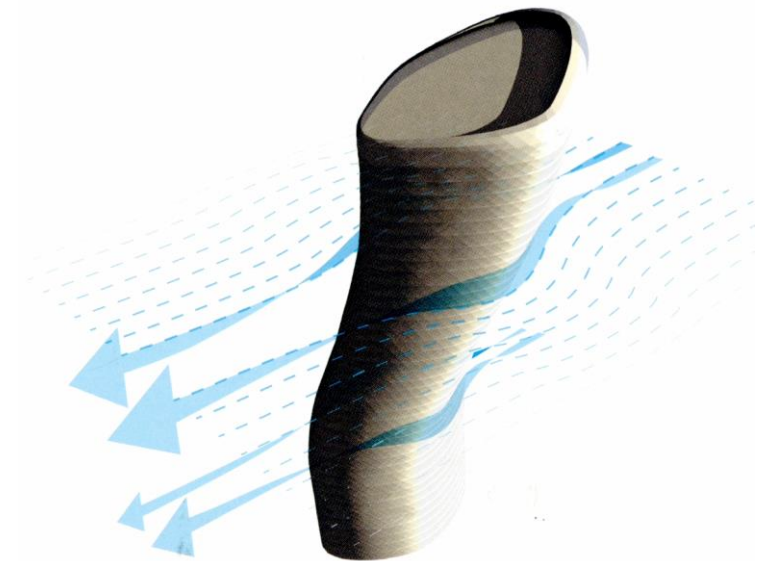
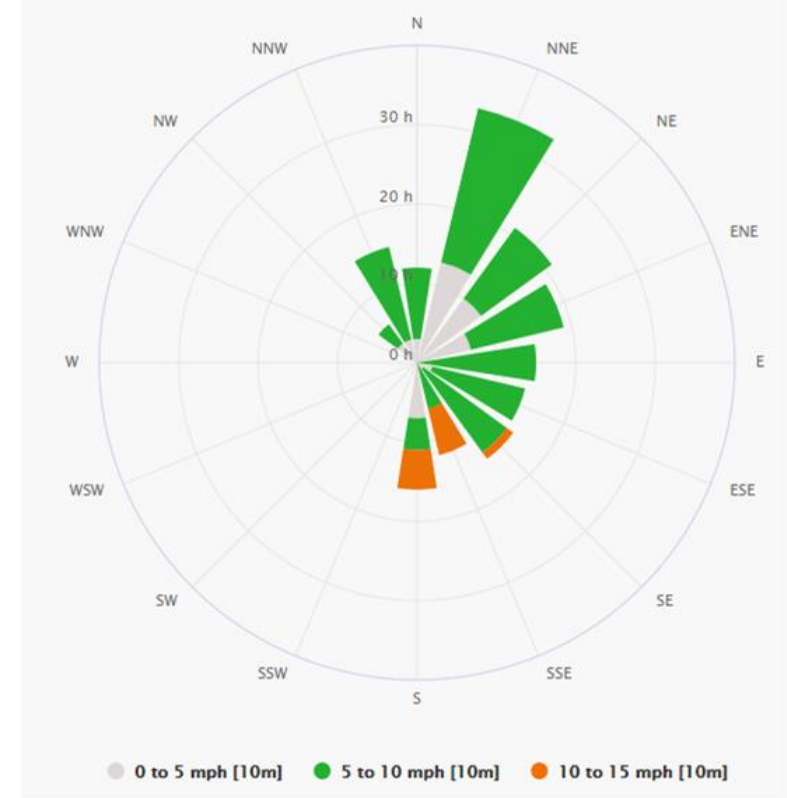
INTERNAL DIAGRID

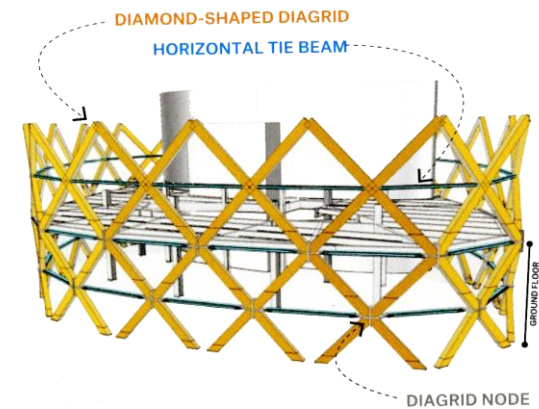
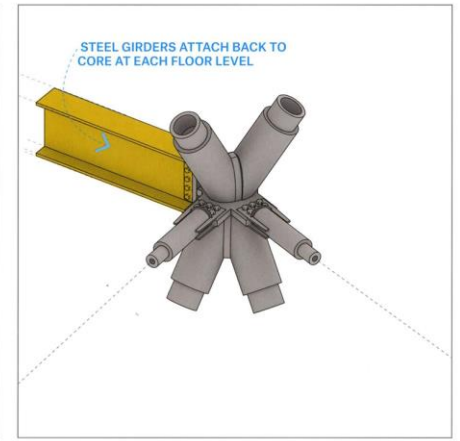
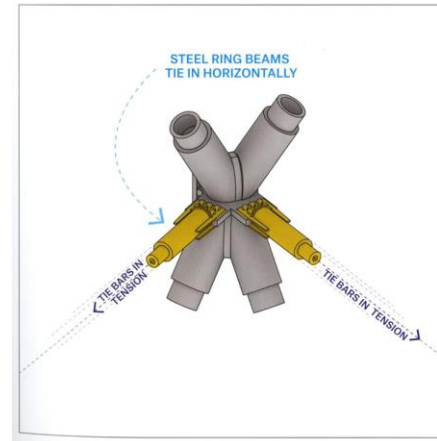
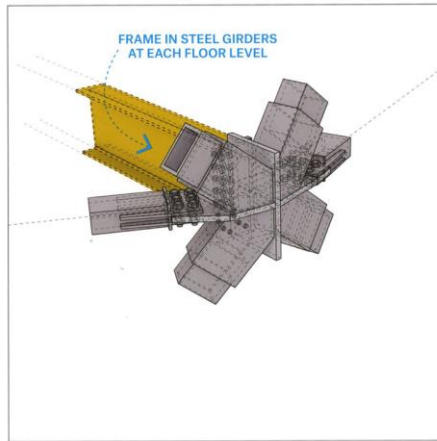
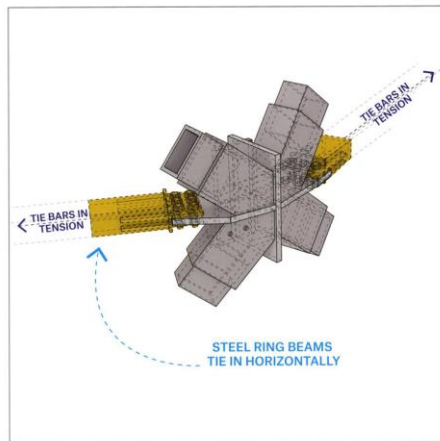
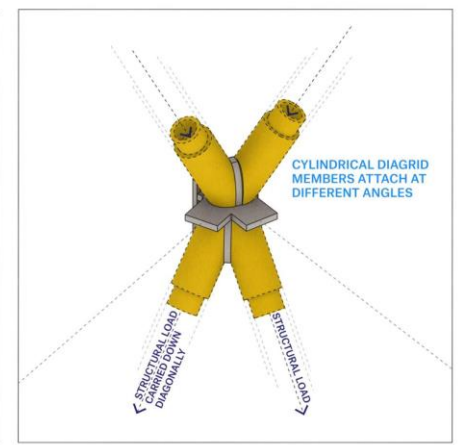
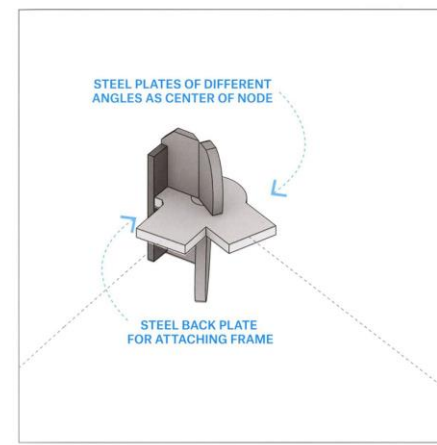
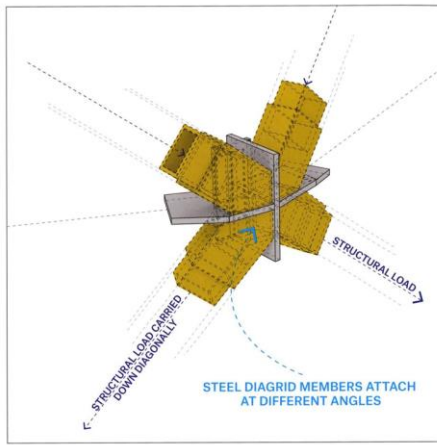
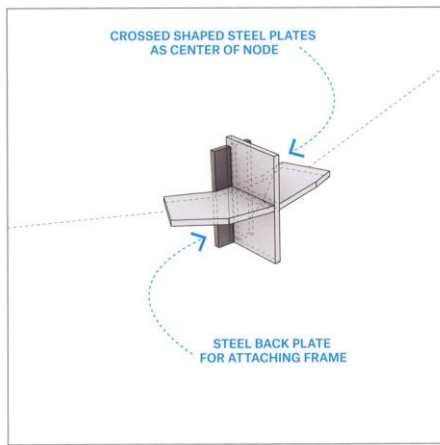


GLASS FAÇADE

LATERAL LOADING

- The primary direction the wind blows in this area is from the north east to the south east, at speeds ranging from 5 to 15 mph.
- The primary lateral load resisting system in this structure is the **diagrid system**.
- The members of the diagrid system, however, vary in thickness according to the variation in the structural stresses experienced in each portion.
- The diagram shows how the funnel shape of the tower responds aerodynamically to the predominant winds
- Typically, a node has seven points of connection, four of which are tied to the diagonals, two others to the horizontal tension beams, and one to a girder supporting the floor.
- The diamond forms are 8 metres in height.
- The diagonals are 600mm by 800mm in cross section

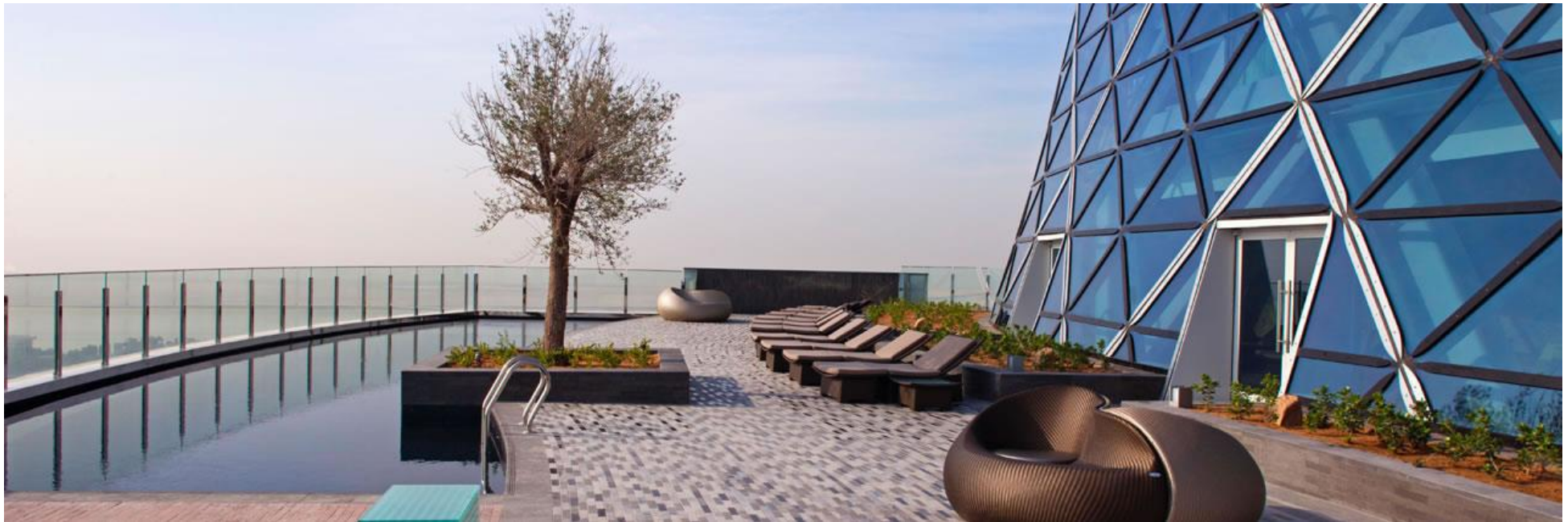
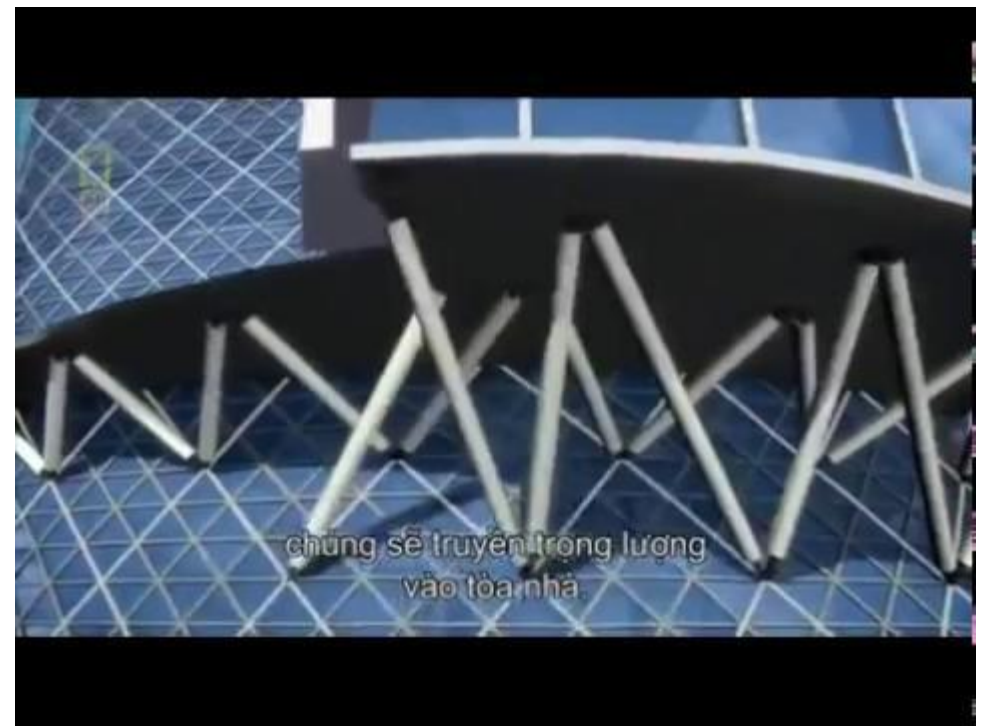




Each cruciform weighs up to 16 tonnes

During the construction of the Capital Gate building, the architects introduced a new design feature cantilevering from the structure.

- The design required a two storey extension **90 meters above the ground**, without visible supports, containing a pool and restaurant. The weight of the water in the pool was estimated to be around 150 tonnes.
- In order to support this load, the structure needed supports from below
- The solution selected was to use **22 underpinned steel struts**, which also met the aesthetic demands of the architects.



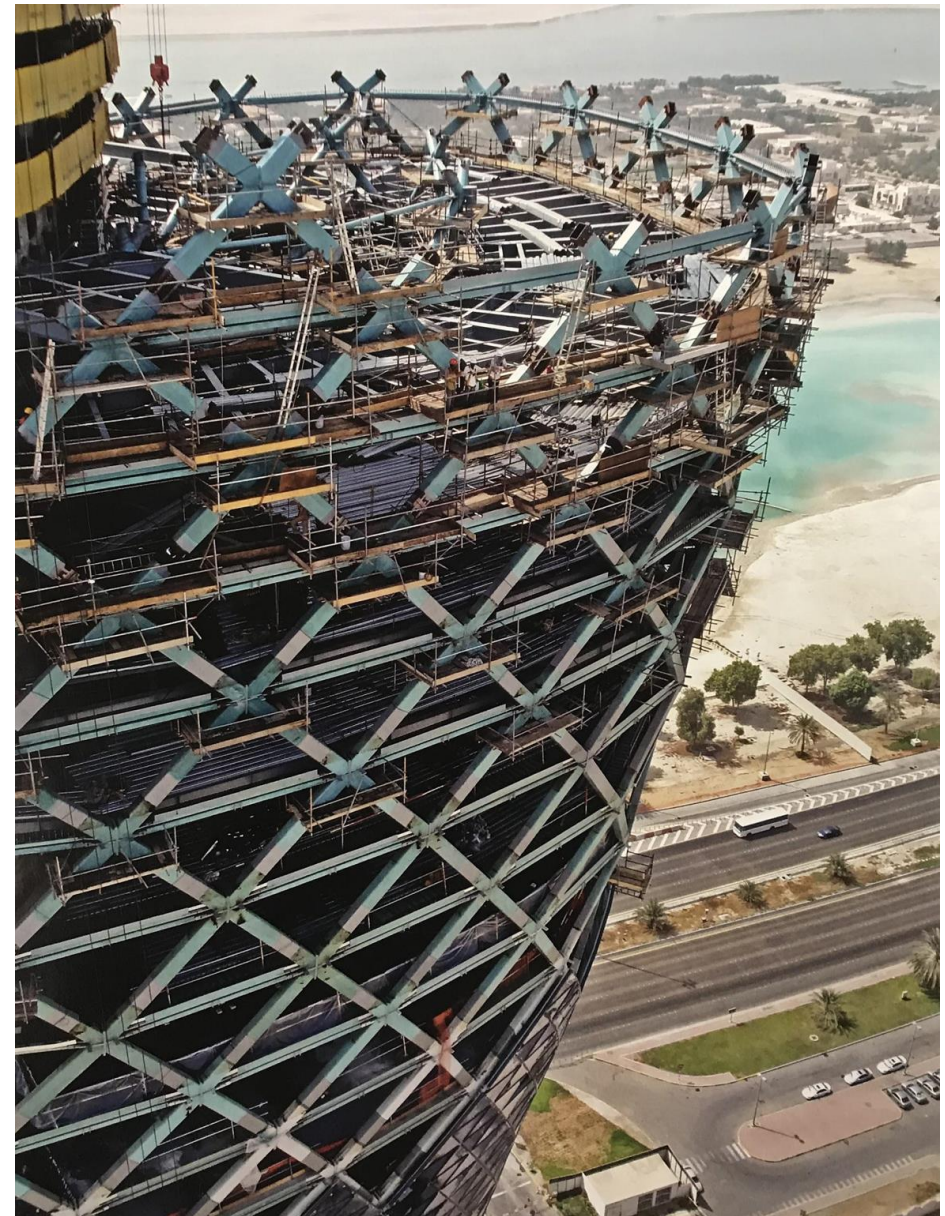
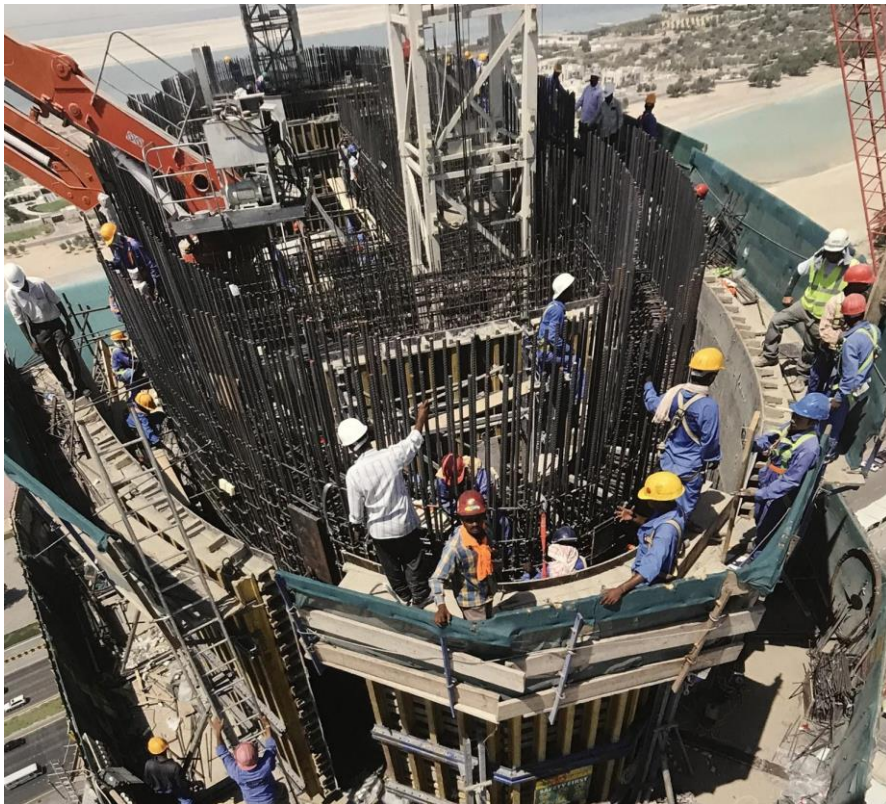
- A design requirement that was put forward 6 months before the construction was to introduce a helipad on the roof.
- This would also be **Abu Dhabi's highest helipad**
- The problem that arose here was the unpredictable wind flows that would be generated which could rip the helipad upward or create a suction that would pull the helicopter off-course.
- The solution was to lower the helideck, which would reduce the height of the helideck to 2 meters above the roof, which helped decrease the threat.

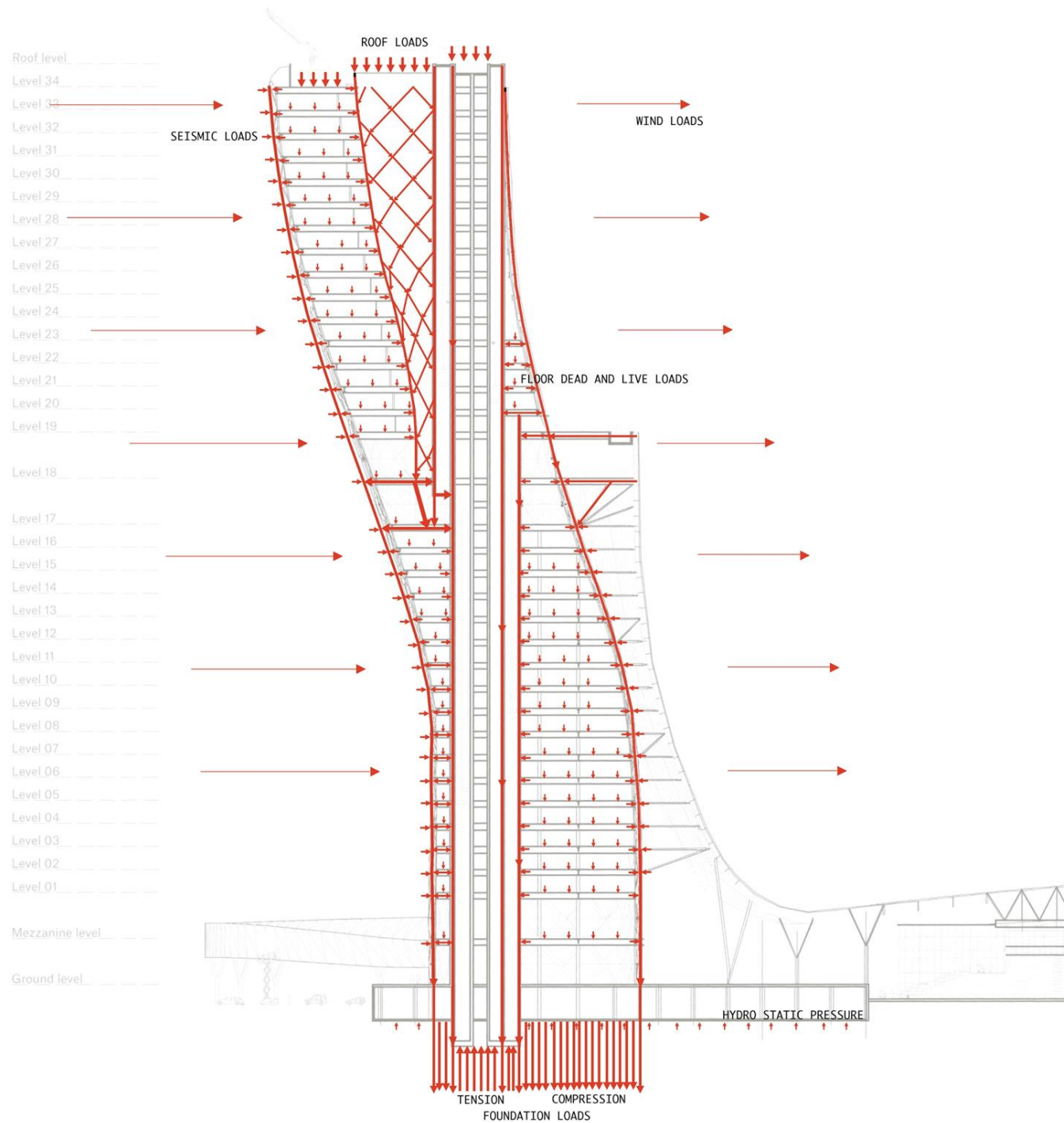


- The ‘splash’ is a sun-shading device which is also an aesthetic element
- It is made of a layer of woven metallic mesh stretched over a metal frame
- At the entrance, the splash is a canopy held up by tree shaped column structures.
- The splash unifies and accentuates the unique form of Capital Gate



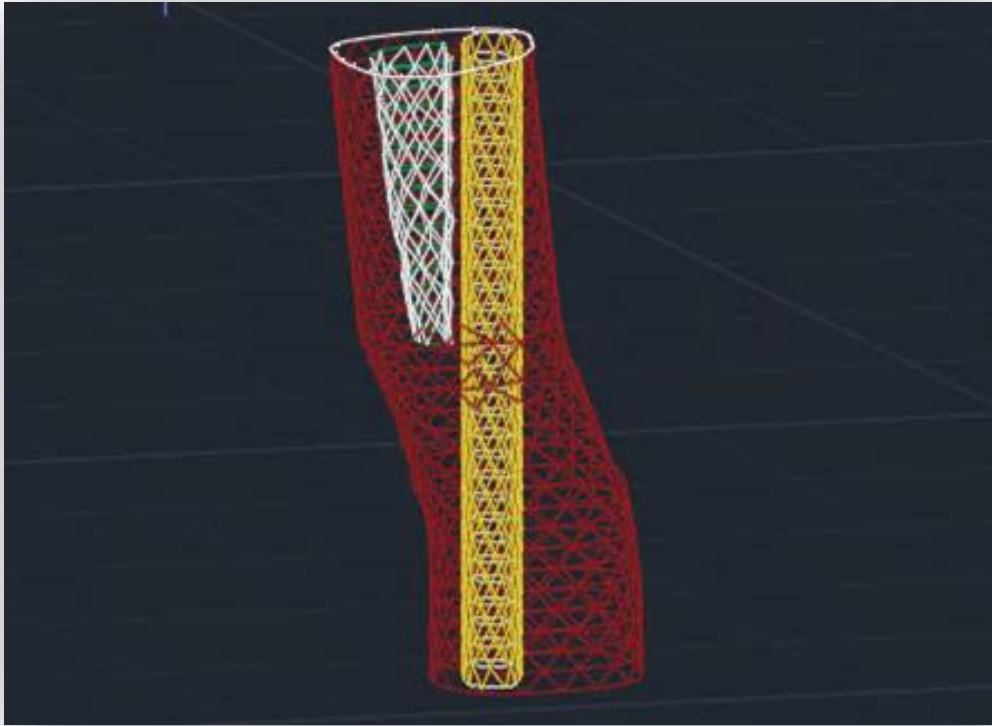
- Total concrete - 79,365,600 lb
- Total steel - 26,400,000 lb
- Total Glass - 46,296,900 lb
- Total pieces of exterior glass - 26,000 triangular glass panels



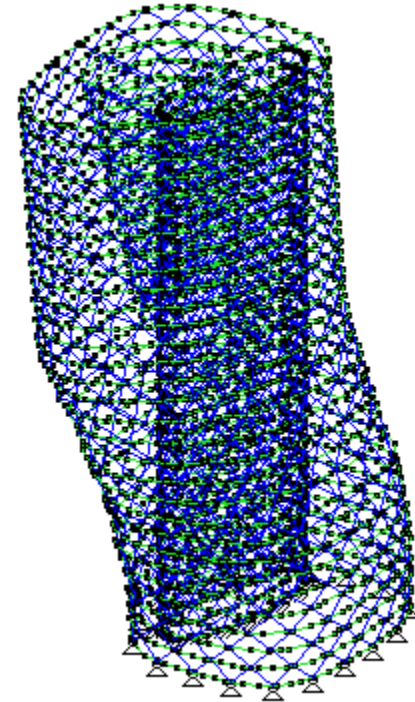


LOAD TRACING

- The exoskeleton of the building is connected to the central core by horizontal steel girders that run from the nodes of the diagrid modules to the core.
- These beams support composite metal decks and concrete floor slabs.
- Each story is 4 meters in height, corresponding to half of the diagrid diamond.
- In the 17th floor service area, eight hefty steel transfer spurs are attached to the core on which sits the base of an internal atrium diagrid.
- The weight of this diagrid is transferred to the core and hence down to the foundation.
- The internal diagrid provides extra internal support for the overhanging upper floors as well as lessening their weight by creating a funnel like opening in them.
- The atrium diagrid is connected to the diagrid exoskeleton by girders spanning the distance between nodes.
- Massive outrigger beams connected to the core support the 12m extension out over the facade.
- These outer cantilever beams are braced back to the nodes of the diagrid of the two floors below.

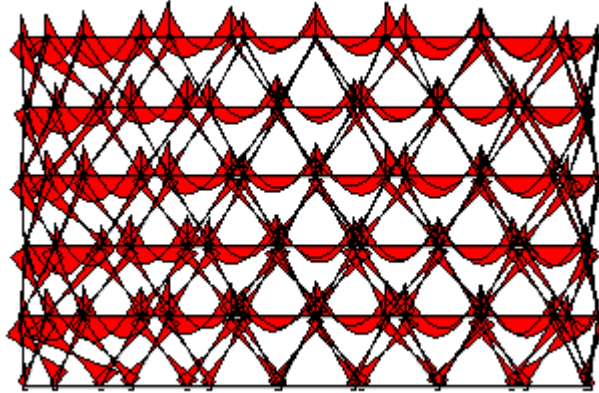


AUTOCAD WIREFRAME OF THE BUILDING
STRUCTURE

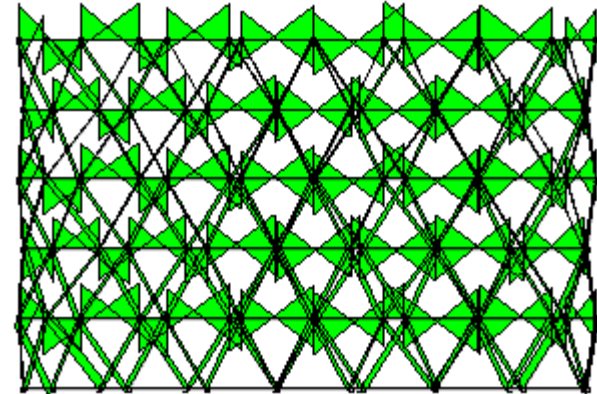


BUILDING STRUCTURE IN MULTIFRAME

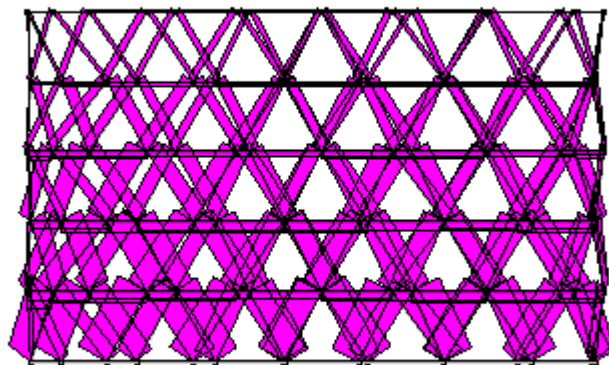
MULTIFRAME ANALYSIS OF A CHUNK OF THE BUILDING CORE



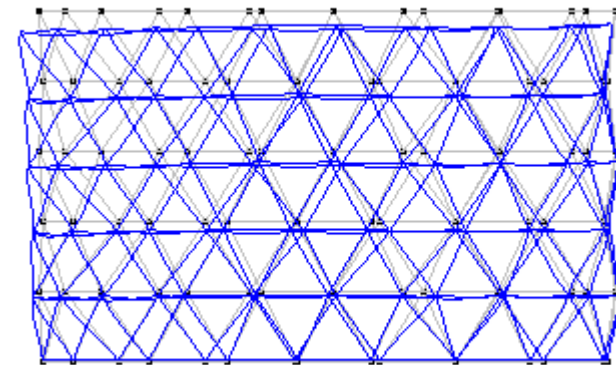
MOMENT DIAGRAM



SHEAR DIAGRAM



AXIAL FORCE DIAGRAM



DEFLECTION DIAGRAM

The Capital Gate building is a very unique structure which was built with one of the world's most advanced construction techniques. Some of the structural innovations used include:

- An interior atrium in the tilting mass.
- A cantilevered restaurant/pool deck opposite to the tilt
- Varying depth of foundation piles to provide proper anchorage.

This structure truly captures the spirit of Abu Dhabi and the original intent of showcasing Abu Dhabi



© Terri Meyer Boake via CTBUH



CONCLUSION

- "Capital Gate Tower, Abu Dhabi". 2017. *Ctbuh.Org*.
<http://www.ctbuh.org/TallBuildings/FeaturedTallBuildings/CapitalGateTowerAbuDhabi/tabid/3380/language/en-GB/Default.aspx/>.
- "Capital Gate Building: The Leaning Tower Of Abu Dhabi". 2017. *Amusing Planet*.
<http://www.amusingplanet.com/2013/03/capital-gate-building-leaning-tower-of.html>.
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