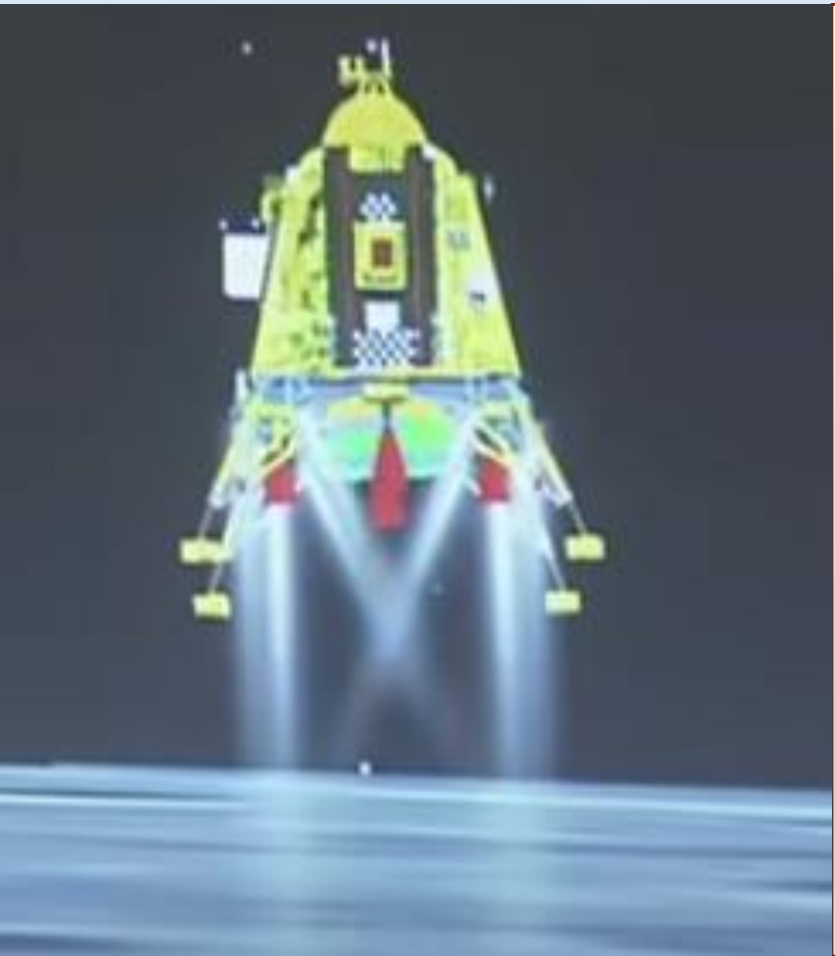
CIVIL INFRASTRUCTURAL CHALLENGES FOR INTERPLANETARY MISSIONS

Engineer's Day Celebration 2024
AT BMS COLLEGE OF ENGG, Bengaluru



Technical Talk

By

Dr. I. Venugopal
Prof. and EX- HoD
Civil Engg. Department, MSRIT
Ex- Group Head, LEOS-URSC-ISRO, Bangalore – 560 017

Organised By
ICI, BENGALURU CENTRE and BMSCE,Bengaluru

On: 05/10/2024

Pride moments for India on 23rd August 2023
LET US RELIVE IT AGAIN..!!

CIVIL ENGINEERS PLAY CRITICAL ROLES IN ALL STAGES OF SPACE MISSIONS

1. Prelaunch phase:

   Realizing Ground-Based Infrastructure i.e. conventional and Unconventional facilities.

2. Post Launch Stage:

   Ground telemetry Tracking Facilities, Deep space networking and antenna Radar structures.

3. Simulation phase:

   Prototype Testing and Validation facilities

CRITICAL PROJECT SCHEDULES:

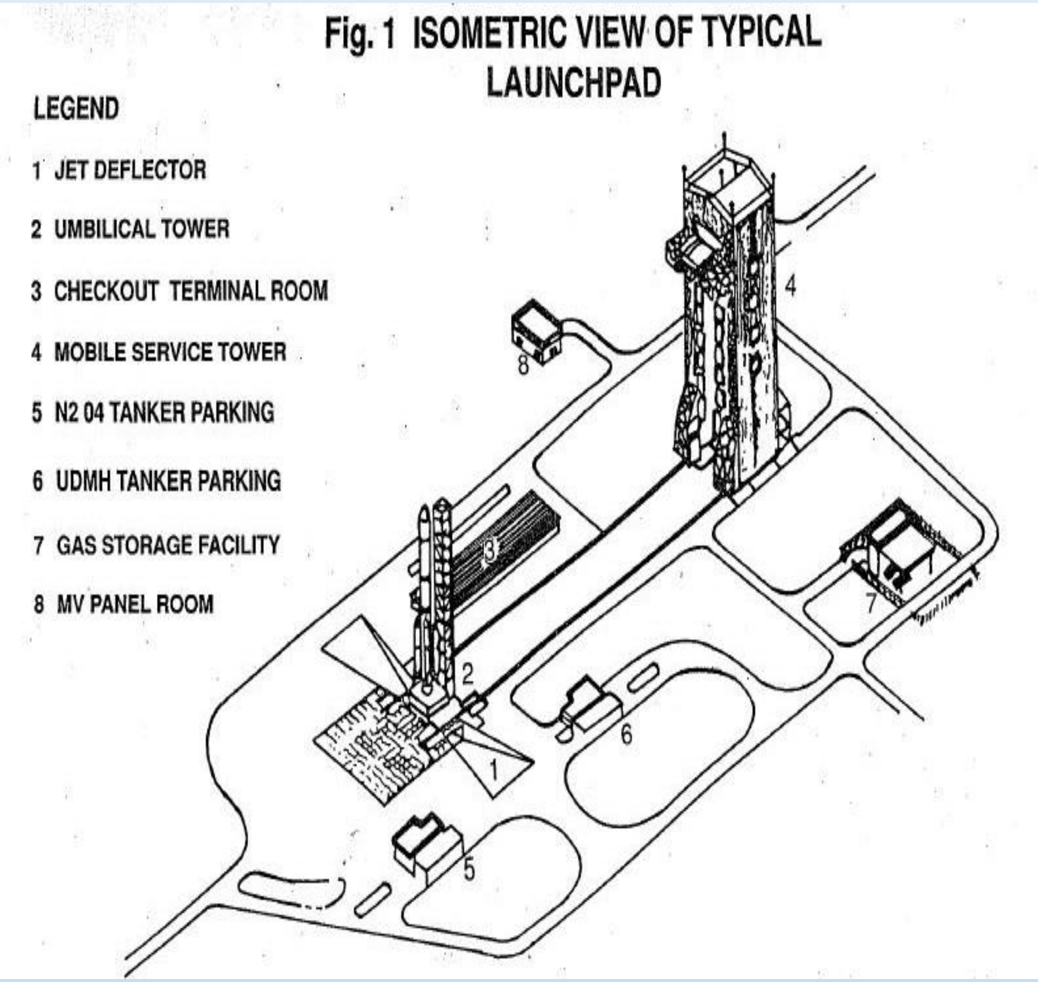
- Day and Night work for civil engineers to hand over facilities on time
- 24/7 hrs. Environmental Maintenance due to Scientific lab works round the clock !!

UNIQUE INFRASTRUCTURE NEEDS
Space Missions are Interdisciplinary

- Infrastructure Engineers i.e. Civil/Mech/Electrical/Electronics play a very significant role in planning/designing/executing and commissioning ground-based infrastructures, like **Launchpads, Mobile Service Towers** along with **RCC tracks, propellant storage buildings, Testing facilities, large-size assembly structures, antenna-radar supporting complexes, clean room buildings of class I in 100,1000,10,000,1,00,000 etc. to handle satellites, laboratory buildings with seismic-machine foundations, simulation facilities, apart from conventional residential/official/institutional buildings, Roads, GLRs,OHTs etc.**
- The facilities are exclusively different from normal civil Engg buildings/structures wrt design loads & Project requirements
- Steel Sliding doors (10mx10m etc)/Cranes/hoists/towers etc required.
- Uninterrupted Power Supply to carryon with operational works
- Design & Maintenance of AC &clean room conditions.

I. Ground-based infrastructure

Ex: Launch Pad: A semi-buried ground structure to support Launch Vehicle like PSLV/GSLV/LVM etc during the launch campaign



Launchpad complex at Sriharikota-Space Port

1000 meters long RCC track for mobile launch pedestal

VAB Stationary but Launch pedestal with Vehicle moves……..

Associated buildings to be designed for acoustic loads. MST should withstand cyclone pressures/wind gust upto 215 KMPH

Unconventional Design Requirements of Launch Pad.

- Civil Structures should be of practically Zero displacement & structures need to be highly stiff and rigid for zero tolerance wrt vehicle alignment errors.
- Predominant forces are Jet impingement pressures of 200 to 300 kN/m^2 , which act on RCC Jet Deflector Duct(JDD)
- JDD is a large RCC Structure whose shape/size and dimensions are finalized based on FLOW MODEL Studies to facilitate free flow of Effluents.
- Excessive Temperature Loads upto 1500^0 C are realized for every launch
- Unbalanced thrust can tilt vehicle alignment *(due to pressure loads of strapons of space launch vehicles at the time of launch.)*
- Earth Pressures/Ground Water Table up-thrust/ vehicle loads under critical wind condition are other forces to be considered

Research Attitude is Essential !!

- Acoustic Loads are of logarithmic functions.

$$dB = 20 \log (P_1/P_2)$$

Where,

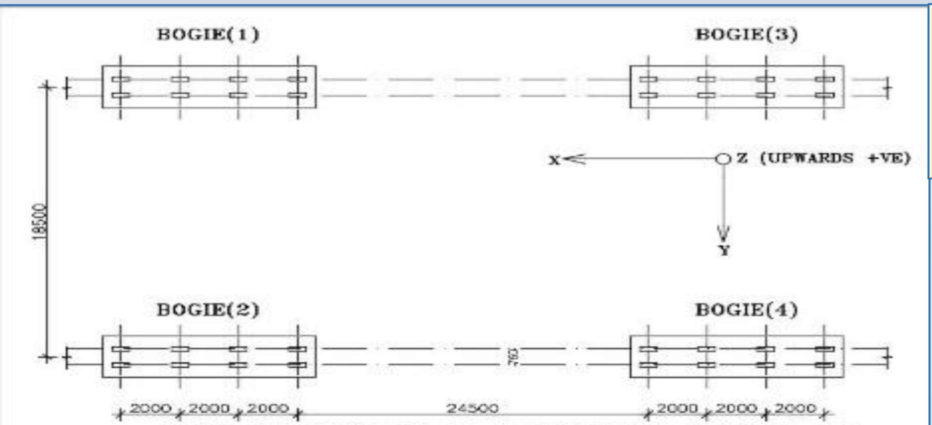
P_1 = acoustic pressure in dynes / sq.cm and

P_2 = reference pressure i.e., 2×10^{-4} dynes / sq.cm

- Civil structures also Need to be designed for probable i.e. eventual blasting pressures of propellants. (As per Blast Code IS: 4991-2013)
- Transient Dynamic Vibro acoustic loading of 140 to 175 decibels act on all buildings during launch. No IS or foreign codes of Practice are available.
- New design philosophy got evolved on concepts of **Blast Resistant Criteria and Detailing**
- A Challenge for all designers in absence of codes and guidelines !!!

PSLV – LAUNCH PAD : **Mobile Service Tower (MST) of structural steel of 3000 Tons weight and of 90 meters height i.e. 30 storied structure moves on an RCC track with 32 wheels for every launch. Each wheel imparts axial load of 125T and transverse shears of around 7 tons on RCC track Differential settlements of track should not be more than 1mm.**

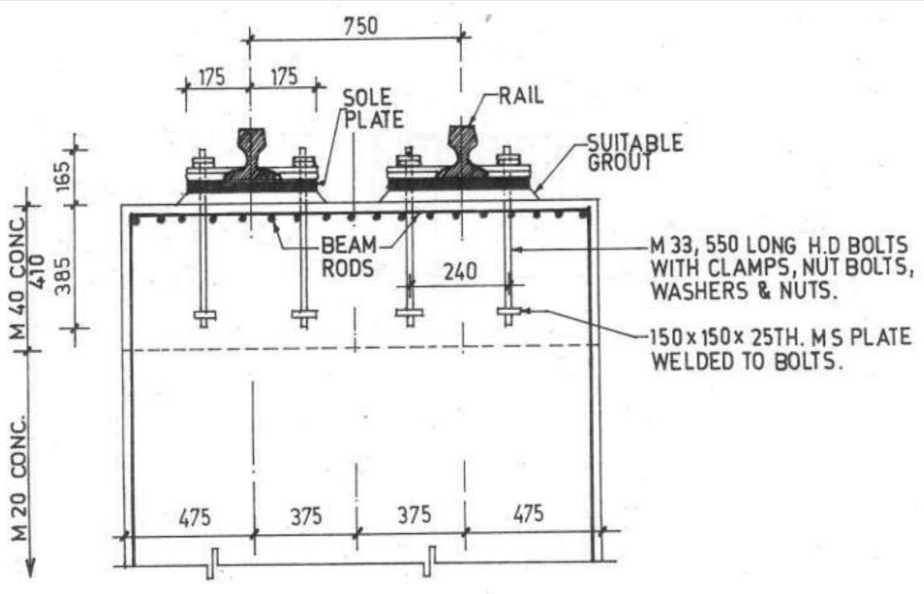
Fuel filling /electronic checks/close-down monitoring operations will take place till T-48 hrs. and at T-2hrs MST retraces back to anchored position



PLAN DISPOSITION OF BOGIES AND WHEELS OF MOBILE SERVICE STRUCTURE

Plan of Mobile Service Tower with Four Bogies
Maximum wheel load: 125T
Shear: 7 Tons

Sole Plate to fix rail Sections



RCC Strip Raft Support Track

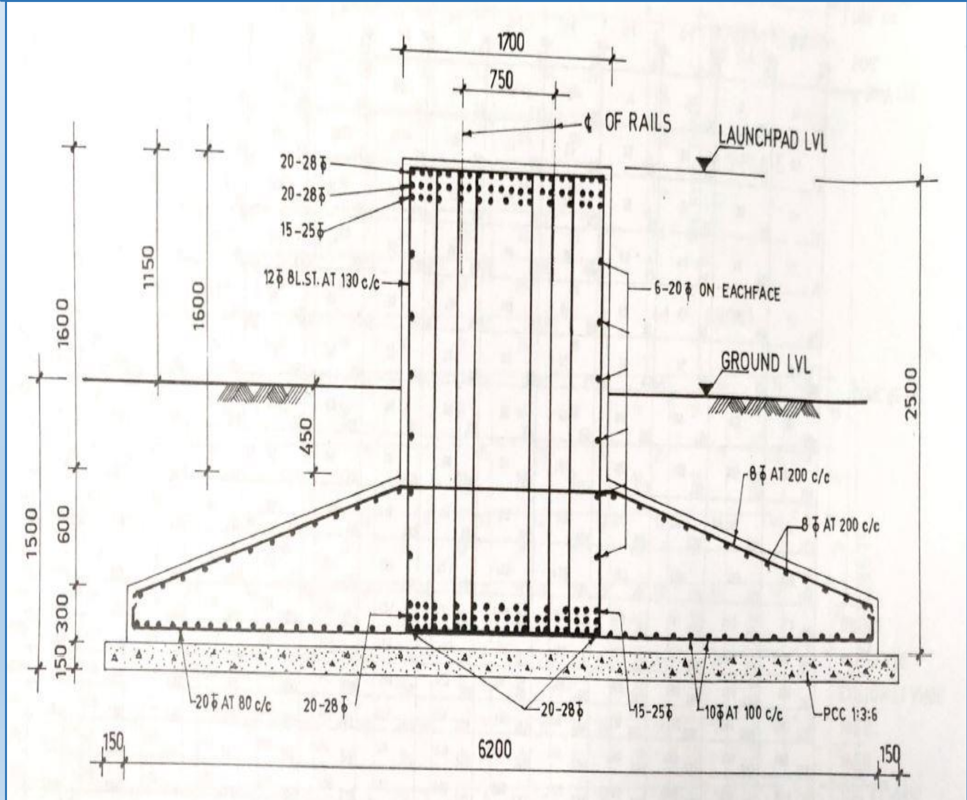
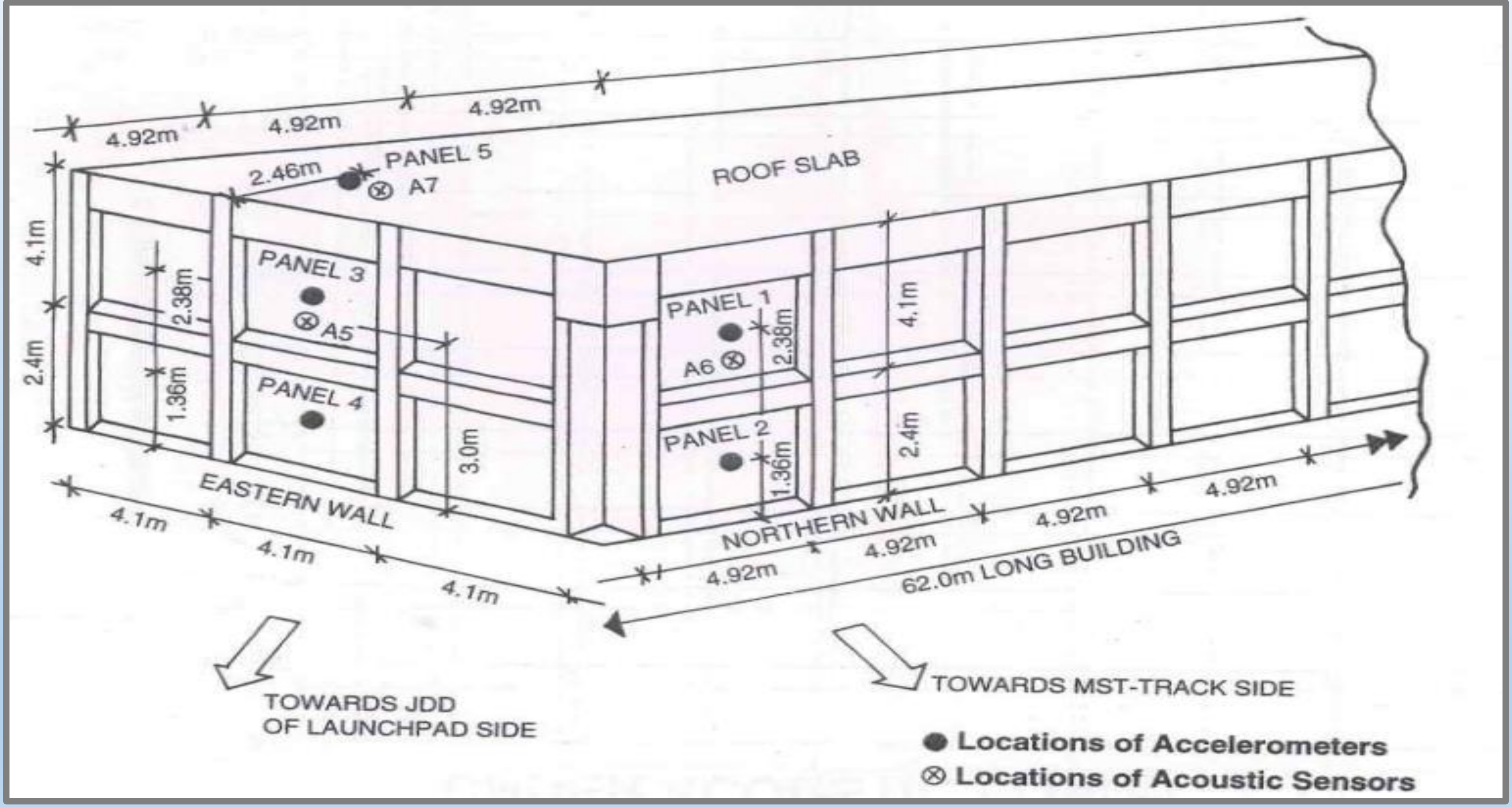


FIG.3. TYPICAL CROSS SECTION OF TRACK FOUNDATION

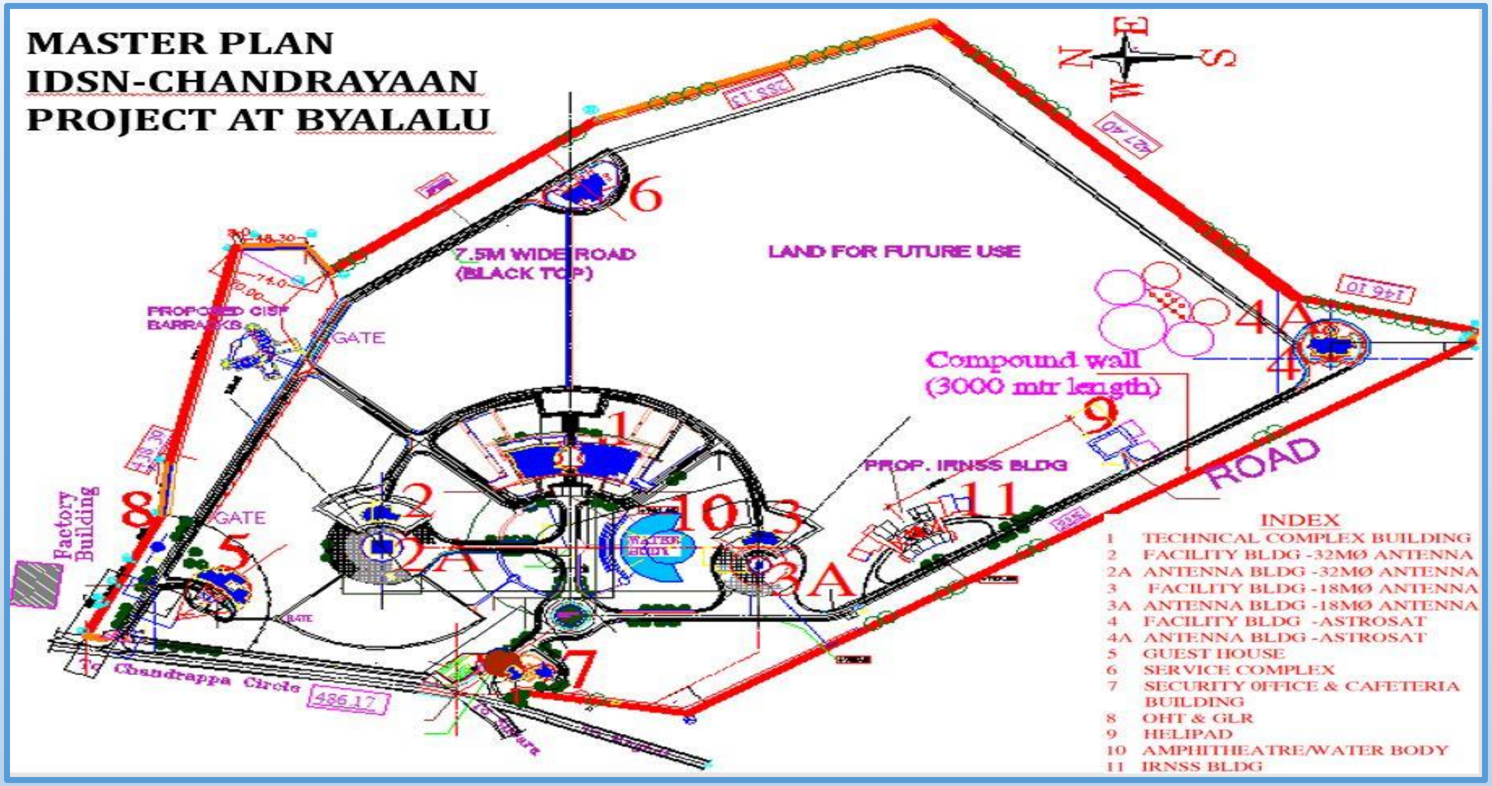
Validation of design Philosophy: Installation of Accelerometers and Acoustic Sensors in RCC walls and slabs to validate Acoustic Design of Civil Engineering Structures (With SERC- Madras Support)

CTR Building (closest to LP)



Experimental and theoretical responses are matched hence design approach validated

POST LAUNCH STAGE: Satellite is tracked and monitored from ground stations at MCF Hassan IDSN Byalalu Village / ISTRAC Peenya and Ground stations at SHAR /BRUNNIE/Mauritius etc.



INDIAN DEEP SPACE NETWORK (to track satellites)

Area: 122 Acres

- Buildings to be free of RF Zone
- Master Planning was a Challenge for Civil Engineers with level difference of 42 mts from N-S

32 m Dia Antenna supporting structure to receive and transmit radio signals RF rays

A CHALLENGE FOR CIVIL AND MECHANICAL ENGINEERST(TODAYS TALK)

SIMULATION FACILITIES FOR CHANDRAYAAN III

- ISRO commissions any project after proto-simulation studies to address intricate behavioral aspects beyond known principles of Engineering/ or available Science
- For Chandrayaan Mission a large quantity of "Moon Soil" was required to simulate the safe landing of the LANDER and also for the movement of the ROVER on lunar terrain. IT WAS DONE BY CIVIL ENGINEERS!!
- LUNAR SOIL –WHEEL INTERACTION STUDIES enabled optimal design of Rover Wheel & Lander leg configurations

TESTING OF ROVER AT ISITE-URSE- ISRO, BANGALORE

Artificial sloping terrain was also created on the test bed for monitoring the movement of rover, under different possible conditions.

For Chandrayaan simulation studies, output of this research work i.e., Lunar highland soil simulant (LSS-ISAC-1) was used for making the test beds. Helium balloon was used to simulate 1/6th g condition.

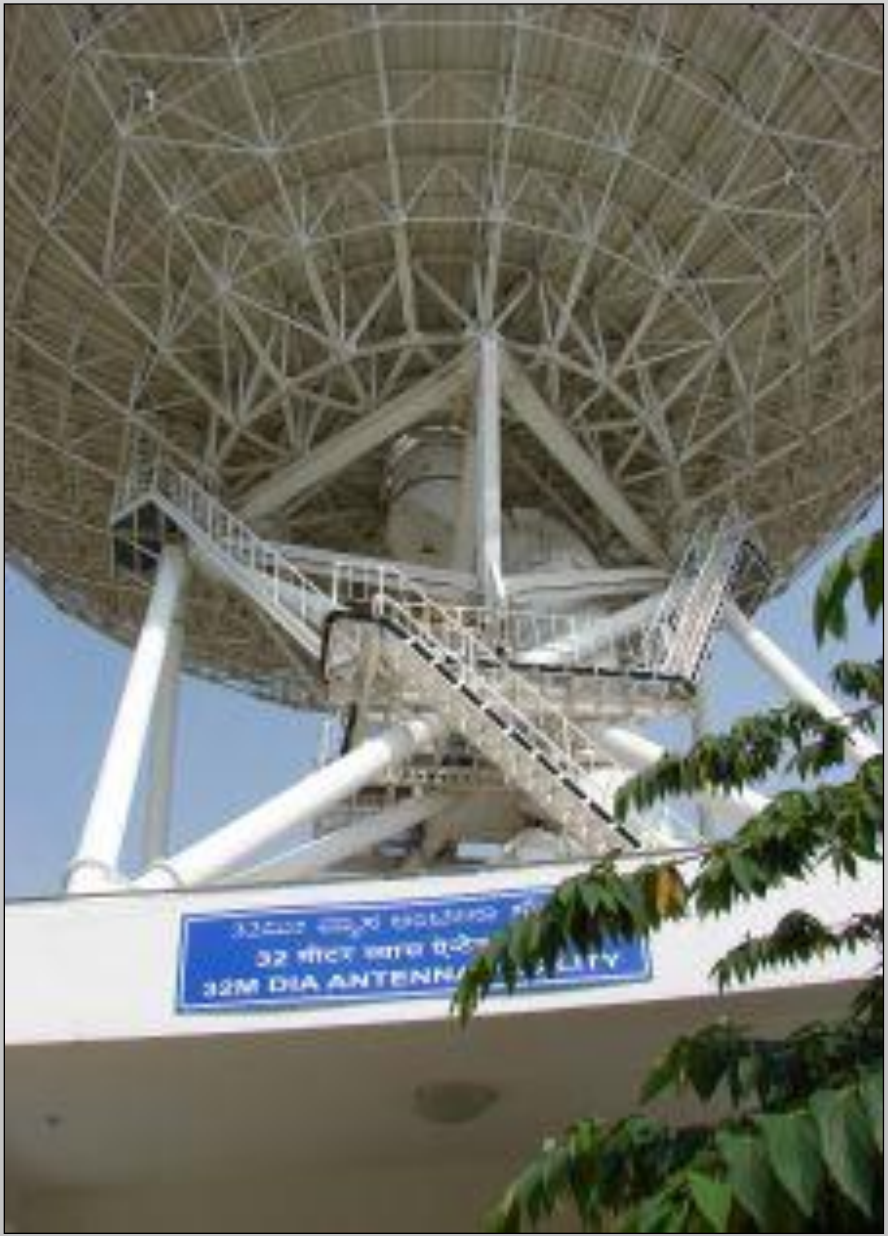
CIVIL ENGINEERS DID GROUNDWORK IN TRUE SENSE

32 Mts DIA ANTENNA – A CASE STUDY

- Wind Loads on Azimath and elevational positions are critical.
- 300 tons steel antenna structure moves on steel rails of Dia 16.9 m, with 360^0 freedom of rotation
- Circular Ring Beam of size 1.4x1.6m to withstand torsion & vertical wheel loads.
- Tracks Satellites of the Moon, Mars/ Any Interplanetary mission – Hence facility of the highest precision is to be designed /detailed and executed
- Also, useful for further Interplanetary missions like Venus – Jupiter- Solar (Aditya), etc.

Possible Settlement of Structure are due to

- Structural Deflection of RCC portion
- Antenna Displacement-Mechanical/Steel/Structural Part
- Foundation settlement, SHORT&LONG TERM
- Together total deflection shall not exceed projects stringent limits
- Tip Rotation shall not be more than 1milli degree i.e.,3.6 arc seconds.



ITS POSITION IS CALIBRATED WRT CELESTIAL BODIES!!

INFRASTRUCTURAL CHALLENGES OF 32M DIA ANTENNA

- A highly reliable network of ground stations is required to track spacecraft at such large distances of 4 lakh kms for Moon to 225 million Kms for Mars
- The facility needs large size reflectors for antennas to converge rays/signals like a "pencil lead" in order to precisely point towards a spacecraft.
- This ground based technical facility consists of 32 m dia reflector/Antenna mount/ Beam wave guide and feed apart from server systems etc.
- In this challenging technical mission, civil structural engineers, had challenges of strategically planning/analysing/designing and executing the civil works i.e., RCC pedestal structure to support gigantic 32000 mm dia antenna structure with huge dead load of around 300 tons, revolving around Azimuth and elevational axes under operating wind loads of 60 kmph and survival conditions of 160 kmph
- More critically, the design need to satisfy and control the deflections/ tip rotations of the RCC structure well within "specified stringent limits" was a major challenge .

PLANNING:

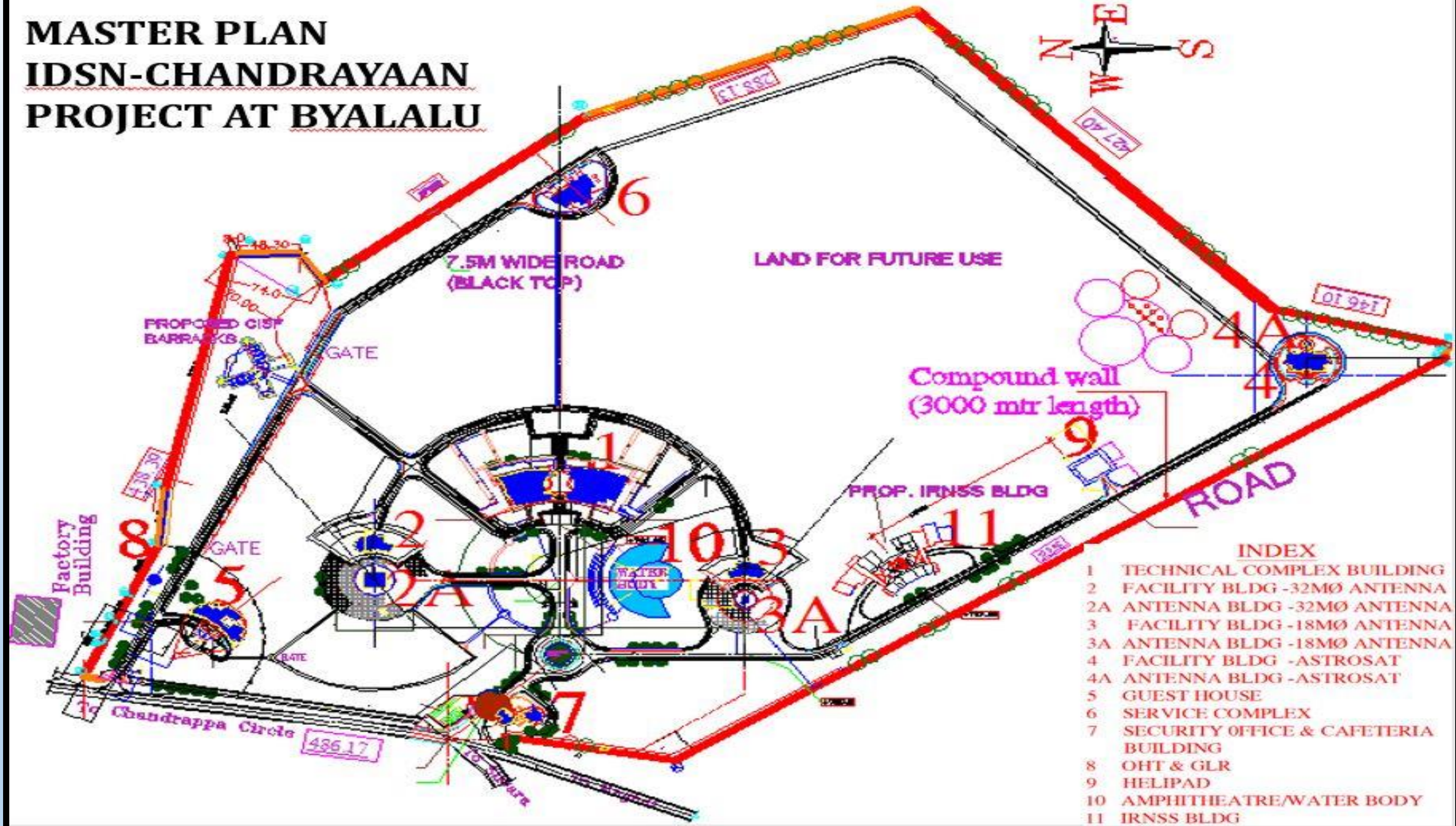
Guiding criteria for planning and locating the facility.

- The area of the locality should be nearer to the city but not surrounded by industrial/Commercial buildings to minimize electronic noise.
- A large land area as much as 100 acres was necessary to establish associated ground based infrastructural facilities.
- The area can be preferably surrounded by hills forming "bowl shaped landscape".
- No high-rise buildings around the site but availability of water, electricity and roads etc... is essential.

DUAL OPERATION CRITERIA:

- RADIO FREQUENCY (RF) radiation: For operational range of antenna in Azimuth for an extent of +40 deg to -40 deg, no human habitation is allowed.
- Antenna Blockage: Adjacent buildings should NOT block the signals during the operational stages
- Movement of antenna in its elevation above 5 degrees should be unhindered

MASTER PLAN IDSN-CHANDRAYAAN PROJECT AT BYALALU



SITE TERRAIN DETAILS & ADVERSE COMPLICATIONS

Highly undulating area with level difference of 42 mts from north to south corner!! . Has got loose soils to rocky strata across width and length.

Essentially a farm-agricultural land with multiple owners. Approached Karnataka state government for the land deal coordination. Transferred the money also, but many legal complications to sort out??

As a civil engg executive, had to face physical assault by the farmers as WE ARE THE FRONT LINE SOLDIERS!!. Resorted to police protection . 43 police personnel accompanied me for daily site visit and also camped!

No hotels or good roads in that remote corner. Pack food and work !! Fear of leopards and snakes also??

CONFIGURATION OF RCC SUPPORTING STRUCTURE

- An octagonal shaped building with 8 nos. of main RCC columns was planned.
- The roofing was planned as a "truncated ribbed conical shape" to facilitate central opening at crown to provide passage for "Beam wave guide”. ARCH ACTION ENABLES LOAD TRANSFER TO OUTER RING BEAM
- A sturdy peripheral ring beam to support Wheel and track system consisting of sole and friction plates erected by series of anchor bolts along the pitch line.
- The height of buildıng was also limited to 6140 mm to avoid fouling of reflector dish in its zero elevational angle with building edges.
- MASER ROOM WITH SEISMIC ISOLATION TO HOUSE ATOMIC CLOCK OF NANO SECOND PRECISION.

SCHEMATIC VIEW OF MECHANICAL SYSTEMS

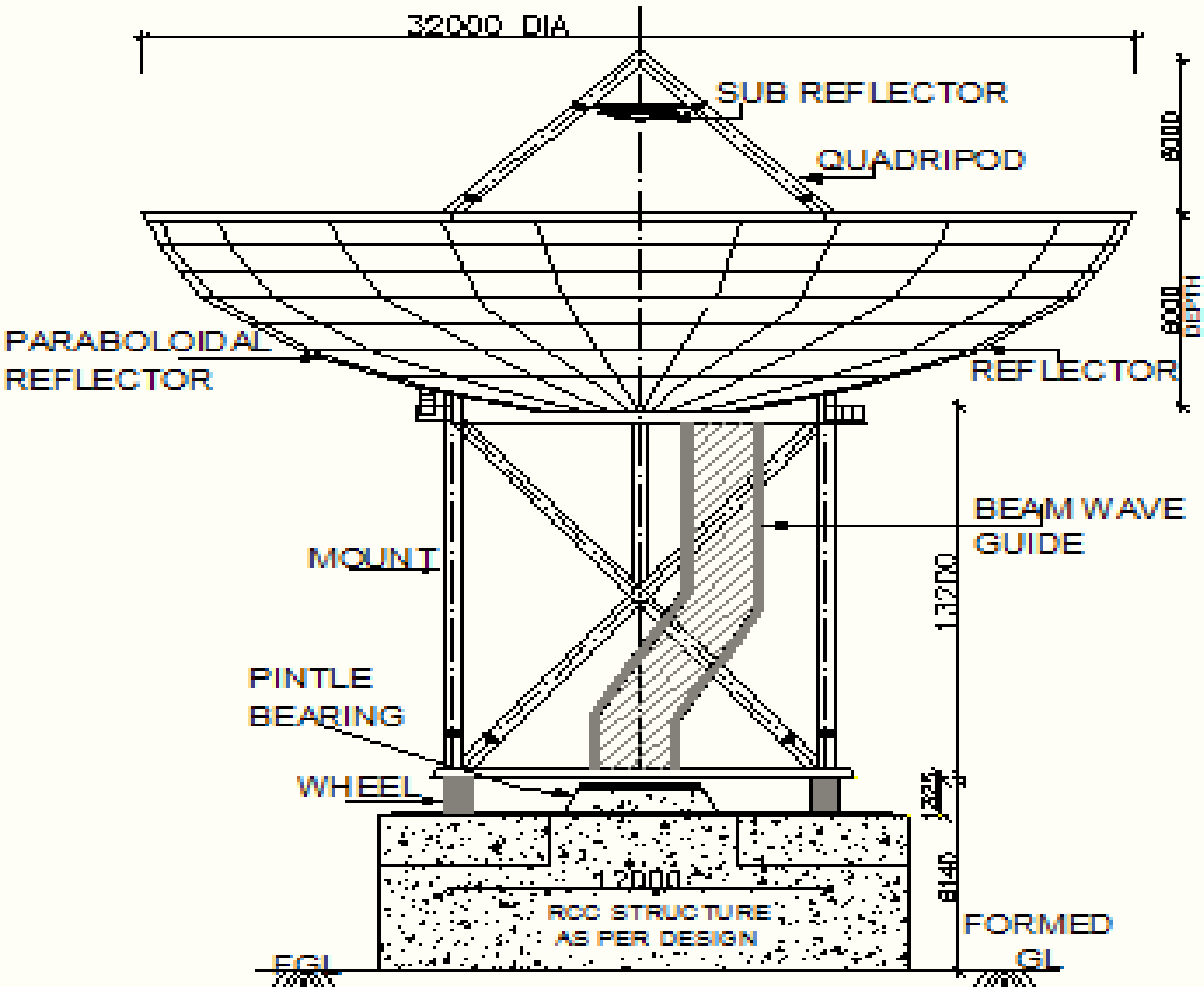


FIG 2: BROAD CONFIGURATION OF 32M DIA RADAR ANTENNA STRUCTURE
(NOTE: ALL DIMENSIONS ARE IN MM)

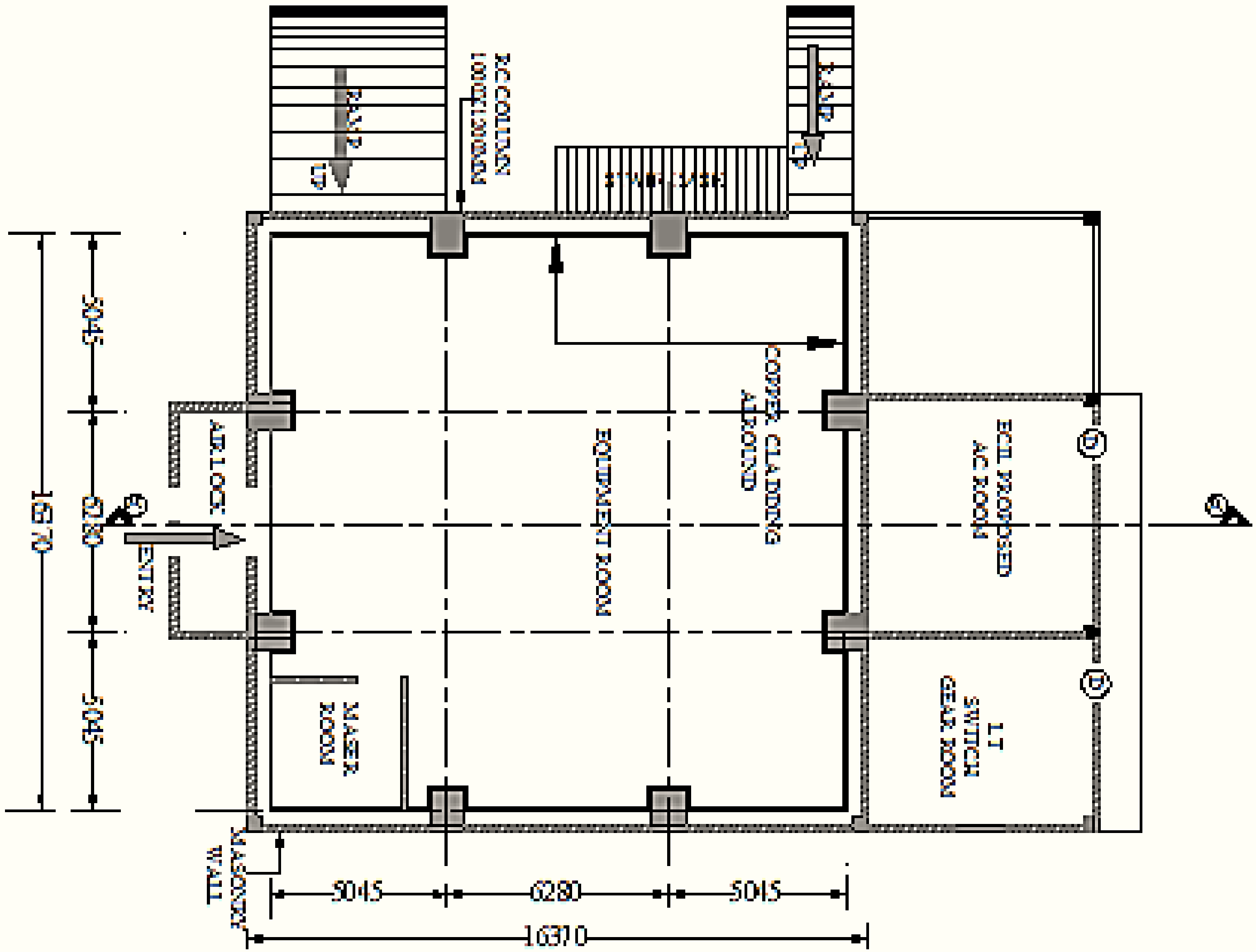


FIG 4: GROUND FLOOR PLAN

SHAPE AND GEOMETRY GOVERNED BY FUNCTIONAL NEEDS OF OPERATION

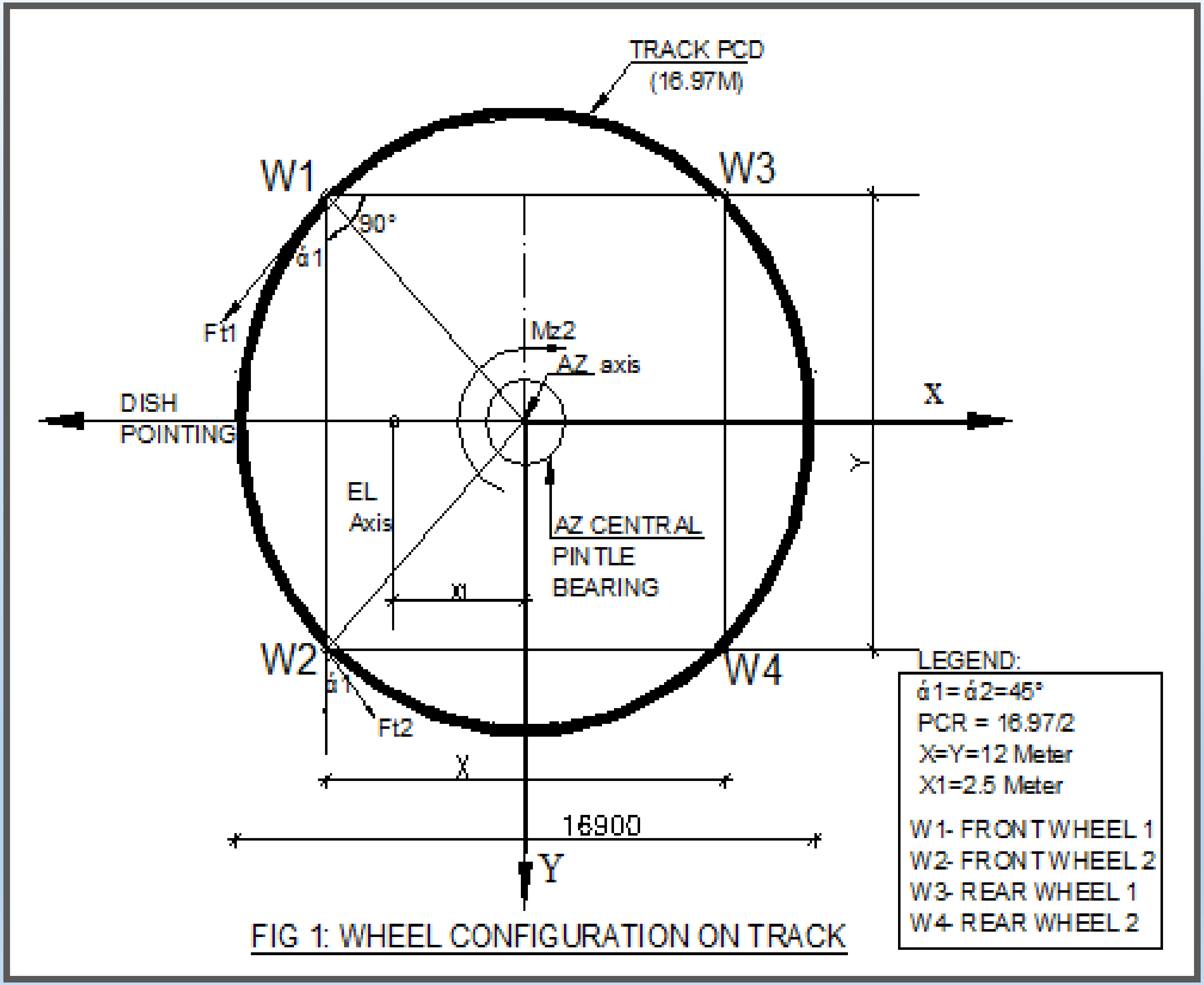


FIG 1: WHEEL CONFIGURATION ON TRACK

WHEEL CONFIGURATION ON TRACK

ROBUST RCC GABLE

FRAME WORK TO

FACILITATE FIXING OF

RAIL SECTION ON PRB

AND TO OPERATE

DISH ie REFLECTOR

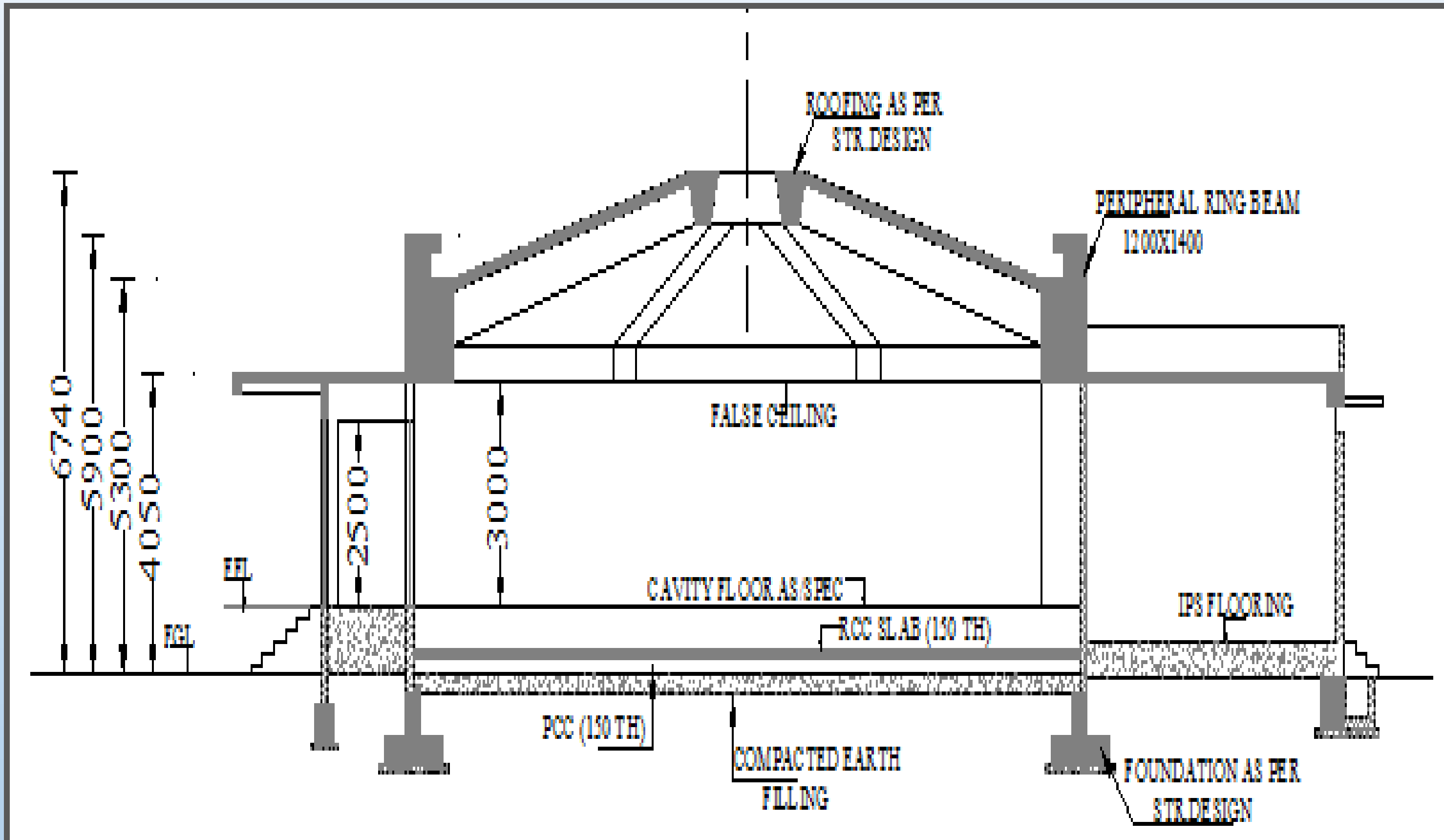


FIG 5: SECTION A-A THROUGH BUILDING

CIRCULAR SHAPE ENSURES UNIFORM STIFFNESS AND SAME LOAD BEARING CAPACITY IN ALL DIRECTIONS FOR SUCH REVOLVING MECHANICAL SYSTEMS

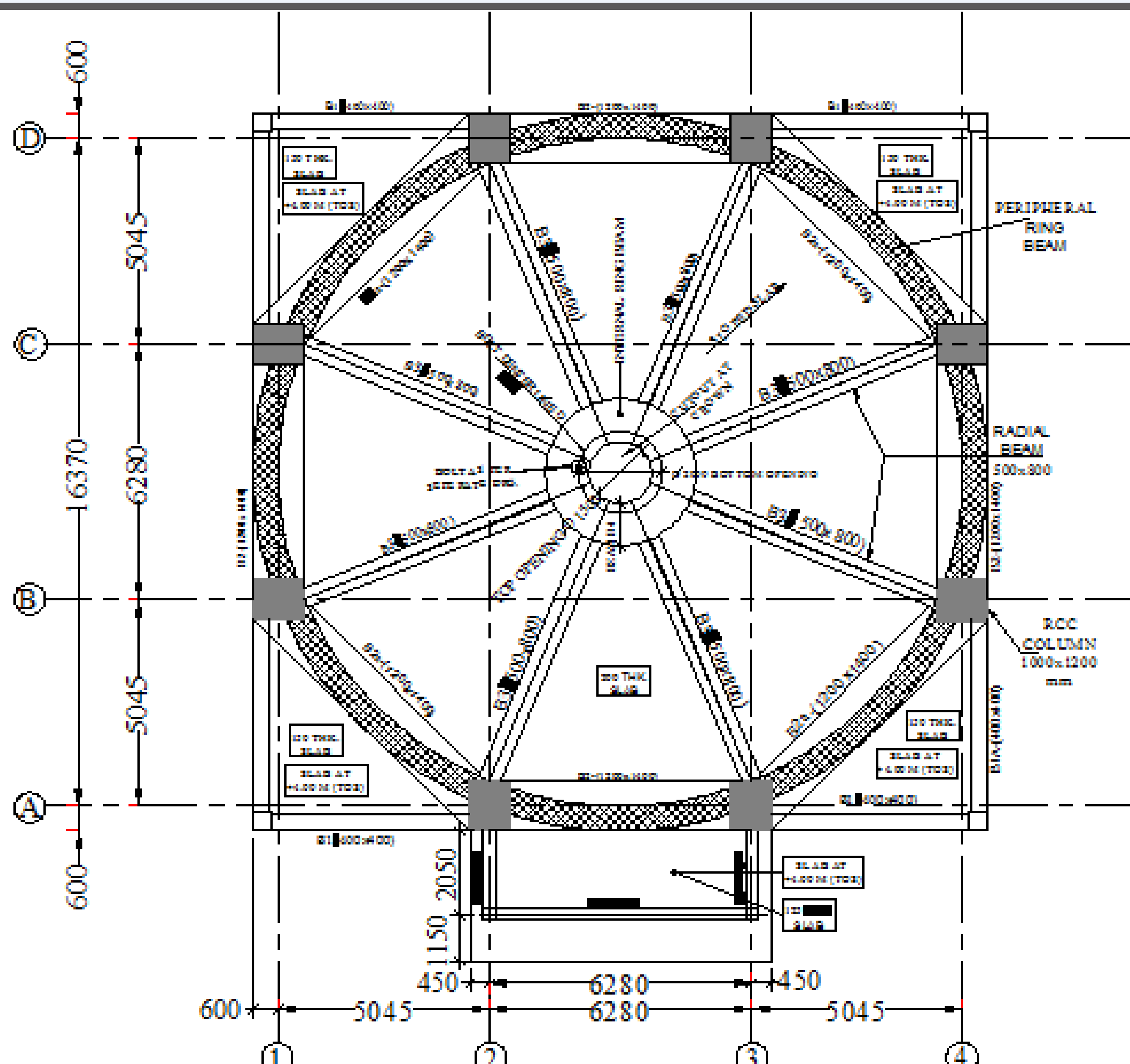


FIG 6: ROOF BEAM LAYOUT

LOAD ANALYSIS:

- The most IMPORTANT ITEM is Assessment of critical wind loads on the Dish structure
- Evaluate critical ie MAX load Under any possible position of antenna for any angle of Azimuth and elevation.
- The geometrical shape of "deep paraboloid" of reflector (with dia of 32m and depth of 6 m) attracts intense wind forces with components of drag and lift.
- It results into Large Vertical and nominal shear Forces onto PRB at respective Wheel Locations AND ALSO ALMOST 2000TMT OVER TURNING MOMENT on to RCC structure at zero elevation angle. AN UNUSUAL DESIGN REQUIREMENT!!!
- The wind is assumed to flow in horizontal direction hence the angle of attack (i.e., angle which the wind makes with plane of reflector rim) is a function of position of reflector which is defined by the altitude i.e., elevation and azimuth angles relative to wind stream.
- Hence VERTICAL PULL& PUSH occurs on daily basis!!

CFD SIMULATION STUDIES

- **Further, the aerodynamic characteristics are also greatly affected by geometrical features like "Depth to diameter ratio'," 'surface solidity ratio' and surface geometry etc.**
- **Hence, a rigorous wind load analysis was carried out by the users using concept of "Computational fluid dynamics' with ten times of "engulfing air domain of volume 320 m x 320 m x 320 m" to evaluate load effects of all fluid characteristics.**
- **IS 875-1987 PART3 FOR WIND LOADS WILL NOT SUFFICE TO EVALUATE WIND EFFECTS FOR SUCH KIND OF CONFIGURATION AND STRUCTURES.**
- **Advent of computing techniques enables us to assess such loads on mathematical modelling basis**
- **In all such Engineering Designs, assessment of Exact Loads is most critical for ensuring Safety & Stability**

360 Degree Movement of Antenna leads to multi Directional Stress Resultants on RCC to structure

SUMMARY OF CRITICAL WHEEL LOAD REACTIONS FROM CFD STUDIESI

Table 1: Summary of wheel load reactions

WHEEL	MAXIMUM VERTICAL LOAD IN TONS Including Gravity & Wind	POSITION
(A) UNDER OPERATING CONDITIONS (60 kmph Wind)		
W1	116.75	AZ 165, EL=30
W2	115.61	AZ=180, EL=30
W3	84.35	AZ=60, EL=0
W4	87.34	AZ=60 EL=90
(B) UNDER SURVIVAL CONDITIONS (160 kmph Wind)		
W1	173.18	AZ =165, EL=30
W2	169.60	AZ=180, EL=30
W3	138.32	AZ=60, EL=0
W4	147.76	AZ=60, EL=0

Legend: AZ= Azimuth angle; EL= Elevation angle

DEAD LOADS:

- Maximum dead load of antenna system gets transferred to ring beam as a set of concentrated MOVING LOADS through four wheels. A RARE PHENOMENA FOR BLDG DESIGN!! MAGNITUDE AND POSITIONS CHANGE CONTINUOSLY!!

i) Reflector assembly consisting of 24 radial trusses, panels, Quadri pod, sub reflector, hub, and backup trusses etc., weighing around 138 tons.

ii) Mounting structure with four wheels, AZ bearing, stairway etc of 155 tons.

iii) Track system with sole plate, friction plates, rail section along with bolts etc,, around 20 tons

iv) Self weight of RCC tower consisting of RCC slabs/Beams/Columns/Masonry walls/Floor finishes etc., totalling to 1400 tons etc..

SEISMIC LOAD ANALYSIS:

The entire structural system with" Lumped mass of antenna" has been checked for seismic loads for Zone II condition as per IS1893-2002 and it was concluded that loads due to "Wind+ Gravity" governs the design.

STRINGENT FUNCTIONAL DESIGN CRITERIA

Apart from usual design requirements as per IS: 456-2000

i) Natural frequency of RCC structure shall not be less than 8Hz.

ii) Tip rotation shall not be more than l milli degree i.e., 3.6 arc seconds.,

iii) Lateral deflection not more than 2 mm.

iv) Structure should withstand 160kmph of survival wind.

v) Factor of safety against overturning shall not be less than 2.5.

vi) Factor of safety against sliding shall not be less than 2.

vii) Factor of safety against uplift shall not be less than 1.5.

viii) Peripheral Ring beam has to withstand a moving load of 175 tons with wheel contact stress of

930 N/sqmm´ on sole plate.

SUCH MULTIPLE FORCE ACTIONS ON REGULAR BASIS WILL BE A TEST OF PERFORMANCE .ANY SLACK IN STIFFNESS CAN RESULT IN UNPERMISSIBLE DESTORTIONS & DEFLECTIONS.

DESIĞN PHILOSOPHY ADOPTED:

- Modelled as 3D space structure with soil structure interaction by duly considering the relevant soil parameters like Shear modulus (G), Poisson's (μ) etc
- Different geo technical Agencies furnished varying values of SBC , G, μ Critical Design Review was required for appropriate adoption as IT IS DEFLECTION CONTROLLED STRUCURE
- A rocky Terrain was a divine gift to contain short term and long term Settlements
- IF SITE WERE TO BE ON LOOSE CLAYEY SOIL, WE COULD HAVE REQUIRED PILED RAFT OR STIFF RAFT MAT FOUNDATIONS TO CONTAIN SETTLEMENTS

Special Design Features adopted

RIGID STRIP RAFT FOUNDATIONS USED

i) To make the entire structure stiff and rigid to increase its natural frequency beyond 8 Hertz as specified by the users.

ii) RCC Column sizes of 1000 mm x 1200 mm and ring beam of size 1200 x1400 mm were required to contain the lateral deflections to within allowable limits

iii) Maximum shear force and bending moments caused for any possible position of moving wheel load of 175 tonsplus lateral shears

iv) Large Width and depth of Ring Beam provided facilitates adequate anchorage of high strength anchor bolts for seating sole and friction plates of width 500mm.

v) The concrete of beam is able to safely resist the Contact stresses under the wheel through the action of bearing compression.

vi) The circular peripheral ring beam is designed for torsion caused by the curved geometry and also adequately strengthened in lateral direction for any eventuality of wheel slippage".

vii) Ribbed Roofing with Radial Beams enabled to increase natural frequency and also to limit tip rotation

viii) 200 mm thick slab provided with flexural steel on top and bottom both ways to withstand point load effect during accidental fall of any heavy segment from antenna structure.

ix) Ductile detailing adopted due to cyclic stresses caused by continuous revolving of antenna structure .

Constructional Alignment Checks:

- Levelling checks by theodolite were constantly verified by LASER TRACKER and also got re confirmed by tilt sensors
- Four wheels need to be integrated to a base frame with orthogonality (90 Deg each for rigid body motion)
- Users have introduced "Molybdenum" sheet in between friction and sole plate to avoid fretting corrosion. Such metal corrosions will spread like a malignancy and penetrates into RCC beam over a period of time, if not controlled in the initial stages.
- Sole and friction plates were aligned to ±O.5mm levelling accuracy throughout the circular track.
- Hollow pipes of alidade structure were filled with high density concrete in order to improve the stability of entire tubular supporting structure due to increased self weight.
- The foundations have been provided with "ROCK ANCHORS" apart from plinth beams in orthogonal directions to ensure fixity
- Seismic isolation was required to be provided for MASER CAGE" to house an "Atomic clock" for accurate measurement of time to a precision of nano second.
- M25 grade of concrete was adopted for all RCC works along with HYSD reinforcement of grade fy=415N/mm

CONSTRUCTIONAL ASPECTS:

- In view of sensitivity of the structure, it was technically decided to cast entire roofing "slabs & beams" in one go without any construction joints etc.
- Such monolithic constructions ensures no cold joints and related leakage issues.
- Peripheral ring beam subjected to axial tension hence main reinforcement was lapped by welding only (or By mechanical splicers of tested capacity can be adopted)
- Anchor Bolts of Sole Plates were necessarily tack welded to beam reinforcement for additional strength against pull out action.
- All internal faces of building have been provided with copper cladding for insulating the radiation.
- Maser Room was provided with a seismic Isolation from rest of the building to house atomic clock of Nano Second Precision.

Two Layers of Steel reift in two directions required to withstand unexpected impact stresses by accidental falls of antenna parts/segments

Sole Plate Fixed to Circular Beam to support antenna frame i.e mount by wheels

Mount in Assembly & Erection with Orthogonality

Reflector panels in assembly and integration at the site (total lifting was not possible)

Copper Cladding For Insulation against Radiation

Majestic Antenna after Assembly and Erection

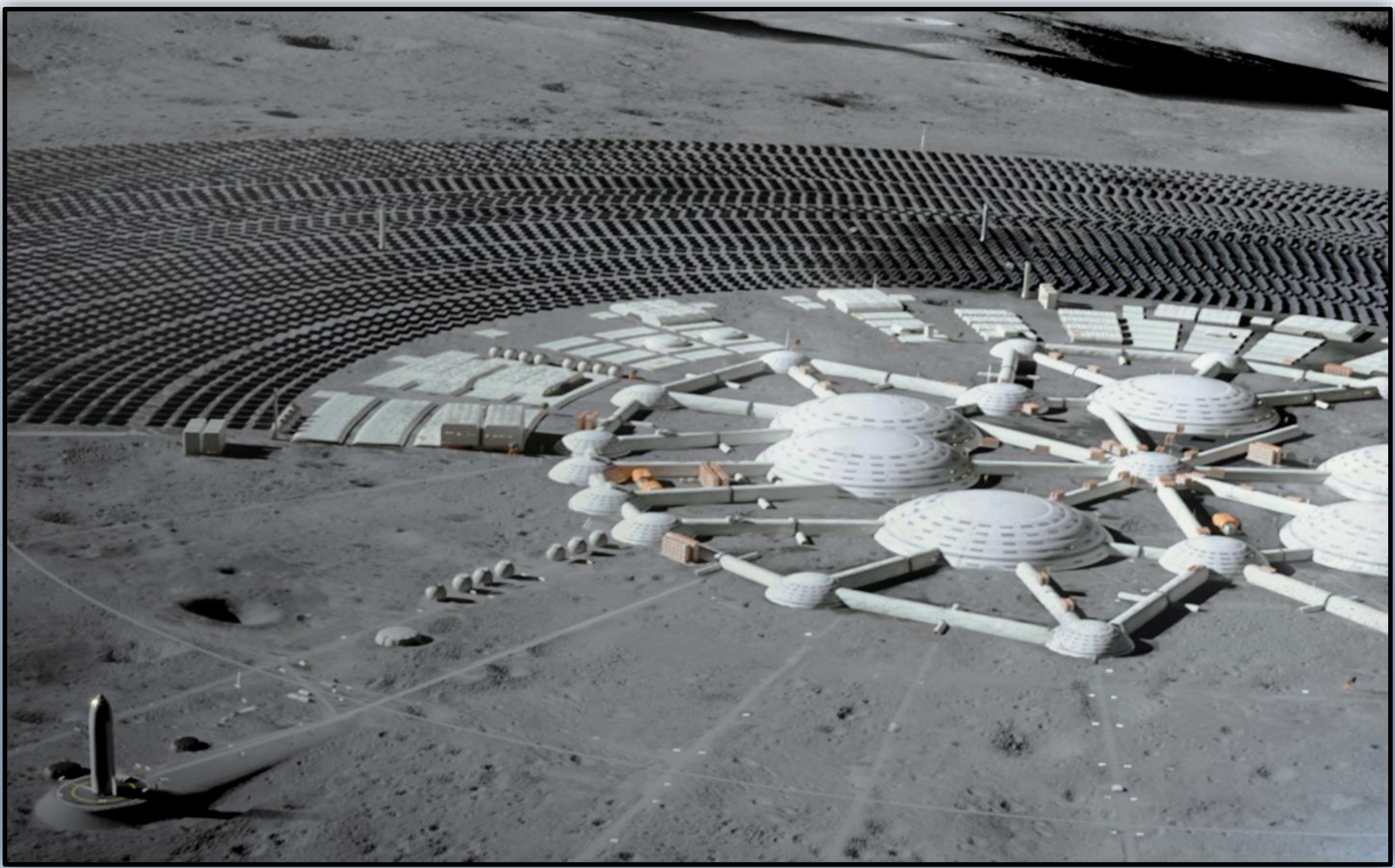
CONCLUSIONS

- It has been proved once again WITH SUCCESS OF MARS AND CHANDRAYAAN MISSIONS that journey to the celestial bodies starts with "**LAYING OF BRICKS BY SMART CIVIL ENGINEERS**“ on the ground.
- The universal construction material i.e. "Concrete" helped us to satisfy multiple design criteria like enhancing natural frequency of entire structure, containing the deflections by increasing moment of inertia in required directions & also resisting all possible stress distributions.
- Such multidisciplinary intricate engineering projects can be successfully accomplished with complete Team work Spirit and perfect communication from one to one.
- Soil parameters play a vital role in assessing settlements , hence realistic evaluation is a must.

CONCLUSIONS (contd……….)

- Space Missions are Interdisciplinary. Hence all Disciplines of Science and Engineering are equally important and have their own roles to play
- Civil Engineers and planners have major and Critical role to play as Project requirements are Unique and Challenging in realization of Infrastructure.
- It being a Research Organization, all Engineers need to be inventive and Creative to handle the Mission needs.
- In context of Interplanetary Space Missions, we all engineers have to gear up with new **thoughts/strategies/technologies** to herald a New era of Space Infrastructure Engineering
- **Civil Engineer Marches ahead and other Scientists will follow even on the Moon………!!**

FUTURE MOON COLONIES BY CIVIL ENGRS ONLY……………………



Thank you all once again ……………