PALAIS ROYALE

A TREND SETTER

DECEMBER 2010, SRI LANKA


idea

APPROACH TO SUSTAINABLE USE OF CONCRETE

- Use high strength concrete to minimize amount of material consumed
- Use appropriate technology to minimize the binder content of concrete (e.g. particle packing and very fine materials)
- Use additions to the utmost to minimize the clinker content
- Use least possible water during construction for
  - Mixing
  - Curing

INITIAL OBJECTIVES IN PLANNING OF PALAIS ROYALE

300 m tall residential building.

Tallest LEED Platinum rated green residential building in the world.

100% on-site sewage treatment, stopping 30 mill. gallons of waste per year.

Most waste used as manure, remaining recycled.

Use of high grade construction materials to minimize consumptions and reduce energy consumptions in construction

Green public spaces at all levels as well as green areas for individual apartments

Utilize such ventilation and power utilization techniques that reduce the power consumption throughout the life of the building

Harnessing solar energy through BIPV cells and wind energy to provide power to all public areas in building

IMPORTANT PLANNING FEATURES

LANDSCAPED TERRACES/ BALCONIES AT APARTMENT LEVELS – GREEN ENVIRONMENT

TRANSFER GIRDER LEVEL – TO ACCOMMODATE DIFFERENT USES IN THE SAME BUILDING.

LARGE SPAN FLOORS AND WIDE COLUMN FREE SPACES AT LOWER LEVELS – MULTIPURPOSE USAGE

HEAVY LANDSCAPING LOADS AT GROUND & AMENITY LEVELS

ALL OPEN TO SKY TERRACES ARE LANDSCAPED – INSULATION LEADING TO LESS ENERGY CONSUMPTION FOR CONTROLLED CLIMATE WITHIN

IMPORTANT ARCHITECTURAL FEATURES

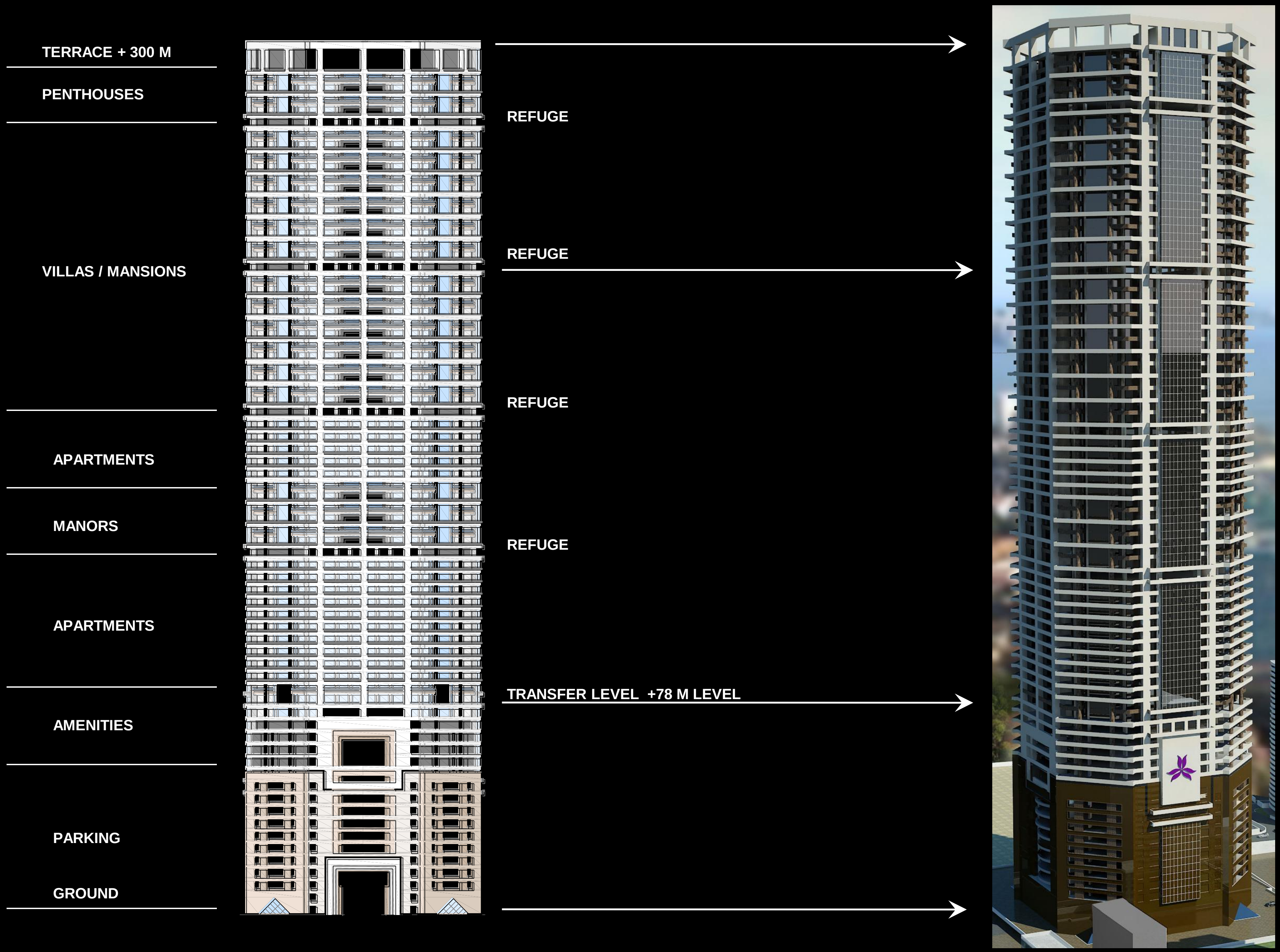
THE BRAHMSTHAN AND THE ATRIUM – 220 MTS. HIGH
– COLUMN FREE SPACE AT CENTER OF BLDG CREATING NATURAL VENTILATION CURRENTS

THE MOAT – LIGHT & VENTILATION TO BASEMENT, REDUCING DEPENDENCE ON MECHANICAL VENTILATION

SKYLIGHT – COVERS THE ATRIUM SPANNING 35MTS, NATURAL LIGHT IN DAY TIME

ROOF CAP – HOUSES SOLAR & WIND ENERGY EQUIPMENTS

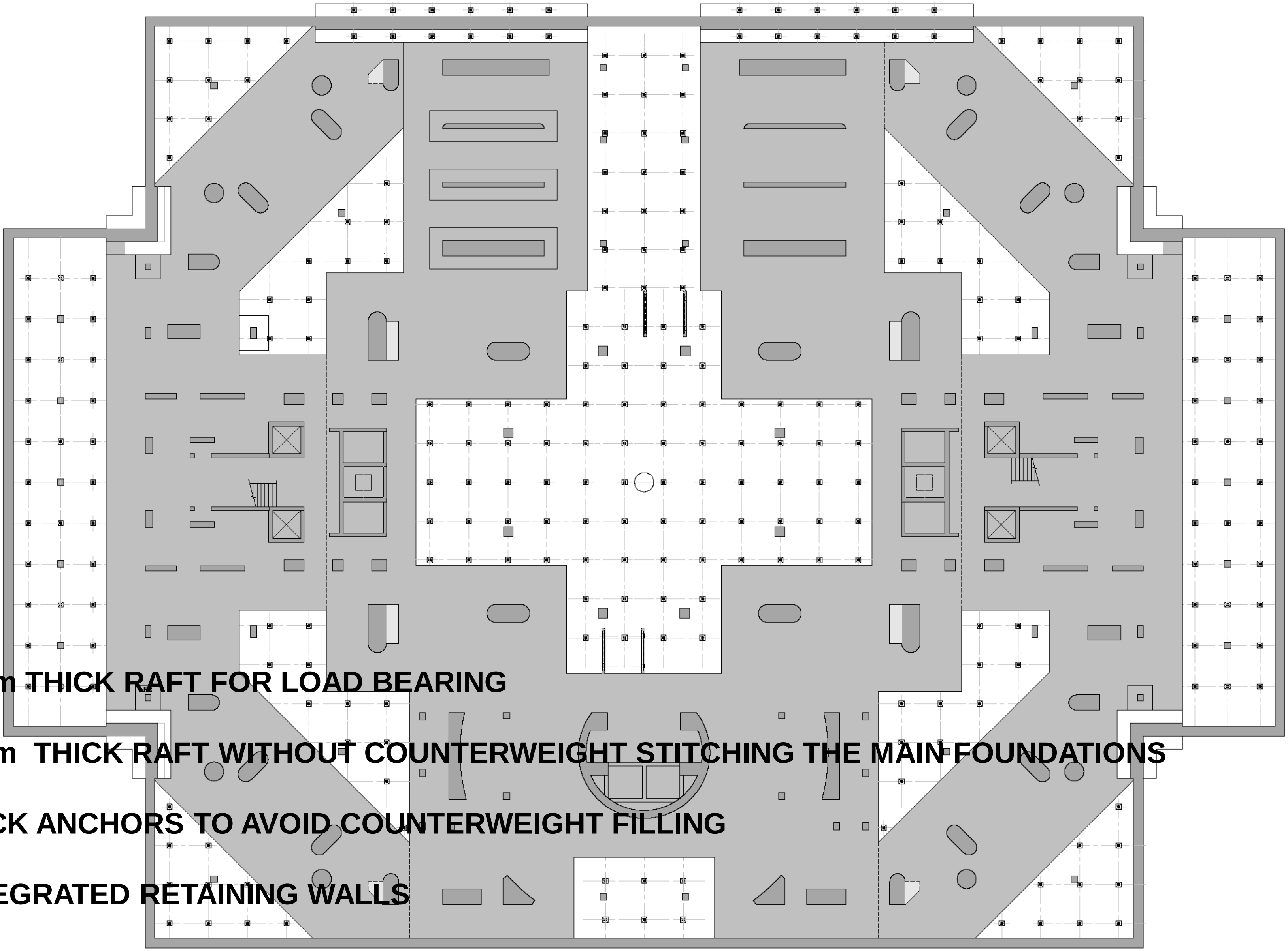
AMENITIES – SWIMMING POOL,MINI GOLF COURSE,,TENNIS COURT,MINI CRICKET GROUND,HEALTH CLUB,SQAUSH COURT, BASKETBALL,…….


TERRACE + 300 M
PENTHOUSES
VILLAS / MANSIONS
APARTMENTS
MANORS
APARTMENTS
AMENITIES
PARKING
GROUND
REFUGE
REFUGE
REFUGE
REFUGE
TRANSFER LEVEL +78 M LEVEL

STRUCTURAL SCHEME

FOR PALAIS ROYALE

FOUNDATION PLAN



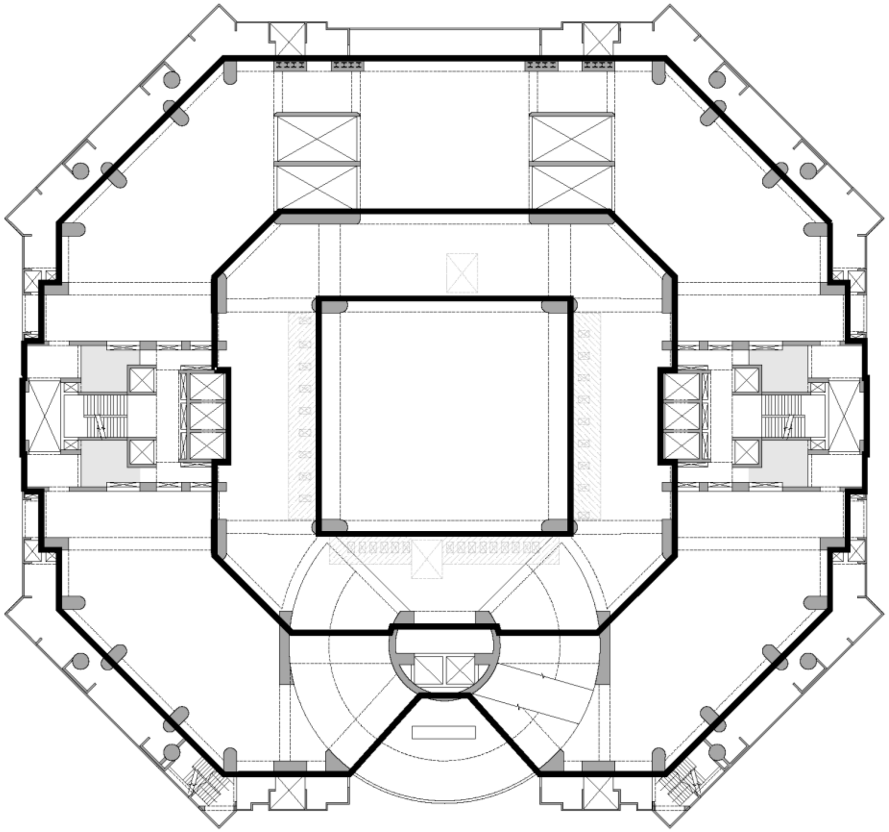
3.5 m THICK RAFT FOR LOAD BEARING

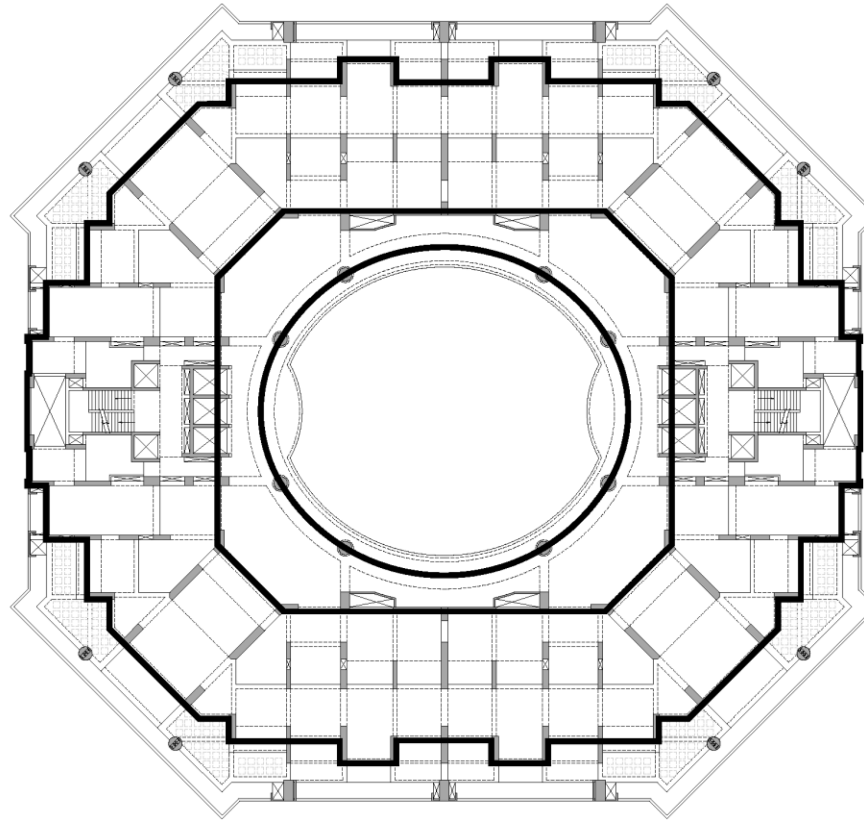
1.0 m THICK RAFT WITHOUT COUNTERWEIGHT STITCHING THE MAIN FOUNDATIONS

ROCK ANCHORS TO AVOID COUNTERWEIGHT FILLING

INTEGRATED RETAINING WALLS

RING STRUCTURE





THREE CLOSED RINGS CONCEPTUALIZED TO FORM A UNIFORM LOAD BEARING SYSTEM

SYMMETRY ADDS TO STABILITY

STIFFNESS CENTRE MOVED AWAY FROM CENTRE

PODIUM LEVELS

LARGE COLUMN FREE SPACES

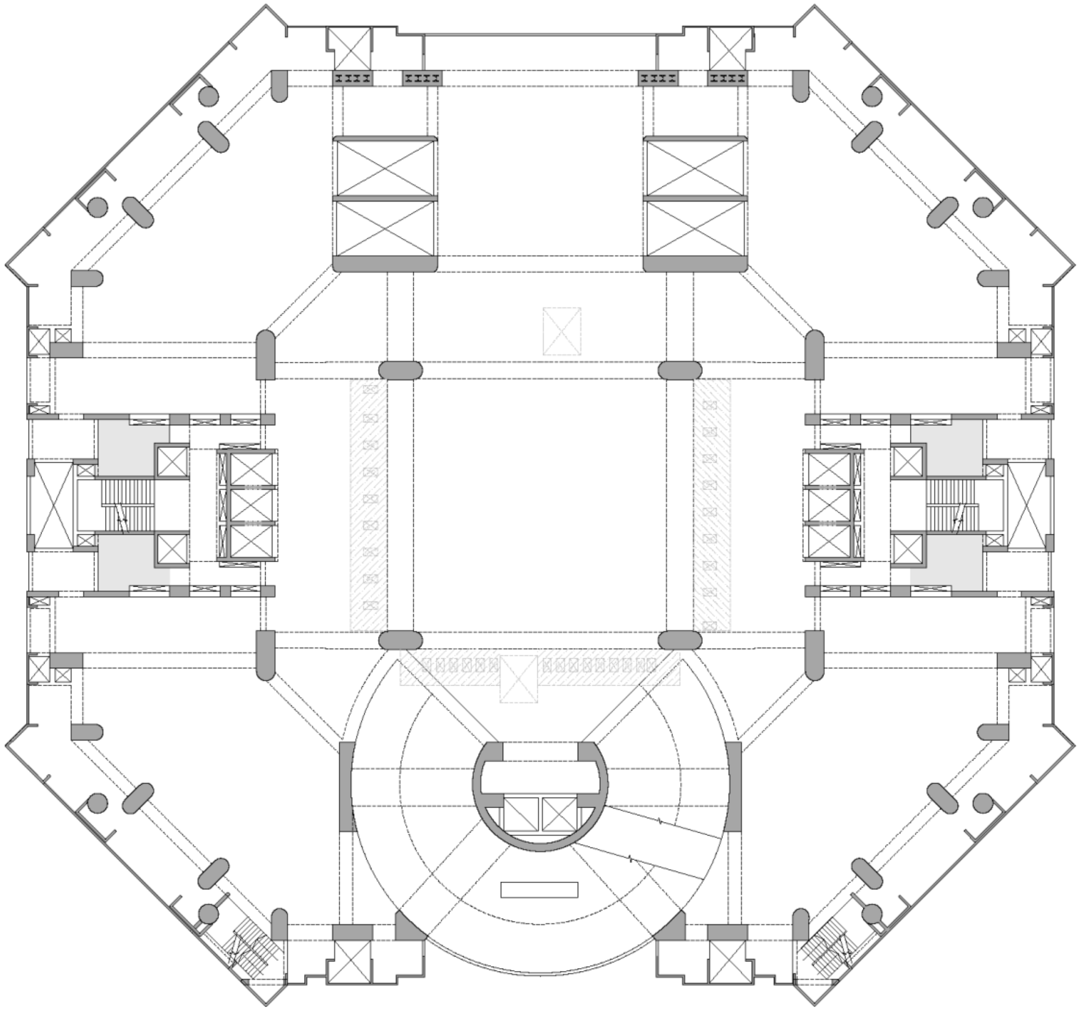
BRAHMASTHAN SLABS

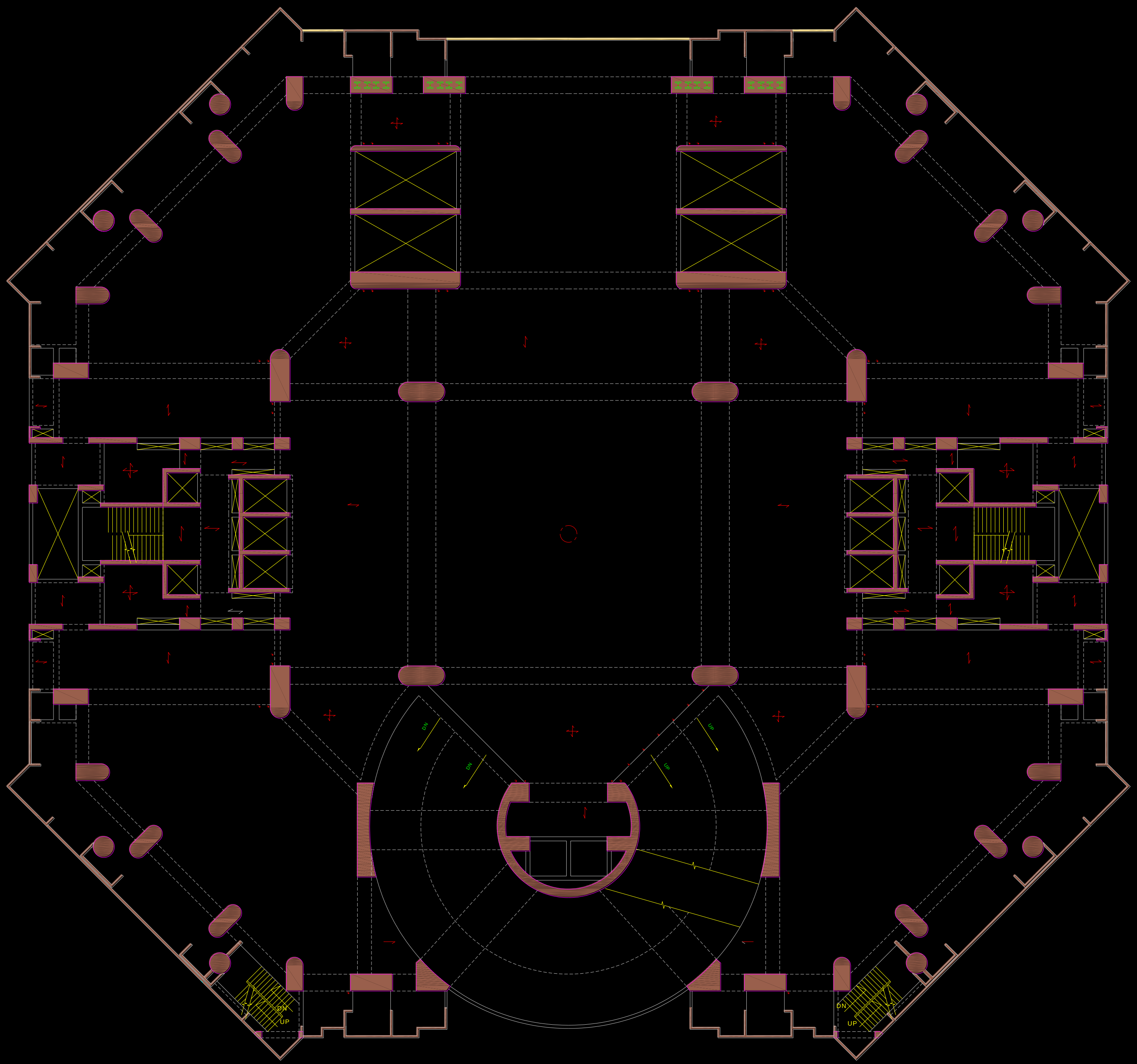
QUADRANT SLABS

RAMP

CORE

FIRE STAIRS





Large span slabs

Continuation of three ring scheme

Car lifts and spiral ramp

Brahmasthan slab 24 m span

Post Tensioned beams

AMENITY LEVEL

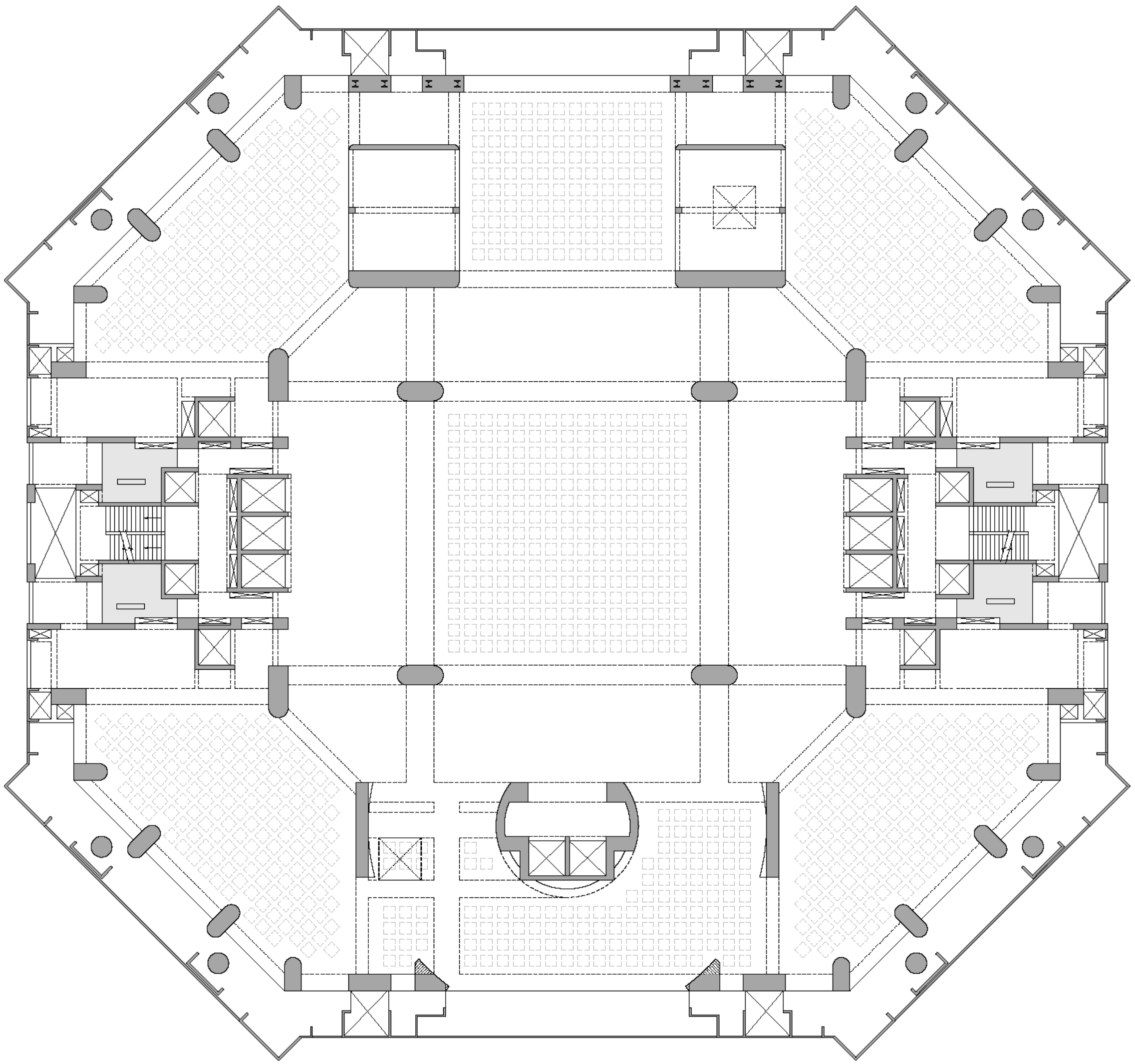
LARGE COLUMN FREE SPACES

BRAHMASTHAN SLAB

QUADRANT SLABS

HEAVY LOADS
POOL
PLAYGROUNDS
SOIL FILL FOR LANDSCAPE
AUDITORIUM

AMENITY 2 DESIGNED FOR SUPPORTING GIRDER BOTTOM CHORD CONSTRUCTION LOADS



GIRDER LEVEL

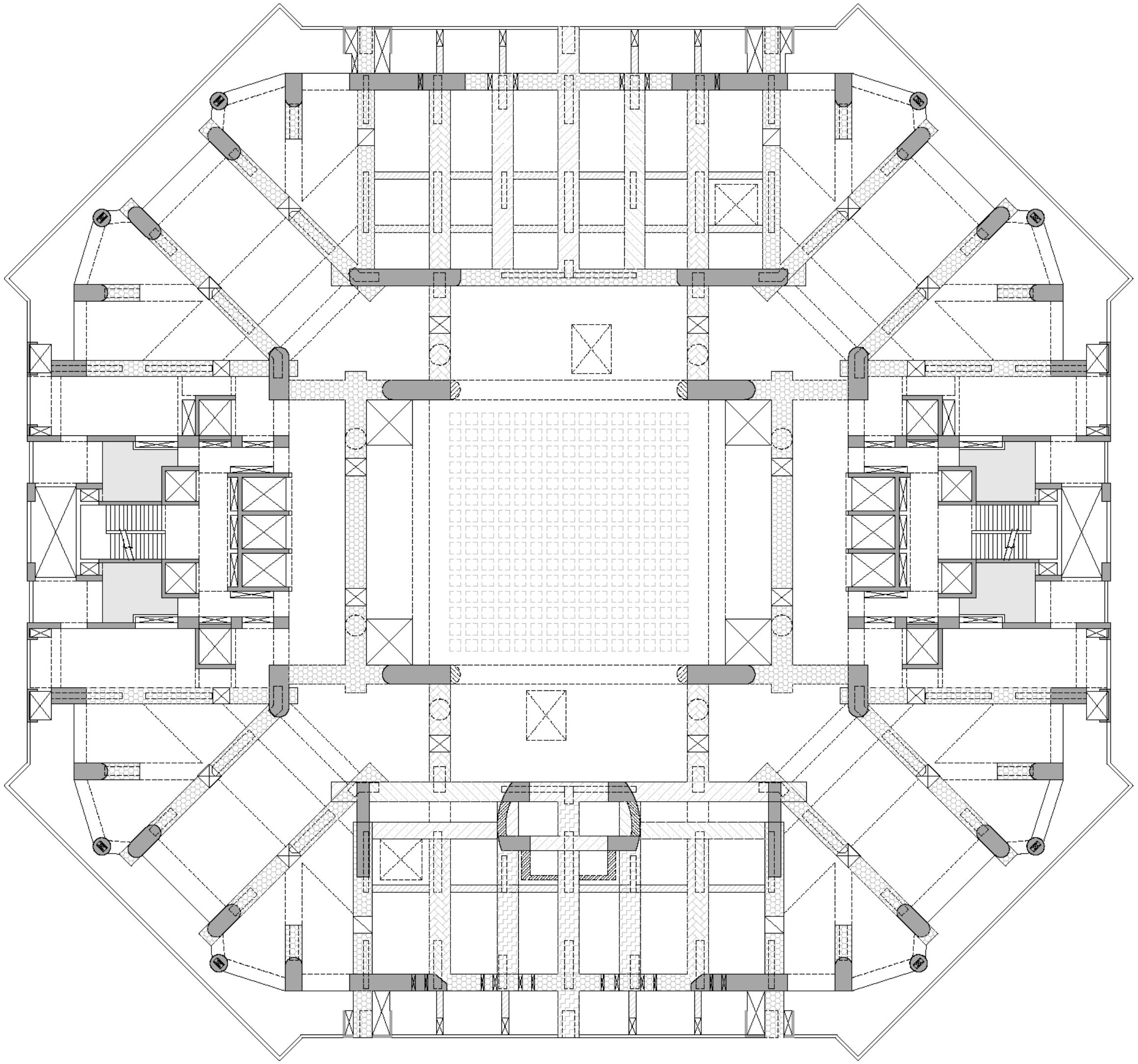
NOMINALLY POST TENSIONED RCC TRANSFER GIRDERS

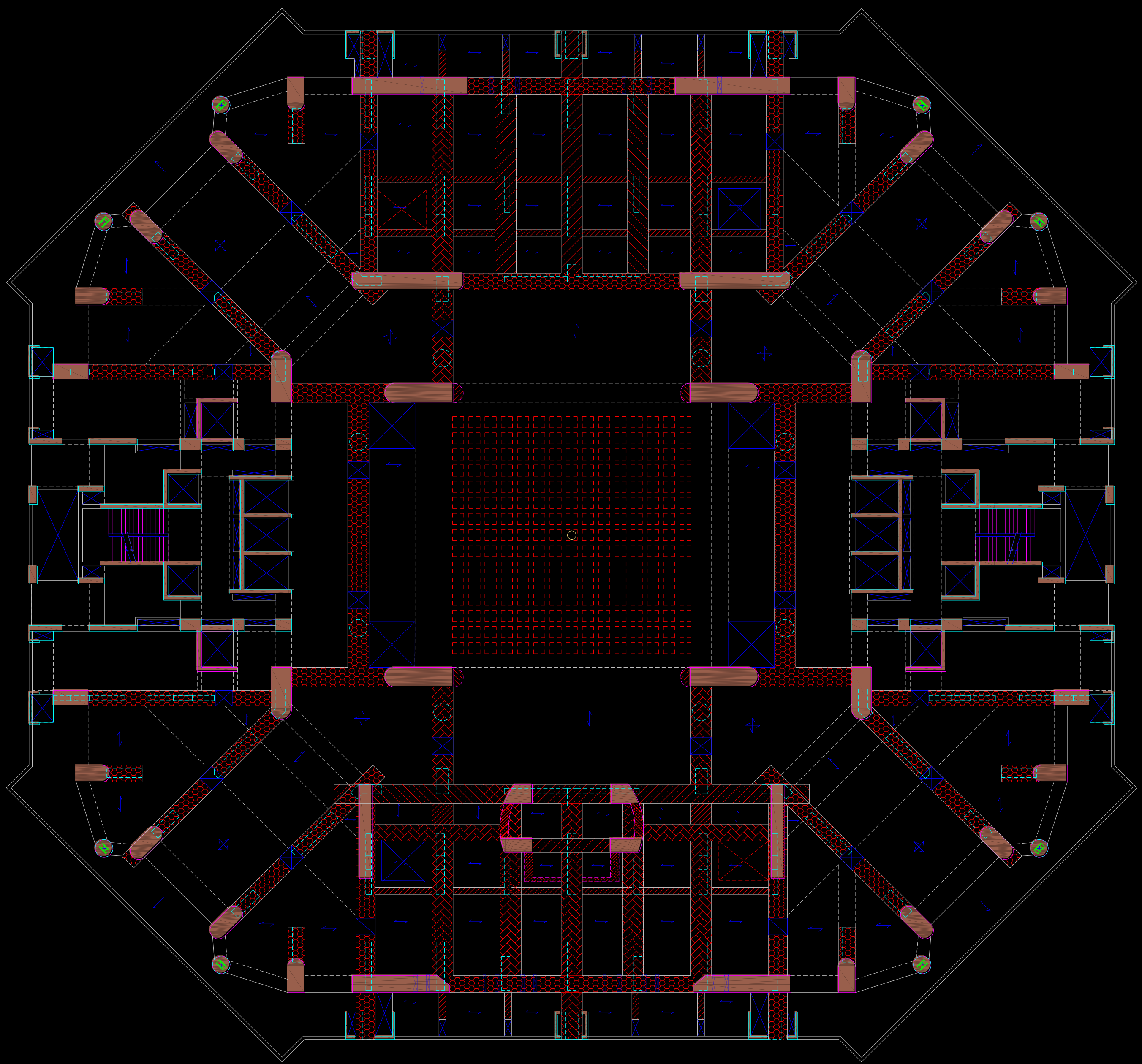
VERTICAL POST TENSIONING FOR MONOLITHIC BEHAVIOUR

BRAHMASTHAN SLAB AS TENNIS COURT

WATER TANKS

EXTREME ENGINEERING DETAILING AND EXECUTION





Transfer Girders 9 m deep RCC

Vertical Post Tensioning

Openings in girders for services

Three tie levels within girder depths

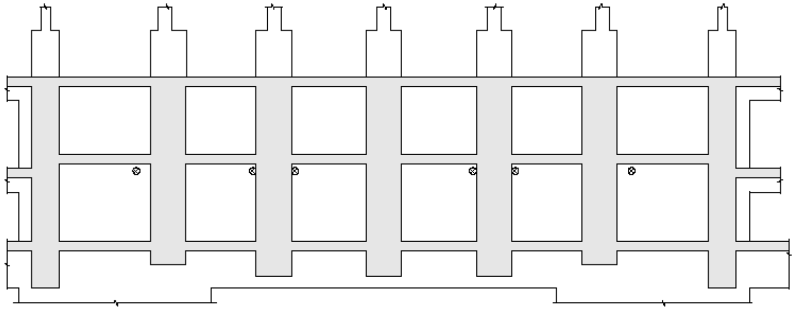
Water tanks at lower tie level

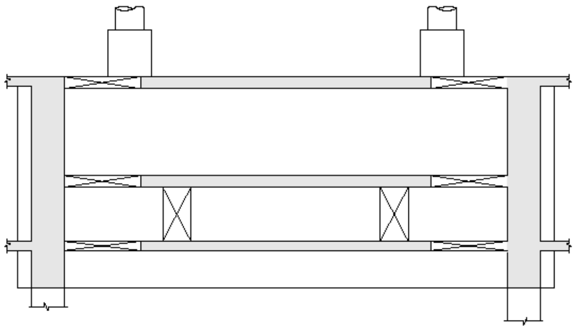
Tennis Court at Girder Bottom Level

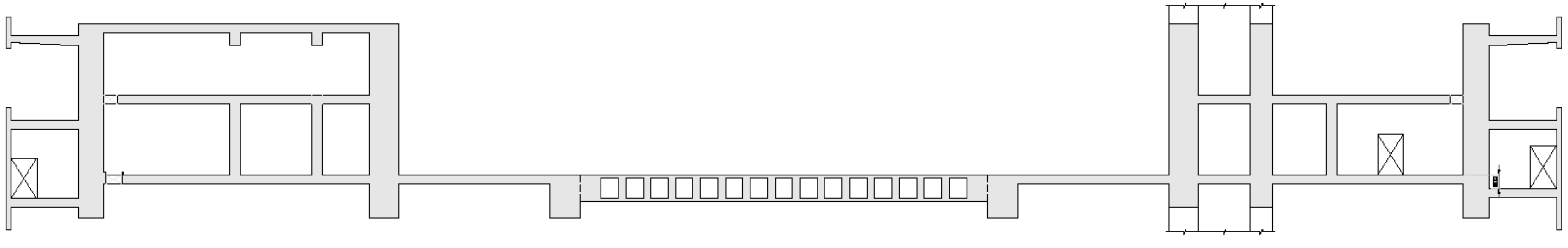
M:60 SCC concrete for girders

Tie beams and diaphragm slabs to achieve integral action

GIRDER SECTIONS







APARTMENT LEVEL PLAN

Concentric Rings of columns

Mass positioned away from centre

Symmetrical Plan

Large cantilevers

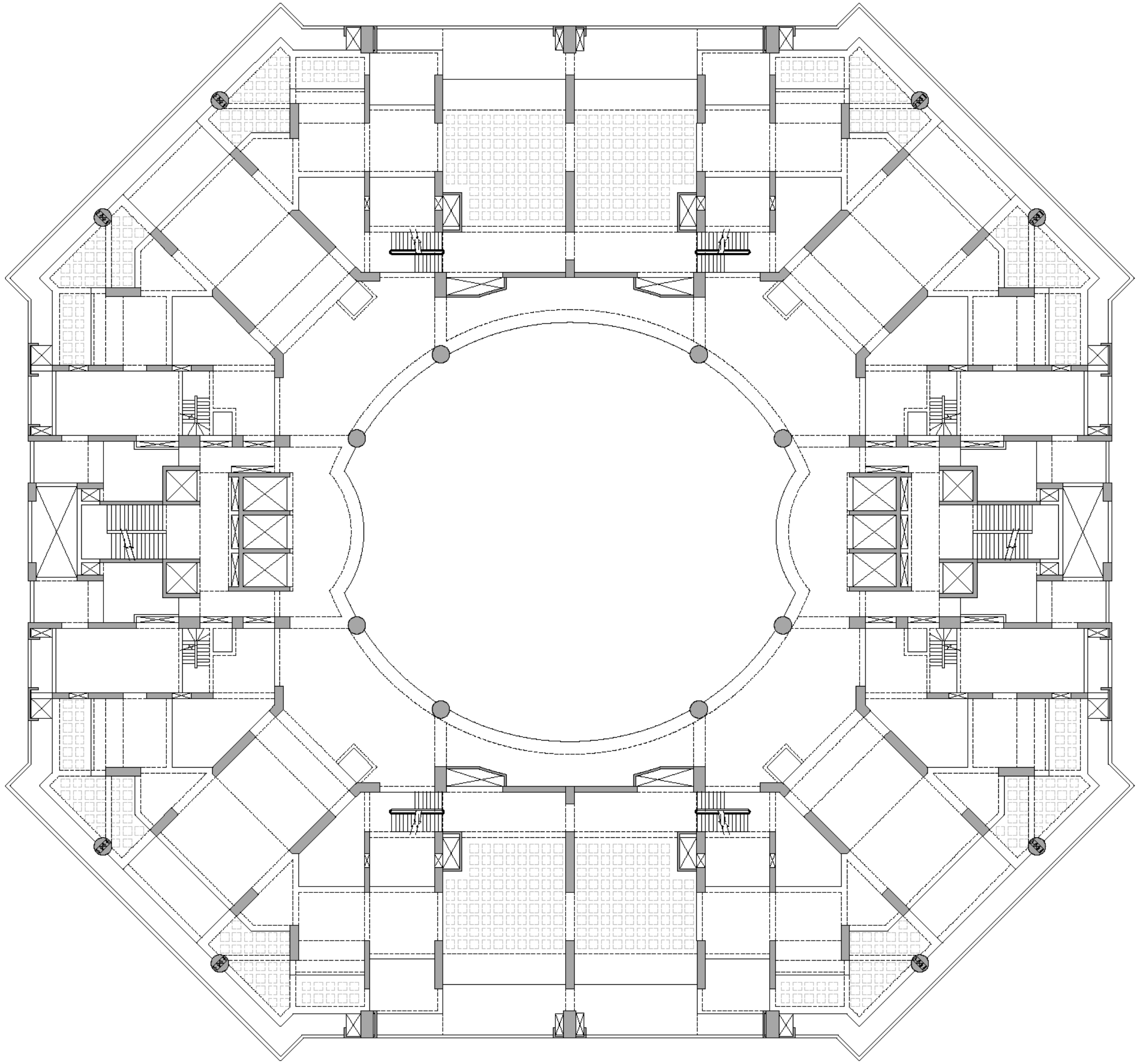
Void slab

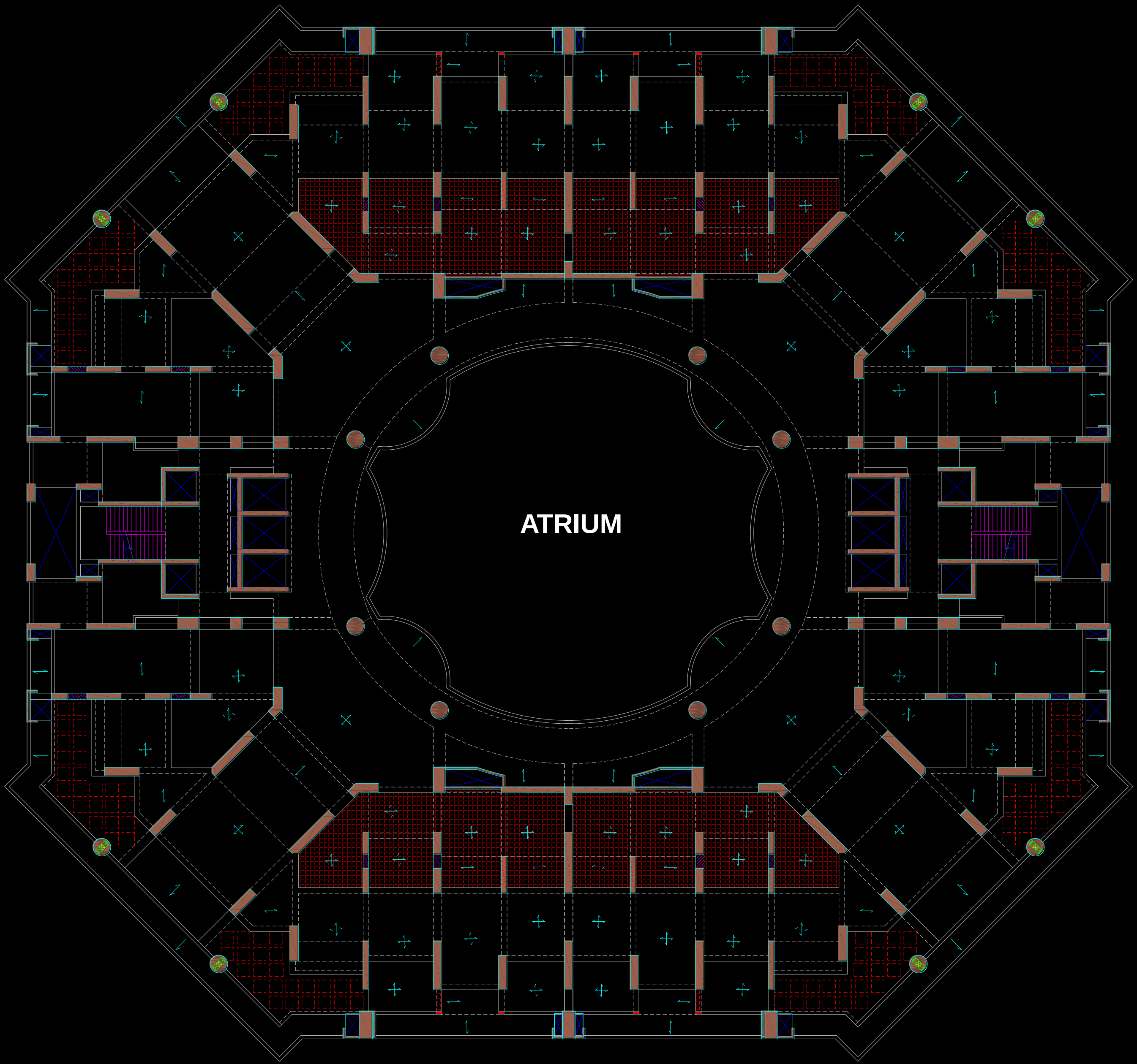
Perfect column beam frames

High headroom facilitated deeper beams

Stiffness distributed evenly in columns and walls

Floor sinking





Column – Beam Frame Scheme

Three concentric rings of columns

Octagonal Plan

Symmetry about each axis

Central Atrium – 225 m high

MANOR ENTRANCE LEVEL

Concentric Rings of columns

Mass positioned away from centre

Symmetrical Plan

Large cantilevers

Void slab

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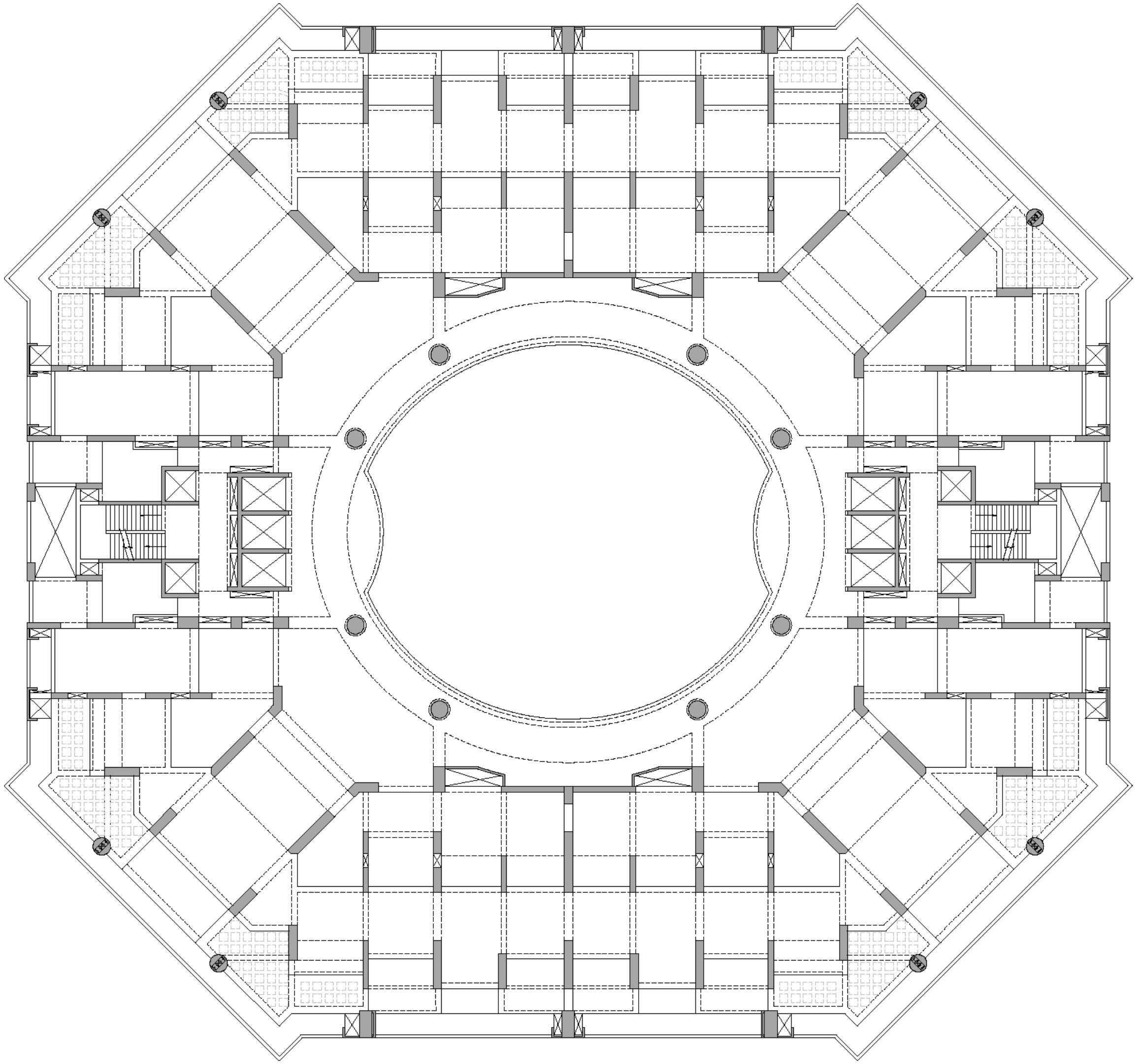
Floor sinking



MANOR UPPER LEVEL

Concentric Rings of columns

Mass positioned away from centre

Symmetrical Plan

Large cantilevers

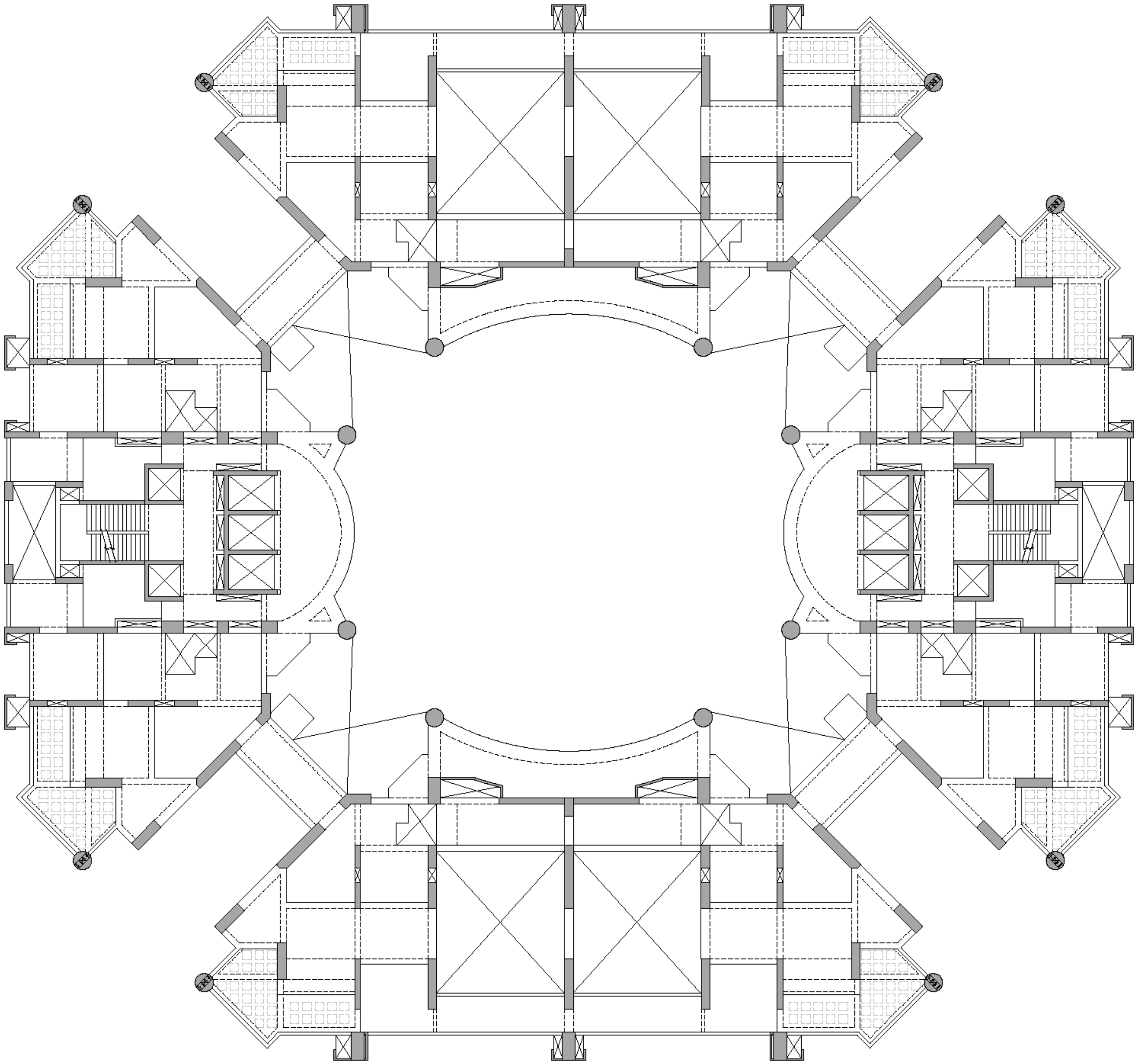
Void slab

Perfect column beam frames

High headroom facilitated deeper beams

Stiffness distributed evenly in columns and walls

Floor sinking



STRUCTURAL PARAMETERS

FOR PALAIS ROYALE

OPTIMIZATION OF CONCRETE QUANTITIES

1. **To reduce the structural member sizes**
   a. **Slab thicknesses**
   b. **Beam sizes**
   c. **Column Sizes**
   d. **Foundation size**

2. **Leading to lesser concrete and reinforcement consumption**
3. **Leading to lesser formwork material**
4. **Leading to lesser power and water consumption for manufacture of concrete, reinforcement and formwork material**
5. **Leading to lesser construction time – thereby requiring reduced power and water for construction establishment**

DETERMINATION OF ACCURATE LOAD PARAMETERS FOR OPTIMIZED STRUCTURAL DESIGN

1. Extensive reference to international guidelines:
   (a) CTBUH guidelines for seismic design of tall buildings (2008)
   (b) Los Angeles Tall Buildings Structural Design Council guidelines for tall buildings (2008)
   (c) Pacific Earthquake Engineering Research Centre – seismic performance objectives for tall buildings (2008)
2. Generation of site specific response spectra and time-histories (undertaken for the first time for a civil application in India).
3. Palais Royale being treated as a Special Structure as defined by IS-1893 (2002).
4. Minimum design base shear scaled to 1 % of the seismic weight.
5. Intrinsic damping for seismic & wind design = 1%
6. Structural elements modeled using cracked section properties.
7. Importance factor of 1.5 used.
8. Seismic deflections under DBE controlled to H/750.
9. Wind accelerations under 10 year return period wind pegged at 10 milli-g

SALIENT ASPECTS OF SEISMIC AND WIND DESIGN

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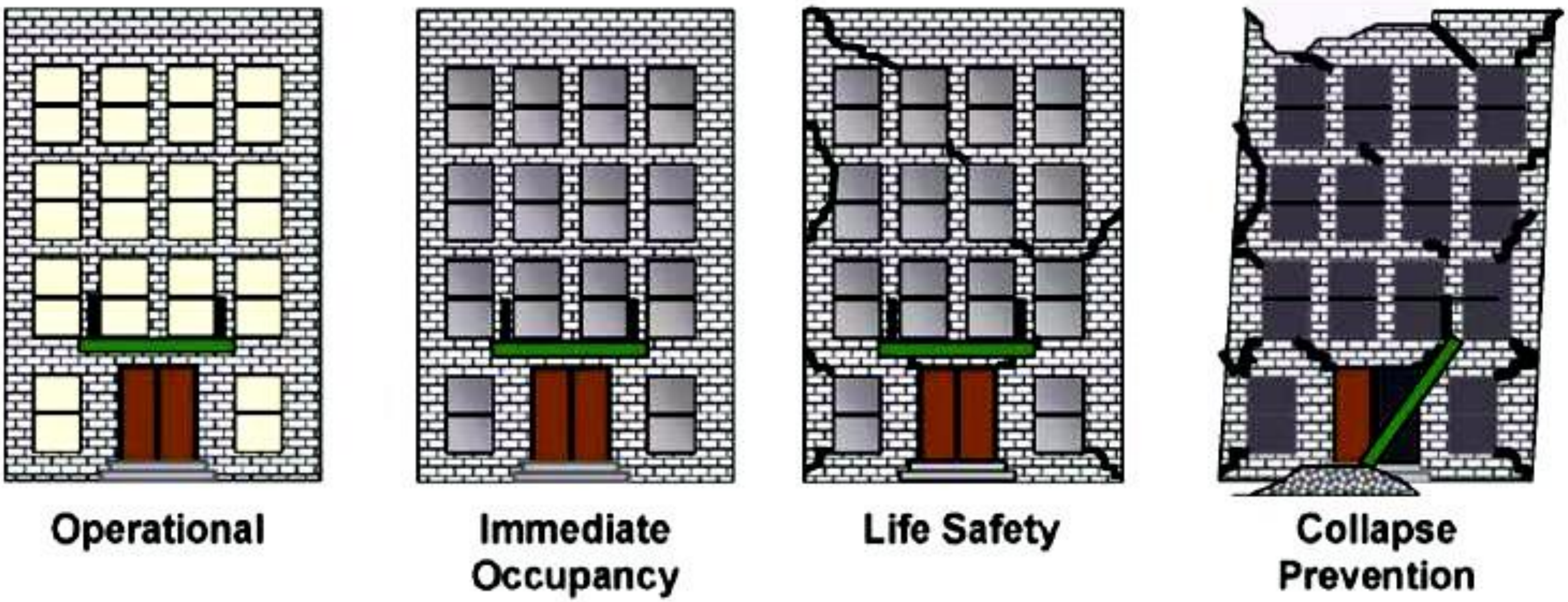
TARGET PERFORMANCE STANDARD

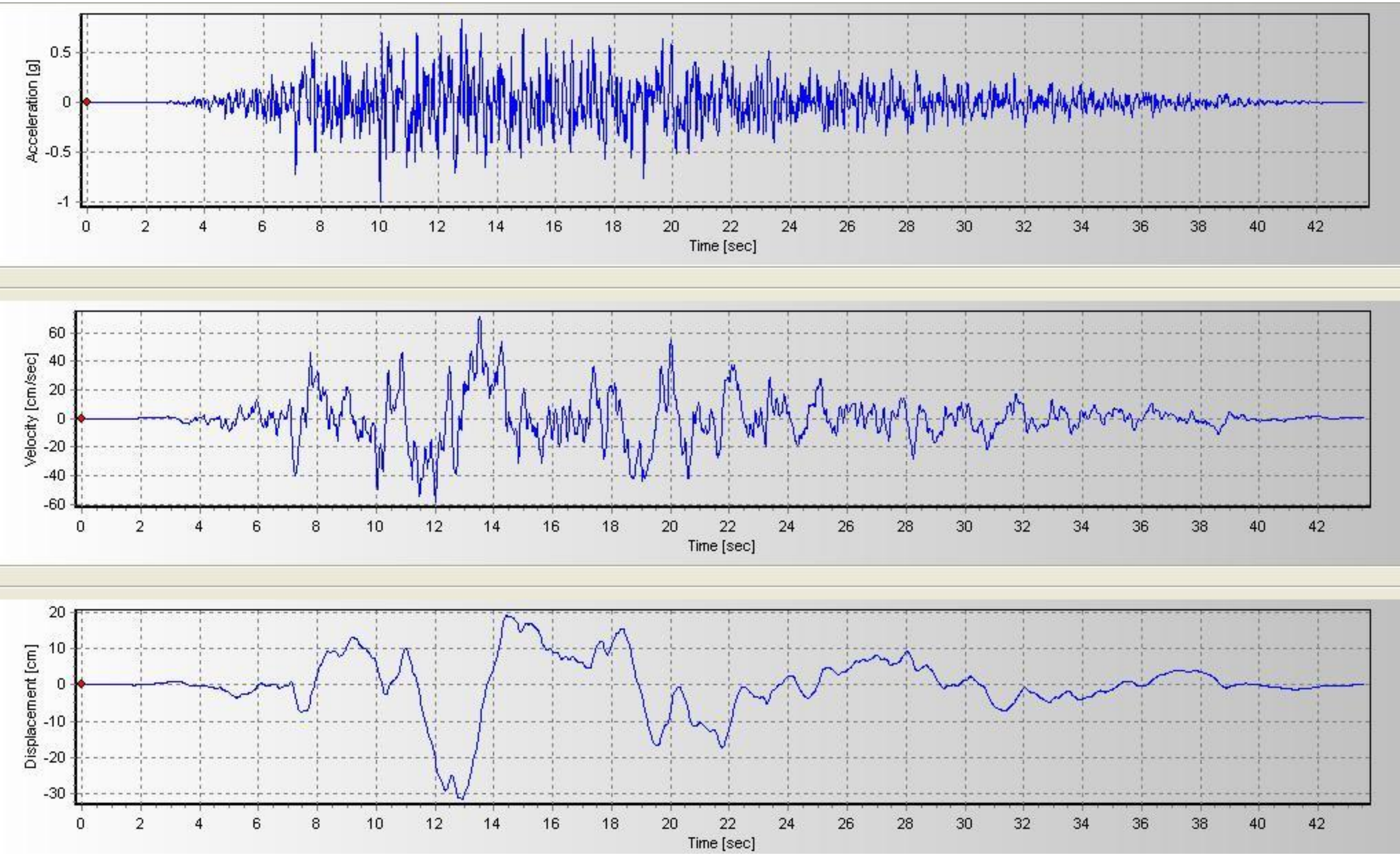


Minimum Acceptable – Immediate Occupancy

BRIEF FOR PERFORMANCE BASED DESIGN

PERFORMANCE LEVEL	MAXIMUM SWAY	ACCELERATION
COLLAPSE PREVENTION / LIFE SAFETY CODE PROVISIONS	H/500 = 600 mm	15 milli – g *
IMMEDIATE OCCUPANCY	H/750 = 400 mm	10 milli – g
OPERATIONAL LEVEL	H/1000 = 300 mm	5 milli – g

SITE SPECIFIC TIME HISTORY



DESIGN CONCEPTS

- FOUNDATION – COMBINED FOOTINGS FORMING A RING RAFT
- BASEMENT –
  - WATERTIGHT STITCHED RAFT ANCHORED TO GROUND WITH PRESTRESSED ROCK ANCHORS TO MINIMIZE THE FILLING MATERIAL
  - RCC PROPPED RETAINING WALLS
- COLUMNS – M:80 SELF COMPACTING CONCRETE
- POST-TENSIONING BEAMS BELOW GIRDER LEVELS
- GIRDERS
  - STRUT TIE / DEEP BEAM MODEL

ALL STRUCTURAL SYSTEMS INTENDED TO LIMIT USE OF CONSTRUCTION MATERIALS

DESIGN CONCEPTS

- BRAHMSTHAN – VOIDED SLABS
- PODIUM – POST – TENSIONED FLAT SLABS
- AMENITY LEVELS – POST- TENSIONED VOIDED SLABS
- GIRDER PERFORMANCE ENHANCEMENT
  - HORIZONTAL POST-TENSIONING – BOTTOM CHORD
  - PROFILED POST-TESIONING – WEB
  - VERTICAL POST-TENSIONING – GIRDER LAYERS
- POST-TENSIONED BEAMS BELOW GIRDER LEVELS

ALL STRUCTURAL SYSTEMS INTENDED TO LIMIT USE OF CONSTRUCTION MATERIALS

MATERIALS OF CONSTRUCTION

CONCRETE	
M:15	**FOR LEVELING PCC**
M:40	**COLUMNS,FLOOR SLABS AND BEAMS**
M:50 & M:60	**COLUMNS,BEAMS,PT FLAT SLAB**
M:80	**COLUMNS,WALLS**
REINFORCEMENT	
Fe 500 and	**REINFORCING STEEL WITH**
Fe 500 D	**ANTI-CORROSION & DUCTILE PROPERTIES**
STRUCTURAL STEEL	
Fe 250	**BEAMS**
Fe 350	**COLUMNS, BEAMS**

USE OF HIGH GRADE MATERIAL PLANNED TO CONSUME LEAST POSSIBLE MATERIAL

STRUCTURAL PERFORMANCE REVIEW

STRUCTURAL PERFORMANCE COMPARISION

PARTICULARS	DEF^N	HEIGHT/DEF	TIME PERIOD	ACC^N	REMARKS
	mm	*ratio*	*sec*	*m/sec^2*	
STATIC	374	**775**	9.893	8.82	LIFE SAFETY
ZONE III	160	1811	10.06	**6.5**	IMMEDIATE OCCUPANCY
ZONE IV	241	1205	10.06	**9.75**	IMMEDIATE OCCUPANCY
SITE SPECTRA	113	2565	10.06	**4.61**	OPERATIONAL
WIND CODE	221	1311	10.06	**8.82**	IMMEDIATE OCCUPANCY
WIND TUNNEL	248	1169	10.06	**10.05**	LIFE SAFETY
E – VALUE	214	1354	9.893	**8.82**	IMMEDIATE OCCUPANCY

DRIFT COMPARISON WITH & WITHOUT DAMPERS

Comparison of Peak Displacements at Various Levels with and wuthout Dampers			
Approx Ht where Displacements measured in meters	Direction of Displacement	Floor Displacements for Building without Dampers (mm)	Dampers Upto Girder Level -136 Dampers of 200 Tons capacity each (mm)
75m	X	294	76
150m	X	374	184
200m	X	272	257
304m	X	556	358
75m	Y	278	89
150m	Y	327	189
200m	Y	290	261
304m	Y	585	370

STRUCTURAL PERFORMANCE AS PER DEFINED DRIFT STANDARDS

BUILDING CONFIGURATION	PEAK DISPLACEMENT IN X – DIRECTION	PEAK DISPLACEMENT IN Y – DIRECTION	STRUCTURAL PERFORMANCE OF BUILDING
WITHOUT ANY DAMPERS	556	585	LIFE SAFETY
WITH 136 DAMPERS UPTO GIRDER LEVEL	358	370	IMMEDIATE OCCUPANCY

CONCRETE

HIGH PERFORMANCE CONCRETE

CONCRETE	USAGE AREAS	DESIRED PERFORMANCE
M:15	FOR LEVELING PCC	PUMPABLE
M:40 SCC	COLUMNS, FLOOR SLABS AND BEAMS	FOR EARLY STRENGTH GAIN REDUCTION IN SIZES AND REBARS
M:50 & 60 SCC	COLUMNS, BEAMS, PT FLAT SLAB	TRANSFER OF LOAD THROUGH FLOOR, EARLY STRENGTH GAIN, REDN IN SIZES AND REBARS
M:60 SCC	9 m DEEP TRANSFER GIRDERS	SELF COMPACTING, EARLY STRENGTH GAIN
M:80 SCC	COLUMNS, WALLS	TO ADDRESS COMPACTION PROBLEMS

Post Tensioning of slabs

Voided Slab – Rebar work in progress

Column Cages


2009/01/03

Self Climbing Core Formwork

Pre-engineered Column Formwork







2010/04/12

Post Tensioning of Transfer Girders

HIGH PERFORMANCE CONCRETE

Normal / vibrated concrete

Retarded Concrete

Surface retarders to avoid cold joints

Surface retarders to facilitate green cutting

Foam concrete for filling in sunken areas

Temperature controlled concrete

Containing heat of hydration for 72 hours to avoid shrinkage cracks

Use of curing compounds

Online NDT

Core testing for segregation

Fibers for water repelling properties for underground elements

Fibers for shrinkage control

Pre construction mock up test

CONCRETE INFORMATION

- **DEVELOPMENT OF HIGH PERFORMANCE CONCRETES**
  - **M:60, M:80 CONCRETES**
  - **AGGREGATE IMPORTANCE**
  - **ADMIXTURE IMPORTANCE**
  - **SELF COMPACTING CONCRETE**

- **FOAM CONCRETE**
- **LIGHT WEIGHT CONCRETE BLOCKS**
- **LIGHT WEIGHT STRUCTURAL CONCRETE**

CONCRETE INFORMATION

M:80 SCC

Target strength	**:**	**90 N/sq.mm.**
Free water cement ratio	**:**	**0.225**
Cement content	**:**	**450 kg**
Fly Ash	**:**	**168 kg/ cu.m**
Micro silica	**:**	**23 kg / cu.m**

Alco Fine was also used at a later stage when it was introduced as a new material in the market.

CONCRETE INFORMATION

Self Compacting Concrete

CONCRETE PREPARATIONS

On site concrete batching plants

Fixed concrete pipelines

Temperature monitoring and control

Admixture dosage control

Fogging system installed

Chilled water system installed

Site laboratory established

Mock up studies

COVERED BATCHING PLANT

EXPERIENCE OF HIGH GRADE CONCRETE

- **POSITIVE POINTS**

- **Consistency was not a problem**
- **Expected strengths enabled gravity column size reduction**
- **Enabled early pre-stressing**
- **SCC ensured integral concrete**

EXPERIENCE OF HIGH GRADE CONCRETE

- **PRECAUTIONARY POINTS**

- **Extraordinary quality control in production and placement**
- **Segregation**
- **Admixture floating to top**
- **Heat of hydration**
- **Brittleness**
- **Bursting cube failure**

EXPERIENCE OF HIGH GRADE CONCRETE

- **PRECAUTIONARY POINTS**

- **Low E values**
- **Slurry too hard to chip at construction joints**
- **Could not afford mistakes or non-achievement of strength**
- **Extremely sturdy formwork**

FOGGING MACHINE

HUMIDITY CONTROL


2010/02/05


Green Cutting of Concrete

Meva Modulur Formwork and Staging

Slabs

Columns

Staging

Transfer Girders

ADMIXTURE SLURRY FLOATATION AT CONSTRUCTION JOINT

STRUCTURAL PERFORMANCE COMPARISION

PARTICULARS	DEF^N	HEIGHT/DEF	TIME PERIOD	ACC^N	REMARKS
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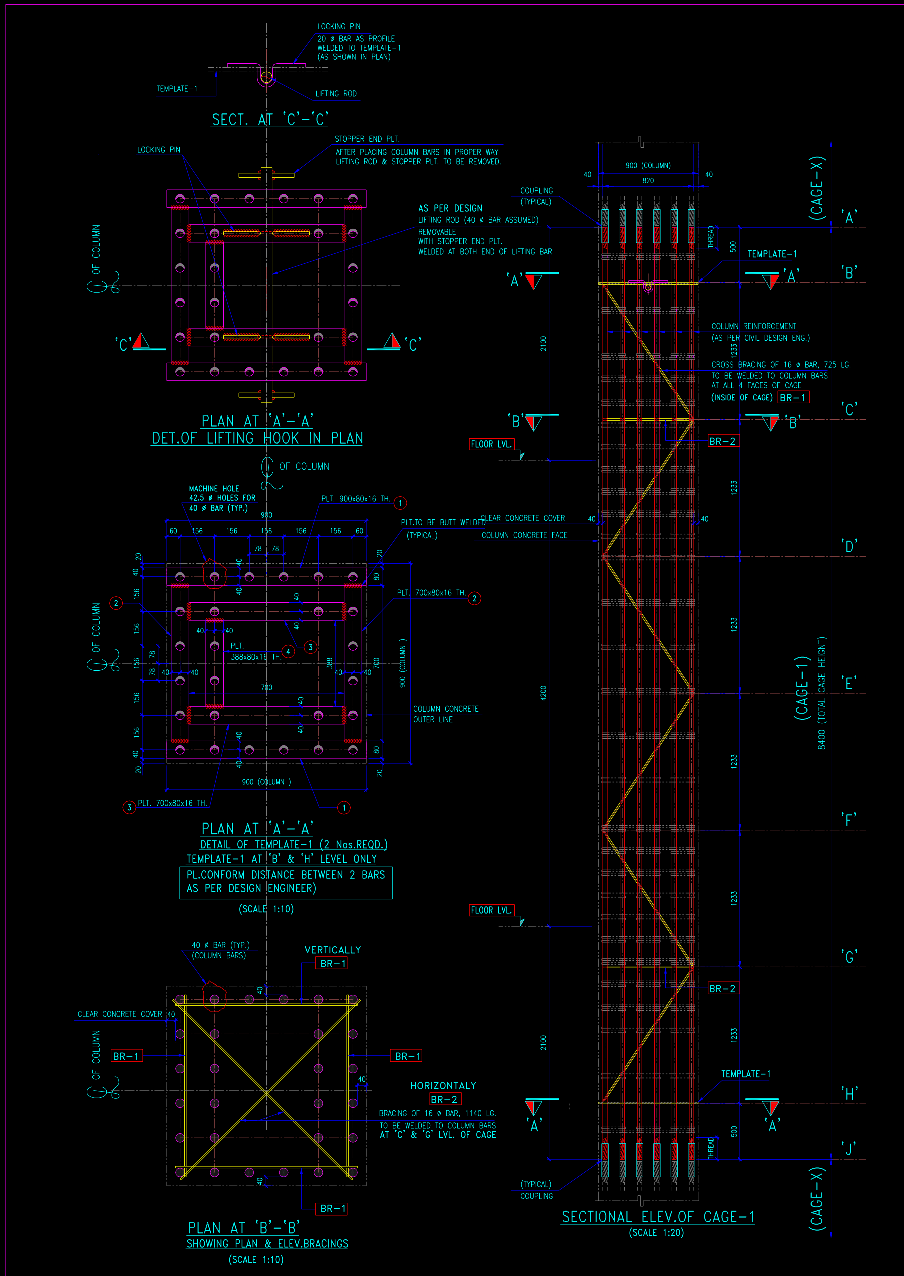
LOCKING PIN
20 ø BAR AS PROFILE WELDED TO TEMPLATE-1 (AS SHOWN IN PLAN)
TEMPLATE-1
LIFTING ROD
SECT. AT 'C'-'C'
LOCKING PIN
STOPPER END PLT.
AFTER PLACING COLUMN BARS IN PROPER WAY LIFTING ROD & STOPPER PLT. TO BE REMOVED.
AS PER DESIGN
LIFTING ROD (40 ø BAR ASSUMED)
REMOVABLE
WITH STOPPER END PLT.
WELDED AT BOTH END OF LIFTING BAR
PLAN AT 'A'-'A'
DET.OF LIFTING HOOK IN PLAN
OF COLUMN
MACHINE HOLE
42.5 ø HOLES FOR
40 ø BAR (TYP.)
PLT. 900x80x16 TH.
PLT.TO BE BUTT WELDED
(TYPICAL)
PLT. 700x80x16 TH.
PLT. 388x80x16 TH.
COLUMN CONCRETE OUTER LINE
900 (COLUMN)
PLT. 700x80x16 TH.
PLAN AT 'A'-'A'
DETAIL OF TEMPLATE-1 (2 Nos.REQD.)
TEMPLATE-1 AT 'B' & 'H' LEVEL ONLY
PL.CONFORM DISTANCE BETWEEN 2 BARS
AS PER DESIGN ENGINEER)
(SCALE 1:10)
40 ø BAR (TYP.)
(COLUMN BARS)
VERTICALLY
BR-1
CLEAR CONCRETE COVER
BR-1
BR-1
HORIZONTALY
BR-2
BRACING OF 16 ø BAR, 1140 LG.
TO BE WELDED TO COLUMN BARS
AT 'C' & 'G' LVL. OF CAGE
BR-1
PLAN AT 'B'-'B'
SHOWING PLAN & ELEV.BRACINGS
(SCALE 1:10)
900 (COLUMN)
820
COUPLING
(TYPICAL)
TEMPLATE-1
COLUMN REINFORCEMENT
(AS PER CIVIL DESIGN ENG.)
CROSS BRACING OF 16 ø BAR, 725 LG.
TO BE WELDED TO COLUMN BARS
AT ALL 4 FACES OF CAGE
(INSIDE OF CAGE) BR-1
BR-2
FLOOR LVL.
CLEAR CONCRETE COVER
COLUMN CONCRETE FACE
FLOOR LVL.
BR-2
TEMPLATE-1
(TYPICAL)
COUPLING
(CAGE-X)
(CAGE-1)
8400 (TOTAL CAGE HEIGNT)
(CAGE-X)
SECTIONAL ELEV.OF CAGE-1
(SCALE 1:20)

Surface Finish from Pre-engineered Formwork

MODERN TECHNOLOGIES LINKED TO SUSTAINABILITY CONCEPT

TECHNIQUE	BENEFITS
PRE-DESIGN SITE SPECIFIC STUDIES AND PRE-DEFINING PERFORMANCE CRITERIA	OPTIMIZATION OF STRUCTURAL DESIGN TO REDUCE CONSUMPTION OF CONSTRUCTION MATERIALS, ENSURING MAXIMUM HUMAN COMFORT – DURING USUAL AND POST-DISASTER CONDITIONS
HIGH GRADE CONCRETE	LESSER CONSUMPTION, ENERGY REQUIREMENT
USE OF MICRO SILICA	HIGH PERFORMANCE ACHIEVEMENT, DURABILITY ENHANCEMENT, LIFE CYCLE COST REDUCES
USE OF WATER REDUCING ADMIXTURES	REDUCTION IN WATER CONSUMPTION
USE OF COUPLERS, CAGES FOR REINFORCEMENT PLACEMENT	REDUCTION IN REINFORCEMENT QUANTITIES, LESSER ENERGY CONSUMPTION

MODERN TECHNOLOGIES LINKED TO SUSTAINABILITY CONCEPT

TECHNIQUE	BENEFITS
USE OF DAMPERS	ENHANCING THE PERFORMANCE OF THE BUILDING, REDUCTION IN STRUCTURAL SIZES LEADING TO REDUCED CONSUMPTION OF CONSTRUCTION MATERIALS
HEAVY DUTY EQUIPMENT	SHORTER CONSTRUCTION TIME, LESS ESTABLISHMENT COST, CONSUMPTION OF POWER AND WATER
USE OF CURING COMPOUNDS	REDUCTION IN WATER CONSUMPTION DURING CONSTRUCTION
USE OF LIGHT WEIGHT MATERIALS	REDUCTION IN MEMBER SIZES, ECONOMY, REDUCED CONSUMPTION

QUANTITIES

ESTIMATED MATERIAL CONSUMPTION

ELEMENT	CONCRETE	REINF	KG/CU.M
Foundation	15350	3500	228
Retaining Walls	2406	500	208
Slabs and Beams below Girder	62347	10721	172
Columns below Girder			
Parapets, stairs, moats above girder			
Girders	12852	5000	389
Slabs and Beams above Girder	63509	10925	172
Columns above Girder	34388	10316	300
Parapets, stairs, moats above girder (assumed)	6350	635	100
Structures above terrace (assumed)	1000	100	100
Total	**198200**	**41697**	**210**

CURRENT STATUS