Prince Mohammad bin Fahd University
College of Engineering
Department of Civil Engineering

Design of a Multistory Carpark Structure at PMU Using a Structural Steel Skeleton

LEARNING OUTCOME ASSESSMENT III

SENIOR DESIGN PROJECT; SPRING 2019

GROUP 1: FINAL PRESENTATION

COORDINATOR
DR. ANDI ASIZ
ADVISORS:
ENG. DANISH AHMED
DR. TAHAR AYADAT

ABDULLAH AL-DAYEL
201300039
NAWAF AL-UBAIDI
201401749

MOHAMMAD ABABTAIN
201402724
ABDULLAH AL-JOAIB
201202749

Outline of Presentation

- Project Objectives
- Project Scope
- Codes and Design Specifications
- Guidelines and Constraints
- Project Description
- Structural Design
- ETABS Modelling
- Geotechnical and Foundation System Design
- Cost Estimation
- Additional
- Summary

Project Objectives

- The structural and geotechnical design of a multistory, steel frame carparking facility.
- To be used for the male student population of Prince Mohammad bin Fahd University.
- Located adjacent to the western border of the university's campus.
- Must safely accommodate a minimum of *1000 vehicles.*

Project Scope

The scope of this project can be attained from a brief description of the chapters included in our report:

Chapter	Description
2 : Project Guidelines and Constraints	***Design guidelines and constraints required to follow.***
3 : Project Description	***A description of the base structure based on and modifications made.***
4 : Structural Design	***The detailed design of the structure's steel frame and reinforced concrete elements.***
5 : Geotechnical Design	***The detailed design of the foundation system and soil improvement done.***
6 : Reinforcement	***Design of the steel reinforcement required for the concrete elements.***
7 : Structural Modelling	***ETABS modelling and analysis of the structure.***
8 : Cost Estimation	***Rough cost estimation of material quantities and prices.***

Codes and Design Specifications

The codes and regulations used throughout this project, are a mixture of local and international design and building codes:

- Ministry of Municipal and Rural Affairs (MOMRA), Kingdom of Saudi Arabia. *Technical requirements for vehicular parking spaces*, 2012.
- Saudi Building Code (SBC). Saudi Building Code structural requirements; Loading and Forces (301), Soil and Foundations (303), Concrete Structures (304), Steel Structures (306). 2007.
- American Institute of Steel Construction. (2015). *Steel Construction Manual (14th ed.).*
- American Concrete Institute. ACI. (2014). *Building code requirements for structural concrete (ACI 318-14).*

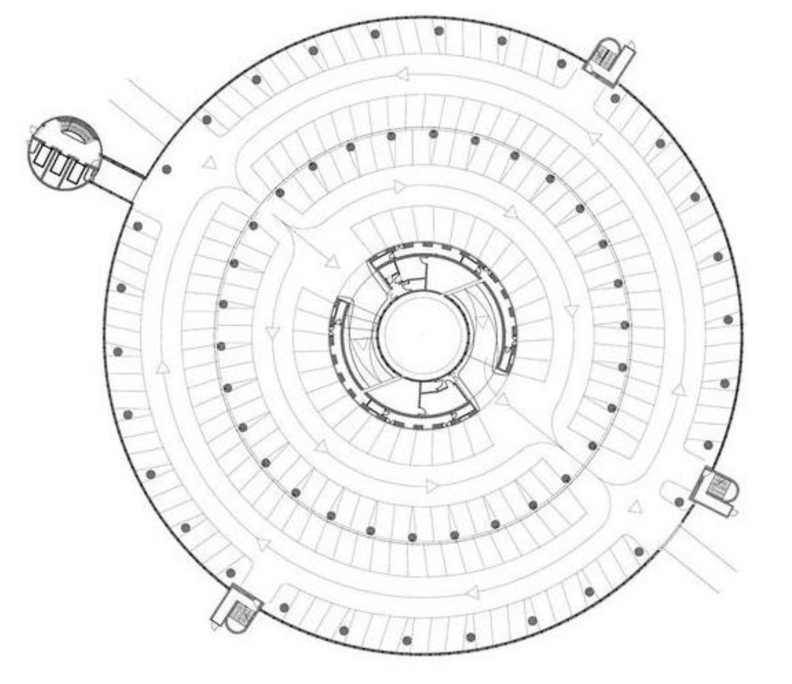
Project Guidelines and Constraints

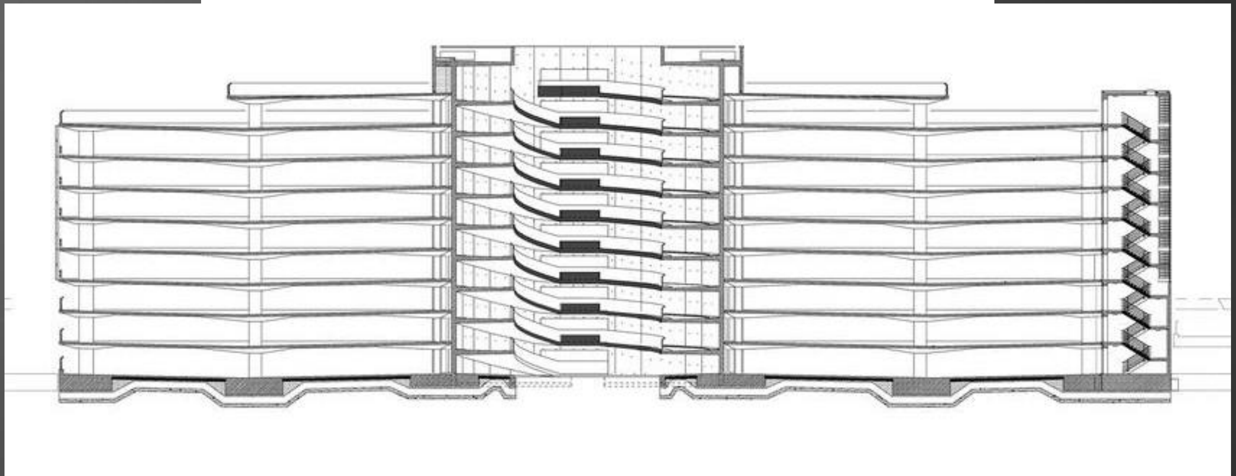
Constraint(s)		Solution
Geotechnical	High water table	Dewatering
	Contaminated “Sabkha” soil	Soil Improvement (Exchange of topsoil)
		Type V; Sulfate Resistant Portland cement for foundations
Material	Concrete	4000 psi / 28 MPa compressive strength
	Structural Steel	60,000 psi / 420 MPa strength; Steel members
Environmental	Keep the visual appeal and green landscapes on campus	Construct the facility outside the campus, on an adjacent lot
	Contaminated Ground-Water and Soil	Transport and disposal in a designated landfill\treatment facility
Structural	Deflection limits, drift and allowable parameters	Consider all possible load combinations and compare with codes and standard parameters
Safety	Student foot traffic to and from the building	Propose a safe and functional pedestrian crossing
Cost	Obtaining a realistic cost estimation	Use local vendor prices as much as possible
	Minimizing overhead cost of project	Introduction of a revenue generation stream

Project Description

Original layout

- Designed by *GMP Architekten GMBH*
- Completed in 2004
- 92 m in diameter
- 29 m in height
- 10 circular floors
- Total parking capacity is 2,115 cars
- Gross site area 62,000 m^2
- Elevation: 2.8 m per floor



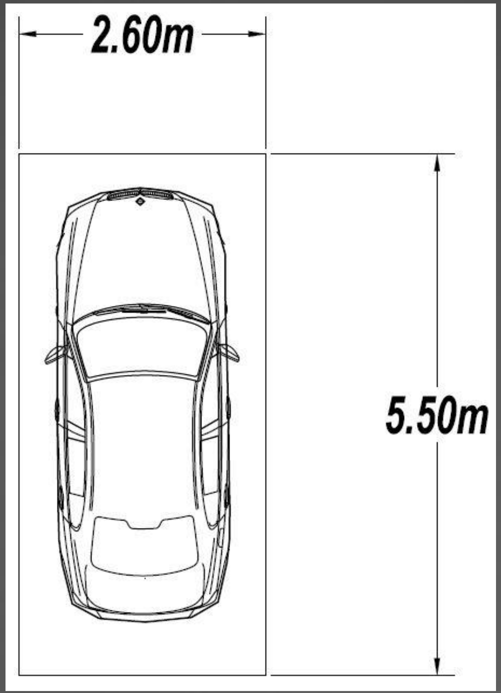


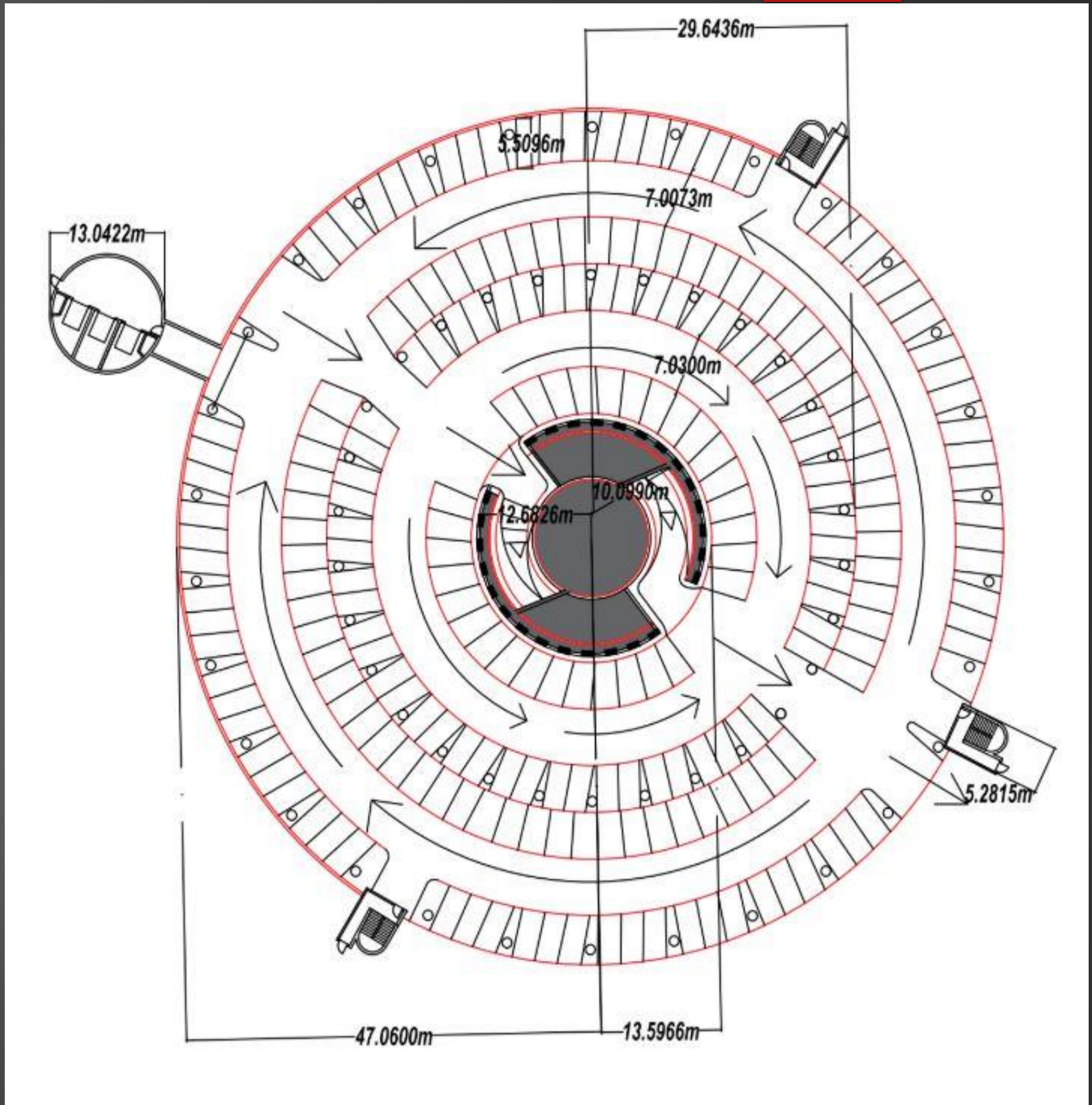
Images courtesy of GMP Architekten, GMBH, Hamburg Germany

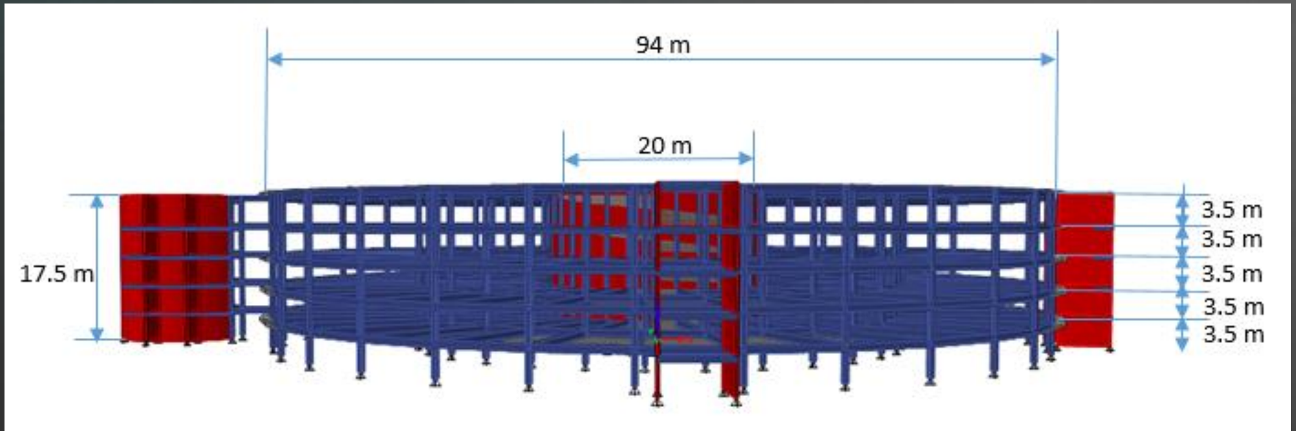
Project Description

Modified layout

- Diameter = 94 m
- Floor area = 7100 m^2
- Site area required = 10,310 m^2
- Elevation per floor = 3.5 m
- Total height = 17.5 m
- New parking capacity **<u>1004 cars</u>**

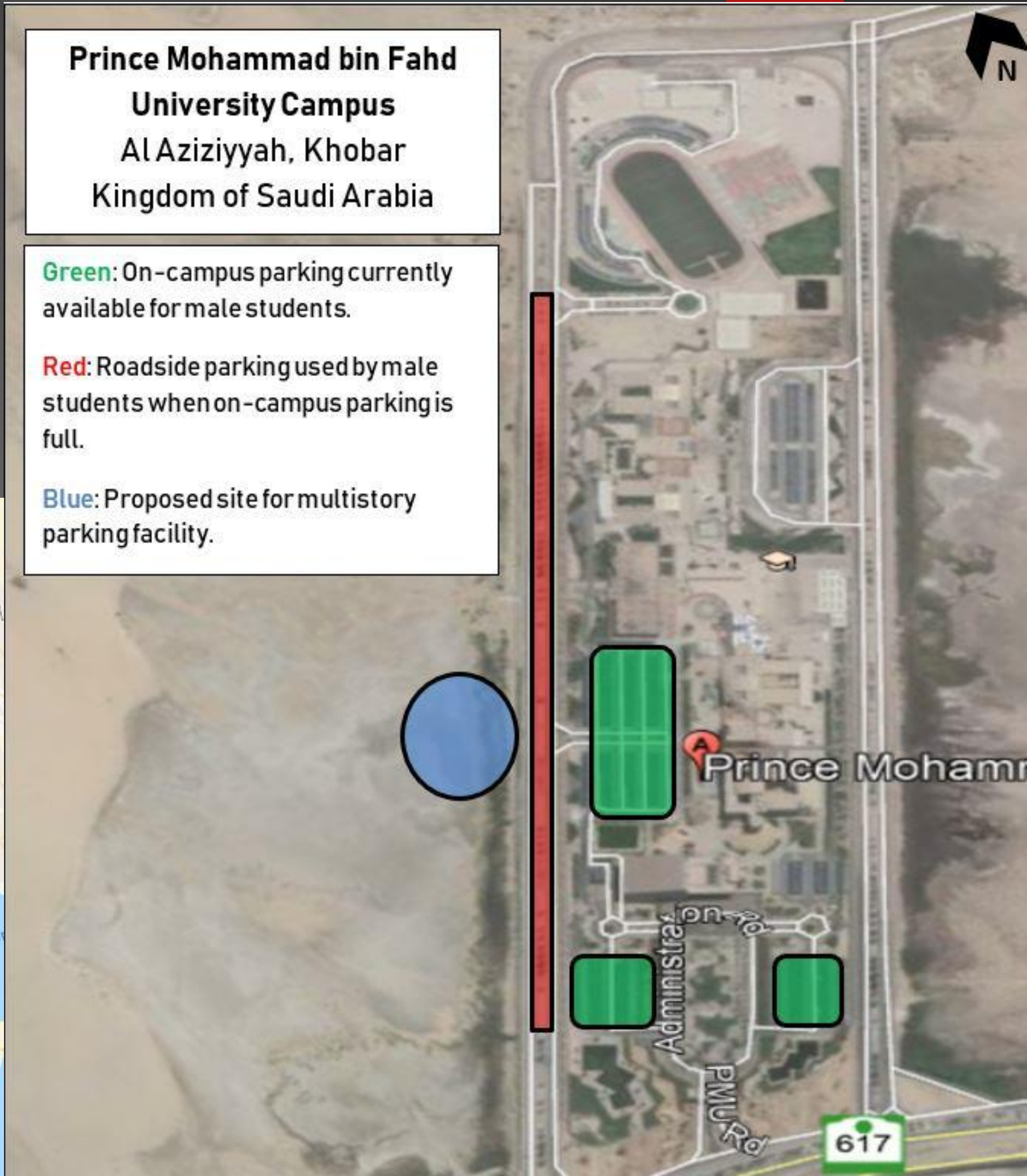






Project Description
Location

Exact location of the project shown in the figure to the right



Structural Design

In this section:

- Structure breakdown
- Load combinations and forces used
- Structural element design:
  - Slabs
  - Beams and Girders
  - Columns
  - Shear Walls

Hamburg Airport's "Rotunda" Parking Building. Retrieved from Arch20.com

Structure Breakdown

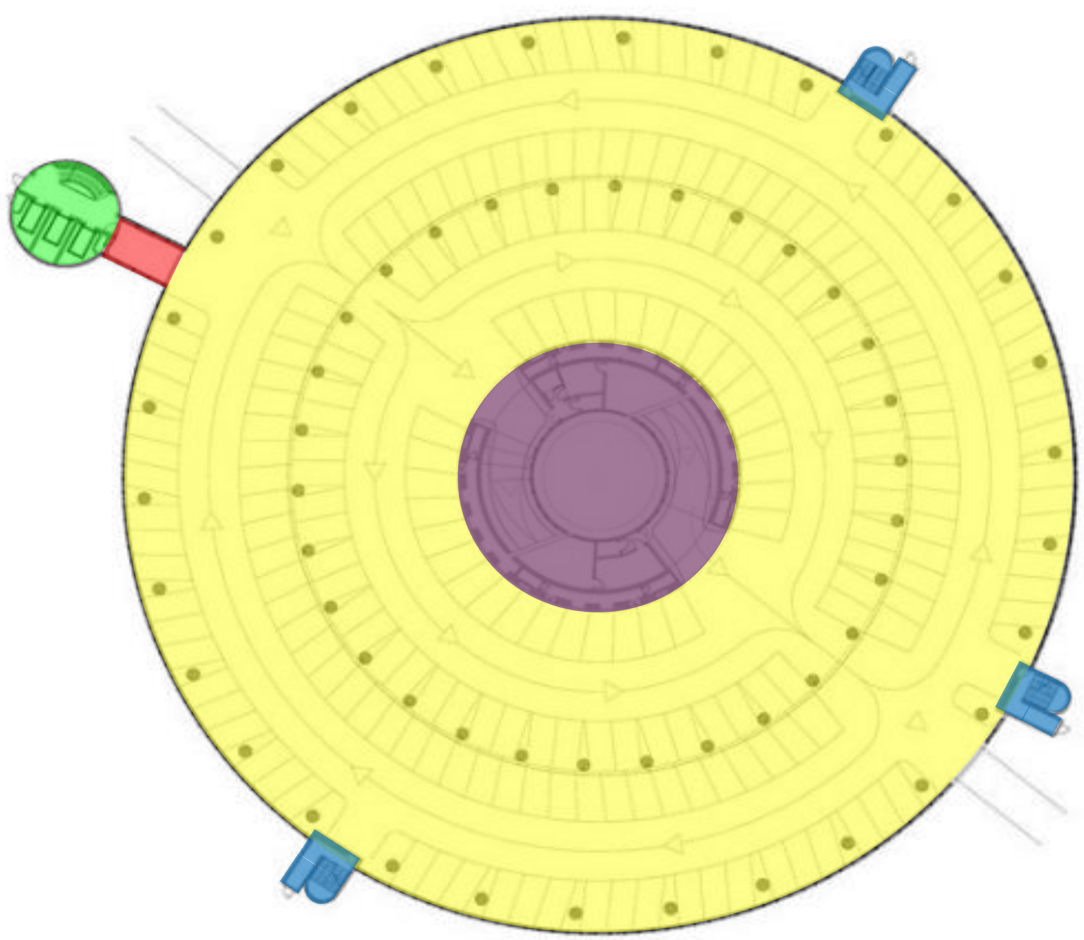
Main Building

Stairs Structure

Elevator Building

Pedestrian Bridge

Ramp Structure



Load combination

General formula and values

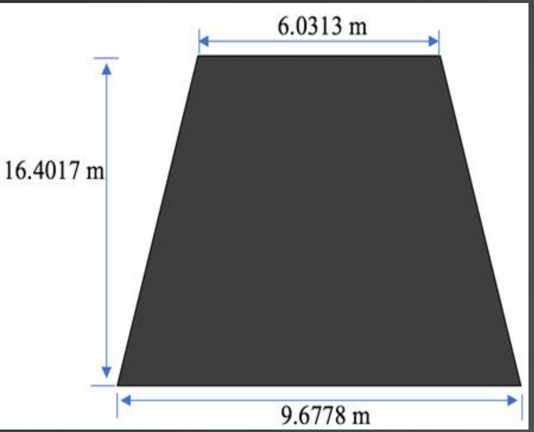
$$U = W_u = 1.2\,(\,L_D\,) + 1.6\,(\,L_L\,) = {}^{kN}/_{m^2} \;\; or \;\; {}^{kips}/_{ft^2}$$

Structure	${}^{kN}/_{m^2}$		${}^{kips}/_{ft^2}$	
	Dead *	Live *	Dead *	Live *
Main	9.058	2	≈ 0.189	≈ 0.0577
Elevators	10.733	2	≈ 0.224	≈ 0.0577
Staircase	8.833	2	≈ 0.184	≈ 0.0577
Pedestrian Bridges	10.733	3	≈ 0.224	≈ 0.0865
Roof	9.258	0.676	≈ 0.193	≈ 0.0195

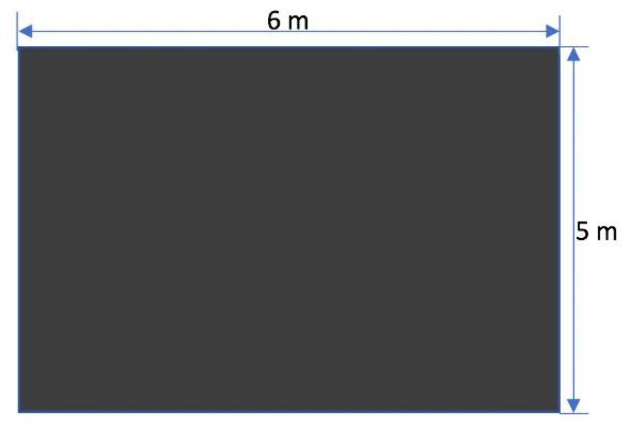
* Retrieved from SBC:301

Preliminary Structural Design

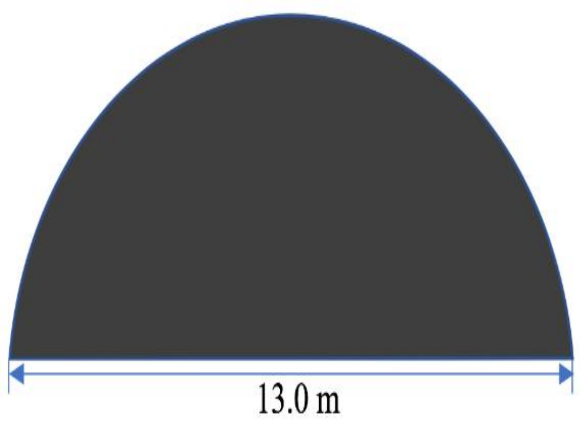
Slab design



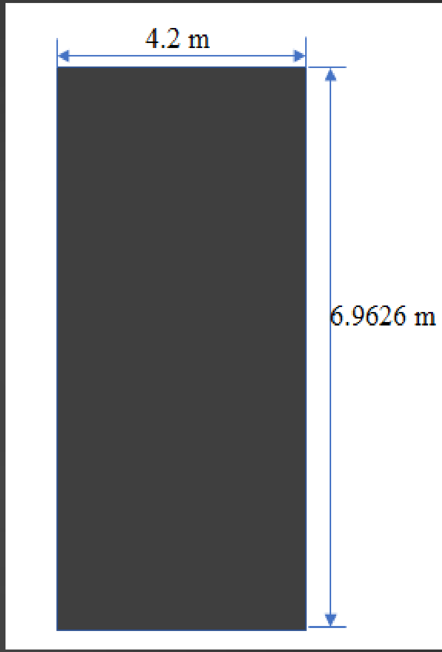
Typical main structure



Stairwell



Elevator building



Pedestrian bridge

Units	mm	in
Main structure	280	11
Stairs structure	153	6
Pedestrian bridge structure	229	9
Elevator structure	229	9
Ramp Structure	*500*	*20*

$$Slab\ thickness = \frac{perimeter}{180}$$

$$Ratio = \frac{Long\ Span}{Short\ Span}$$

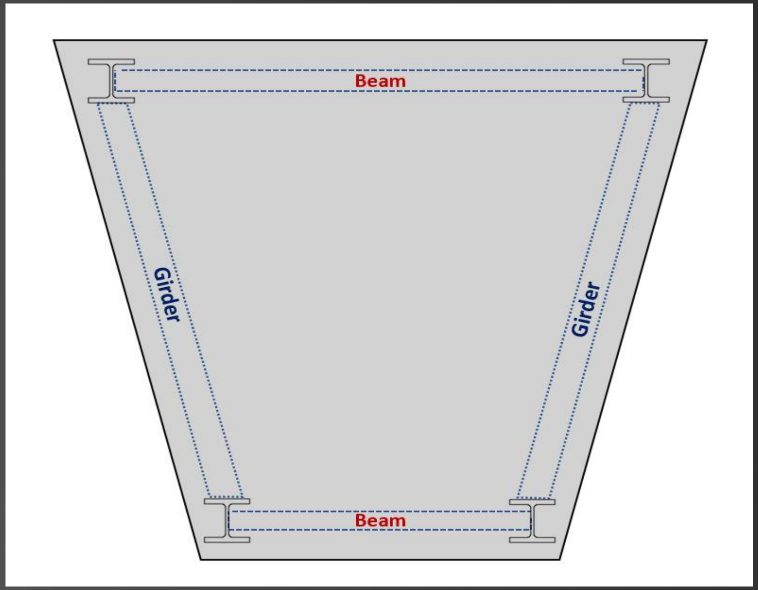
Preliminary Structural Design

Example of a Beam and Girder design for main structure

$$I_y = \frac{W_u \, l_x}{6} \left[3 - \left(\frac{l_x}{l_y} \right)^2 \right]$$

or

$$I_y = \frac{Wu \, Lx}{3}$$

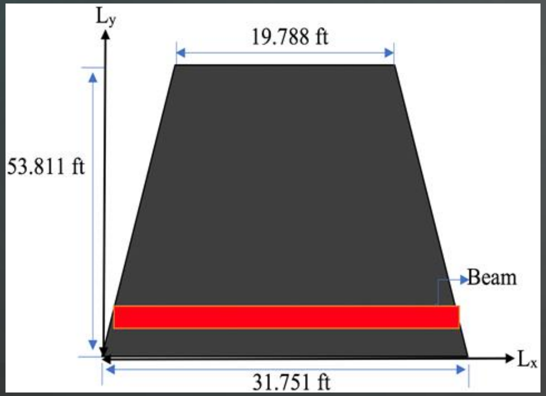


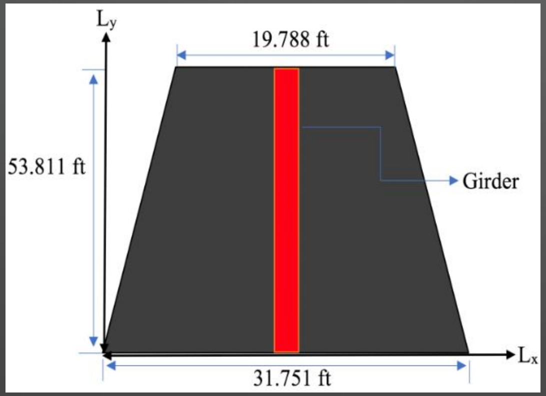
$$\delta_{all.} = \frac{l}{240}$$

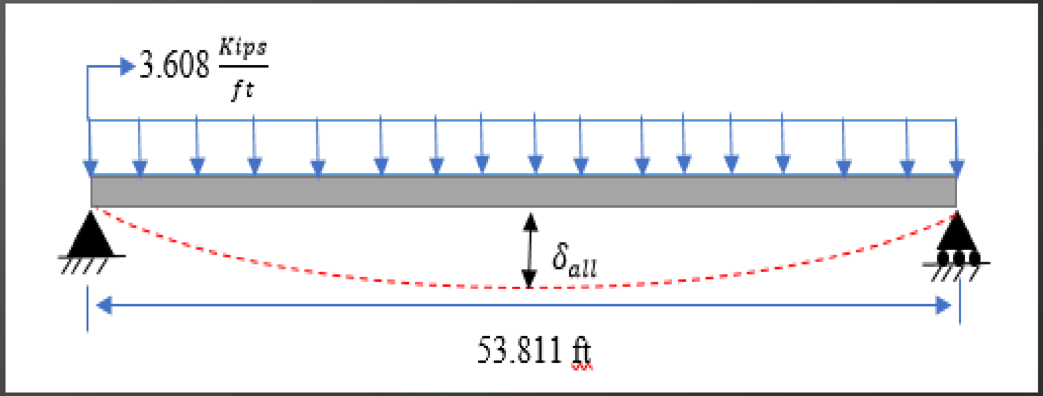
$$M = \frac{w \, (L)^2}{8}$$

$$\delta = \frac{M \, (L)^2}{C_1 I_x}$$

$$V = \frac{w.l}{2}$$



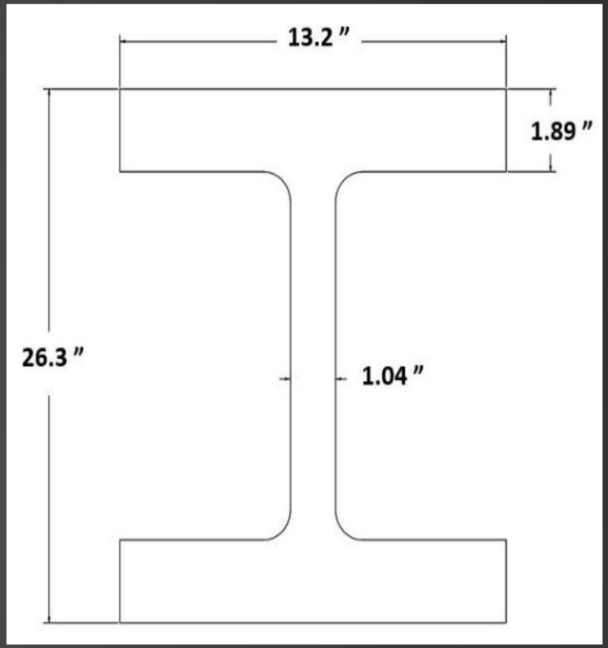




Preliminary Structural Design

Summary of Beam and Girder sections

Element Location	Type	Section Used
Main Structure; Roof	Girder	W 24 x 250
Main Structure; Roof	Beam	W 24 x 94
Main Structure; Typical floor	Girder	W 24 x 279
Main Structure; Typical floor	Beam	W 24 x 68
Elevator Building	Beam	W 24 x 279
Pedestrian bridges	Beam	W 14 x 38



W 24 x 250

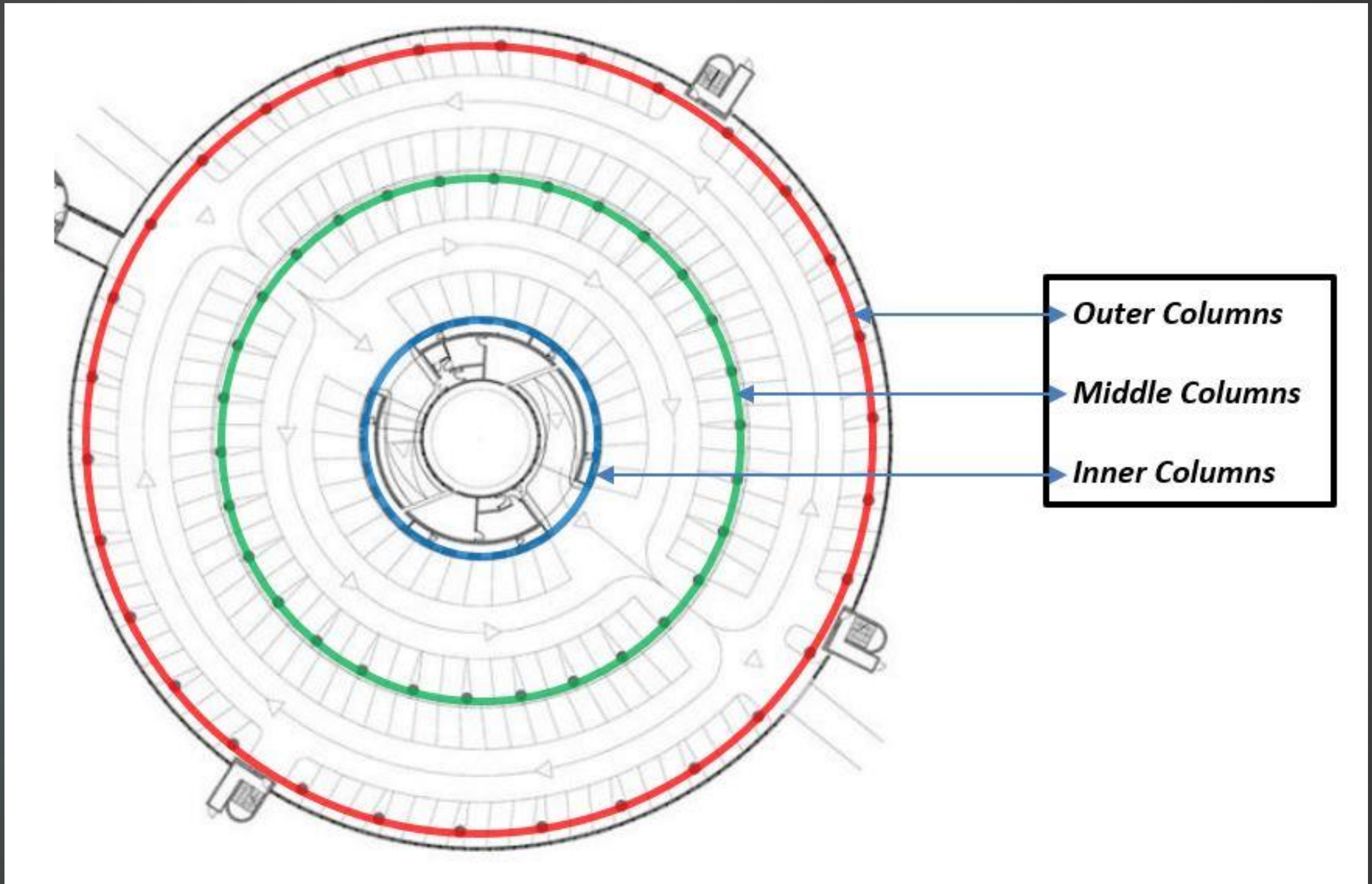
Preliminary Structural Design

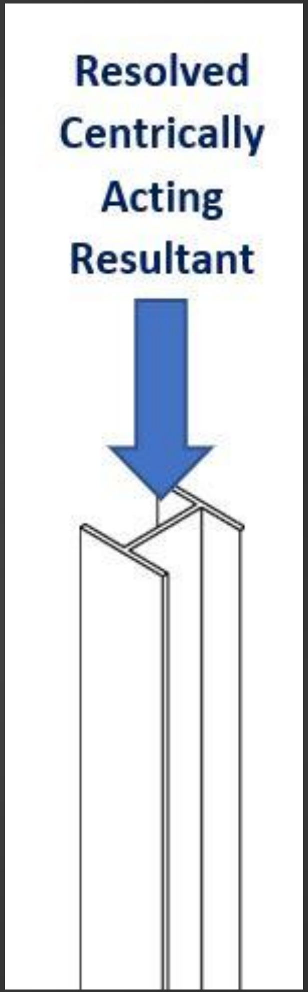
Example of column design; main structure

$$R = \frac{w.l}{2}$$

$$\lambda = \frac{kl}{r}$$

$$\emptyset P_n = A_g \, \emptyset F_{cr}$$

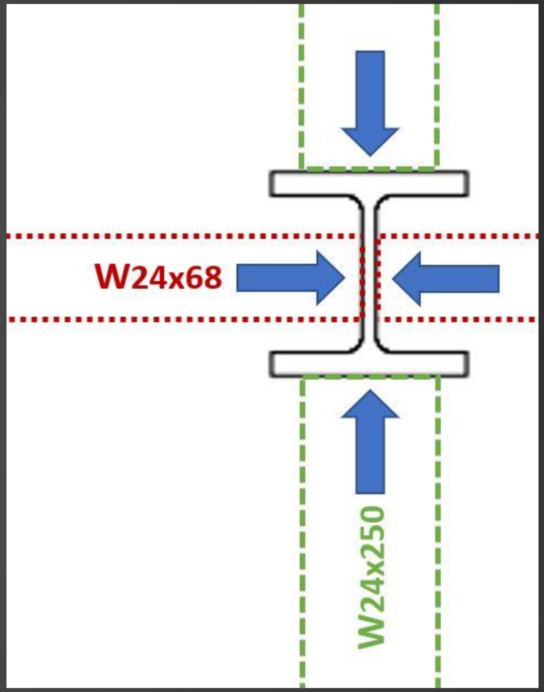




Preliminary Structural Design

Summary of main structure columns

Story No.	Inner columns	Middle columns	Outer columns
5	W12x26	W12x58	W12x45
4	W12x65	W14x176	W12x120
3	W12x65	W14x176	W12x120
2	W12x106	W14x283	W12x190
1	W12x106	W14x283	W12x190



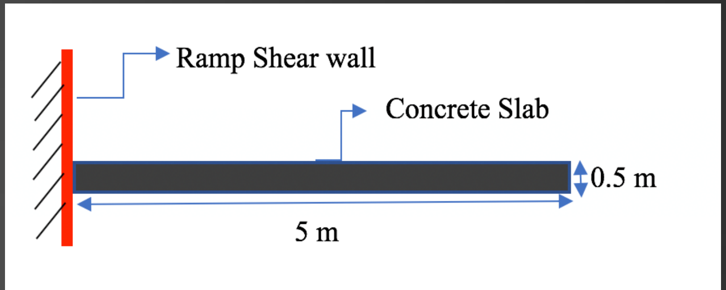
Girder and Beam orientation to columns

Preliminary Structural Design

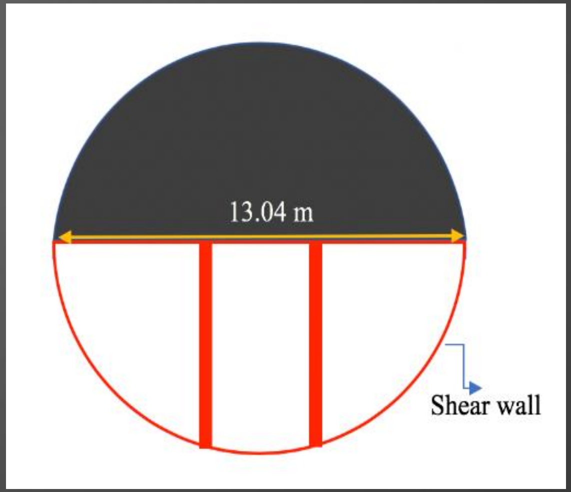
Example of a shear wall design with summary of thickness

$$\emptyset P_u = \emptyset\, r \,[\, 0.85\, f'_c \,(A_g - A_{st}) + f_y\, A_{st}]$$

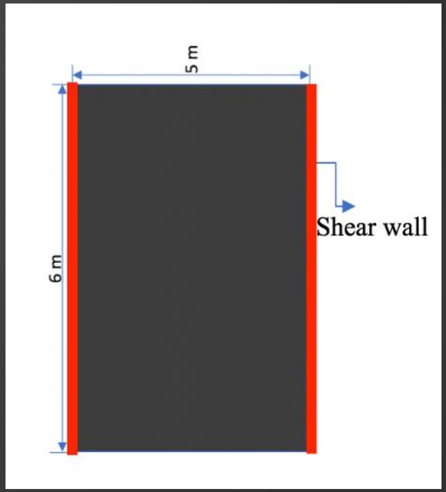
Shear wall thickness		
Unit	**mm**	**in**
Stairs	100	4
Elevator	203	8
Ramp	152	6



Ramp



Elevator



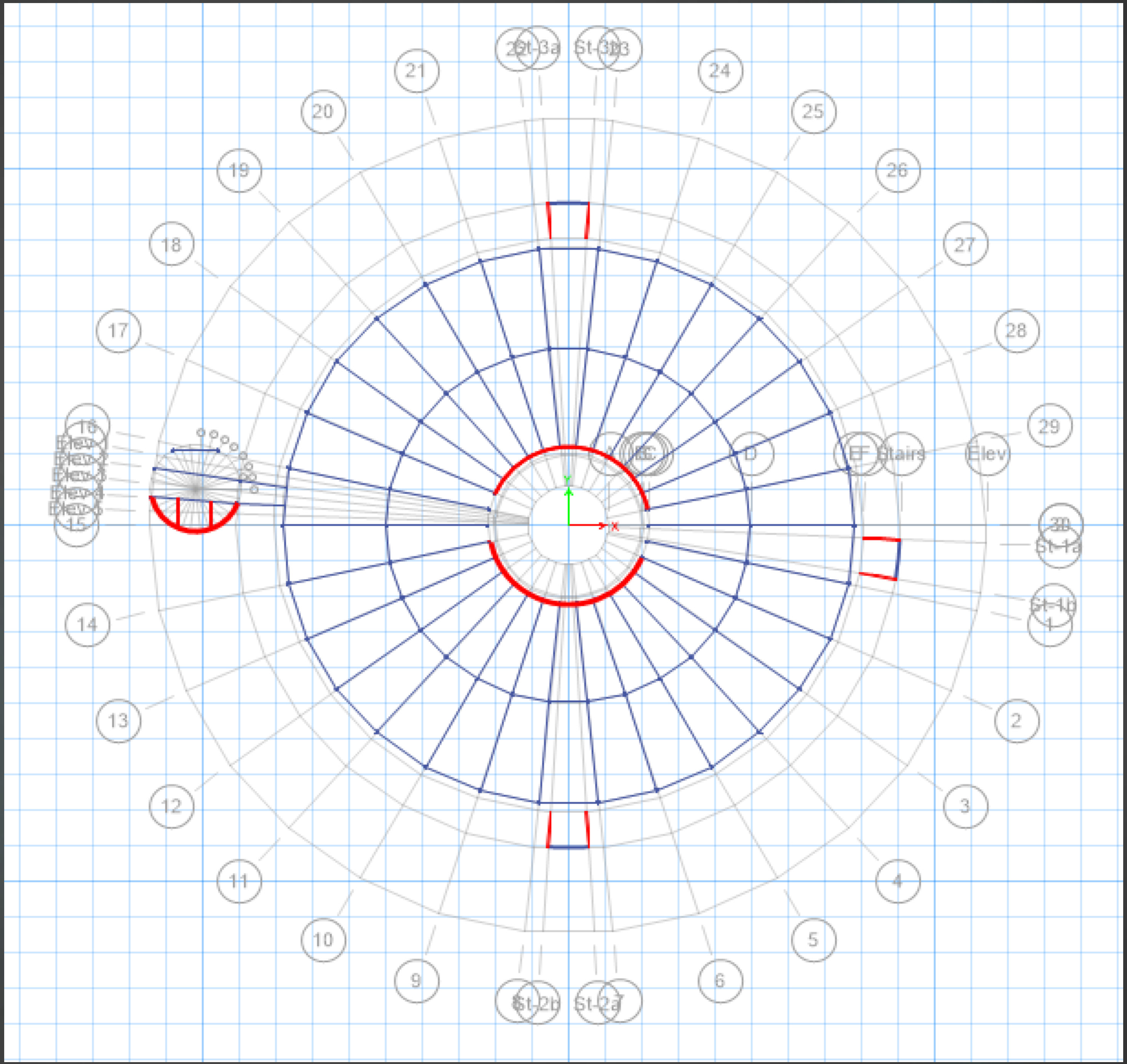
Stairs

ETABS Modelling and Analysis

Computers and Structures Inc. CSI© ETABS©
Extended Three Dimensional Analysis of Building Systems

- Gridlines
- 3D view of the structure
- Members Analysis
- Deflection Mapping
- Moving load Simulation
- Wind - Drift Analysis
- Connection design

Gridlines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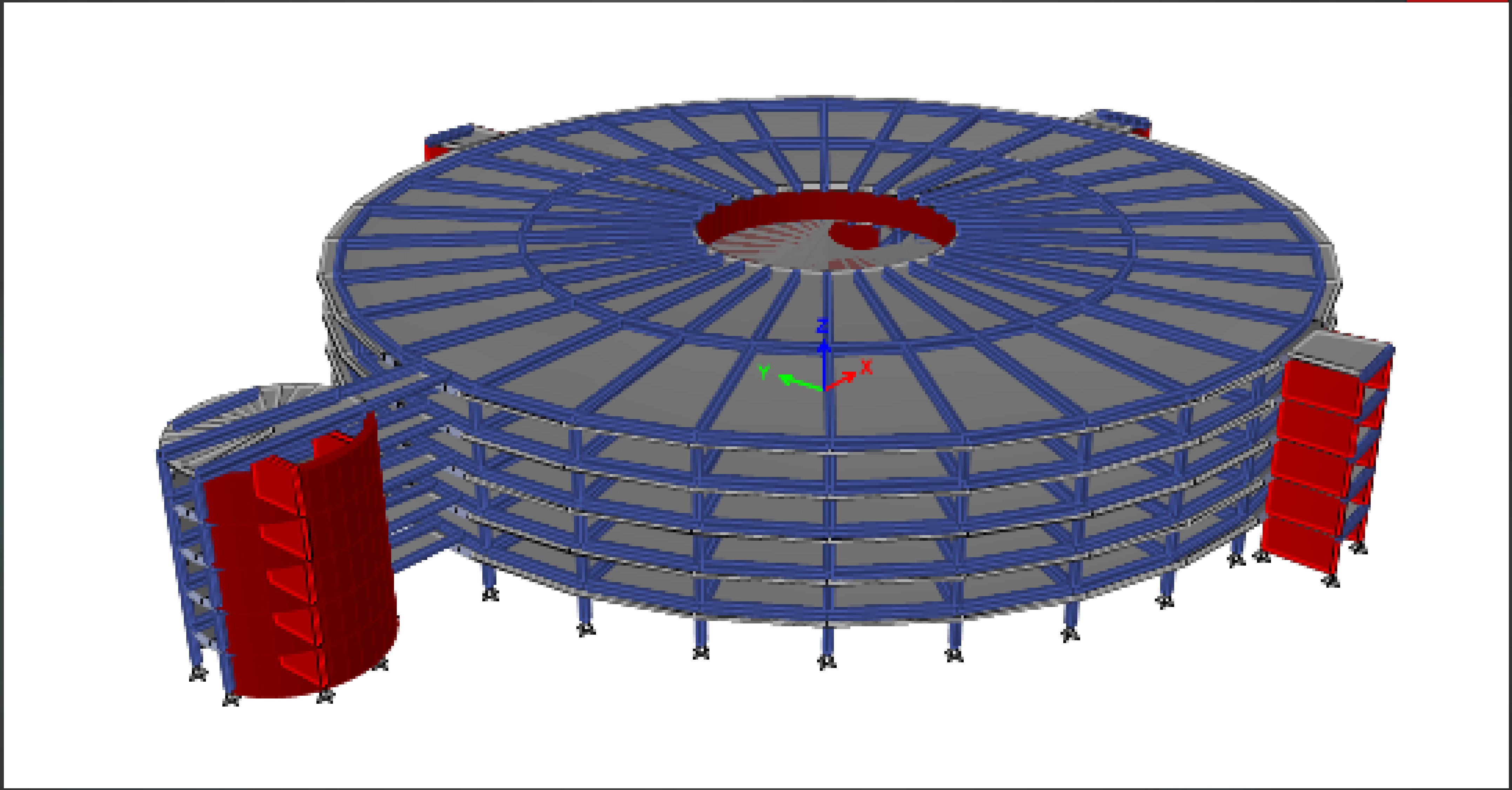
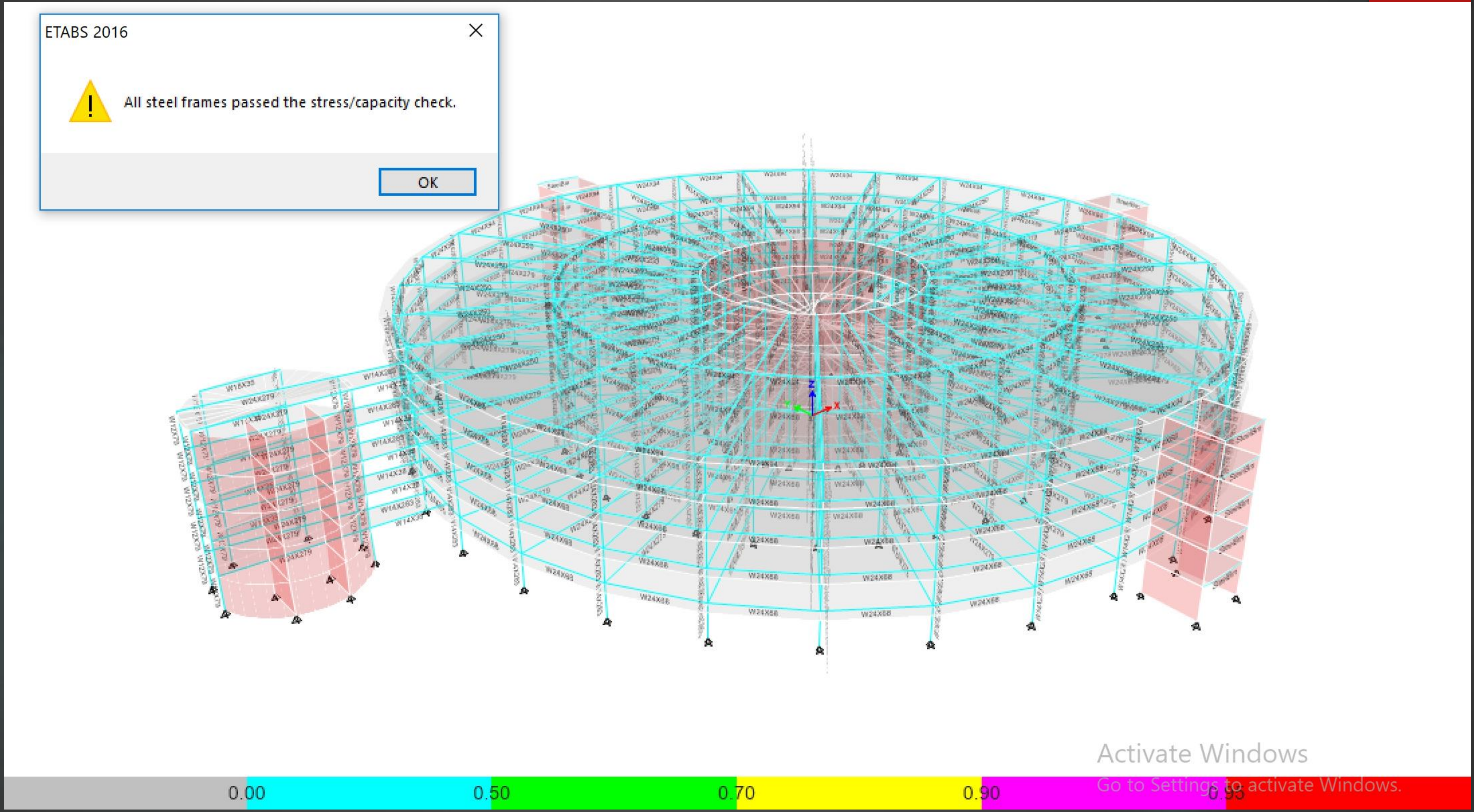
2
D
Stairs
Elev
St-1a
St-1b
St-2b
St-2a

3D View



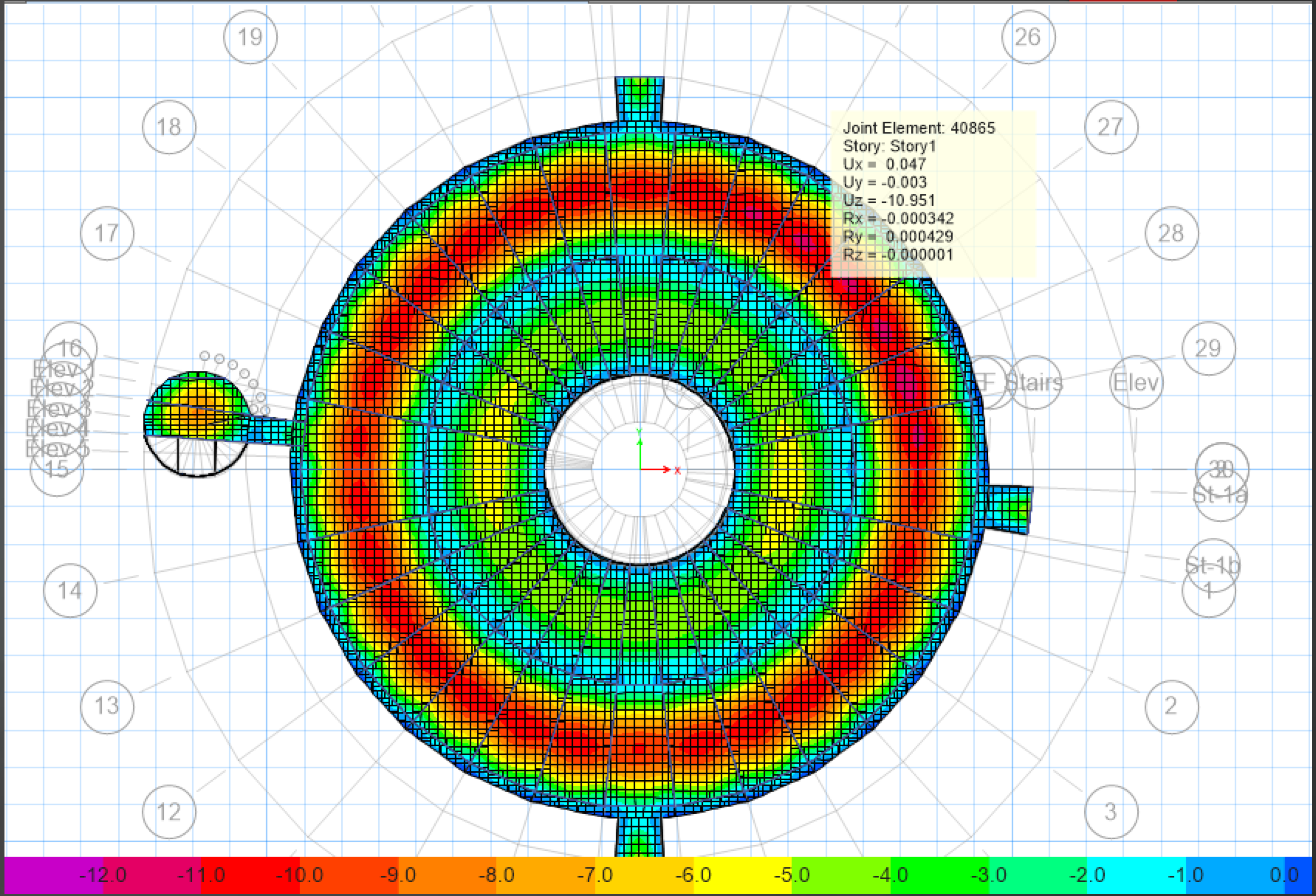
Members Analysis



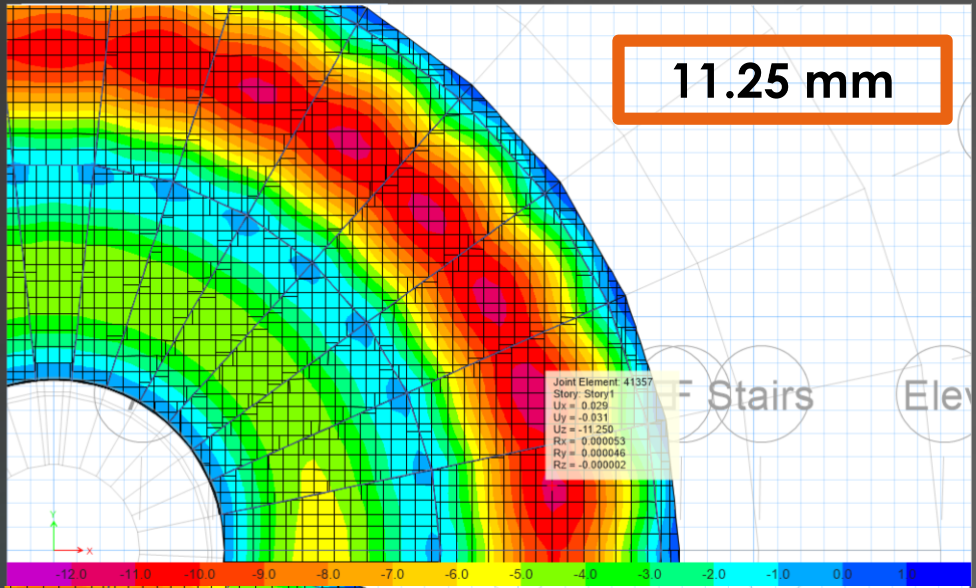
Deflection Mapping

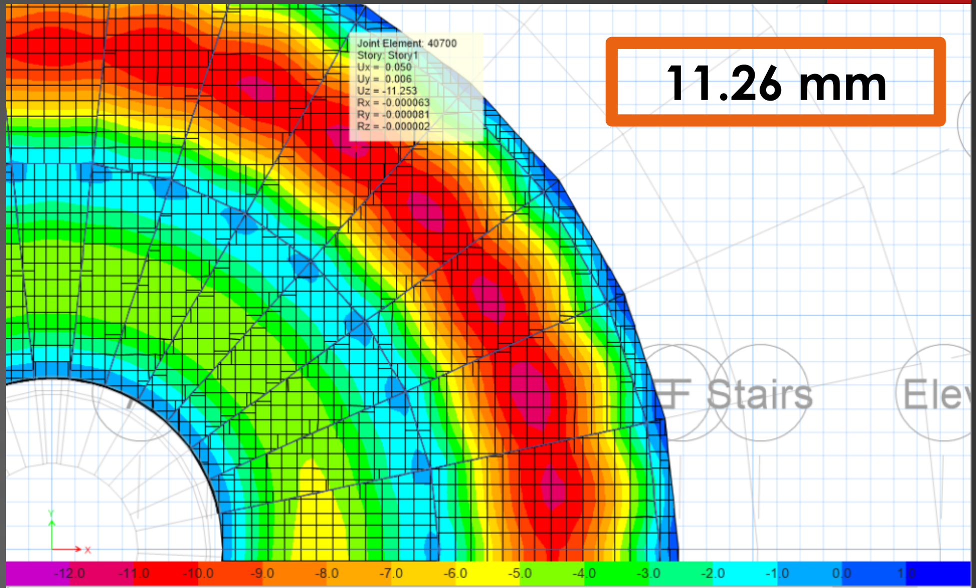
Allowable = *25 mm*

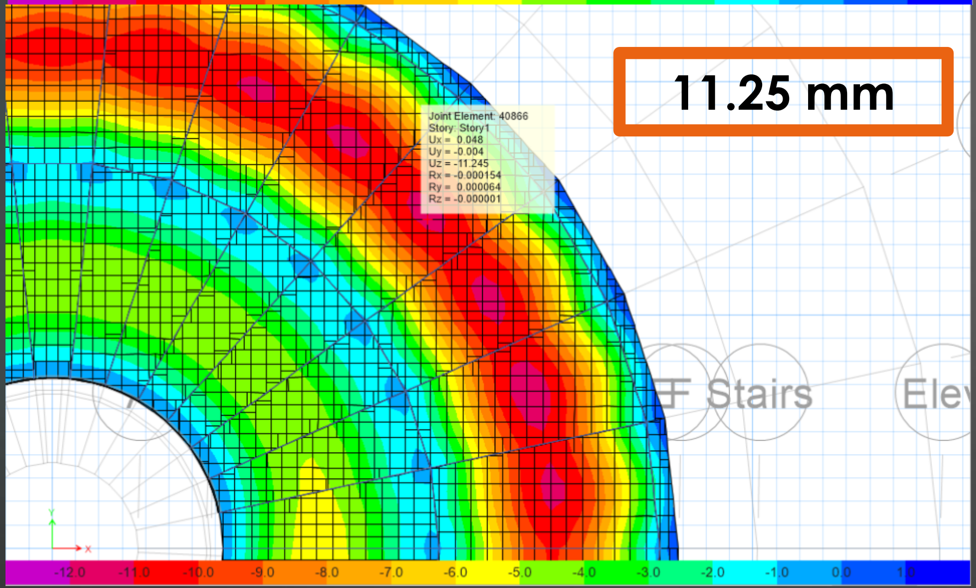
Highest deflection of lowest floor = *11 mm*

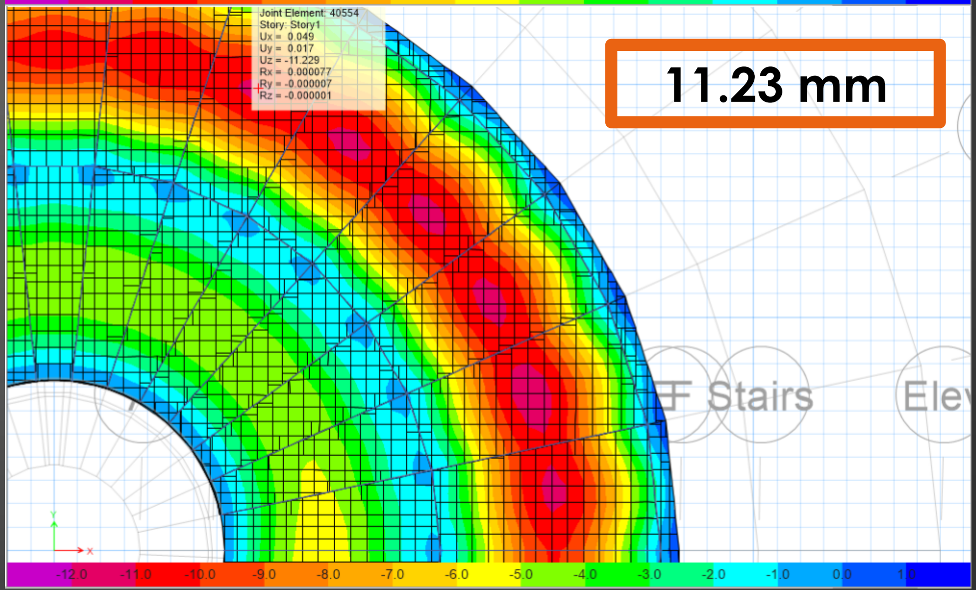


Moving Load Simulation







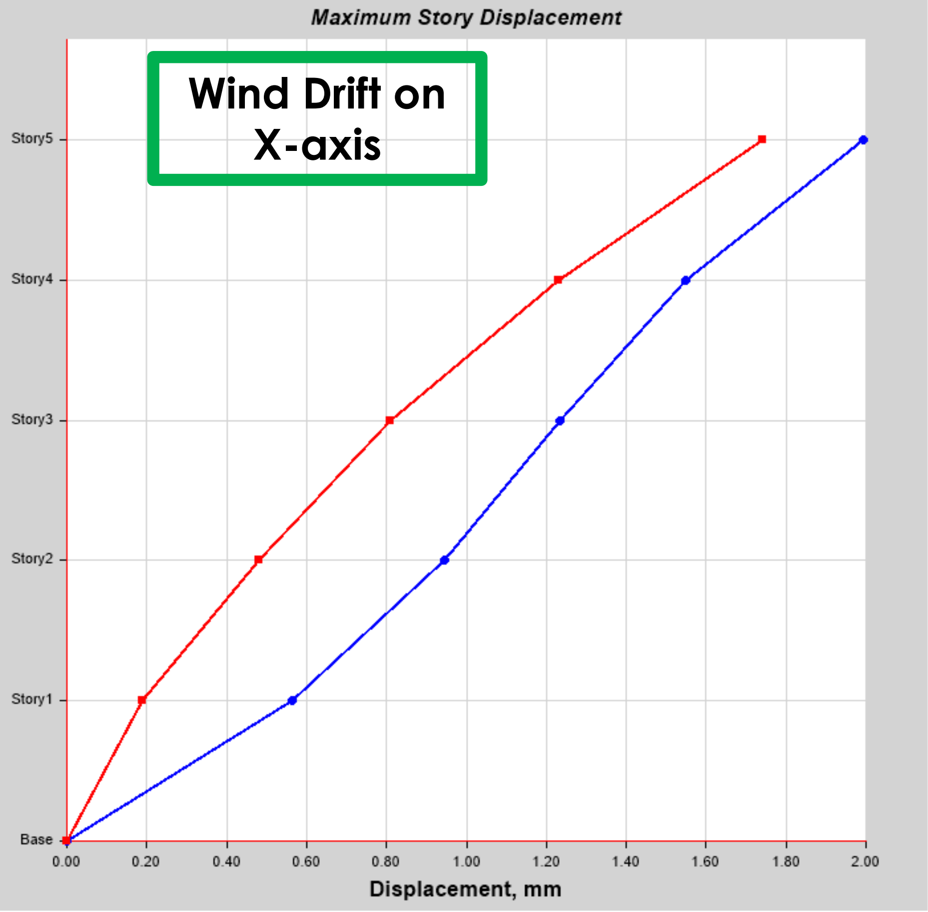


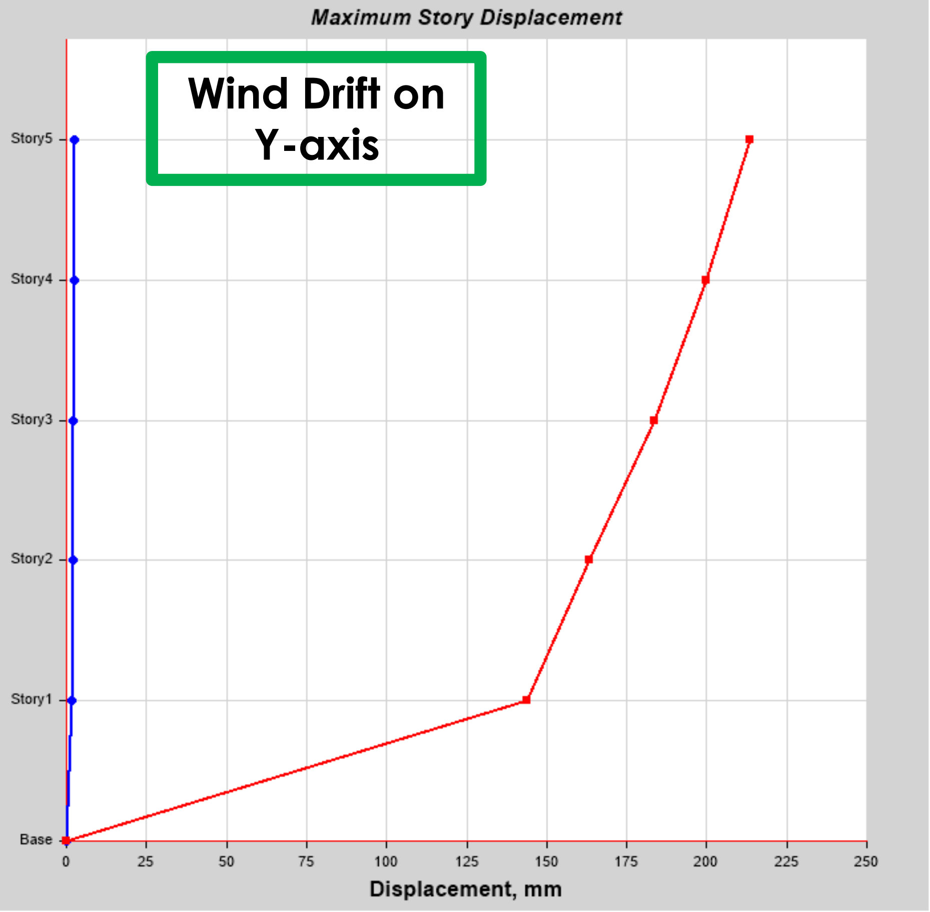
Drift Analysis

According to SBC specifications for the max allowable wind drift on a structure; 2% of the structure's total height:
17.5 m x 0.02 = 0.35 m = 350 mm

Max drift on X –axis = 2 mm

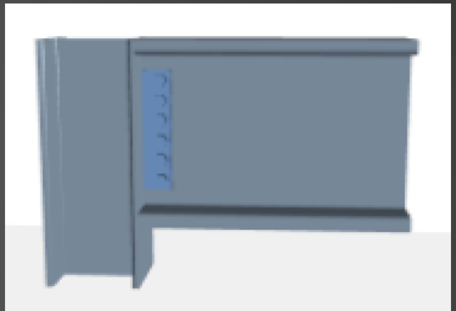
Max drift on Y – axis = 220 mm



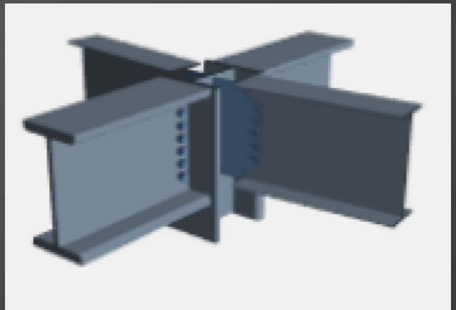


Connections

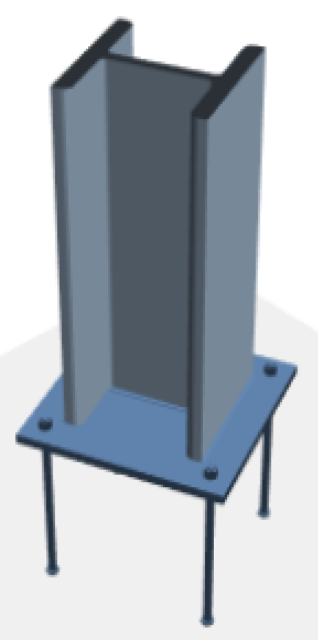
Item	Beam-Beam	Beam-Column	Column-Footing
Bolt types	A325-N	A325-N	A325-N
Bolt size	M32	M32	M32
Hole type	STD	STD	STD
Plate Material	A992 f_y 50	A992 f_y 50	A992 f_y 50
Plate thickness (mm)	9.4	12.5	25
Weld Material	E70XX	E70XX	E70XX
Weld thickness (mm)	100	100	150



Beam – inner column Connection



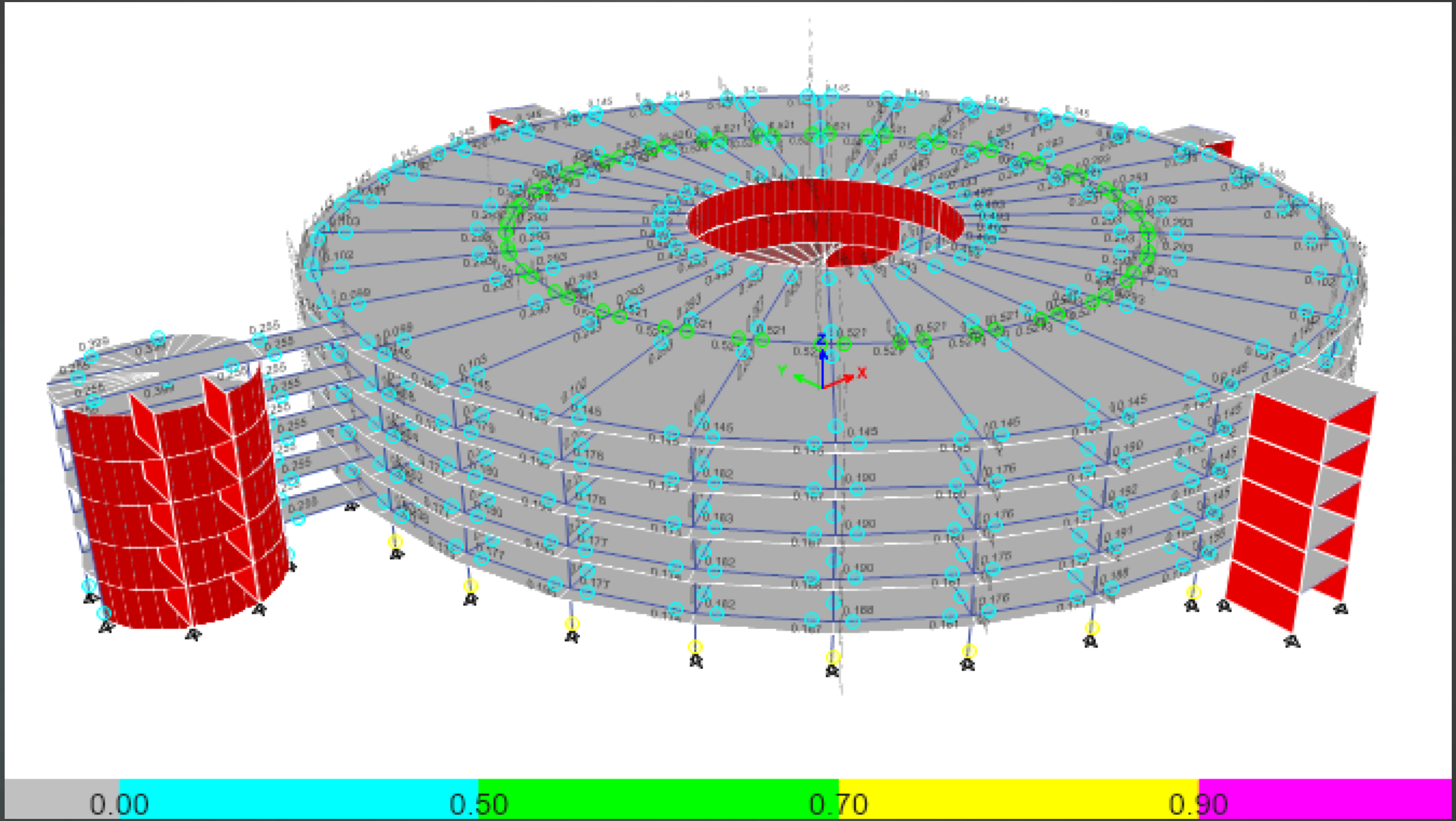
Beam – Middle column Connection



Column - Footing Connection

Connections

Connection Analysis



Geotechnical and Foundation System Design

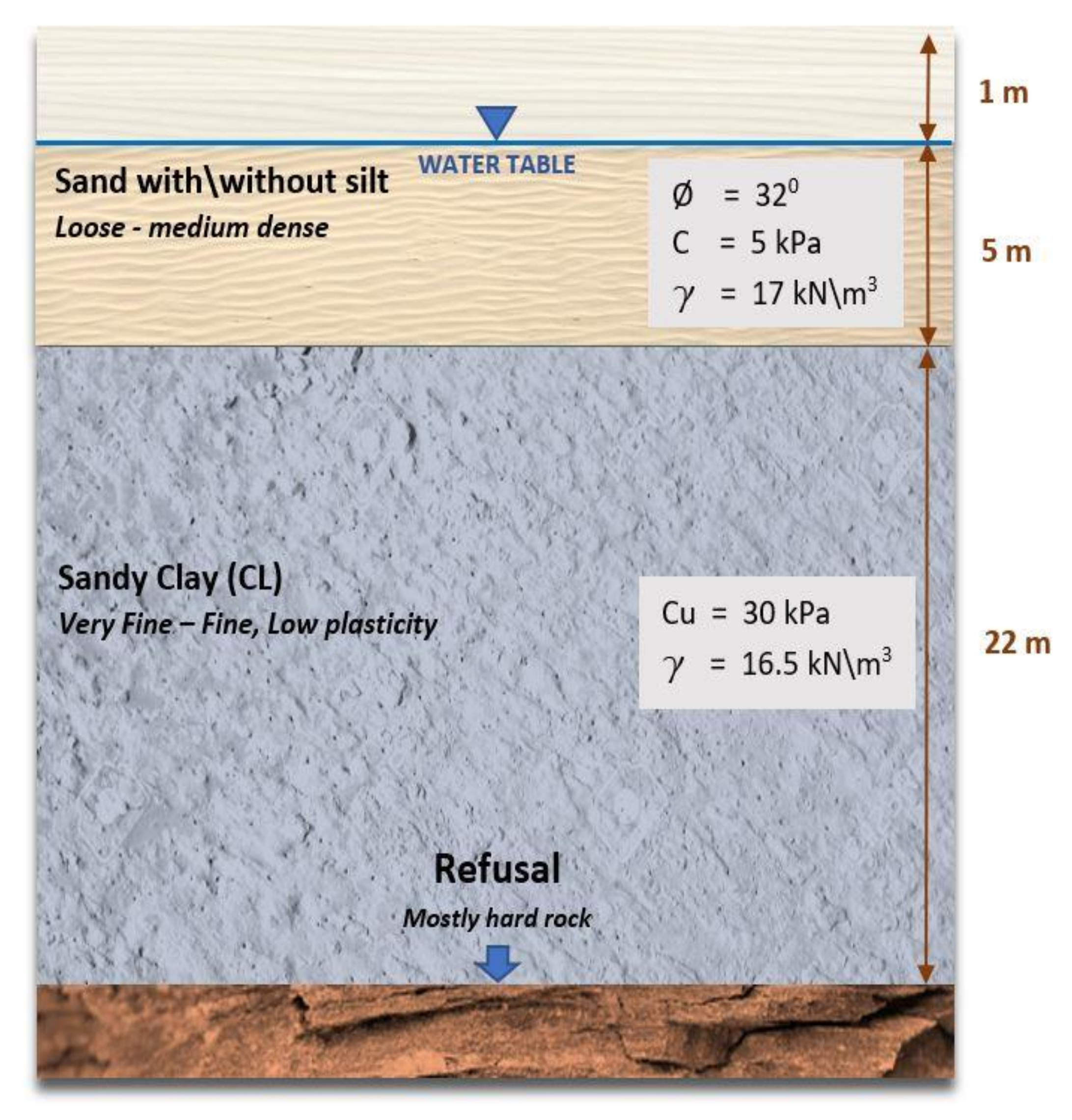
> *"It is not the beauty of a building you should look at; it's the construction of the foundation that will stand the test of time"*
>
> *David Allan Coe*

In this section:

- Native Soil Profile and Improvements Made
- Deep Foundation Solution
- Shallow Foundation Solution

Obtained Soil Profile and Chemical Analysis

- High water table
- Problematic "Sabkha soil".
  - High Sulfate and Chloride content.
  - Low bearing capacity
- Findings indicate a need for:
  - Soil remediation
  - Minimization of clay settlement; Mat "raft" foundation resting on a pile system.

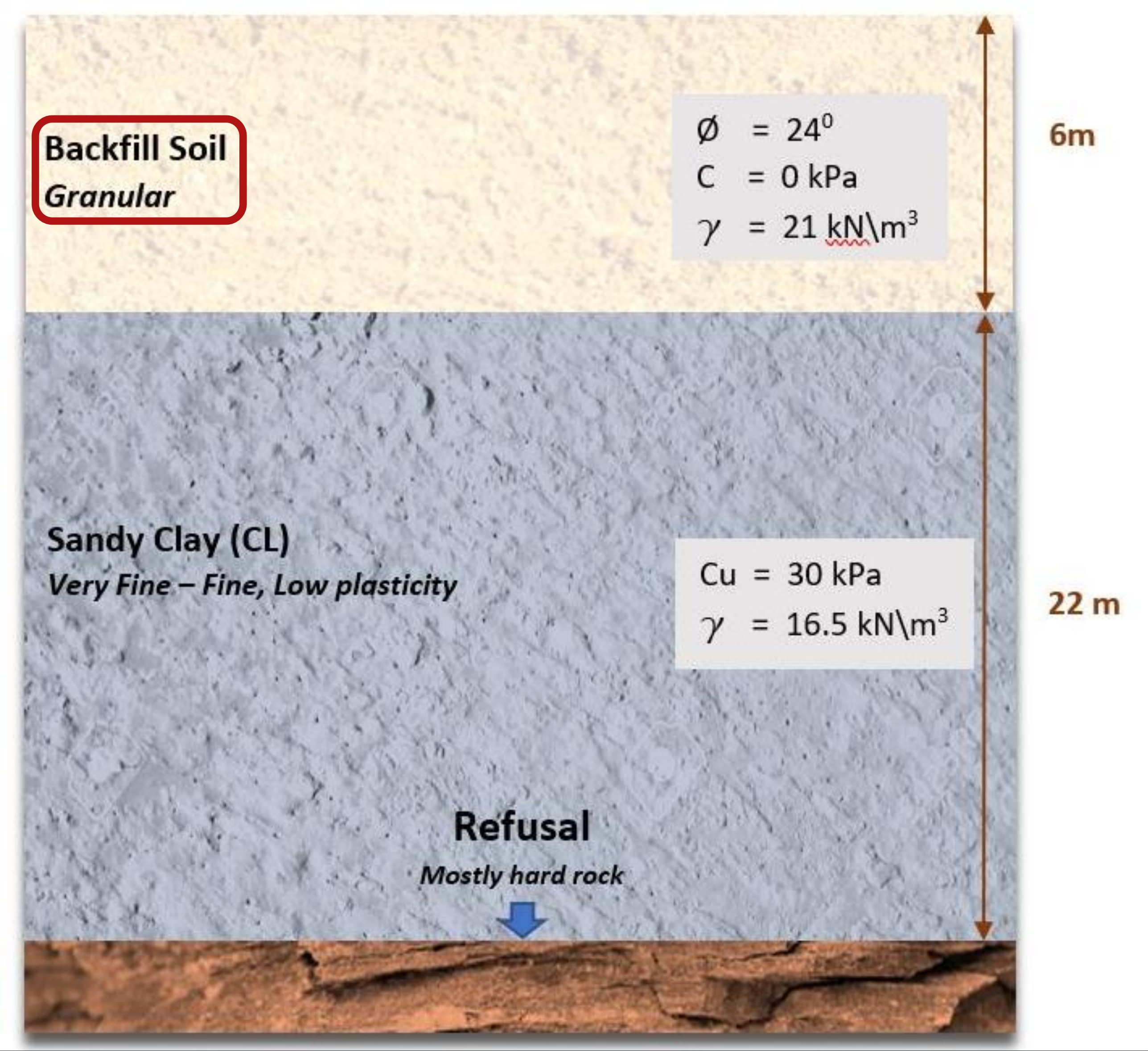


Chemical Analysis of Soil Composition

Sample No.	Depth (m)	Chlorides %	Sulphates %
1	1.00	0.381	0.391
2	1.00	0.321	0.400
3	3.00	0.088	0.375
Average		**0.24**	**0.38**
		Max permissible value > 0.05 % [1]	Max permissible value > 0.3 % [1]

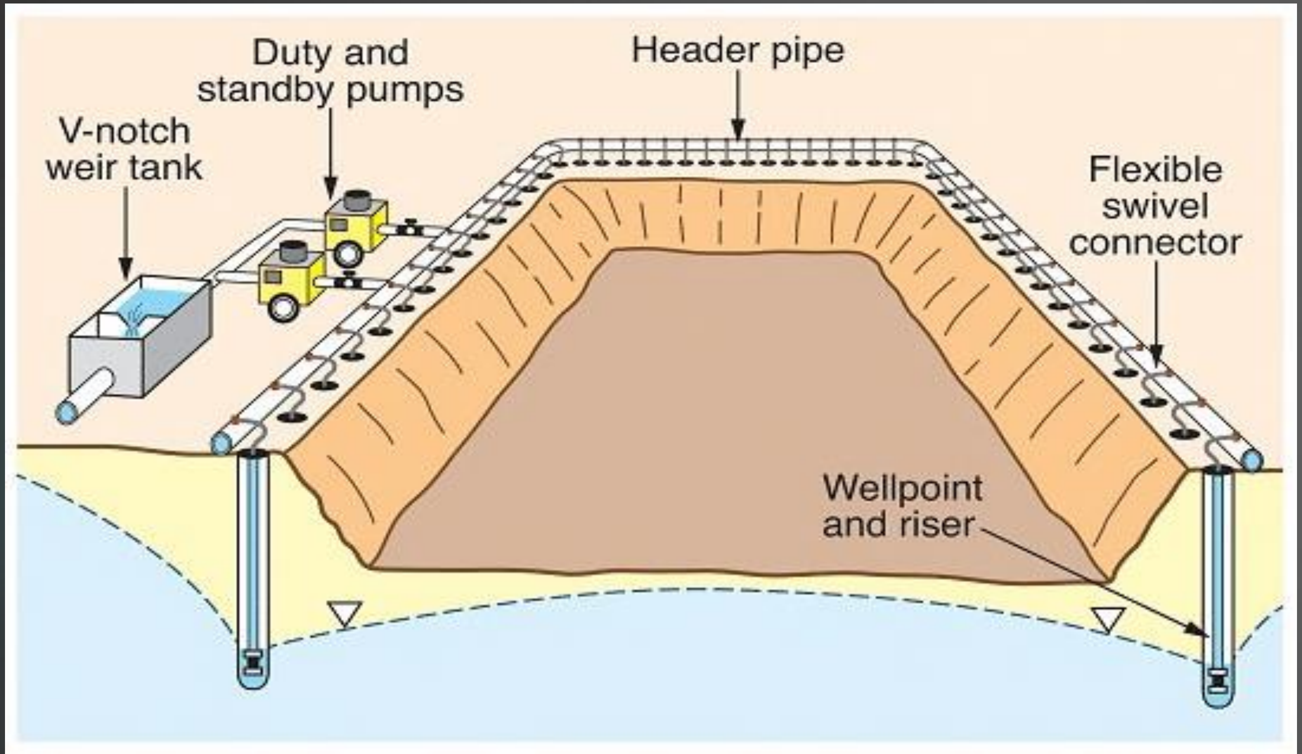
Modified Soil Profile

- Our recommendation for the management of the problematic top layer, is a complete exchange of the layer.
- The new material would be a denser granular soil with the following characteristics.



Temporary Dewatering

Single-Stage, Wellpoint-Dewatering



Courtesy of Shand P, et al; Guidance for Dewatering of Acid Sulphate Soils

Temporary solution to improve construction conditions:

- *Safety on site.*
- *Concreting of elements in contact with soil.*

Deep Foundations; Piles

$$Q_u = Q_p + Q_s$$

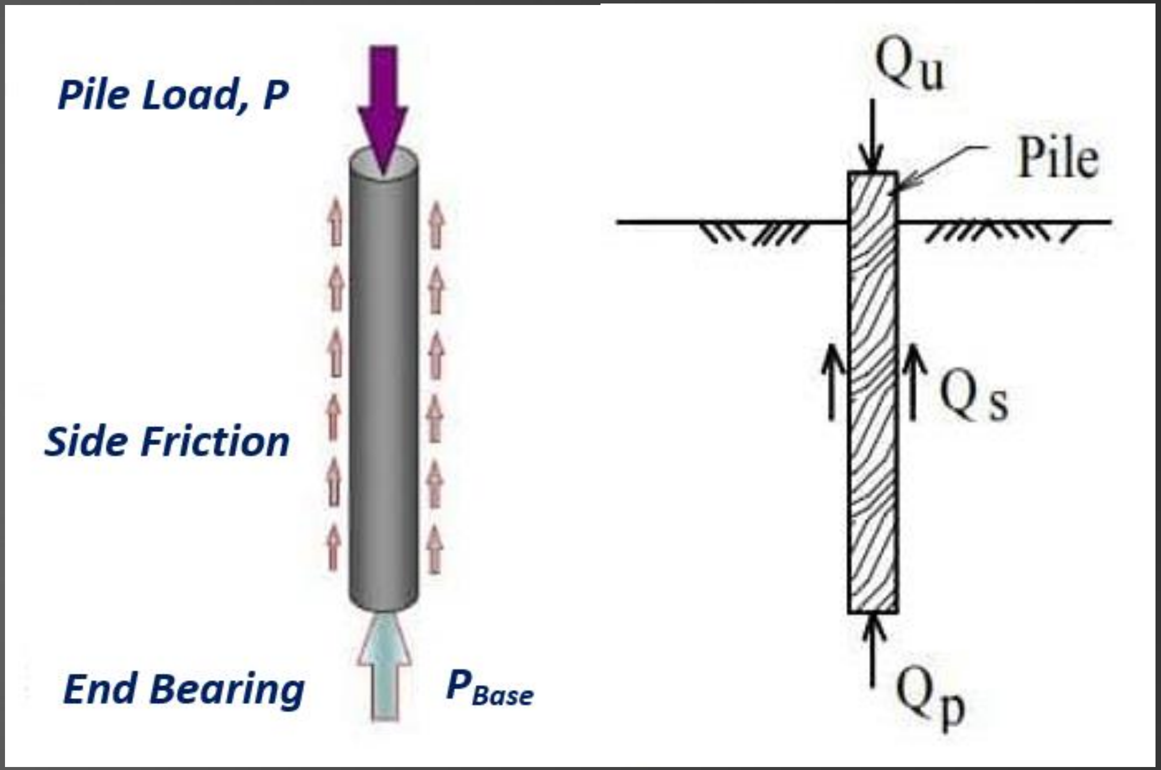
$$Q_{all} = \frac{Q_u}{FS}$$

Where:

$$Q_s = \sum \alpha C_u p \Delta L$$

$$Q_{p\,(rock)} = A_p q_p$$

No	Diameter (m)	Q_{all} (KN)
1	*0.3*	*202*
2	*0.4*	*290*
3	*0.5*	*388*
4	*0.6*	*496*



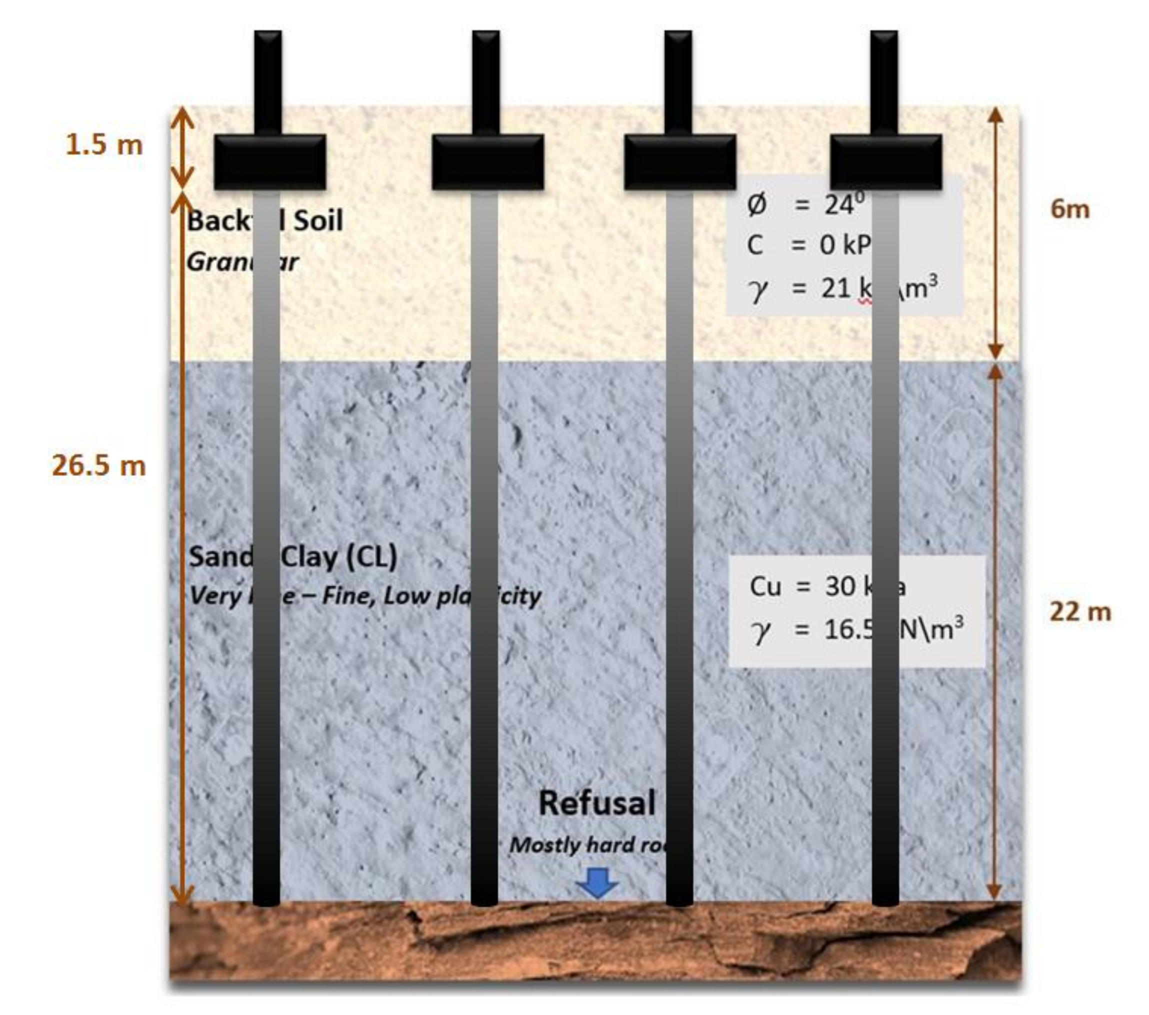
Retrieved from *theconstrcutor.org*

Isolated foundation

Solution tested is a *1.5 m x 1.5 m* footing

$$q_u = 1.3\, c\, N_c + q\, N_q + 0.4\, B\, \gamma\, N_\gamma$$

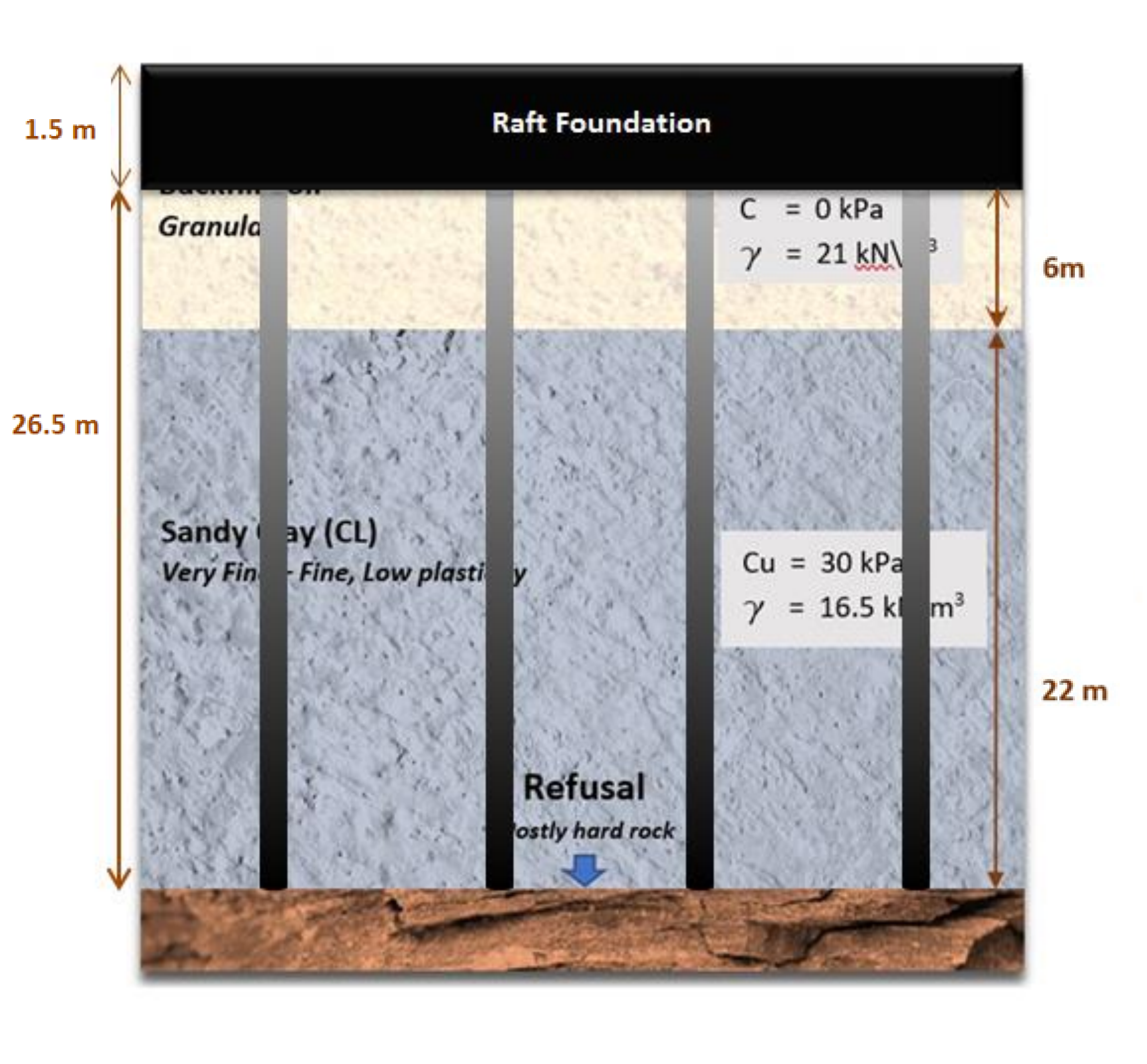
Dimensions	Unit (m)
Embedment Depth	*1.5*
Width	*1.5*
Length	*1.5*



Raft Foundation

$$U = b_o d \left[\phi \, (0.34) \sqrt{f'_c} \right]$$

$$\therefore \; The\ Thickness\ of\ the\ Raft\ (d) = 1.25\ m \approx 1.5\ m$$



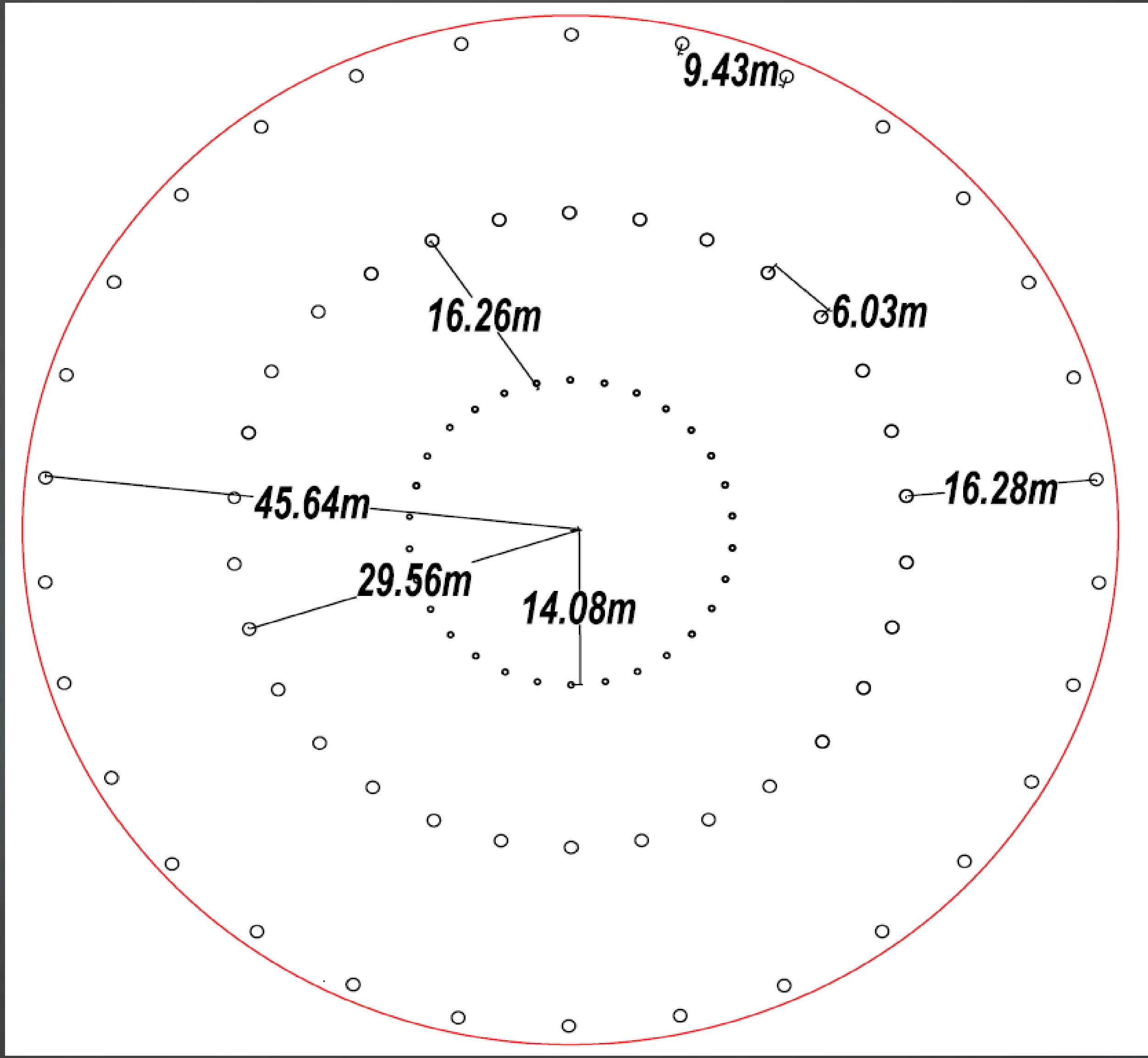
Point Soil Pressure Under Each Column

$$q_{(x,y)} = \frac{Q_{total}}{A} \pm \frac{M_y x}{I_y} \pm \frac{M_x y}{I_x}$$

$$q_u = c\, N_c F_{cs} F_{cd} F_{ci} + q\, N_q F_{qs} F_{qd} F_{qi} + \frac{1}{2} B\gamma N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i}$$

Critical Point Pressure (KPa)		Bearing Capacity of the Soil (KPa)
23.602	<	56,452

Pile Distribution Plan



Reinforcement

In this section:

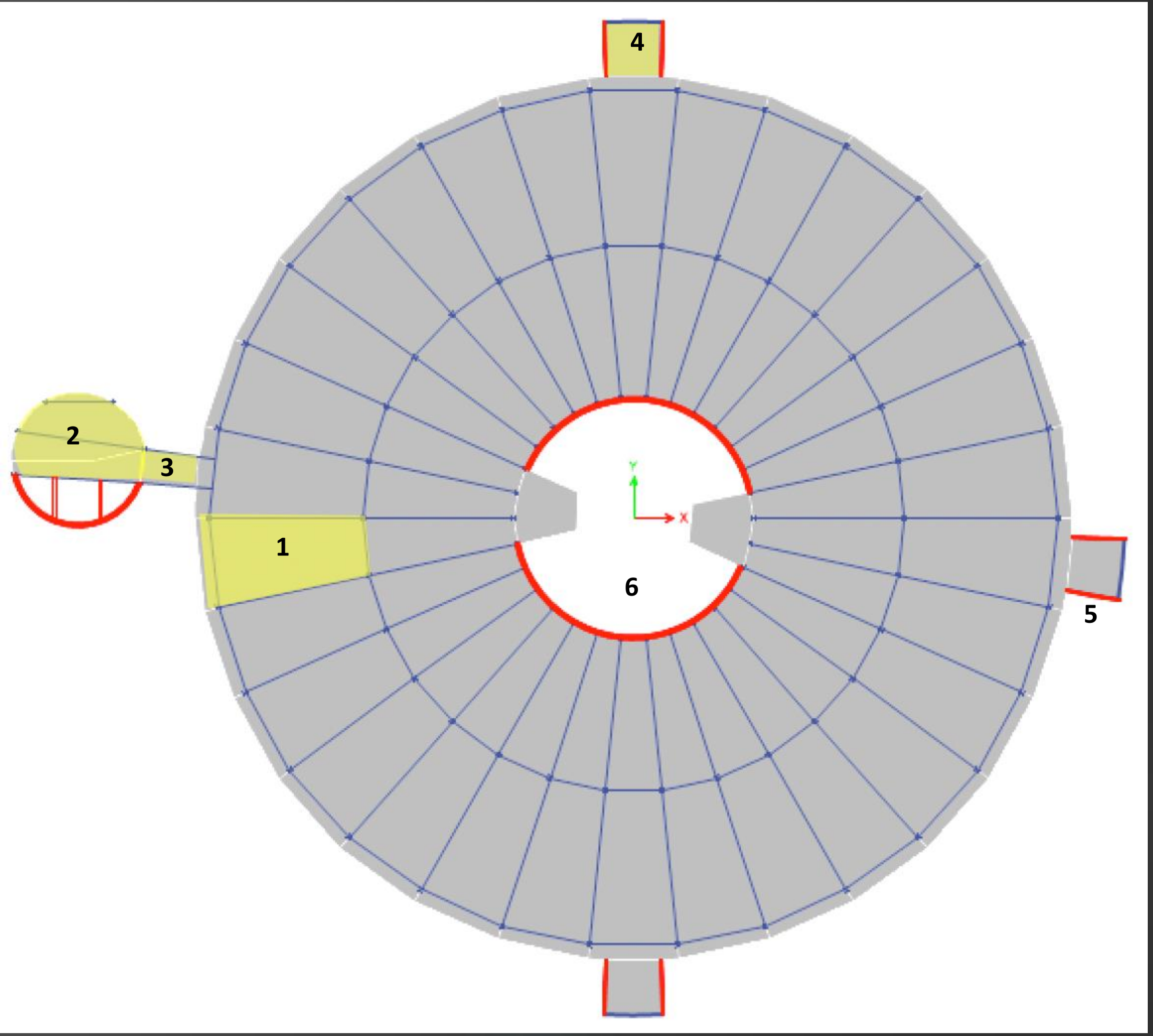
- Types and Load Cases
- Reinforcement Methods
- Slab Reinforcement
- Shear Wall Reinforcement
- Raft Reinforcement

Reinforcement

Types of slab, and shear wall segments:

1) Main Structure Slab
2) Elevator Structure Slab
3) Pedestrian Bridge Slab
4) Stair Structure Slab
5) Stair Structure Shear Wall
6) Ramp Shear Wall
7) Elevator Structure Shear Wall

Load Case / Location	DL	Combo	DL + W_x	DL + W_y
Main Structure	49.344	50.811	18.856	35.078
Stair Structure	8.577	7.619	11.34	6.956
Pedestrian Bridge	12.304	21.371	11.69	11.79
Elevator Slab	35.281	44.357	21.446	25.749



Locations of Elements Considered for Reinforcement Design

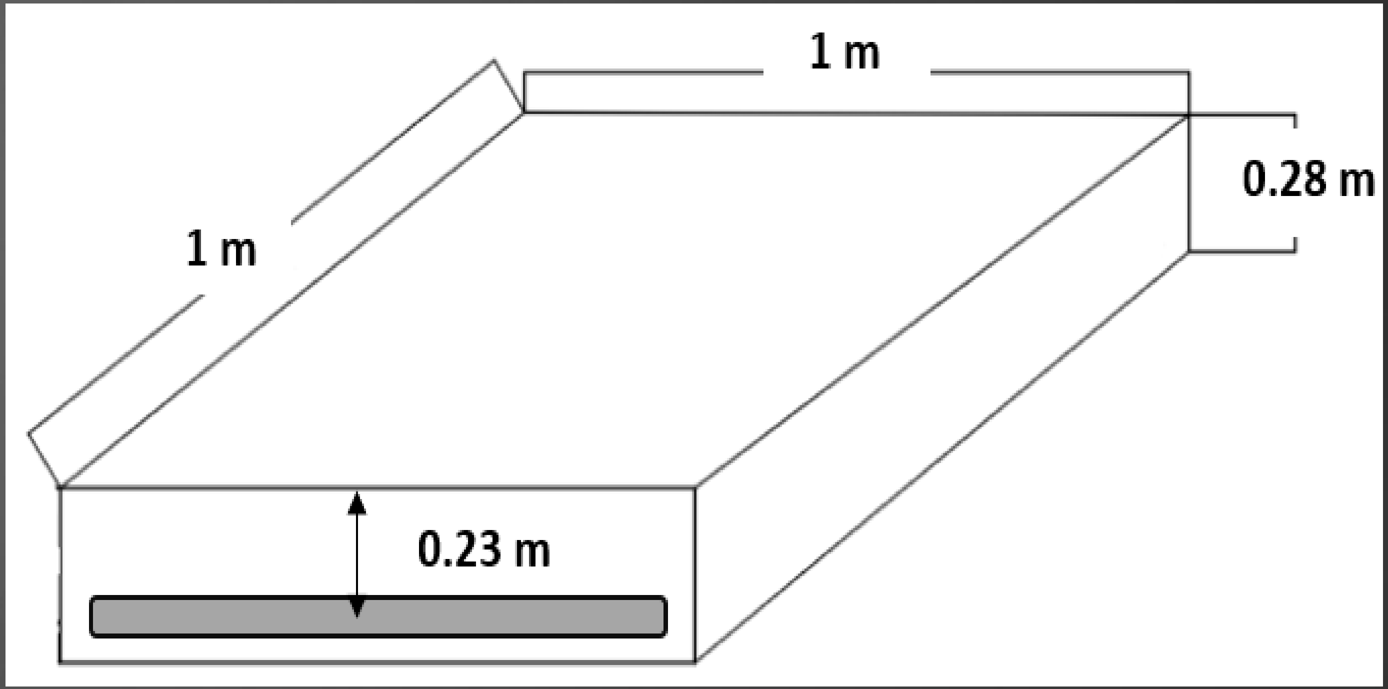
Reinforcement Calculation Method

$$\bar{k} = \frac{M_{max}}{\emptyset\, b\, d^2}$$

$$\rho = \frac{0.85\, f_c'}{f_y}\left[1 - \sqrt{1 - \frac{2\,\bar{k}}{0.85\, f_c'}}\,\right]$$

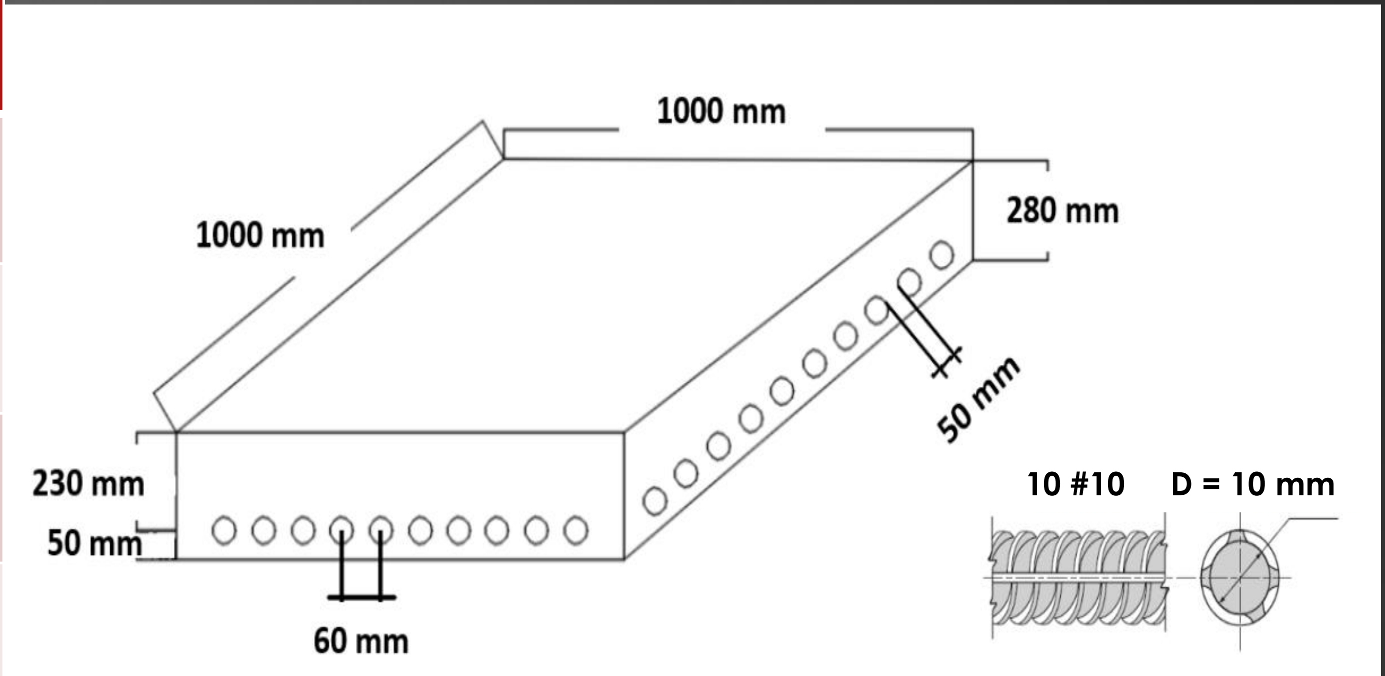
$$A_s = \rho\, b\, d$$

$$S_{max} = A_{one\ bar}\,\frac{b}{A_{s\,(required)}}$$



Slab Reinforcement

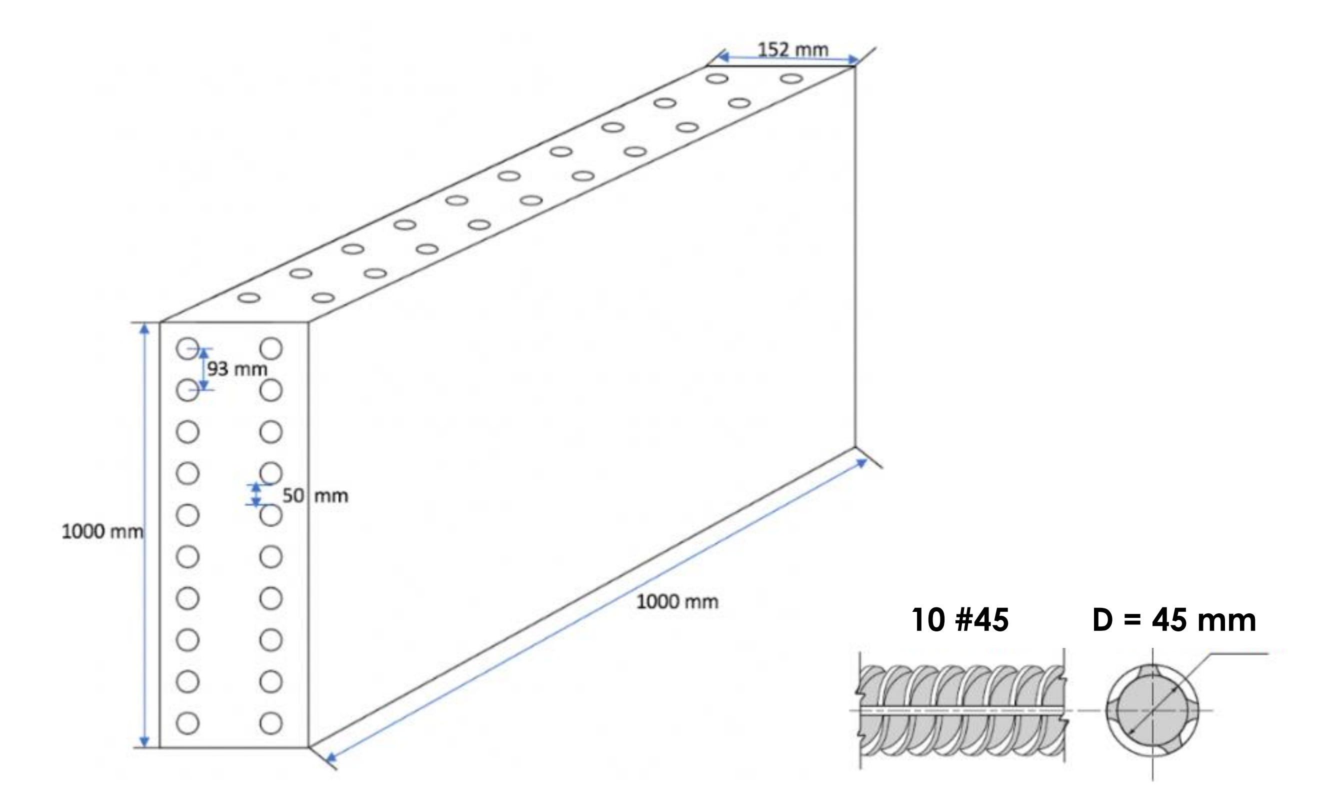
Structure	No. Bar	Diameter (mm)
Main Structure	*10*	*10*
Elevator	*5*	*10*
Stairs	*5*	*10*
Pedestrian Bridge	*10*	*10*
Ramp Structure	*6*	*13*



Main Structure Slab Reinforcement

Shear Wall Reinforcement

Structure	No. Bar	Diameter (mm)
Main Structure	10	43
Elevator	19	25
Stairs	20	16



Ramp (Main Structure) Shear Wall Reinforcement

Raft Reinforcement

$$q_{av} = \frac{q_{first} + q_{last}}{2}$$

$$Soil\ Reaction = q_{av}\ L\ B$$

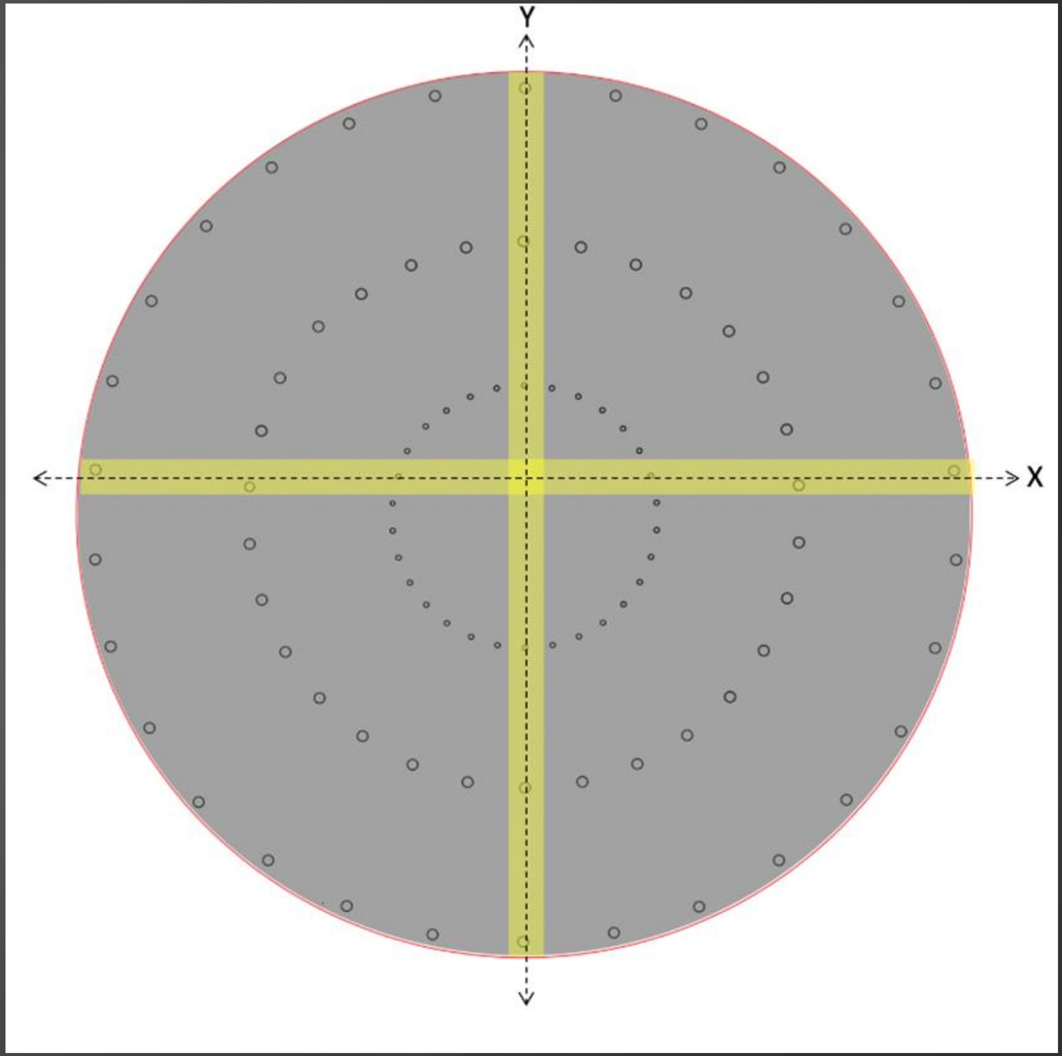
$$Load_{\ avg} = \frac{soil\ reaction + \sum Q}{2}$$

$$q_{av\ (modi)} = \frac{Load_{avg}}{L\ B}$$

$$F = \frac{\sum Q}{Load_{\ avg}}$$

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

Modified Critical Strip Point Loads (kN)				
NO.	Inner	Middle	Outer	direction
9	*513.387*	*4158.060*	*3085.892*	*X direction*
23	*480.825*	*4116.437*	*3314.105*	



Location of Critical Strips on X and Y axes.

Raft Reinforcement

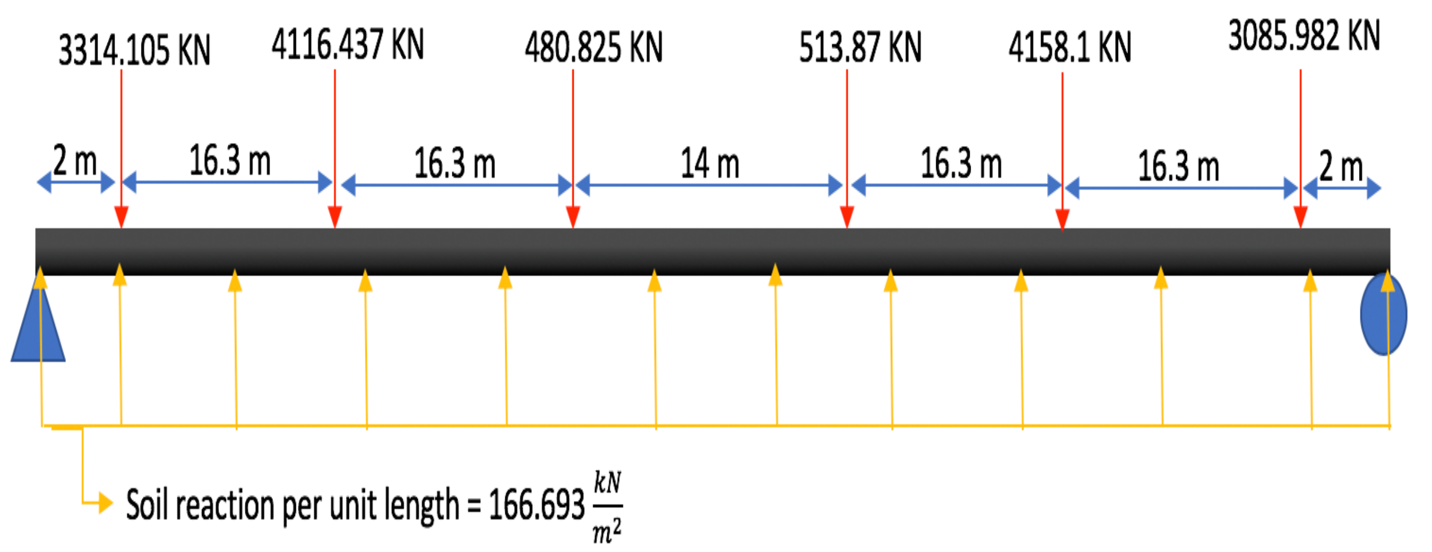
$$M' = \frac{Moment\ max}{B}$$

$$M_u = M'(F)$$

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

$$a = \frac{A_s f_y}{0.85 f_c{}' b}$$

Spacing	Diameter (mm)	Spacing (mm) c/c	As provided (mm^2/m)
Top	25	175	2805.7143
Bottom	25	175	2805.7143



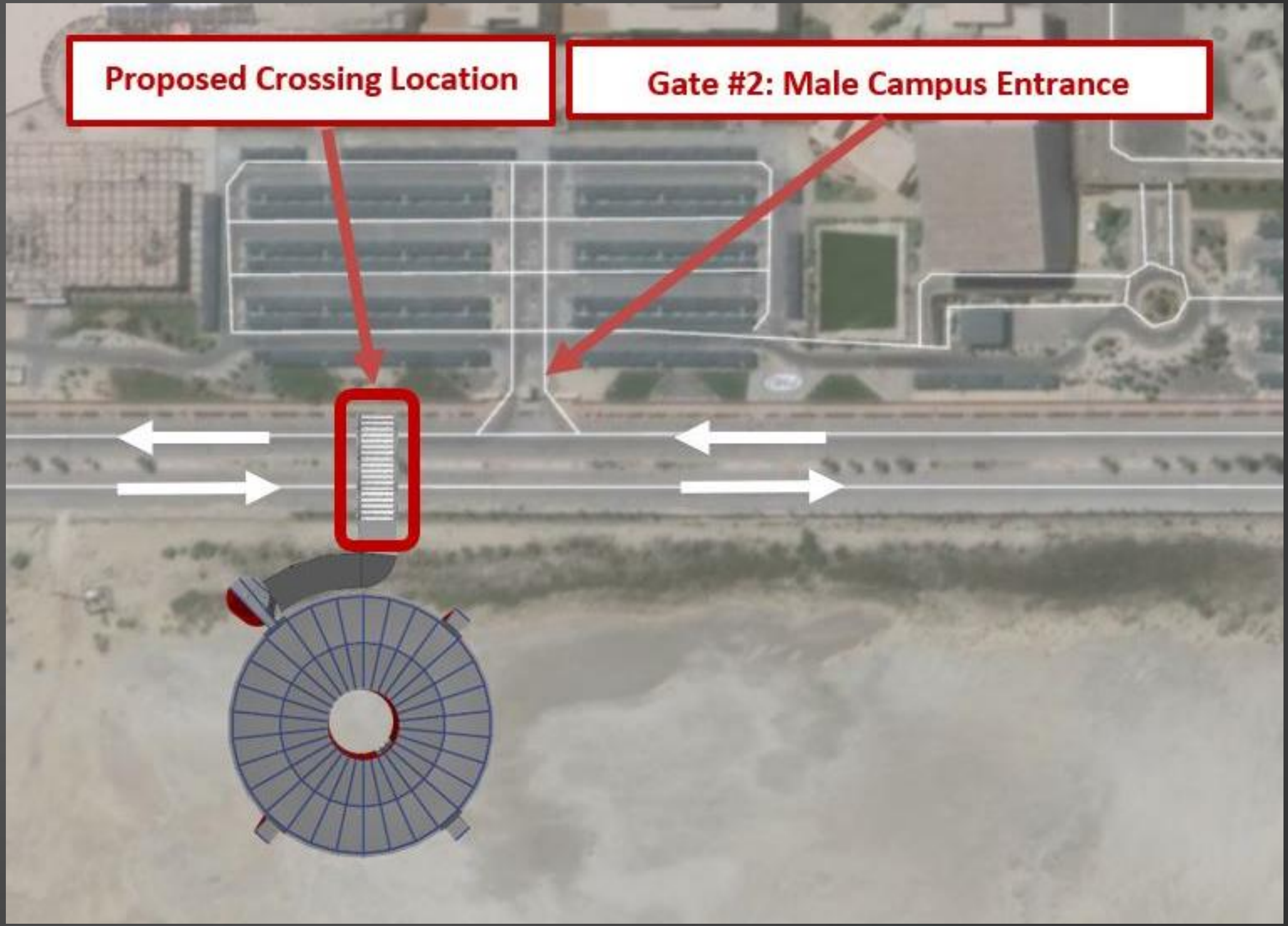
Representation of Strip as a Simply Supported Beam

Cost Estimation

Total Material Cost		
No.	**Material**	**Cost (SAR)**
1	Steel Members; Including Galvanization, Connections and Transport	*23,283,000*
2	Pre-Mixed Concrete; 4000 psi, Type III & Type V	*10,053,944*
3	Steel Rebar Reinforcement	*17,294,400*
4	Epoxy Sealant Coating and Marker Painting	*2,498,321*
5	Deep Foundation; Driven, Steel-Pipe-Piles	*363,266*
Total Cost SAR		*53,492,931*
Total Cost USD		*14,266,113*

Additional Pedestrian Crossing

- A safe pedestrian passage to and from the parking structure.
- Directly to Gate #2; Male Entrance
- Raised platform with proper traffic signage and markings.



Additional Solar Roof

Cost Recovery Proposal

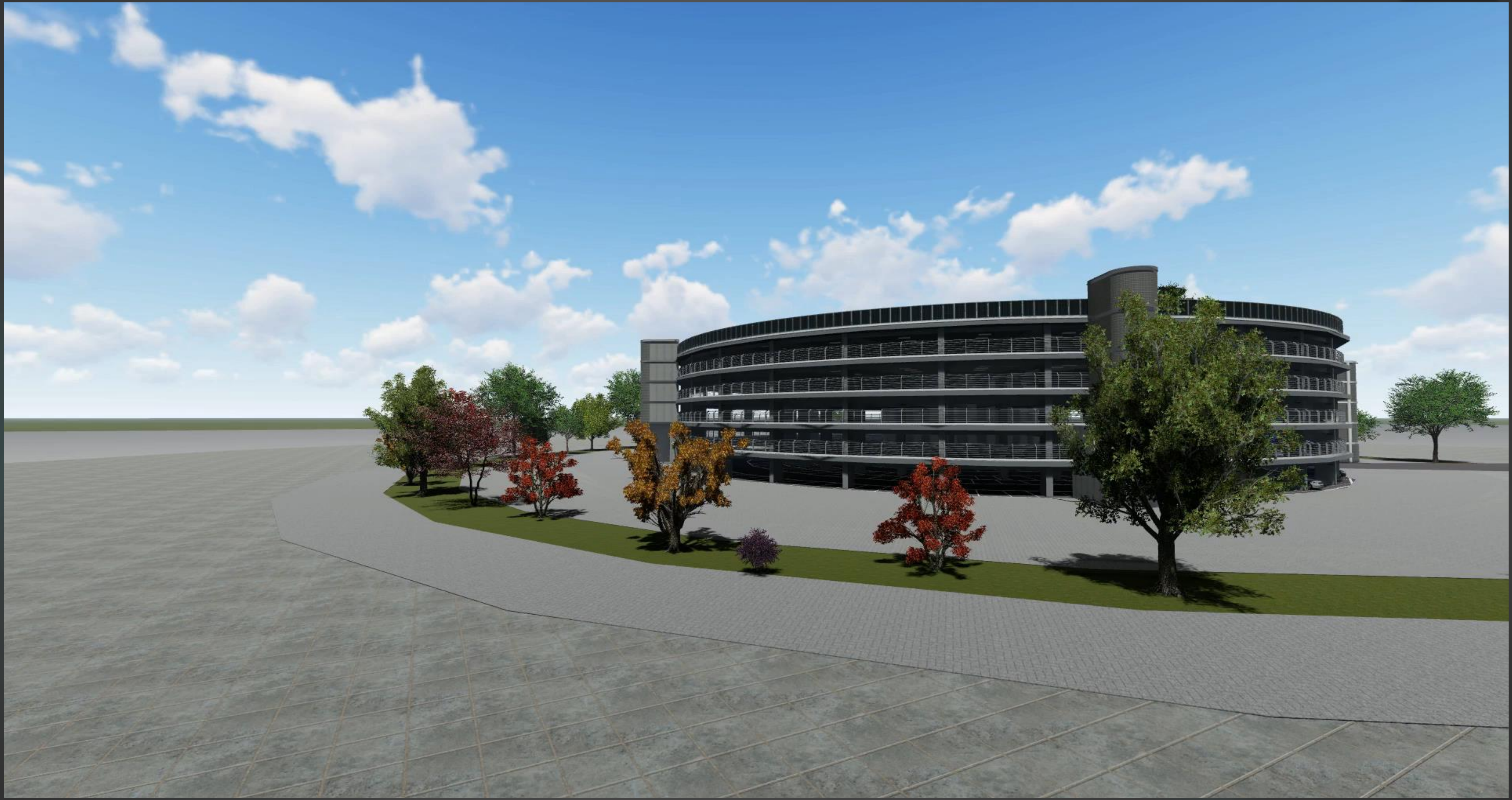
Surface area considered = 3500 m^2
Panel area = 1.96 m^2
Total Wattage = 660 kW
Total output / annum. ≈ 2,200,000 kWh
Cost of Solar Roof ≈ 1,367,000 SAR

Considering a 0.15 SAR/kWh tariff
Total Yearly recovery ≈ 396,000 SAR/annum.

Recovery of Panels Cost ≈ 3.45 years

72 cell, 370 W Monocrystalline Panels; Image courtesy of *Alibaba.com*

Apple Park Solar Roof; Image courtesy of *dezeen.com*



شكرًا جزيلًا

Thank You

ありがとうございました