Analysis and Design of Air Traffic Control (ATC) Tower

ABSTRACT

Air Traffic Control (ATC) towers are one of the strategic and vital structures for the functionality of each airport. Air Traffic Control (ATC) tower is a mandatory aeronautical facility for the operation of the airports and these are operated by Airport Authorities of India (AAI). Seismic performance and the demands of ATC towers significantly differ from common structures. Air traffic control (ATC) is a service provided by ground-based air traffic controllers who direct aircraft on the ground and through controlled airspace, and can provide advisory services to aircraft in non-controlled airspace. In this paper, the seismic performance of Air Traffic Control (ATC) tower which are located in zone- IV, according to Indian standard code of Seismic 1893(Part-1) -2016 is investigated through numerical simulations. In this time Airports are very important for economic growth. The demand for airport capacity has been growing very fast and private sector companies are also investing in airports infrastructures. In this research is focusing on the local influence around the globe, ex.-geographically, weather, social and building conditions. we are used the ETABS software for the designing and analysis of ATC tower with (G+6) story's having a ground floor are planned for UPS panel and IT server purpose and all other floors are proposed for technical block.

INTRODUCTION

HISTORY

The first powered flight was made by the Wright brothers on 17th December 1903 and from this historical moment the global aviation development started. During the World War I the development of aviation technology, aircraft manufacturing and pilot training accelerated furthermore resulting in increasing aircraft traffic and speeds. This led to safety concerns due to the lack of control capacity and the leaders of the aviation industry concluded federal action was needed to set safety standards.

In 1929 the first air traffic controller was hired. His name was Archie W. League and his "control tower" was a wheelbarrow, which functioned as carriage for his chair, umbrella and signal flags. League sat down along the runway directing the aircraft with the signals "Go" or "Hold". However this technique was soon out-dated by the introduction of the radio technology that allowed air traffic control to expand beyond airport boundaries.

The first radio equipped control room was opened in 1930 at Cleveland's Municipal Airport and can be seen as the first air traffic control tower in the world. In the following five years about twenty other air traffic control towers were built in the United States. Another milestone in the aviation development was the introduction of air traffic control centers in 1936. From that time airlines began tracking their flights between airports along their route, to ensure more safety.

During, and after, the World War II the need for passengers transport increased even more. The largest impact the World War II had on the aviation was the development of the radar. With this invention air traffic controllers were able to track airplanes very closely by a synchronized transmitter and receiver, which revolutionized air traffic control. The last major development in the aviation was the introduction of the jet engine in the late 50's. Larger and faster planes were being built and travelling by plane became more and more accessible and ordinary for the world.

Air Traffic Control (ATC) towers is one of the most strategic and necessary buildings in each airport, as functionality of each airport directly depend on the operation of ATC towers. Seismic design and the performance of ATC towers are challenging matters for structure engineers.

LITERATURE REVIEW

Adnan, M. Vafaei & A.K. Mirasa, These members are concluded the linear and non liner seismic analysis of a tall air traffic control (ATC) towers in 2012. In this paper, the seismic performance of Kuala Lumpur International Air traffic control tower is investigated through numerical simulations. Linear and nonlinear analyses are carried out and obtained results are compared. Results show that, in comparison to modal response spectrum analysis, equivalent static analysis overestimates overturning moments, drifts and lateral displacements. Moreover, linear analysis underestimate base shear, drifts and overturning moments in comparison to the results of nonlinear time history analysis. Furthermore, when the pile-foundation system is not considered in the nonlinear FE model, the damage severity at the mid-height of the tower is underestimated.

J.H. Hartmann, are concluded the research over feasibility study of air traffic controls towers around the globe in August, 2014. Air traffic control towers are very unique buildings. Most countries possess only one or a few towers and the specific knowledge of the technical and functional design of these towers are owned by a few consultants around the world. the overall objective of this thesis research is to perform an international investigation regarding the main local influences in order to provide an economical optimal structural design methodology for ATC towers which can be used to design these towers anywhere around the globe. Next, these optimal structural solutions are simulated to understand and to quality how the local boundary conditions relate with the structural design characteristics. E.g. how does an earthquake load compare with a wind load in certain countries, or how does a steel variant compare with a concrete variant. Unfortunately it is not possible to determine which structural design is the most economical solution, but this thesis research provides a design methodology which gives the designers a direction towards the most optimal solution when they take the specific cost aspects into account.

B.J. Sullivan, H. S. McKenzie & A.E. Philpott -2017, The new air traffic control tower for Airways Corporation of New Zealand (Airways) is located at Lyall Bay, Wellington. The nine storey structure, references windy Wellington and has been designed to lean into the prevailing northerly wind by architects Studio of Pacific Architecture. The building's structure has been designed to meet onerous performance criteria, befitting the buildings designation as a critical post-disaster IL4 facility. The building has also been designed to meet client specific wind vibration criteria and to withstand tsunami inundation. Architectural requirements, including the 12.5 degree lean and the column-free tower cab add further to the structural challenges of this project. The adoption of a base isolated solution allowed far greater freedom to consider more dramatic architectural forms. The leaning structure and single central cab column could not have been achieved without a base isolated solution. At the same time, the cost of the base isolation solution was mitigated by savings in lateral structure and foundations. Careful collaboration between structure and architecture has been vital to ensure a rational structural form is maintained and to avoid numerous transfer structures. Tsunami inundation was considered a significant risk and a level of structural tsunami mitigation was deemed important to the client. Coastal Engineering advice from Tonkin & Taylor as well as international design guidance, ASCE 7-16 Chapter 6 – draft 2015, Tsunami Loads, helped to inform this process. The resulting building incorporates a unique structure that addresses the natural hazards of this exposed Wellington site, whilst addressing the complex functional and urban design objectives.

Simon HOSimon HO, Fergus McCORMICK, Julian SHEPPARD,- This paper over The Delhi Air Traffic Control Tower: Engineering, architecture and design with TMD for the tallest ATCT in India in September (2012). This short paper will discuss the design and structural challenges that were overcome on the Delhi Air Traffic Control Tower project, which will be one of the tallest in the world. As well as providing for the operational requirements of the air traffic controllers for the future, the architectural aspiration is to build a Air Traffic Control Tower that is internationally recognized, contemporary and provides an architectural landmark to Indira Gandhi International Airport, whilst continuing to embody the history and unique regional characteristics of India and be a source of pride for the employees of Delhi International Airport.

Project Brief

Brief description of building:

The proposed ATC tower cum technical block consists of towers comprising G+6+floor+ terrace Ground levels are planned for UPS panel & IT server purpose and all other floors are proposed for technical block.

Architectural view

Building Location:
Site for the proposed project of ATC tower cum technical block, Situated in seismic zone-5.

Functional Requirements:
The building consists of Ground+6floor+Terrace floor. The functional purpose of this building is for technical block.

Floor Height:

Ground Floor 2.10 m
1St. Floor 3.50 m
2nd. Floor 3.50 m
3rd. Floor 3.50 m
Tower Gallery 3.50 m
Apron Control 3.50 m
Control Tower 4.20 m
Terrace Floor 4.950 m

SITE SOIL CONDITION

The subsoil investigation consisted of drilling of exploratory borehole at three locations including conducting Standard Penetration Tests as well as collecting soil samples for various laboratory tests. In field as well as laboratory tests provisions set by relevant bureau of Indian Standard codes of practice were strictly followed. Field investigation consisted of 100mm vertical boring in three locations covering the area of the plot. During boring, changes in soil stratification were identified by the feel and color of the wash. Colour, odour etc. were visually identified during the process of boring.

Since the underlying stratum up to 4.50m depth is of softer consistency, so shallow foundation of any kind has been found to be unsuitable because of high compressibility & low bearing capacities. So, the analysis for estimation of bearing capacities for shallow foundation is not done. As an alternative proposed structure may be allowed to rest on cast in situ RCC Pile. Pile foundation derives support from subsoil at deeper depths if stronger layer at a suitable depth is available. However, for this case, good bearing stratum has been found to be available beyond 7.50M below G.L. So, suitability of bored cast in situ RCC pile is studied.

The subsoil in general is stiff from a depth of about 7.50m. Because of this, bored cast-in-sit RCC pile of 10.0m, 12.0m & 15.0m length can be suggested & capacity of such pile lengths have been examined. Cut off level is considered as 1.0m below G.L.

METHODOLOGY

The process, summarized below, has been used for the design and verification of the control tower;

1. Preliminary Design of pile isolation system to achieve a target isolated period and damping was completed using a single degree of freedom spreadsheet.

Materials of construction

Reinforced Concrete:

The cement used for RCC work in the sub structure & super structure will be OPC (Grade 43and 53) conforming to IS: 8112-1989 and 12269-1987. All RCC works will be mechanically vibrated to produce dense, sound and durable concrete as per specifications. The water quality used in all stages of construction shall strictly conform to IS: 456-2000.

The grade of concrete in the location at beam/slab-column junction shall be kept matching with the column grade below. However, the extend of this concrete into the slab shall be limited to 300 mm surrounding the column outline

The following grades of Reinforced concrete shall be adopted:

CONCRETE ITEM	CONCRETE GRADE	Max. Size of Aggregate (mm)	Type of cement used in Design Mix.
Pile foundation &columns	M40/M30	20	OPC
Shear Walls	M60/M50/M40/M30	20	OPC
Beams & Slabs	M30/M40	20	OPC
Water tanks	M30	20	OPC

All reinforcing steel to be used in the structural elements shall be:
High yield strength deformed TMT bars with a minimum yield stress of 500 MPa, a minimum elongation of 14.5% and other specifications conforming to IS: 1786 shall be adopted for 8mm to 32mm dia bars.

S.NO	BEAM SIZE	COLUMN SIZE	SHEAR WALL SIZE
1.	250 X 450 MM	500 X 500 MM	300 MM THICK.
2.	250 X 500 MM	750 X 750 MM	350 MM THICK.
3.	250 X 600 MM		
4.	250 X 700 MM		
5.	250 X 750 MM		
6.	350 X 750 MM		

STRUCTUAL DESIGN LOADS AND CRITERIA
Structural design actions for the ATC project have been determined in accordance with the loadings standard IS: 875 (Part I)-1987 and IS: 1911 and with a minimum design life of 50 years as required by the Building Act.
Plan of building

Loads
Dead Loads:
Following unit weights of building materials have been considered in accordance with IS: 875 (Part I)-1987 and IS: 1911.

▪ Reinforced cement concrete - 2.5 T/m3
▪ Plain cement concrete - 2.4 T/m3
▪ Brick masonry including plaster - 2.2T/m3
▪ Cement mortar / plaster - 2.1T/m3
▪ Floor finish (stone/tile) - 2.4 T/m3
▪ Brick bat coba for terracing/waterproofing roof - 2.0T/m3
▪ Moist, sweet earth for filling of planters - 2.0 T/m3
▪ Foam Concrete - 1.0 T/m3
▪ AAC Block Masonry - 0.75T/m3
▪ Note: Floor Finish shall be considered 75mm thick for retail and 50 mm studio.

Live Loads:

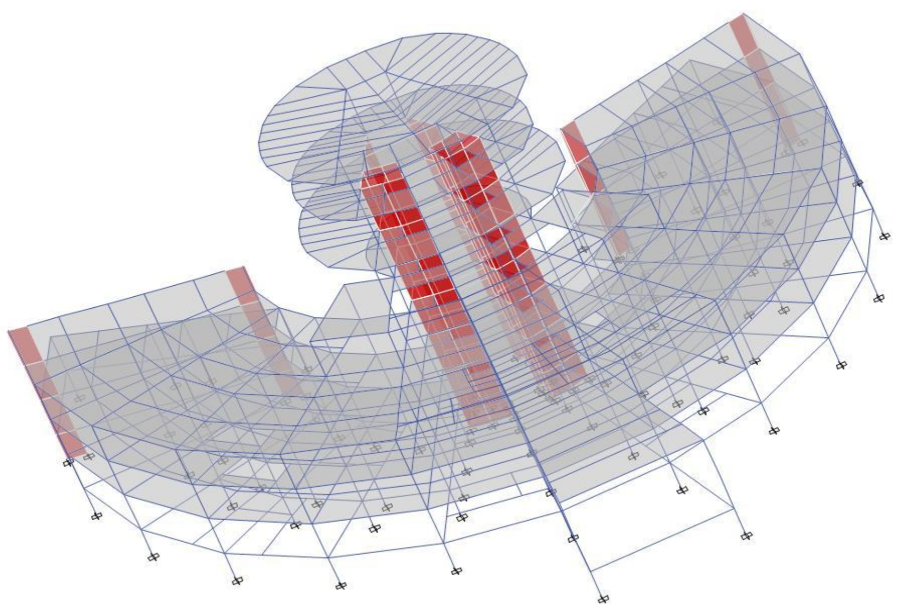
Following live loads have been considered in design in accordance with IS:875 (Part II)-1987.

- Live loading Typical floor 0.30 T/m2
- Live loading common passage staircase& balconies 0.40 T/m2
- Live load at terrace floor 0.15 T/m2
- Live loads (for construction) 0.10 T/m2
- Electrical room 0.50T/m2
- Refuge Area 0.50T/m2
- Lift machine room 1.0 T/m2
- Server room 1 T/m2
- Cafeteria 0.50T/m2
- AHU 0.40T/m2
- Toilet room 0.2 T/m2
- Pump room 0.75 T/m2
- UPS battery 1.0 T/m2
- Services including false ceiling 0.05 T/m2
- Partition 0.10 T/m2
- Cafeteria Load 0.5 T/m2

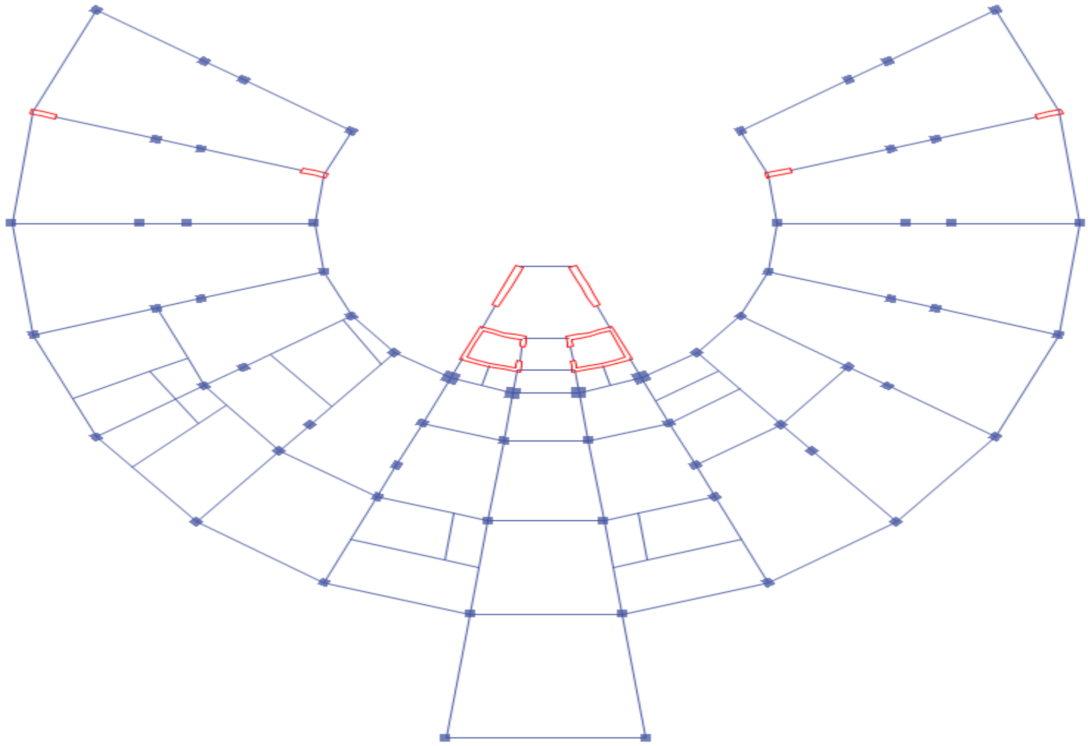
Wall Load-AAC blocks.

- 250mm.thk. Wall = 0.098Ton\m run\ m height
- 125mm.thk. Wall = 0.073Ton\m run\ m height

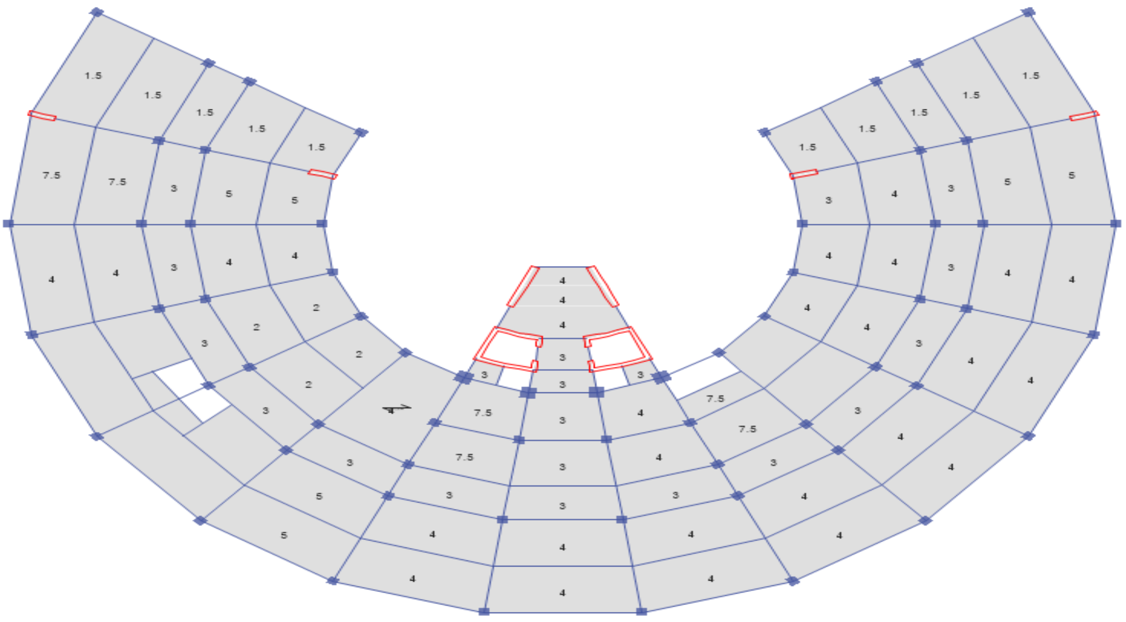
ETABS FILE 3D VIEWS:



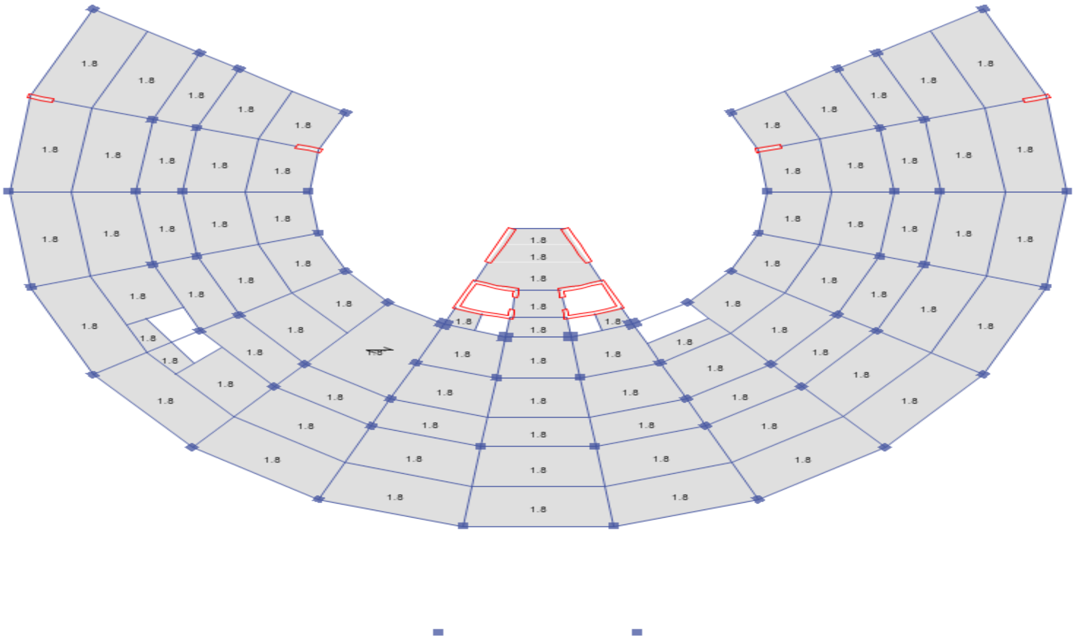
PLINTH LEVEL



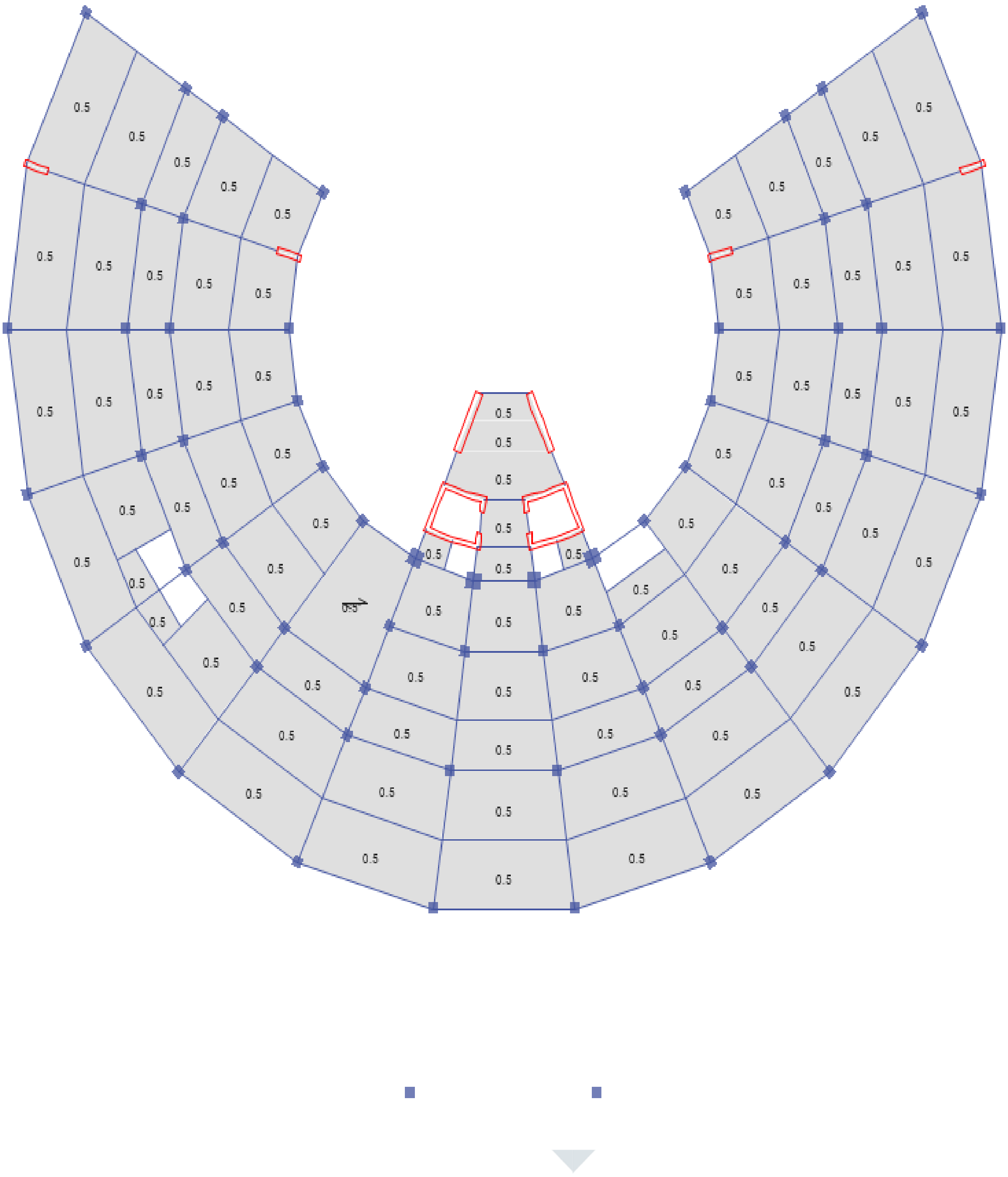
First floor live load .



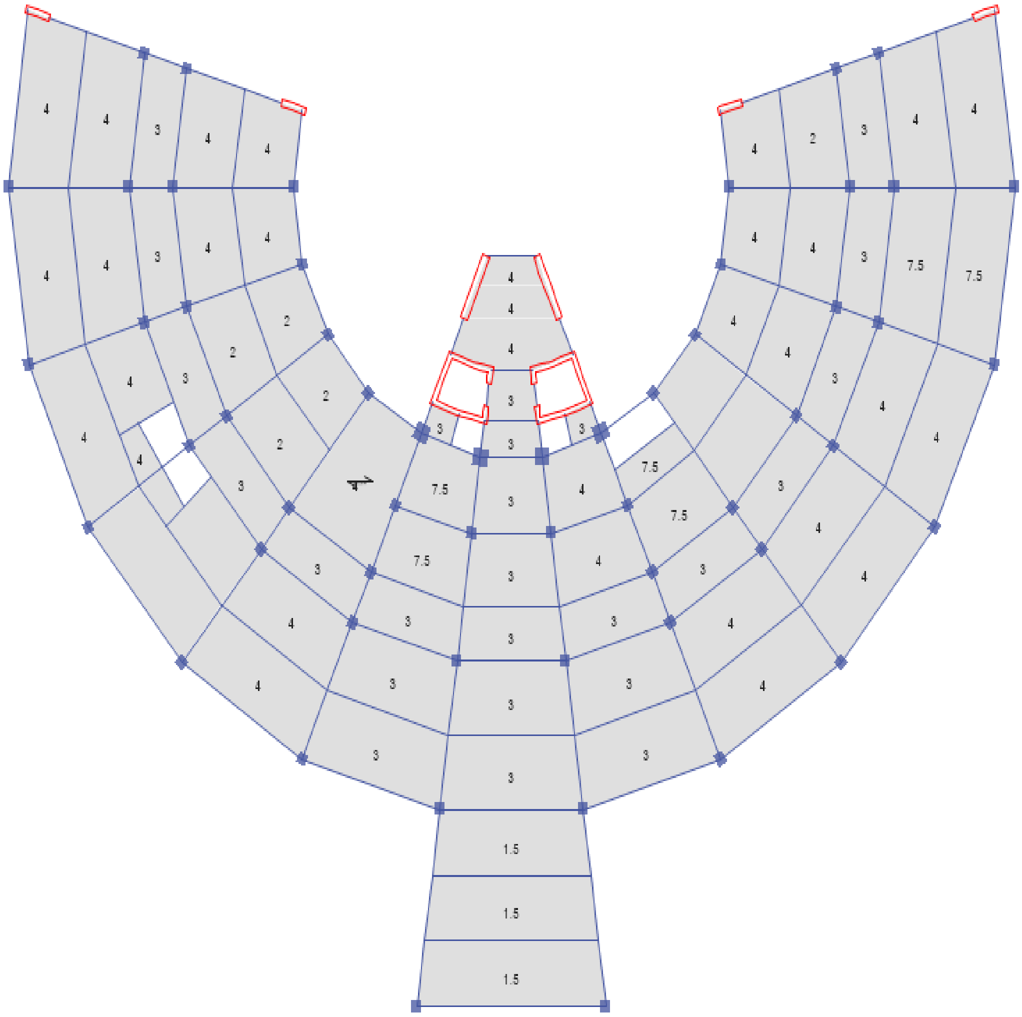
First floor
super imposed dead load .



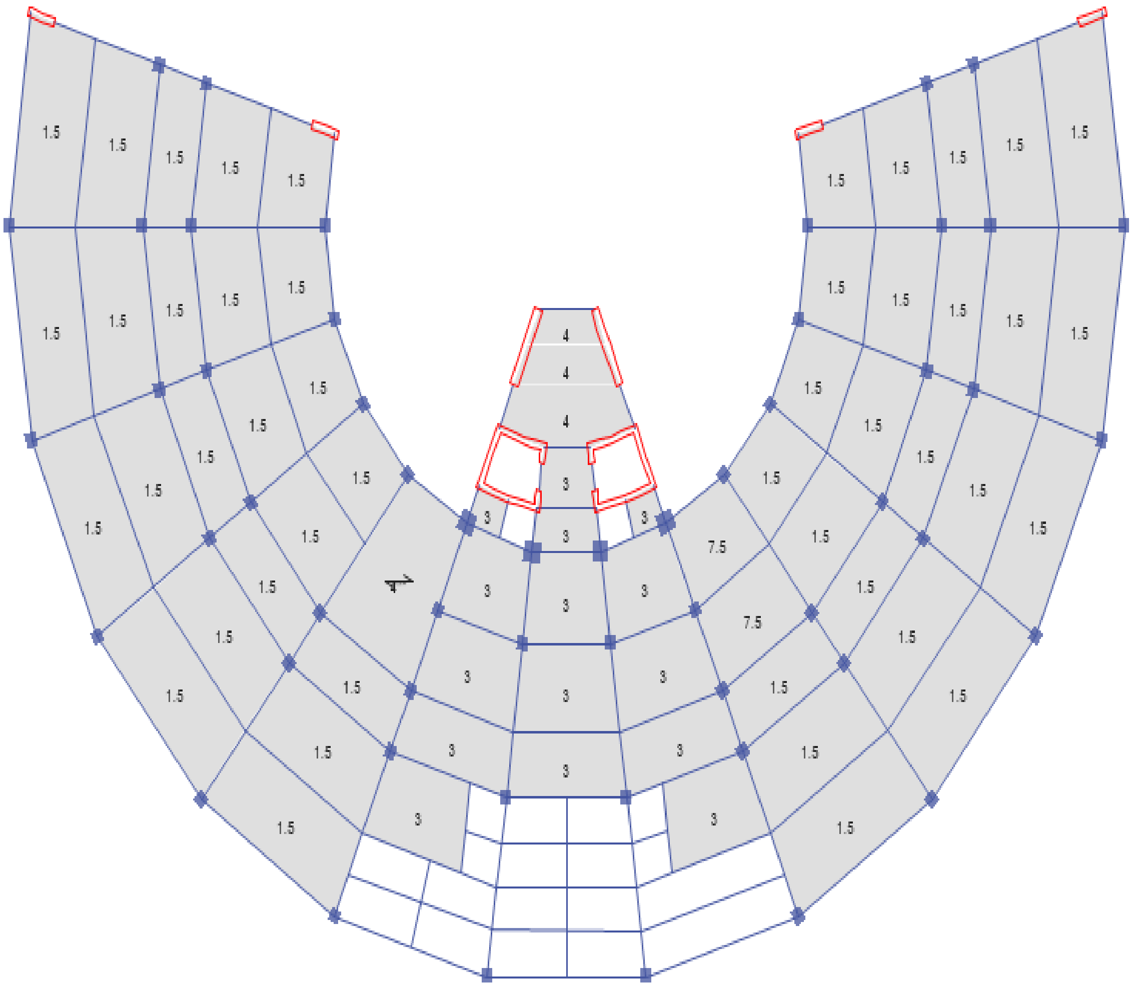
First floor service load



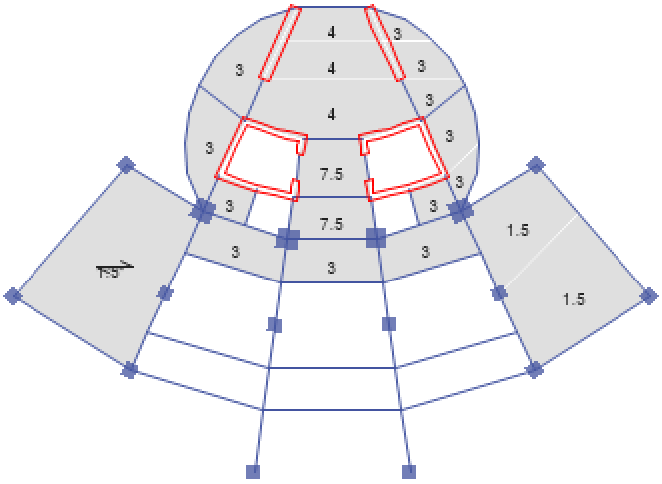
2nd floor live load



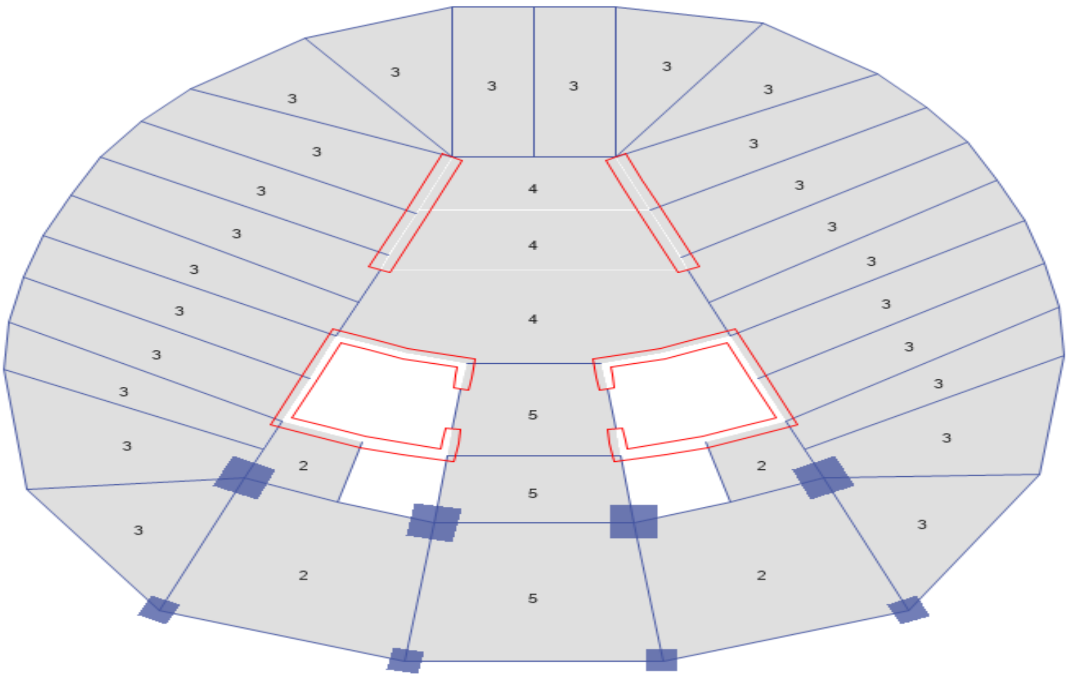
3rd floor live load



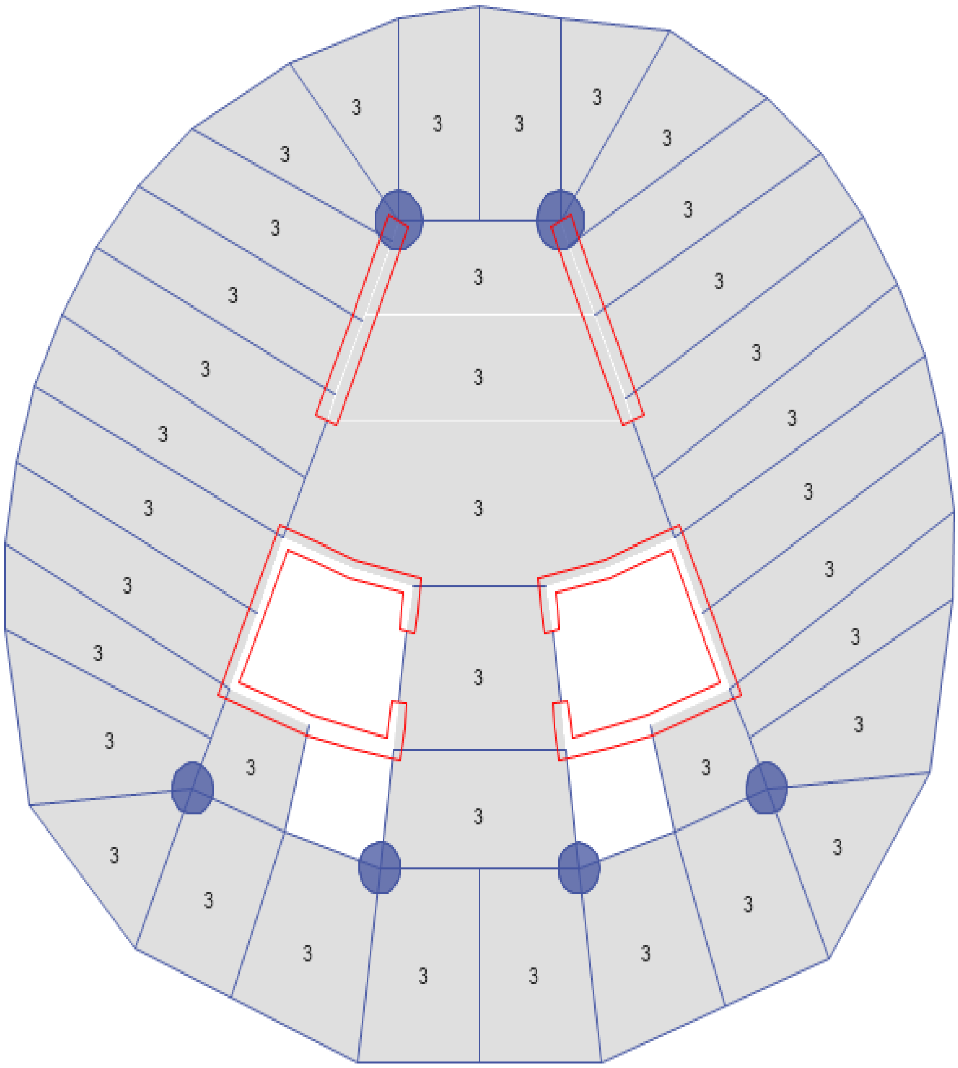
Tower Gallery floor live load



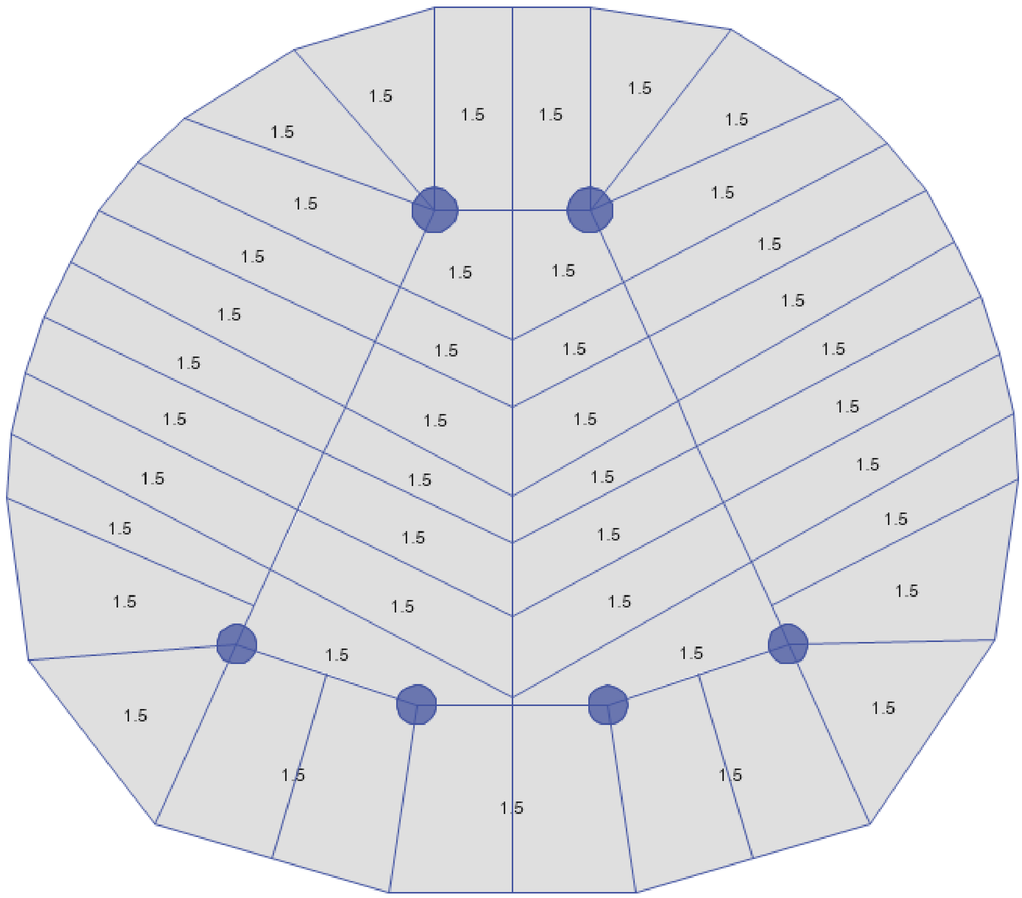
Apron Control floor live load



Control tower floor live load



Terrace floor live load



Wind Loads.

Wind loads have been worked out based on basic wind speed of 47 m/s, terrain of category-4 structure as per I.S 875 (part 3) 2015. Basic input data for the wind analysis assumed as follows:

Basic Wind speed Vb = 47 m/sec (as per Appendix –A)
Terrain category = 3
Risk coefficient factor k1 = 1.0 (as per clause 5.3.1)
Terrain, height & structure size factor k2 = Varies as per code.
Topography factor k3 = 1.0
Importance factor for cyclonic region k4 = 1.0
Wind directionality factor K_d (as per clause 7.2.1)
Area averaging factor K_a (as per clause 7.2.2)
Combination factor K_c (as per clause 7.3.3.13)

Seismic loads

As per IS1893-2016 (Reaffirmed 2017) the proposed building fall under seismic zone-IV
Zone Factor (Zonal V), Z = 0.36
Response reduction factor R = 5.0
Importance factor (Table-8) I = 1.2
Damping, Dm= 5%
Time period shall be as per clause- 7.6.2b of IS: 1893-2016 (Reaffirmed 2017)

Design live loads under Earthquake

As per clause7.3.2of IS1893-2016 while calculating for seismic forces full dead load plus full of imposed load shall be considered. Live load on terrace will be omitted except for stationary equipment's.

Temperature & Shrinkage Loads

The temperature load analysis shall be done in case length of structure with more than 45m longer dimension for tower area for seasonal and diurnal variation and for shrinkage effects, converted in to equivalent temperature for applying in ETABS model.

Method of design

The design of RCC Columns, beam& slabs will be done using IS456-2000, IS 1893-2016 & SP-16.
Load combinations considered for design of superstructures are as follows: -

- 1.5(D.L+ Reduced L.L) as per Fig.1of IS: 875–1987(Part-2)
- 1.5(D.L± Wind in X-direction)
- 1.5(D.L± Wind in Y-direction)
- 1.2(D.L+ k1*L.L ±Wind in X-direction)
- 1.2(D.L+ k1*L.L ±Wind in Y-direction)
- 0.9(D.L) ± 1.5WindinX-direction
- 0.9(D.L) ± 1.5WindinY-direction
- 0.9(D.L) ± 1.5(EQX±0.3EQZ)
- 0.9(D.L) ± 1.5(EQY±0.3EQZ)
- 0.9(D.L) ± 1.5(RQX±0.3RQZ)
- 0.9(D.L) ± 1.5(RQY±0.3RQZ)
- 1.2(D.L ± KLL±EQX±0.3EQZ)
- 1.2(D.L ± KLL±EQY±0.3EQZ)
- 1.2(D.L ± KLL±RQX±0.3RQZ)
- 1.2(D.L ± KLL±RQY±0.3RQZ)
- 1.5(D.L±EQX±0.3EQZ)
- 1.5(D.L±EQY±0.3EQZ)
- 1.5(D.L±RQX±0.3RQZ)
- 1.5(D.L±RQY±0.3RQZ)
- 1.4(D.L±TL)
- 1.05(D.L±TL)+1.28LL
- 1.05(D.L±TL) ±1.2EQX
- 1.05(D.L±TL) ±1.2EQY
- 1.05(D.L±TL) ±1.2RQX
- 1.05(D.L±TL) ±1.2RQY
- 1.05(D.L±TL±LL±EQX)
- 1.05(D.L±TL±LL±EQY)
- 1.05(D.L±TL±LL±RQX)

- 1.05(D.L±TL±LL±RQY)
- 1.05(D.L±TL) ±1.2WL)
- 1.05(D.L±TL±LL±WL)

Serviceability combinations:

- 1.0(D.L+ Reduced L.L)
- 1.0(D.L± Wind in X-direction)
- 1.0(D.L± Wind in Y-direction)
- 1.0(D.L+ 0.8*L.L±0.8*Wind in X-direction)
- 1.0(D.L+ 0.8*L.L±0.8*Wind in Y-direction)
- 1.0(D.L± EQ in X-direction)
- 1.0(D.L± EQ in y-direction)
- 1.0(D.L± RQ in X-direction)
- 1.0(D.L± RQ in y-direction)
- 1.0(D.L+ 0.8*L.L±0.8*EQ in X-direction)
- 1.0(D.L+ 0.8*L.L±0.8* EQ in Y-direction)
- 1.0(D.L+ 0.8*L.L± 0.8*RQ in X -direction)
- 1.0(D.L+ 0.8*L.L±0.8* RQ in Y-direction)

Symbols:
D.L-Dead loads
L.L- Live loads
E.Q– Earthquake loads
R.Q– Dynamic Earthquake loads
TL – Temperature load
WL – Wind load
K1 - 0.5 for live load class 400Kg/m2
K1 – 0.25 for live load class up to300Kg/m2

Foundation Design

For light structures, safe bored cast in situ Rcc piles 500/600dia shall be used. However, Bored CIS Piles (500mm to 600mm dia) are used wherever higher loads are to be transmitted. Pile design is carried out as per stipulations of IS 2911-part 1 for bored CIS piles & IS 2911-part3 for under-reamed piles

<u>Design of 500 Dia pile:-</u>

L= length of pile from raft bottom = 15000mm
D = diameter of pile = 500mm
Grade of concrete, f_{ck} = M30

Safe load compression capacity of pile P = 62 T (from soil report
Factor load(P_u) = 1.5x62= 93 T

Moment due to fixed Lenth M = PxL_f
= 3.15x3.31 = 10.43 T-m

Factor moment M_u = 1.5x10.43= 15.64 T-m

d' = 75+20/2 =85 mm
d'/D = 85/450 = 0.17
$Pu/f_{ck}/D^2 = 930000/30/500^2 = 0.124$
$Mu/f_{ck}/D^3 = 15.64x10^7/30/500^3 = 0.042$
Therefore, p/f_{ck} = 0.03
p= 0.3*30=0.9%
Therefore, minimum reinforcement required = 0.9% of area of pile
= $0.9/100*(3.14/4*500^2) = 1431mm^2$
Provided reinforcement in pile = 10-16Ø(Ast = $2000mm^2$

Design of 600 Dia pile:-
L= length of pile from raft bottom = 22000mm
D = diameter of pile = 600mm
Grade of concrete, f_{ck} = M30

Safe load compression capacity of pile P = 169 T (from soil report)
Factor load(P_u) = 1.5x169=253.5 T

Moment due to fixed Lenth M = PxL_f
= 7.9x4.5 = 35.55 T-m
Factor moment M_u = 1.5x35.55 = 53.33 T-m

d' = 75+20/2 =85 mm
d'/D = 85/750 = 0.11
$Pu/f_{ck}/D^2 = 2535000/30/750^2 = 0.15$
$Mu/f_{ck}/D^3 = 53.33x10^7/30/750^3 = 0.042$
Therefore, p/f_{ck} = 0.03
p= 0.03*30=0.9%

Therefore, minimum reinforcement required = 0.9% of area of pile
= $0.9/100*(3.14/4x750^2) =3975mm^2$

Provide reinforcement in pile = 8-20Ø+8-16Ø (Ast = $4112mm^2$)

Stability

Stability of structure against overturning and sliding as per Clause 20.0 of IS: 456 -2000 is followed in the design and listed as below.

i. Factor of safety against overturning:

Restoring moment shall not be less than 1.2 times the maximum overturning moment due to the characteristic dead load and 1.4 times the maximum overturning moment due to the characteristic imposed loads.

ii. Factor of safety against sliding: 1.4
In both the above cases, 0.9 times of characteristic dead load only to be considered in the design.

Serviceability Requirement

This is given with following limitations:

I. For Vertical deflections for beams, slabs etc.(Total load deflections) =Span/250 for Serviceability.
II. Lateral displacement of Structure = Height/ 500.
III. For Cracking-
   a. For water retaining structure=Cracked section, limitingcrackwidthto0.1mm
   b. Drift- The maximum horizontal relative displacement due to earthquake forces between two successive floors shall not exceed 0.004 times the difference in level between these floors.

Analysis, Model & Software Used

The building has been analyzed and designed as RCC structure using ETAB software for Tower.
For foundation design SAFE Software shall be used.

Concrete Cover

Concrete Clear Cover to All Reinforcement Including Links (As per Clause 21.4 and 26.4.3 of IS: 456-2000).

Column	: 40 mm
Beams continuous	: 40 mm
Beams simply supported	: 60 mm
Simply supported Slabs	: 45 mm
Continuous Slabs	: 35 mm
Foundation	: 50 mm
Retaining wall	: 30mm (earth face)
	: 25mm (inside face)
Water Tank wall	: 30mm

CONCLUSIONS

The building form and design requirements have created a set of structural design challenges that are far greater than a typical commercial development of similar scale. Close collaboration with all project team members has been crucial to ensure that these challenges have been addressed and resolved through the design process. The resulting design answers these challenges but in a very rational and conscious manner, resulting in a design that is both efficient and functional.

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IS: 875 (Part-2):1987, Indian Standard Code of Practice for Design Loads (Other than Earthquake) (Imposed Loads) for Buildings and Structures, Bureau of Indian Standards, New Delhi.

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IS: 1893(Part-1):2016, Indian Standard Criteria for Earthquake Resistance Design of Structures, Bureau of Indian Standards, New Delhi.

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