Learning Outcome Assessment III
Final Presentation

# Design of 170 Storey Tower
# Located in Jeddah, Kingdom of Saudi Arabia.


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# Outline

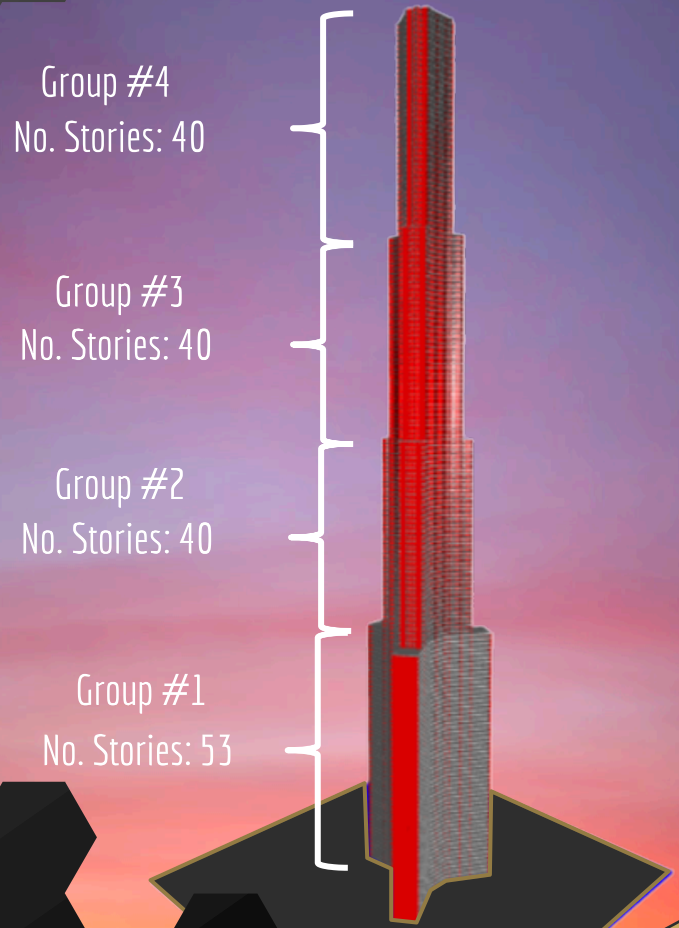

01 Objectives
02 Project Description
03 Structural Design
04 Geotechnical Design
05 Reinforcement Details
06 Cost Estimation
07 Conclusion

# Objectives

- Modeling and idealizing the structure in the ETABS 2016 software.
- Structural design of the super structure of the tower.
- Geotechnical design of the most appropriate and safe foundation system.
- Rough cost estimation of the tower structure.
- Obtaining the most important project constraints.

# Project Description

- Initial Floor Area = 3284 $m^2$
- Total Number of stories= 170
- Cumulative Area = 384,532 $m^2$
- Tower Division :
  - Group 1: (B3-50)  Parking, Mall and Residential
  - Group2 : (51-90) Commercial
  - Group3: (91- 130) Entertainment and Private Residential
  - Group4: (131-170) Entertainment and Residential



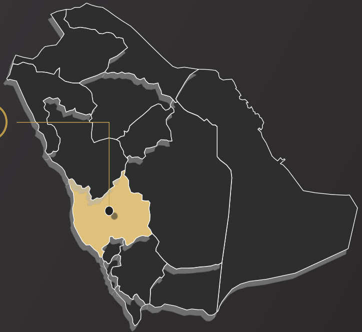

Source: ETABS

# Project Description

Tower Location


Jeddah Airport

Jeddah



Makkah Governorate

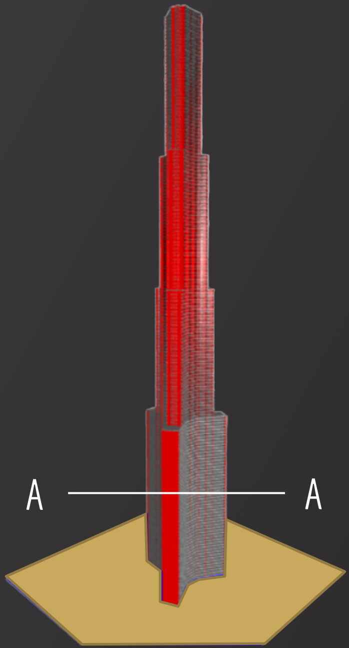
Saudi Arabia

# Project Description

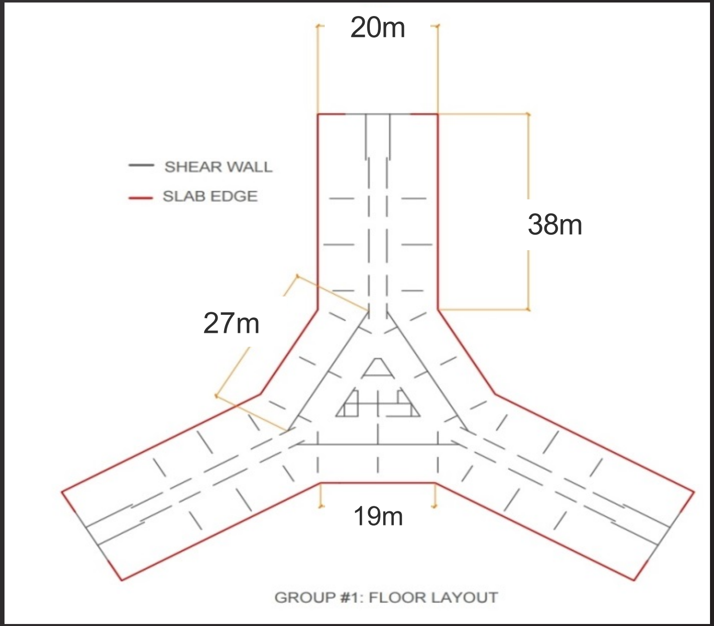
## Modified Layout.

Main structural components:

- Slab
- Shear-walls




A-A cross section




Area = 3284 $m^2$

# Project Description

## Project Alternative

The Project will be designed for:

- High Strength Concrete (HSC)
- Normal Strength Concrete (NSC)

The project alternatives will be Compared based on:

- Cost.
- Serviceability.
- Environmental impact.

# Project Constraints

## Structural design

- Code requirements.
- Minimizing structural elements size.
- Unique structural design.

## Geotechnical

- Dewatering.
- High rise building / soil profile.

## Environmental / Material

- Optimizing the material used.

## Project Cost

- Minimizing the cost in the safe limit.

# Project Constraints

Table #1: Constraints and Solution.

| Constraints | | Solution |
|---|---|---|
| Structural design | High rise building / Lateral load | By selecting the Y-shape / Maintaining the moment of inertia. |
| Environmental / Material | Optimizing the material used . | Using HSC to minimize The elements cross section. |
| Geotechnical | High level of water table (near to ground surface). | Dewatering. |
| Project Cost | Previous constraints affect the cost of the project. | Depends on the constraints. |

# Structural Design

## STRUCTURAL LOAD

- Load Distribution.
- Dead and Live Load.
- Wind Load.
- Seismic Load.
- Load Combinations.

## STRUCTURAL ELEMENTS

- Slab Design.
- Shear-wall Design.

## ETABS MODELING.

- Verification of Result.
- 3D View.
- Slab Deflections.
- Structural Drifts.
- Verify the ETABS Results.

# Structural Design

## Project Design method.

- Strength Design Method (SDM)

  This method based on:

  1. Increase the load applied by factor.

  2. Decrease the material strength by reduction factor.

- Working Stress Design Method (WSD)

  This method based on:

  1. Carrying load .

  2. Material strength.

**The method used is strength design method (SDM) to ensure the design safety.**

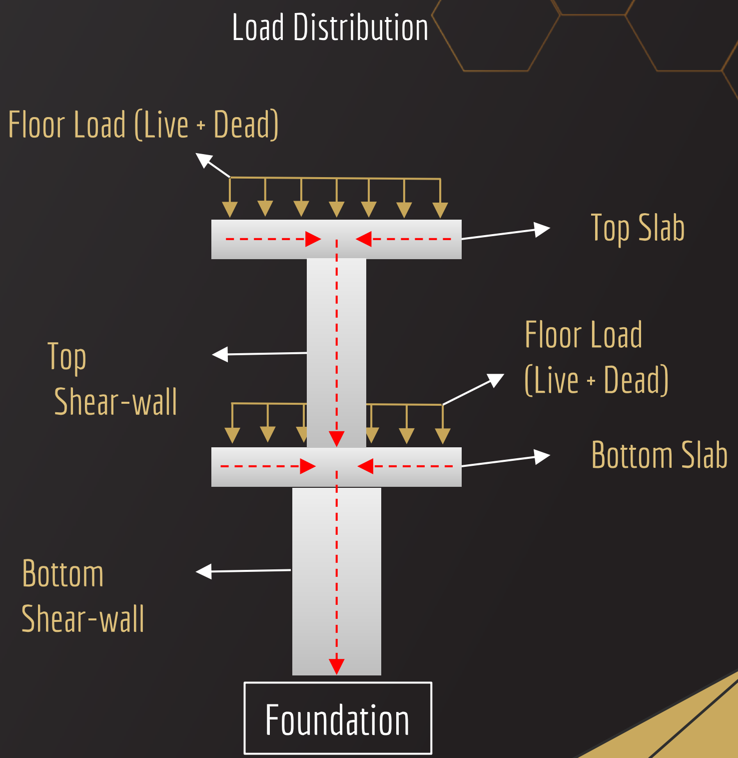
# Structural Design (Loads)

## Load Distribution.

1. Calculating the top floor load (including the self-weight of the slab) and it will be acting as point load on the top shear wall.

2. Calculating the bottom floor load (including the self-weight of the slab).

3. Finding the sum of bottom floor service load + the load carried by the top shear wall (the summation will be the point load acting on the bottom shear wall).



# Structural Design (Loads)

## Dead Load.

- The Dead load acting on the structure:
  - Slab self weight. → ( thickness * density)
  - Finishing Load.

Density of reinforced concrete =

23.5 kN/m3

Table # 2 : Dead load Break-Down

| Dead Load | |
|---|---|
| **Load** | **Value (kN/m²)** |
| Plaster on Tile | 0.2 |
| Tile | 0.6 |
| Mechanical Duct | 0.25 |
| Slab self weight | Thickness * 23.5 |

# Structural Design (Loads)

- Loads Break-Down.

Table # 3 : Dead and Live Loads Taken From SBC

| Location | Dead Load $^{kN}/_{m^2}$ | Dead Load $^{lb}/_{ft^2}$ | Live Load $^{kN}/_{m^2}$ | Live Load $^{lb}/_{ft^2}$ |
|---|---|---|---|---|
| Parking | 1.05 | 22 | 2 | 42 |
| Mall | 1.05 | 22 | 5 | 104.5 |
| Hotel | 1.05 | 22 | 5 | 104.5 |
| Mosque | 1.05 | 22 | 5 | 104.5 |
| Gymnasium | 1.05 | 22 | 5 | 104.5 |
| Offices | 1.05 | 22 | 2.5 | 52 |
| Restaurant | 1.05 | 22 | 5 | 104.5 |
| Mechanical Room | 1.05 | 22 | 10 | 209 |
| Museum | 1.05 | 22 | 5 | 104.5 |
| Apartments | 1.05 | 22 | 2 | 42 |
| Observation deck | 1.05 | 22 | 5 | 104.5 |

# Structural Design (Loads)

- Wind Load.

  - Wind Speed of Jeddah = 150 km/h

$$F = q_z G C_f A_f$$

$$q_z = 0.0473 \times 10^{-3}\, k_z k_{zt} k_d V^2$$

# Structural Design (Loads)

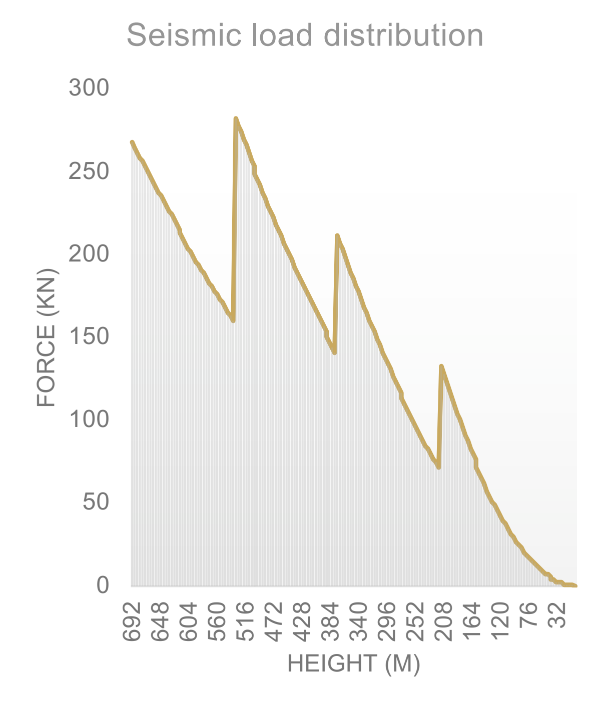
- Seismic Load.

  - Since the soil properties is not known in our site we shell use site class D according to ASCE7-10 section (11.4.2)

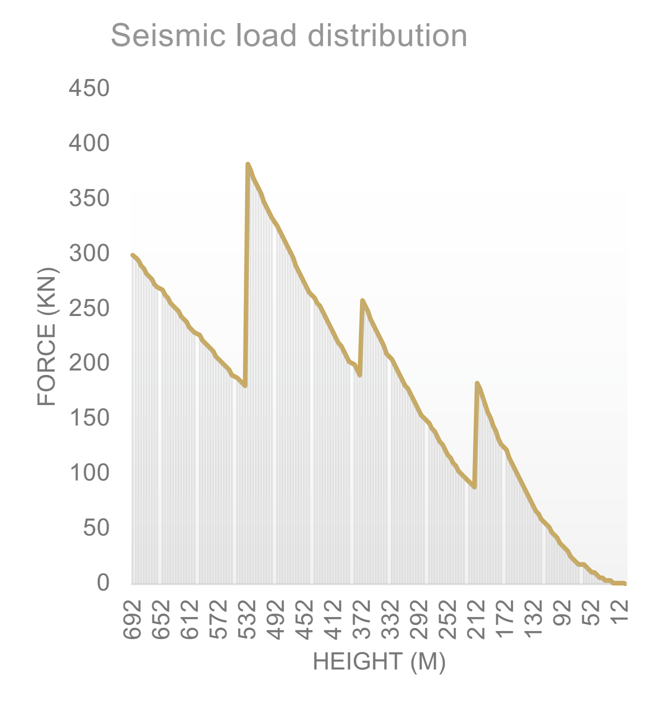
$$V = C_s W$$

$$F_x = C_{vx} V$$

# Structural Design (Loads)




← Seismic Load Distribution →




HSC : High Strength Concrete

NSC : Normal Strength Concrete

# Structural Design (Load)

## Load combination.

- The Load combination has been taken from the (ASCE7-10).
- Dead and Live Load Combination: $P_u = 1.2\ D_L + 1.6\ L_L$
- Wind Load Combination: $Wind\ load = 1\ D_L + 1\ W_L$
- Sesimic Load Combination $Seismic\ load = 0.9\ D_L + 1\ E_L$

$D_L$ = Dead Load, $L_L$ = Live Load, $W_L$ = *Wind Load*, $E_L$ = *Earthquake Load*

# Structural Design (Elements)

## Slab Design.

- Classification of slab :

$$\text{Ratio} = \frac{\text{Long Span}}{\text{Short Span}} = \frac{16.5}{9} = 1.8 < 2$$

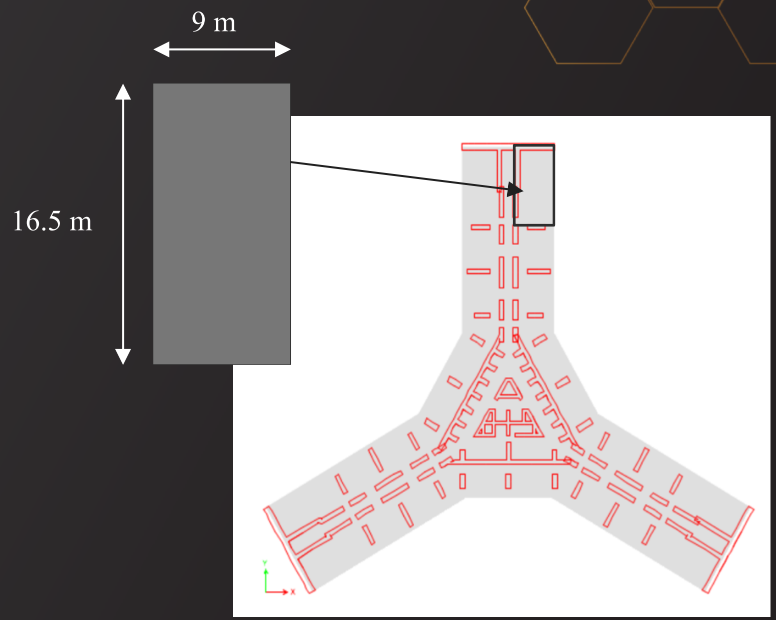
- Types of slab's ratio:

One-way: $\text{Ratio} \geq 2$
Two-way: $\text{Ratio} < 2$

→ we have Two-way Slab

- Determining the minimum slab thickness:

$$\text{Slab thickness} = \frac{\text{parameter}}{180}$$




Effective Area of the Slab Souce: ETABS

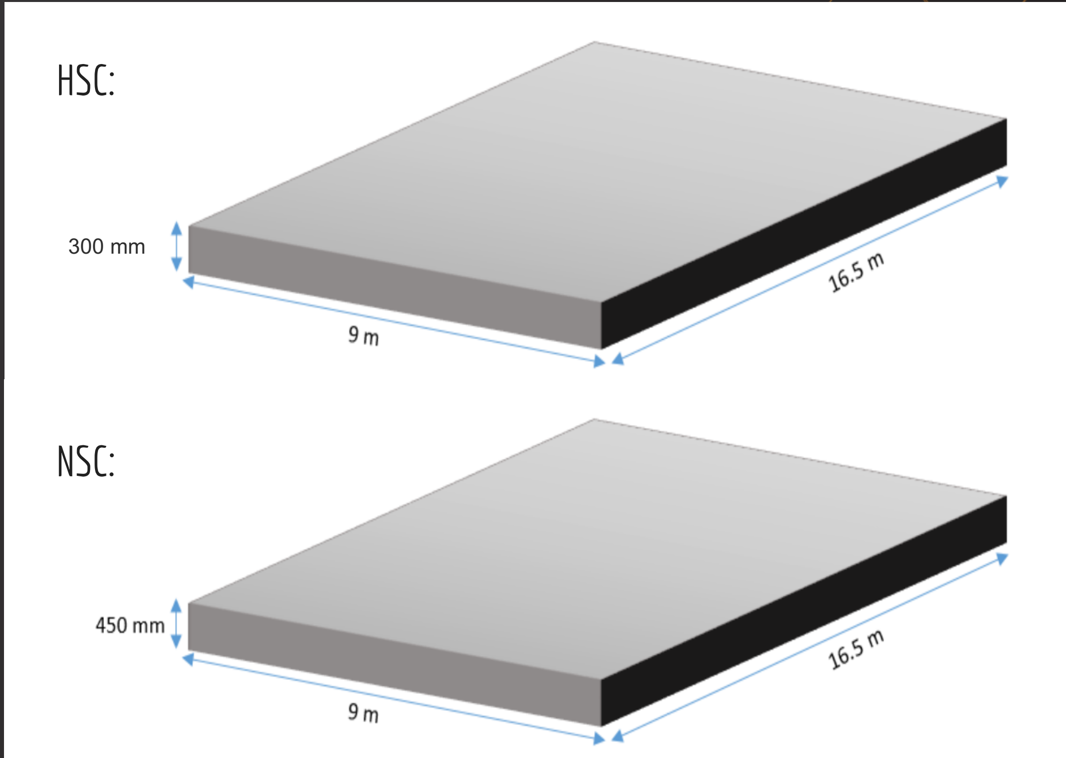
# Structural Design (Elements)

- Slab Design.

Table # 4 : Slab Thickness.

| Material Type | Slab thickness (mm) |
|---|---|
| HSC | 300 |
| NSC | 450 |

Slab cross section.

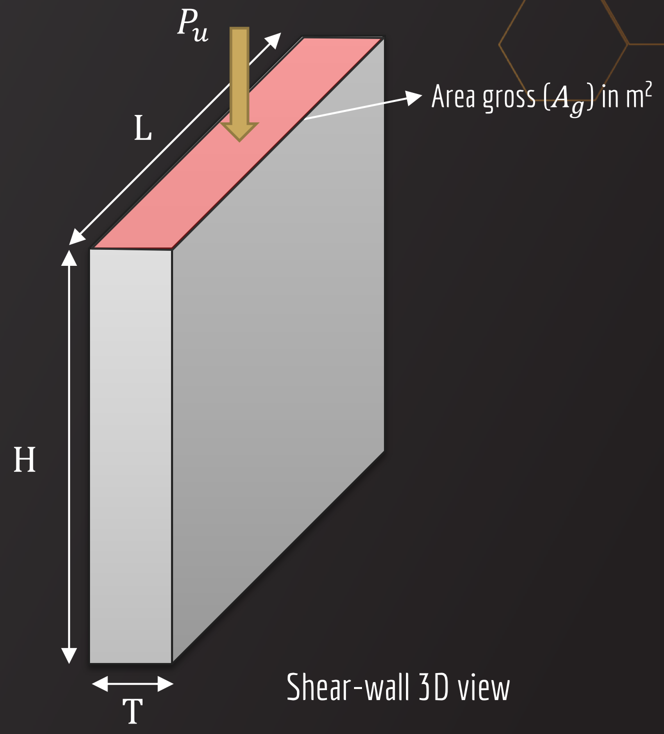


# Structural Design (Elements)

- Shear-Wall Design.

  - Shear-Wall Design Equation:

$$\phi P_u = \phi\alpha[0.85\, f_c'(A_g \times A_{st}) + f_y \times A_{st}]$$




Shear-wall 3D view

# Structural Design (Elements)

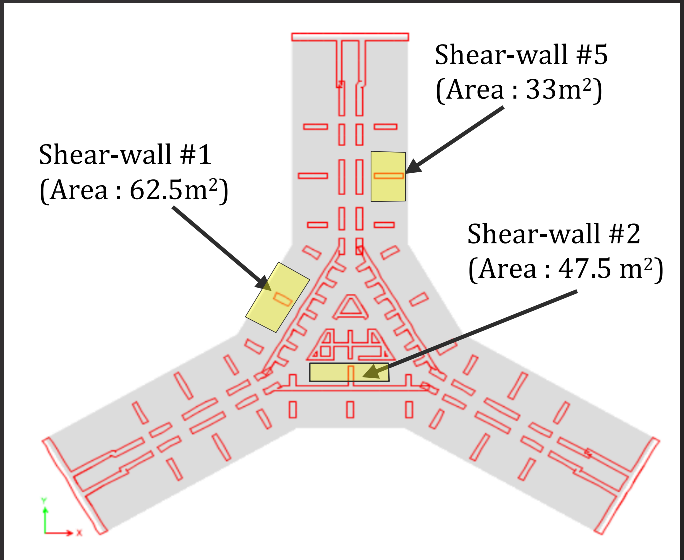
- Shear-Wall Design.

- Location of Critical shear walls.

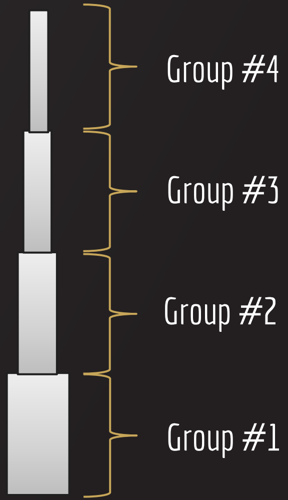
- Critical Shear-walls identified based on:

  1. Has largest effecive area.
  2. Carried the largest load.

Critical Shear-Wall Location




Elevation Cross section



# Structural Design (Elements)

- Shear-Wall Design.

Table# 5 : Shear-Wall Thickness (m)

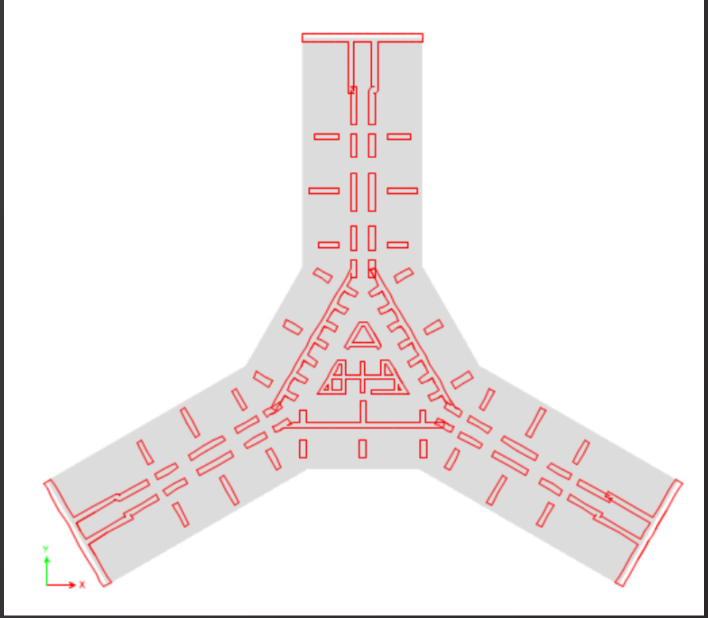
| Shear wall | Shear-Wall length | Tributary area ($m^2$) | Thickness of Group 1 | | Thickness of Group 2 | | Thickness of Group 3 | | Thickness of Group 4 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | HSC | NSC | HSC | NSC | HSC | NSC | HSC | NSC |
| SW#1 | 3m | 62.5 | 1.2m | 1.8m | 0.7m | 1.6m | 0.3m | 1.2m | 0.2m | 1m |
| SW#2 | 4m | 47.5 | 0.9m | 1.5m | 0.5m | 1m | 0.5m | 1m | 0.2m | 0.6m |
| SW#5 | 5m | 33 | 0.9m | 1.5m | 0.5m | 1m | 0.5m | 1m | - | - |

HSC: High Strength Concrete (10,000 psi)
NSC: Normal Strength Concrete (5,000 psi)

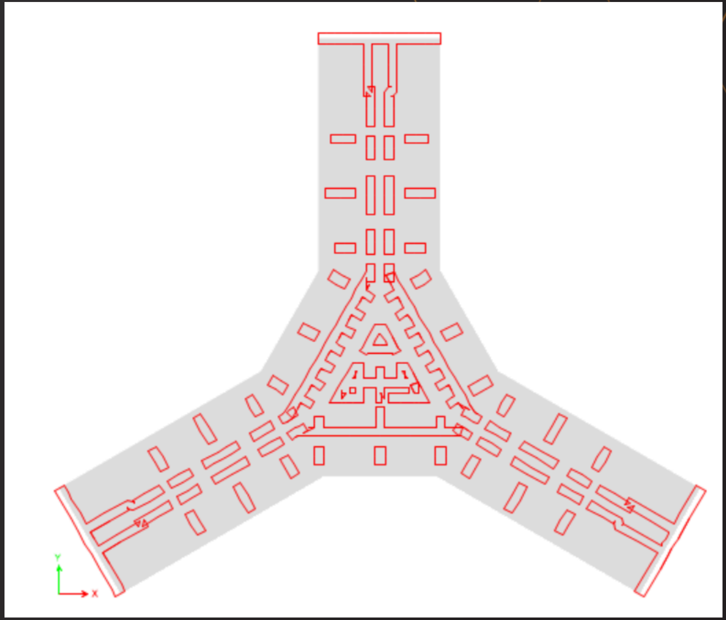
# Structural Design (ETABS)

- Layouts.

- The difference between the HSC and NSC Shear-wall thickness.



HSC



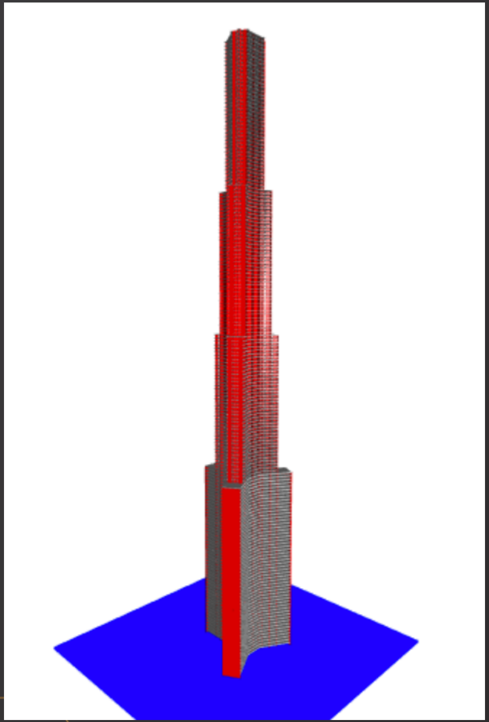
NSC

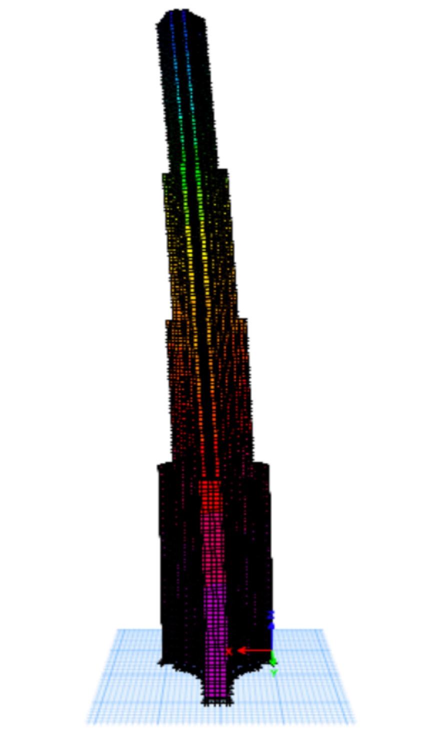
Source: ETABS

# Structural Design (ETABS)

- Project View.

3D View





Wind affect

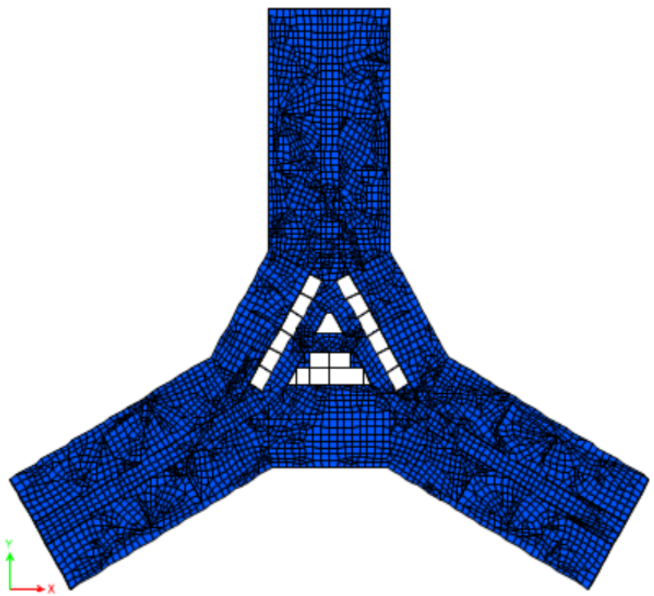
Source: ETABS

# Structural Design (ETABS)

- Deflection.

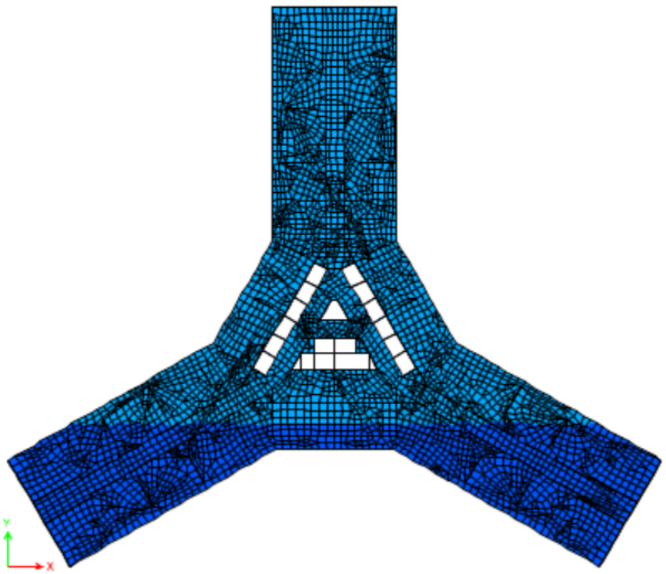
Allowable defflection = 25mm

$\delta_{Max} = 16mm$




HSC

$\delta_{Max} = 20mm$



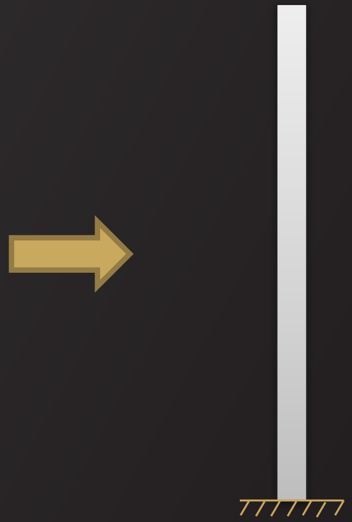

NSC

Source: ETABS

# Structural Design (ETABS)

- **Verification of ETABS for the wind and earthquake Results.**
  - The Tower will be simplified as cantilever column by maintinig the moment of inertia.
  - Earthquake and wind load will be calculated manually.
  - The load will be distributed along the cantilever column as point load.
  - The semi-hand calculation will be compared to the software result.

Actual Tower



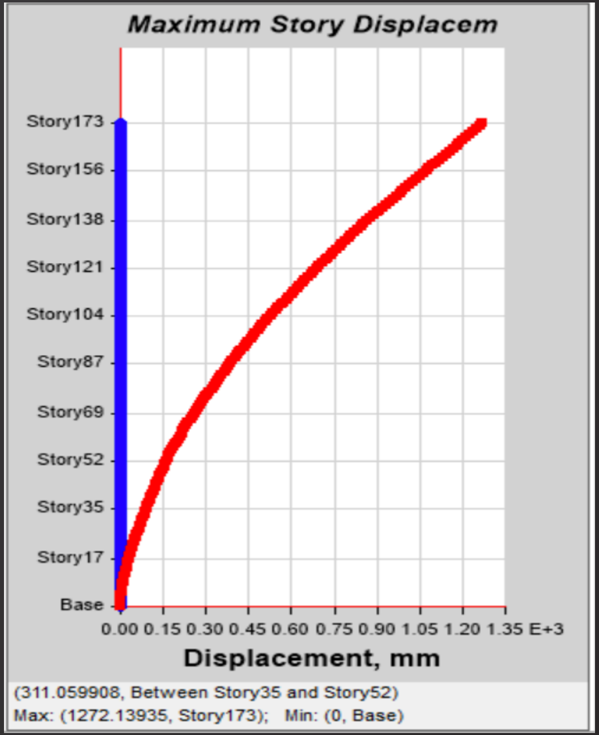
Simplified Tower

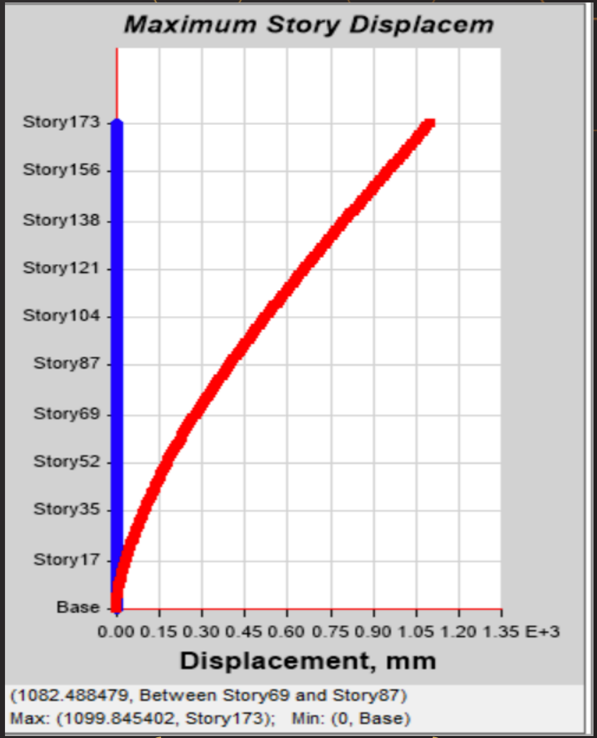
# Structural Design (ETABS)

- Wind Drifts (Actual Tower).

$$\left(\delta_{all} = \frac{H}{500}\right)$$

$$\delta_{all} = \frac{680}{500} = 1.36m$$



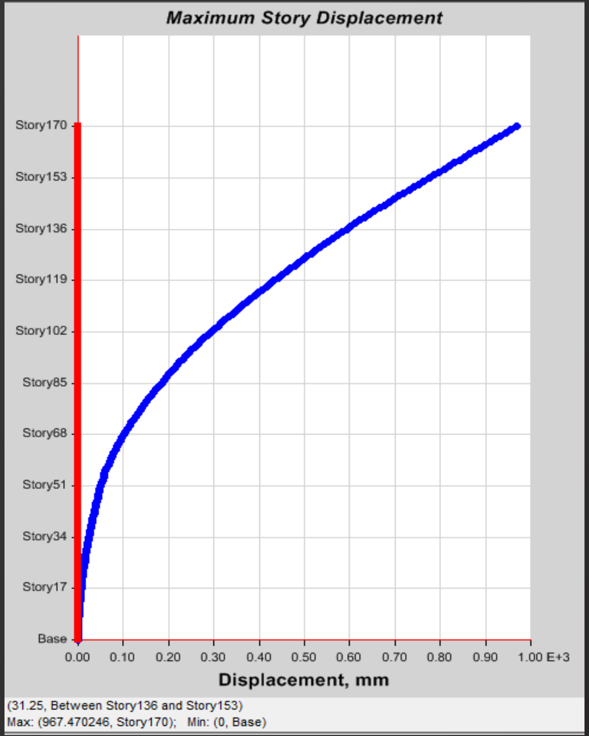



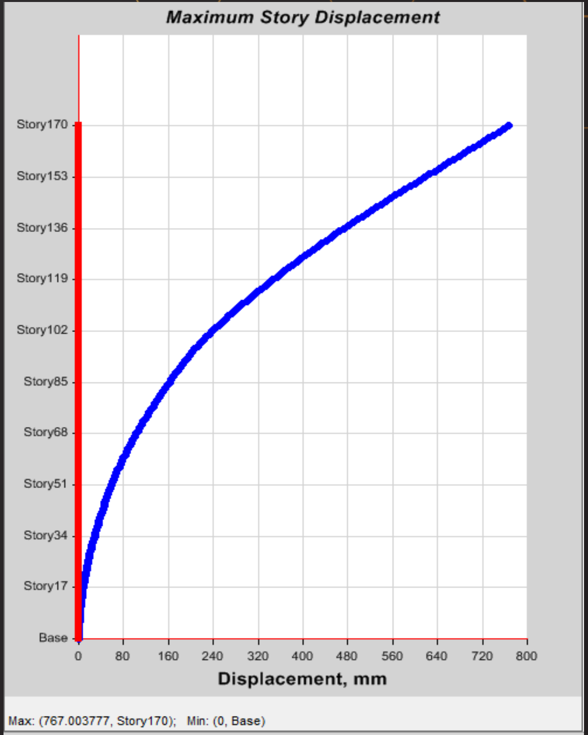

(HSC = 1.27m) Source: ETABS (NSC = 1.1m)

# Structural Design (ETABS)

- **Wind Drifts (Simplified Tower).**

- The semi hand Calculation for the Wind drift. Which is very close to the ETABS result, So ETABS results is Verified.




HSC = 0.967m

Source: ETABS

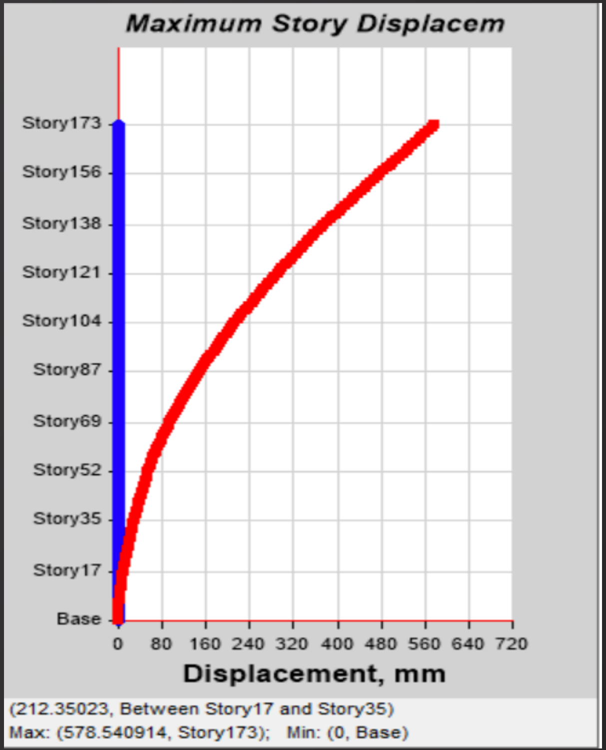
NSC = 0.767m

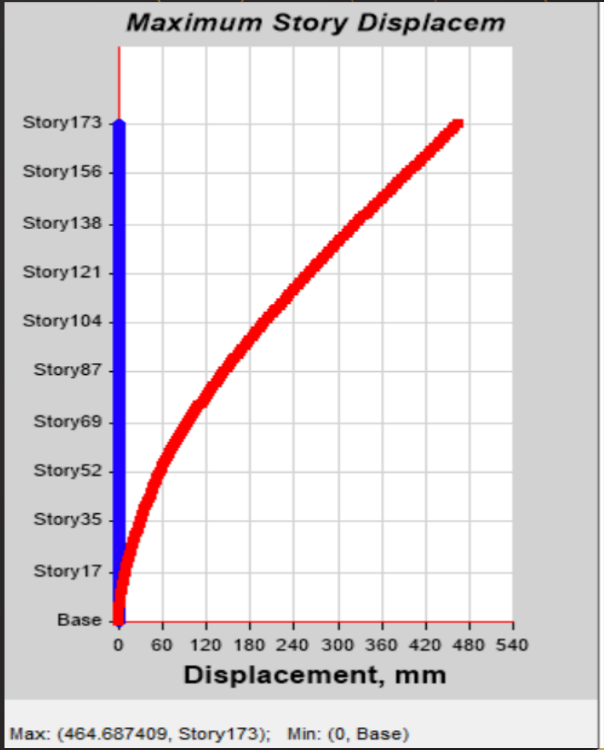
# Structural Design (ETABS)

- Seismic Drifts (Actual Tower).

$$\delta_{all} = \frac{H}{500}$$

$$\delta_{all} = \frac{680}{500} = 1.36m$$




HSC = 0.57m

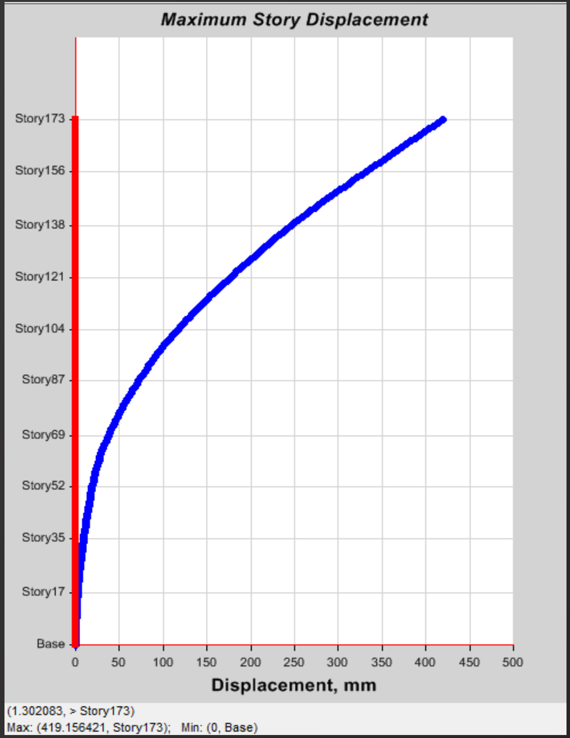
Source: ETABS

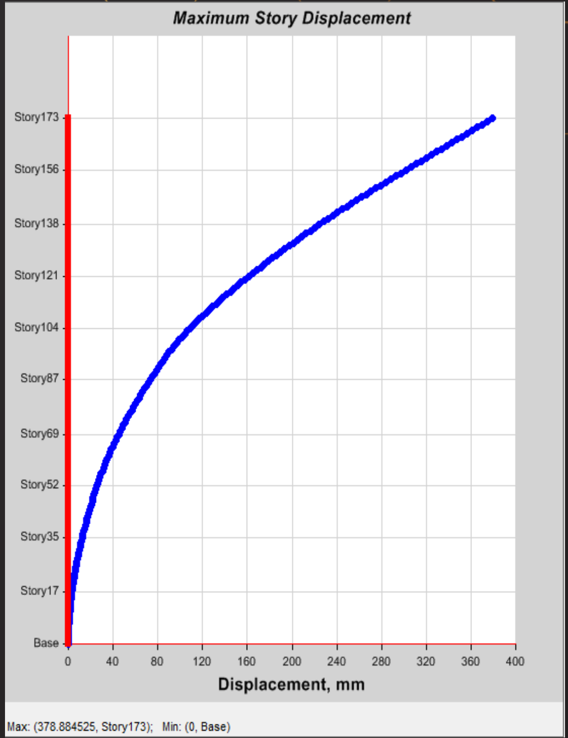
NSC = 0.46m

# Structural Design (ETABS)

- Seismic Drifts (Simplified Tower).

  - The semi hand Calculation for the seismic drift. Which is very close to the ETABS result, So ETABS results is Verified.




HSC = 0.42m Source: ETABS NSC = 0.38m

# Geotechnical Design

## Soil Profile

- Detailed Soil Profile.
- Summary of the Soil Profile.

## Piled Raft Foundation

- Raft Foundation Design.
- Group of Piles Design.

# Geotechnical Design

- Detailed soil profile.

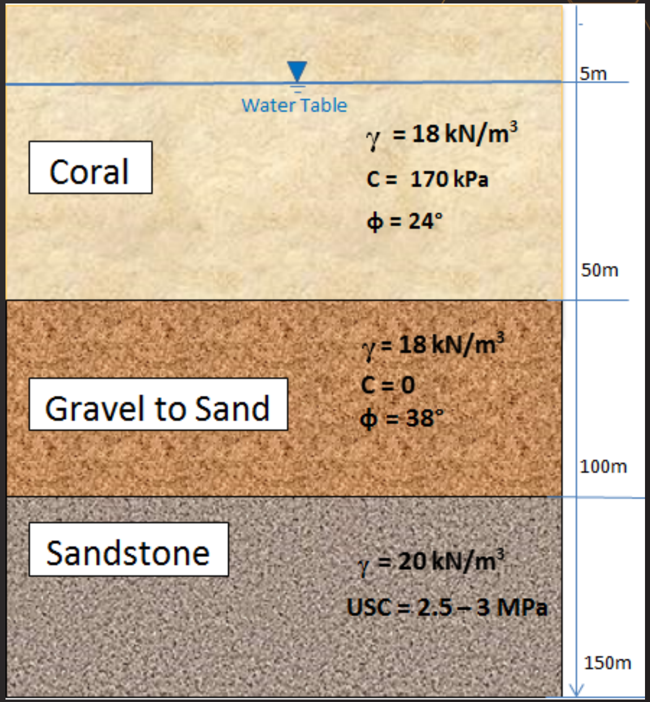
Table # 6: Design values. (Source: Langan Engineering & Environmental Services)

| Material | Elevation, MSL (m) | Modulus of Deform (MPa) | Friction angle | Cohesion (kPa) | Poisson's ratio | USC (MPa) |
|---|---|---|---|---|---|---|
| Coralline Limestone and siltstone inclusions | 5 to -40 | 500 | 24 | 170 | 0.35 | 1.5 to 2.5 |
| Coralline Limestone, siltstone inclusions and Gravel/conglomerate | -40 to -60 | 500 to 150 | 24 | 170 | 0.35 | 3 |
| Gravel/conglomerate and decomposed sandstone | -60 to -90 | 150 | 38 | 300 | 0.35 | 1.5 |
| Decomposed Sandstone and Gravel/conglomerate | -90 to -110 | 150 to 500 | 24 | -- | 0.35 | 3.2 |
| Sandstone | -110 to -125 | 900 to 1200 | -- | -- | 0.35 | 2.5-3 |
| Sandstone | -125 to -200 | 1200 | -- | -- | 0.3 | 2.5-3 |

# Geotechnical Design

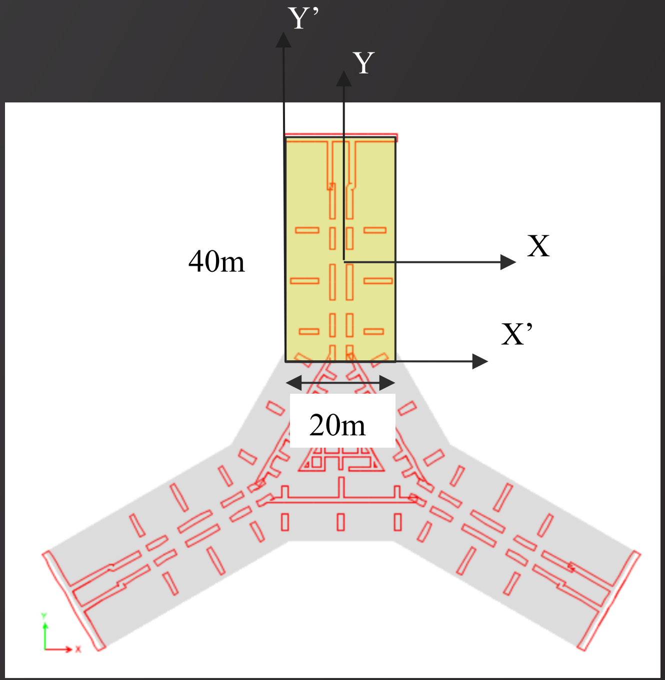
- Summary of the soil profile.

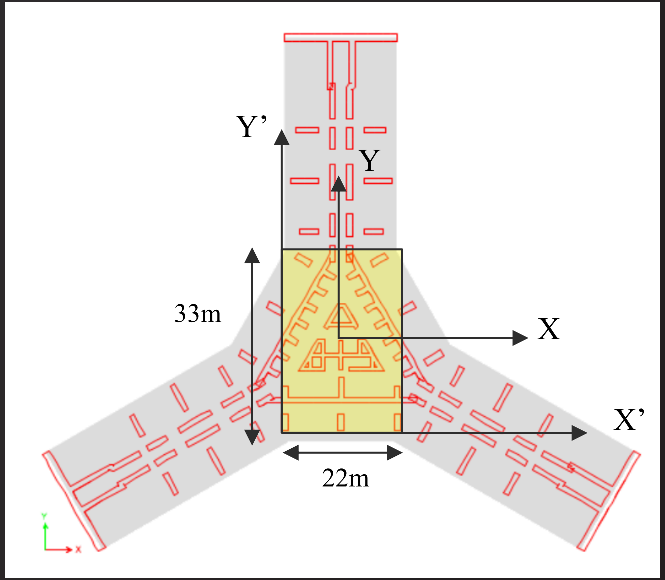
  - The first 50m are coral , which is can be considered as filled soil.
  - After passing 50m, it becomes Gravel to sand for a height of 50m .
  - Below the first 100m is Sandstone.
  - Water Table at depth of 5m.



# Geotechnical Design

- Raft Foundation Design.




Wing Section

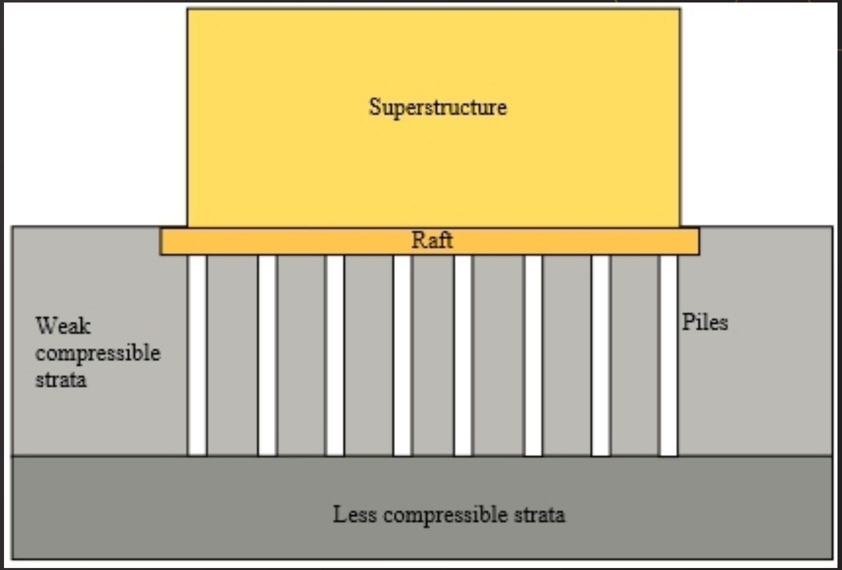
Source: ETABS

Core Section

# Geotechnical Design

- **Raft Foundation Design (Continued).**

$$\left( \phi U = b_o d \, [\phi \, 0.34 \sqrt{f_c'}] \right) \rightarrow \text{Raft thickness} = 4\text{m}$$




Raft piled foundation system Source: Designing Buildings

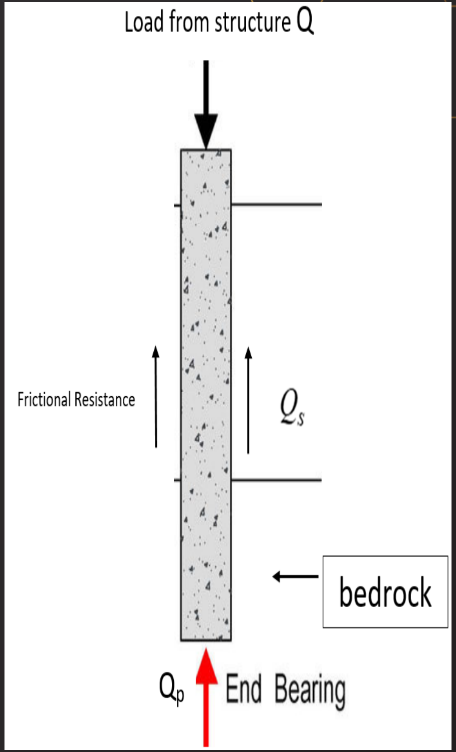
# Geotechnical Design

- **Group of Piles Design.**
  - Two group of piles are designed.
  - Piles of depth: 150m and 200m.

$$Q_u = Q_s + Q_p$$ Where:

$$Q_p = A_p \, q_p$$

$$Q_s = \sum P \, \Delta L \, f$$




Single Pile

# Geotechnical Design

## Group of Piles Design (continued).

- Wings Group of piles:

  D=1.5m , L=150m

  Single pile capacity ($Q_{all}$) = 34,719 kN

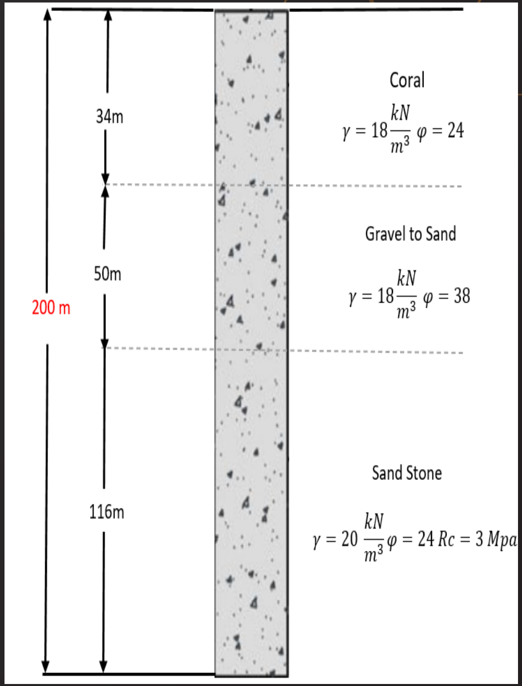
  Number of piles in each wing = 80 piles

- Core Group of piles:

  D= 1.5m, L= 200m

  Single Pile Capacity ($Q_{all}$) = 52,381 kN

  Number of piles in the core = 97 piles




Properties of Soil

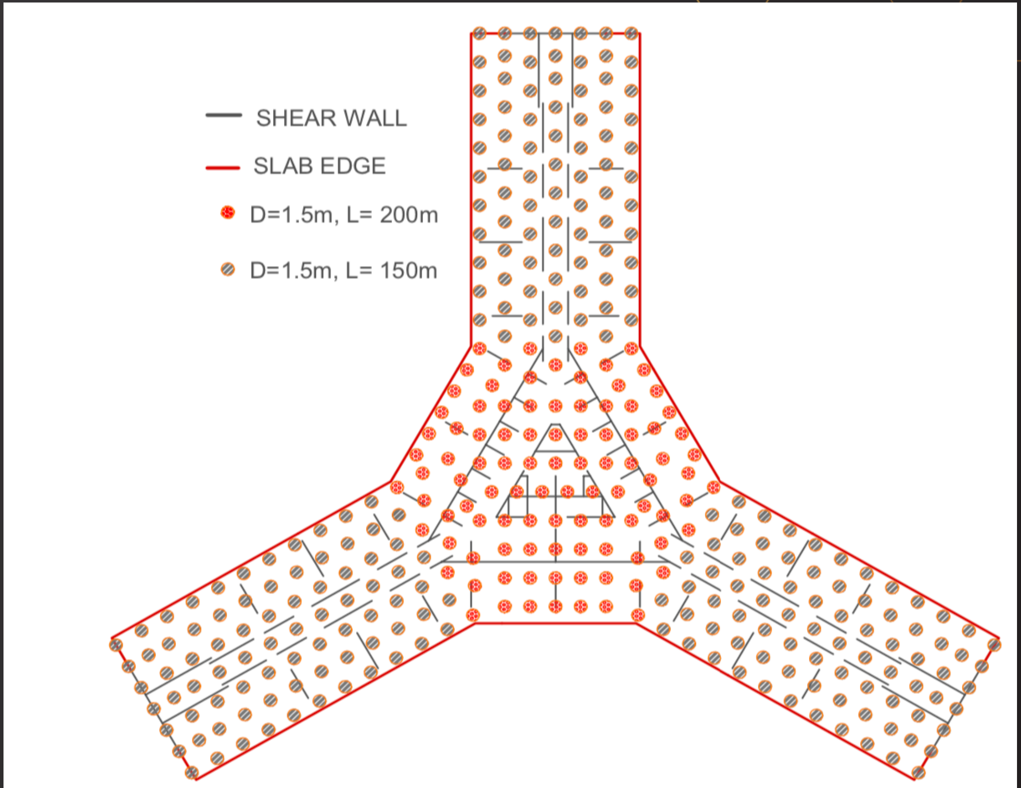
# Geotechnical Design

## Group of Piles Design (continued).

- Total Number of piles= 337 piles
- Average Center-to-center spacing = 3.5m

$2D_{pile}$ < center-to-center spacing < $3D_{pile}$

$$\left( \therefore \frac{3.5}{1.5} = 2.33 \right) \rightarrow \text{Check}$$



# Reinforcement

## Slab Reinforcement

- Methodology of Design.
- Reinforcement Details.
- Cross Sectional View.

## Shear-wall Reinforcement

- Methodology of Design.
- Shear-wall #1 Reinforcement Details.
- Reinforcement Summary.

## Raft Reinforcement

- Strips Section.
- Methodology of Design.
- (Wing, X-axis) strip Reinforcement Details.
- Cross sectional View of the Rafts.

# Reinforcement (Slab)

- Methodology of Design.

Ratio of Steel to Concrete

$$\left( a = \frac{A_{st}\, f_y}{0.85\, f_c'\, b} \right)$$

Ultimate Moment Calculation.

$$\left( M_u = \emptyset\, A_{st}\, f_y \left(d - \frac{a}{2}\right) \right)$$

# Reinforcement (Slab)

## Reinforcement Details (HSC).

- Slab thickness: 300 mm
- Positive moment: 525 kN.m/m
- Negative moment: 450 kN.m/m
- Area of steel required (Top): 4173mm²/m
- Area of steel required (Bottom): 4914mm²/m

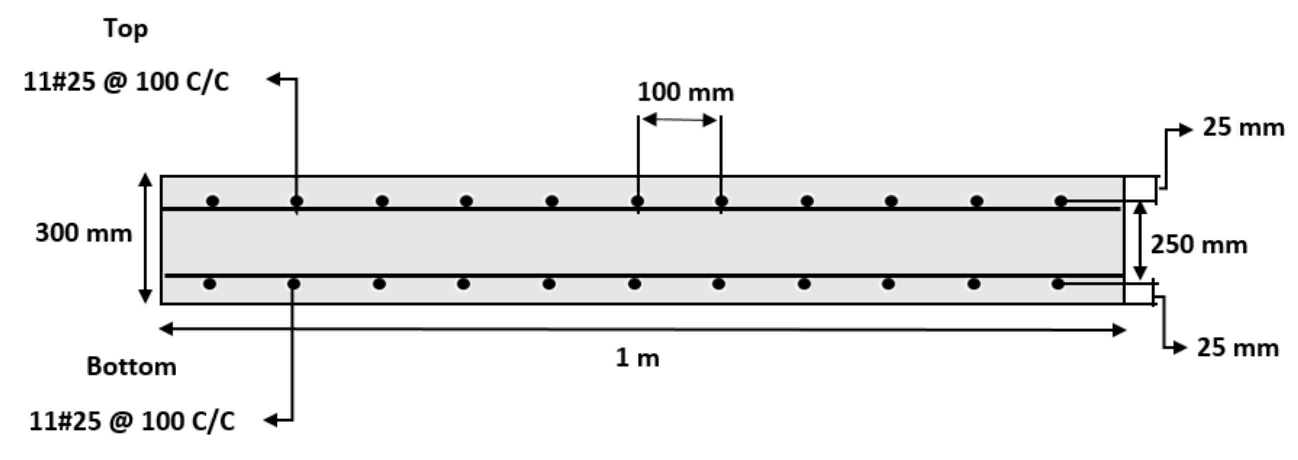
**Notation**

Top: 11 #25 @100mm c/c
Bottom: 11 #25 @100mm c/c

Provided Area of steel for each: 5400mm²/m

# Reinforcement (Slab)

- Slab Cross section for 1m width.



# Reinforcement (Shear-wall)

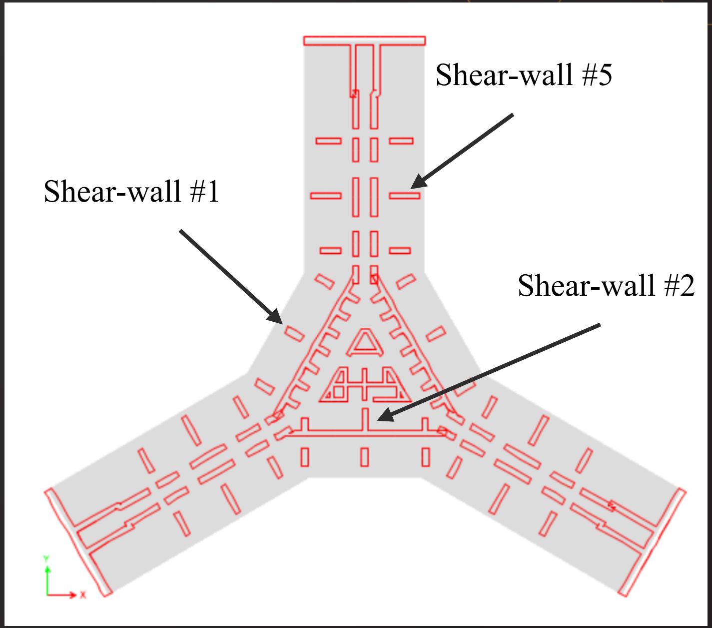
- Methodology of Design.

$$\rho_{min} = \frac{3\sqrt{fc'}}{f_y}$$

$$\rho_{max} = 0.75\left[\frac{(0.85)(0.65)fc'}{f_y}\right]\left[\frac{600}{600+f_y}\right]$$

$$A_{st(\min)} = \rho_{min} \times b \times d$$

$$A_{st(\max)} = \rho_{max} \times b \times d$$



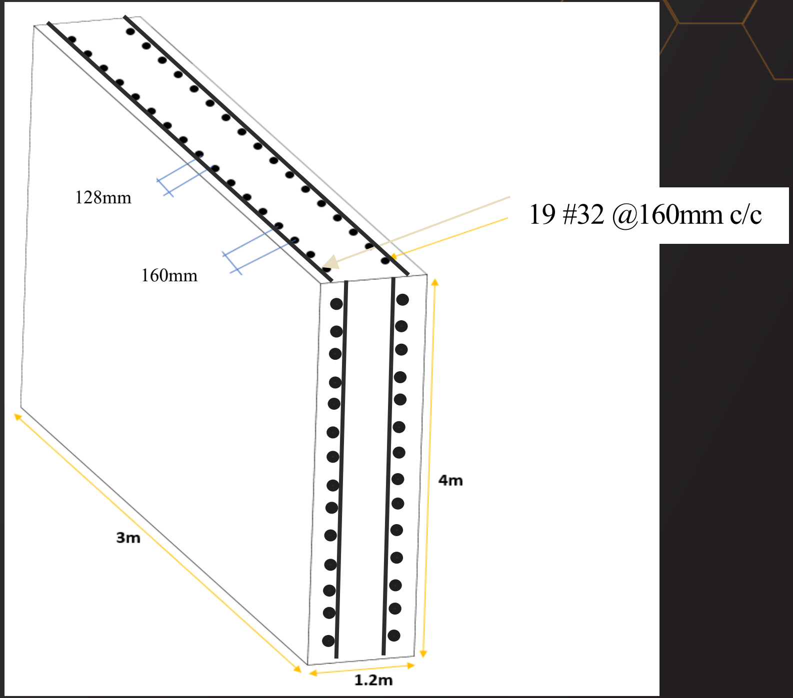

Shear-wall Location

# Reinforcement (Shear-wall)

- **Shear-wall #1 Reinforcement.**
  - Area of steel provided: 15,000mm$^2$ for each top and bottom.
  - Reinforcement Notation:

    Top: 19 #32 @ 160mm c/c
    bottom: 19 #32 @ 160mm c/c

  - $A_{st\,(min)}$ = 7,200 mm2
  - $A_{st\,(provided)}$ = 30,560 mm2 → Check
  - $A_{st\,(max)}$ = 144,000 mm2




Reinforcement Details

# Reinforcement (Shear-wall)

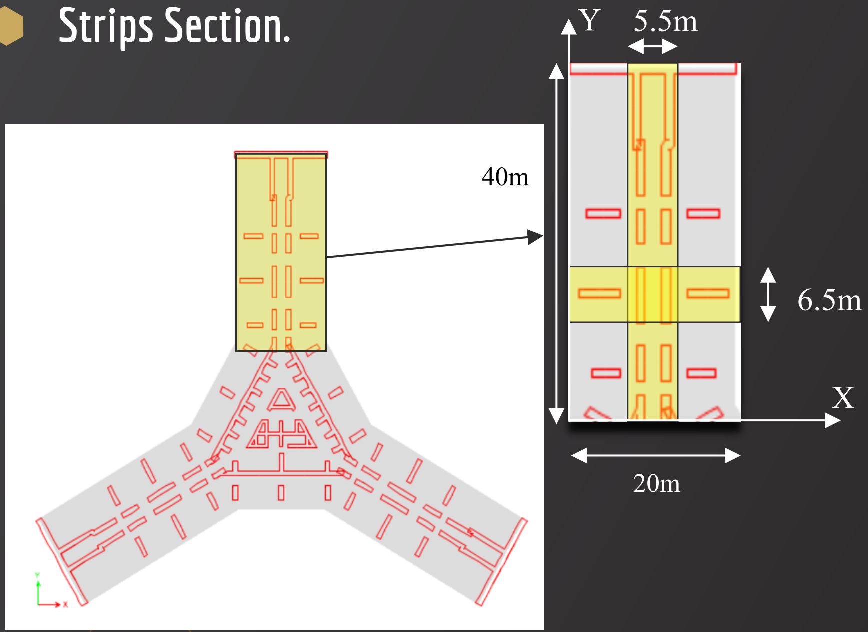
- Reinforcement Summary.

Table # 7 Shear-wall Reinforcement Summary

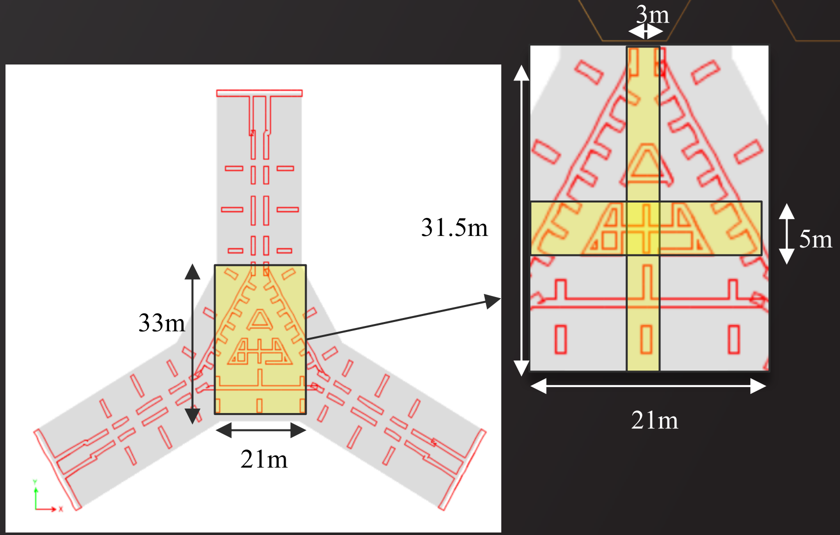
| Shear-wall No. | HSC | | NSC | |
|---|---|---|---|---|
| | Notation | $A_{st(Provided)}$ (mm2) | Notation | $A_{st(Provided)}$ (mm2) |
| SW#1, G#4 | 19 #32 @160mm c/c | 30,560 | 72 #57 @143mm c/c | 367,453 |
| SW#5 , G#3 | 19 #29 @270mm c/c | 25,100 | 19 #29 @270mm c/c | 25,100 |

# Reinforcement (Raft)

- Strips Section.




(Wing Section)




(Core Section)

# Reinforcement (Raft)

## Methodology of Design.

- Dividing the section into two strips.
- Modeling the strips as simply supported beam.

Equations used

$$q_{av} = \frac{q_{initial} + q_{final}}{2}$$

$$Soil\ Reaction = q_{av} \times B_1 \times L$$

$$Avg\ Load = \frac{soil\ Reaction + Q_{strip}}{2}$$

$$q_{av(modi)} = q_{av} \times \frac{Avrage\ Load}{soil\ Reaction}$$

$$F = \frac{avrage\ Load}{Q_{strip}}$$

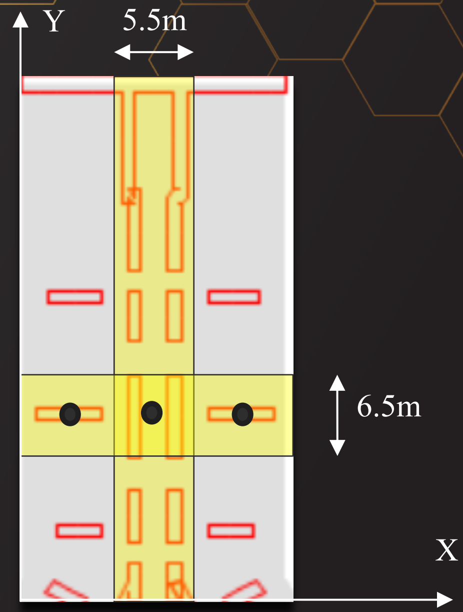
$$q' = q_{av(modi)} \times B_1$$

# Reinforcement (Raft)

- Wing section X-axis strip Reinforcement Details.

Table #8 Strip Load Values

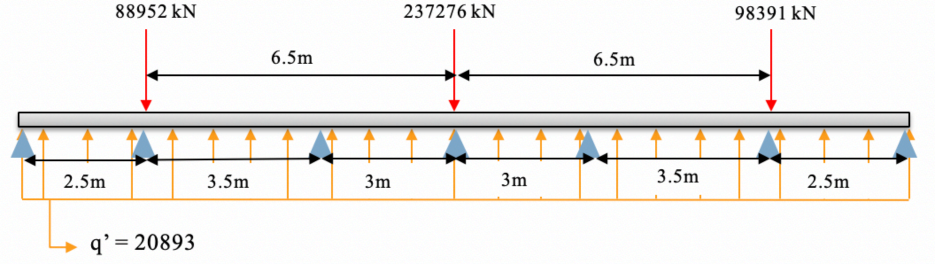
| Shear-Wall | Soil pressure (q) (kN/m²) | Load (Q) (kN) | $q_{avg}$ (kN/m²) | Soil Reaction (kN) | Avg Load (kN) | $q_{avg(modi)}$ (kN/m²) | q' (kN/m) | F |
|---|---|---|---|---|---|---|---|---|
| Left | 3513 | 104650 | 2667.5 | 346775 | 416869.5 | 3214.4 | 20893 | 0.85 |
| Middel | - | 279148 | | | | | | |
| Right | 1812 | 10566 | | | | | | |



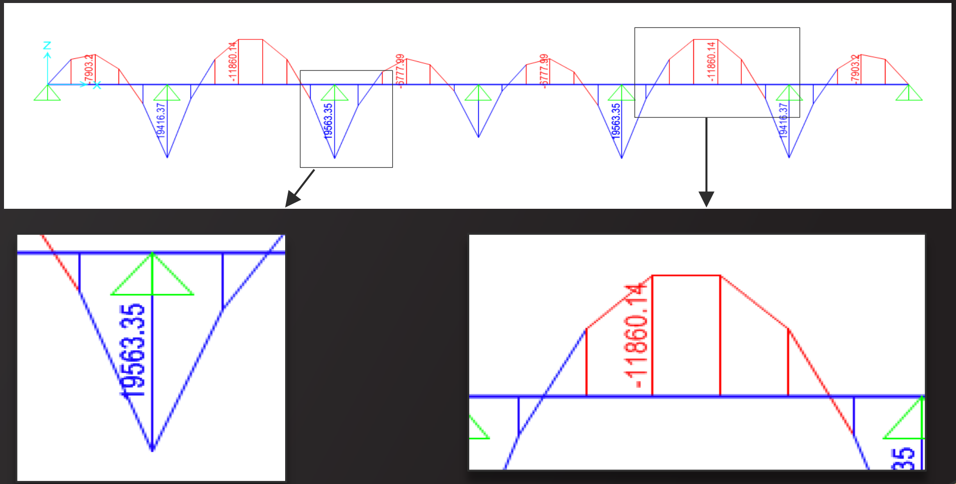
# Reinforcement (Raft)

- The Piles reaction will be modeled as pin support according to the pile location.
- The Load is multiplied by Factor F=0.85

- Load distribution



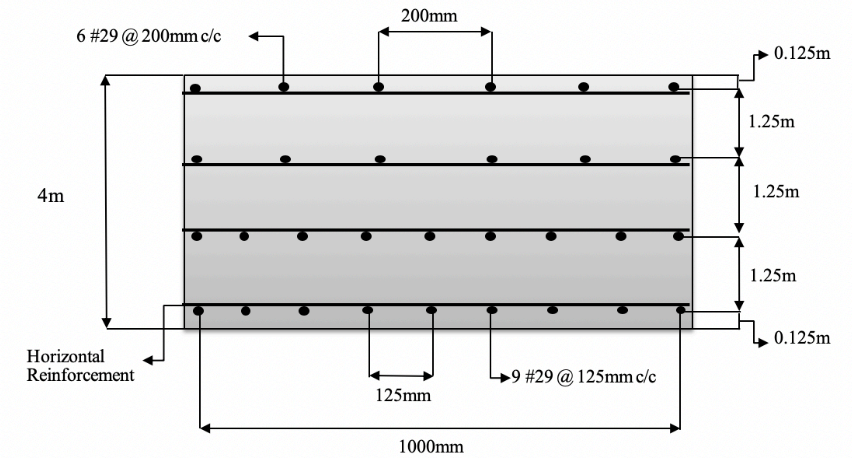

- Moment Diagram



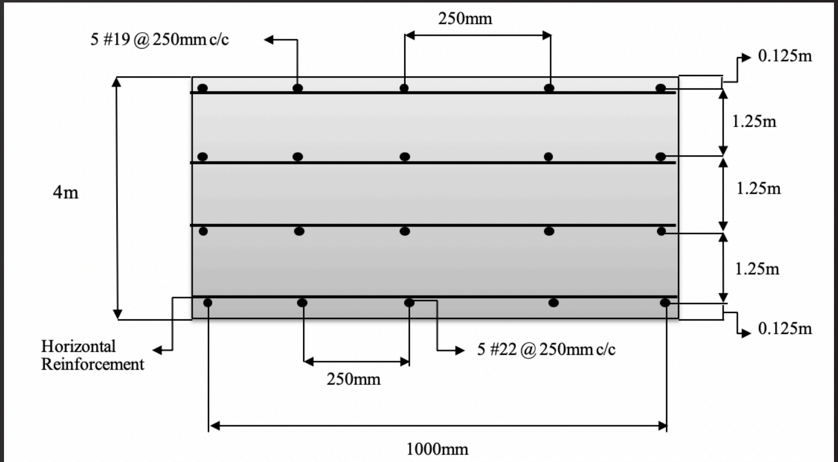

( * Moment digram generated by SAP 2000 Software )

# Reinforcement (Raft)

- Cross sectional View of Wing section.



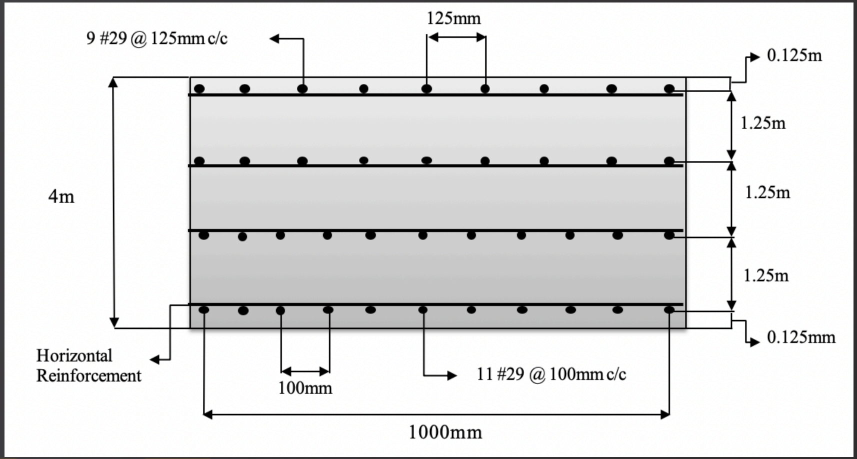

( Y-axis strip )



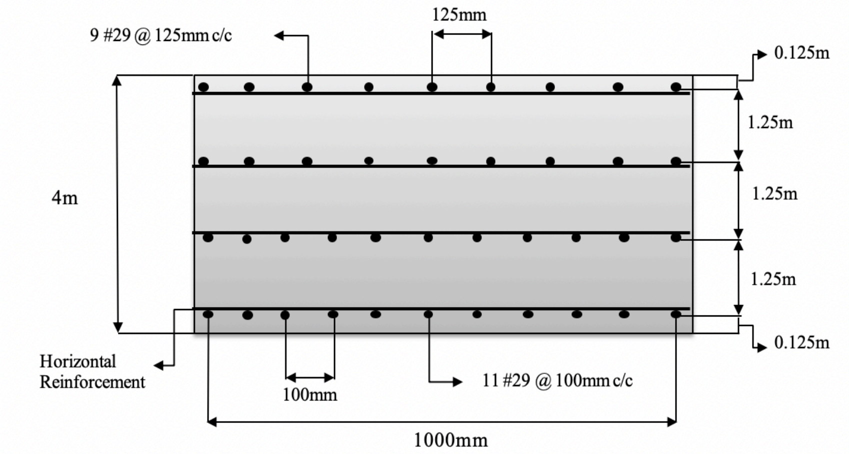

( X-axis strip )

# Reinforcement (Raft)

- Cross sectional View of Core section.




Y-axis strip




X-axis strip

# Cost Estimation

## Estimation Method.

- Unit Price Method.
- Cost of 70 MPa Concrete : 418 SR/$m^3$
- Cost of 40 MPa Concrete : 210 SR/$m^3$
- Cost of Rebar Reinforcement : 2300 SR/Ton

## Estimation process.

- Volume of Concrete.
- Volume of Reinforcements. → (2% of concrete Volume)
- Cost of Reinfocements + Concrete.
- Cost of finishing. → (60% of total cost)

# Cost Estimation

## HSC

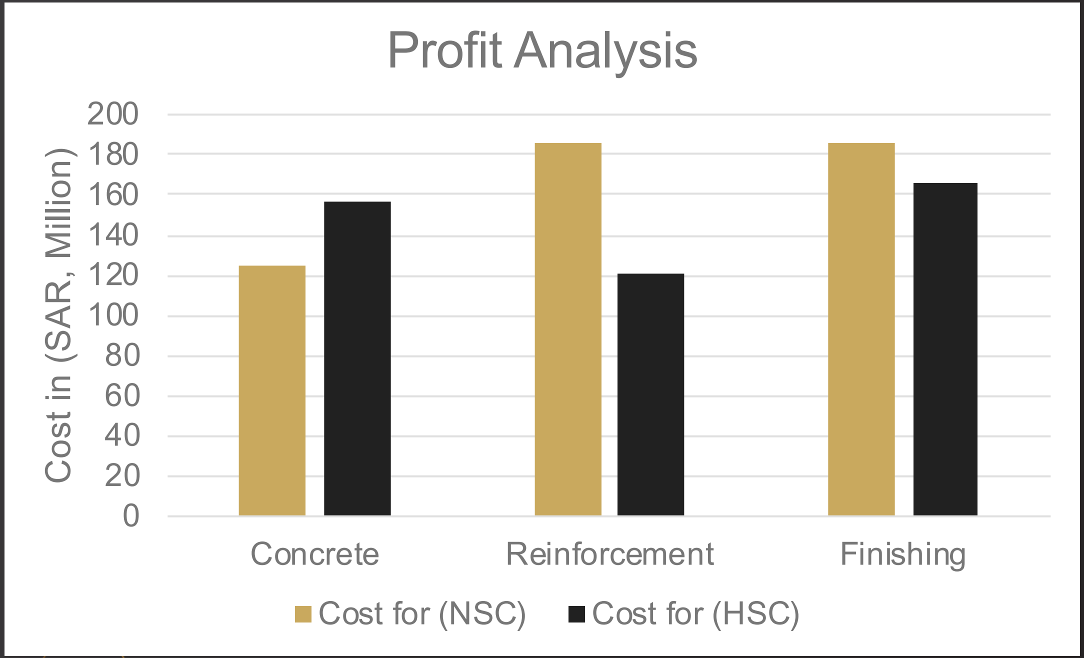
| No | Elements | Cost |
|---|---|---|
| 1 | Concrete | 156,447,333 SR |
| 2 | Reinforcement | 120,516,320 SR |
| 3 | Finishing | 166,178,192 SR |
| Total Cost in (SAR) | | 443,141,845 SR |
| Total Cost in (USD) | | 117,955,124 USD |

## NSC

| No | Elements | Cost |
|---|---|---|
| 1 | Concrete | 124,362,255 SR |
| 2 | Reinforcement | 186,499,106 SR |
| 3 | Finishing | 186,516,816 SR |
| Total Cost in (SAR) | | 497,378,177 SR |
| Total Cost in (USD) | | 132,391,705 USD |

# Cost Estimation

- Profit Analysis.



# Conclusion

- The superstructure design ensure the Safety and serviceability .
- The superstructure have been analyzed through ETABS software.
- The structural style which is slab resting on shear-walls shows an effective resistance to lateral load.
- The tower Y-shape provides high moment of inertia to end up with stiff building.
- The Foundation System provide the adequate bearing capacity.
- HSC is sustainably, eco-friendly, and more environmentally than NSC.

# References

اللجنة الوطنية لكود البناء السعودي
Saudi Building Code National Committee

كود البناء السعودي
Saudi Building Code

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# Thank you

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