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Possibility of tall towers in India for capturing uninterrupted solar energy

Dr. Heleena Sengupta[1], Arun Kumar Chakraborty[2]
[1]*Professor & Head of the Department*
[2]*M.Tech Student*
Department of Civil Engineering
Techno India University, Salt Lake, Kolkata
[2]*Correspondence Author*

Abstract: This paper presents an ambitious new idea of constructing Tall towers in India for capturing uninterrupted solar power. India presently depends mainly on coal fired thermal plant which is outdated in most of the advanced countries for pollution aspect. Nuclear power plants are not possible in the present context for socio-economic-political reasons in India. On the other hand, wind energy and hydro power available is not sufficient to cater all over India. Moreover, present system of collecting solar energy requires large area and is climate dependent (i.e not suitable in cloudy or rainy seasons). So, construction of one km & above high circular shaped chimney type towers can be used only for uninterrupted solar power as such towers would raise solar panels above obstructing geological features or above cloud level, and expand the surface area available for uninterrupted solar power generation. The amount of solar power that could be gathered from these regions depends on how tall a tower can be built to support the solar panels. The present paper proposed the possible location in Bangalore (southwest part) for such high tower due to lower earthquake and wind load as it is in earthquake zone II as per IS 1893 part 1 (2016) and basic wind speed 33 m/s as per IS 875 Part3 (2015). The circular piled raft type foundation is also very much feasible in this location because the hard bedrock is available below 8.5m from the ground level. Interestingly, the maximum height of cloud level in Bangalore is generally about 450 m (as per the data available) above the ground level. So, construction of 1km tall tower is proposed at Bangalore (southwest part) in this paper. The top 500m height above the cloud level may be used to provide more than 6.0 MW uninterrupted solar power generation.
Keywords: Tall tower, uninterrupted solar energy, Bangalore, earthquake & wind load, piled raft foundation.

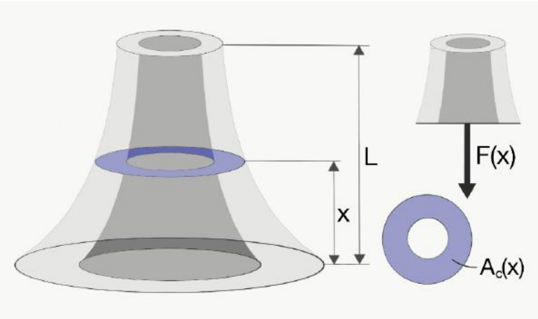
1.0 Introduction

All over the world, demand of electric power consumption is increasing gradually and the necessary land for living is rapidly decreasing. It is a key requirement to survive anywhere. For that reason, multi-storied buildings are become the best choice for construction in Metro cities where a small amount of individual property is limited. To take care of the increasing demand for producing uninterrupted and large amounts of power, a promising solution is to utilize solar energy by providing solar panels on the tall towers at such a height where clouds or other atmospheric circumstances can't affect the upcoming sunlight, and also where the sunlight intensity will be considerably higher than ground level. Suitable locations have to be fixed considering minimum wind force as well as earthquake load to make the tower structurally stable.

In this present study, a model of a one kilometre tall tower has been proposed in this paper consisting of a total of 100 intermediate floors (each floor-to-floor height is considered as 10m) and an outer base diameter is assumed to be 60 m at ground level. The stability of the proposed tower at Bangalore is analyzed using Staad pro along with detailed design considerations is also discussed in the present paper for the feasibility of such tall towers. These towers can be fitted with plenty of solar panels made up of photo voltaic cells

2.0 Proposed Shape of Tower

Some researchers have tried to do the modelling of such tall towers using analytical approach and by making some assumptions (Ruppert et al[1]). They tried to find out the maximum height of these towers that can be built. They considered the limitations imposed by both compressive strength and buckling. To explore the structural limitations of a concrete tower, they modelled a circular structure that gets exponentially thinner with height. It was found that the stress in the tower is independent of the wall thickness at the base area and stays roughly constant as the walls become thinner with height. Theoretically, then, the walls could be infinitely thin, and the tower would still be self-supporting.



Tower specifications:

L is the tower's total height,
x the height of a considered cross section, and
$A_c(x)$ the cross-sectional area of the concrete at height x.
F(x) is the total force applied on a given cross section of height x by the weight of the above concrete.

Fig.1: Modelling of tower by Ruppert et al[1].

3.0 Possible Location in India:

Bangalore (southwest part) may be chosen as the location of the tower as it is in earthquake zone II as per IS 1893 part 1 (2016), basic wind speed 33 m/s IS 875 Part3 (2015) and also because the hard bedrock is available below 8.5m from the ground level. Interestingly, the maximum height of cloud level is generally about 500 m (as per the data available). So, construction of 1km high tower can provide top 500m height for uninterrupted solar power generation.

3.1 Material to be Used:

M60 grade of concrete and Fe500 grade of steel can be used as construction material for such tower in India.

3.2 Possible Foundation:

As hard bedrock is available at a reasonable depth from the ground surface**,** so piled raft foundations which is subjected to a combination of vertical, lateral and overturning forces are preferred for tall buildings. The design philosophy should be based on both ultimate load capacity and settlement criteria.

4.0 Calculation of the Geometrical Properties

In order to explore the structural limitations of a concrete tower, a circular structure that gets exponentially narrower with height has been modelled. The cross-sectional area at a given height x above the base is described by $A(x) = A_0\, e^{-kx}$ …Eq (1), where A_0 is the cross-sectional area at the base of the tower, k is the exponent by which the tower cross-section shrinks ($k \geq 0$), and x is the height above the base. The thickness of the tower's walls also decreases with the same exponent, k. The cross-section of the concrete walls by height is given by $A_c(x) = A_{c,0} e^{-kx}$ …Eq (2), where $A_{c,0}$ is the cross-sectional area of the walls at the base of the tower. Furthermore, $A_{c,0} = A_0(1 - b)$ where b is a unit less parameter which determines the fraction of the tower that is hollow.

Assuming 60m as base diameter,

Base area of the tower, $A_0=(\frac{\pi \times 60^2}{4})$ m^2= 2827 m^2

K=0.0061 /m

From eq. 01 and eq. 02, area of different floors, thickness of concrete wall has been calculated and detailed tabulated form is not shown here due to paucity of space.

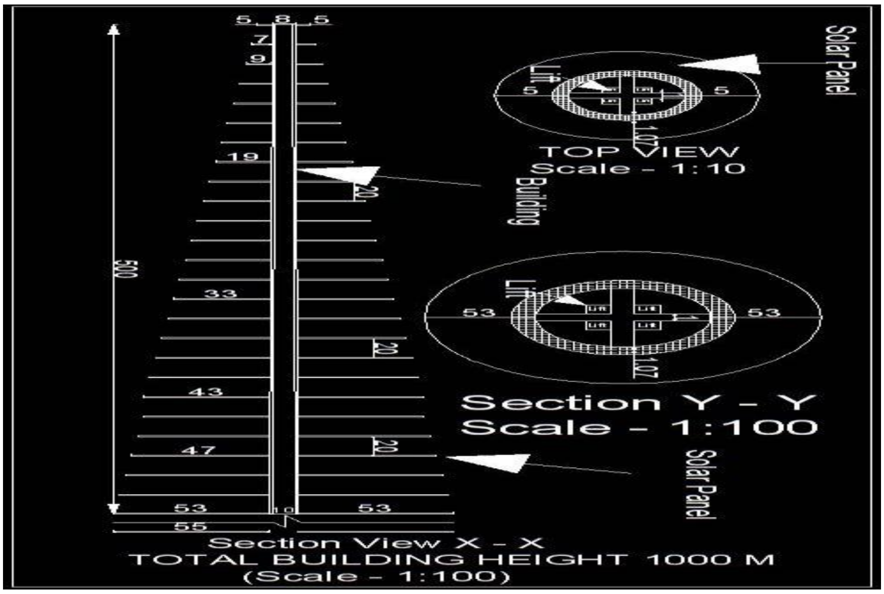


Fig.2: Section view of the top 500 metres and framing arrangement for solar panels

4.1 Possible Production of Solar Energy from Such 1 Km Tower:

In upper 500m (Ref. figure-2) around the building wall and also at various levels at an interval of 20 m, solar panel can be installed (as shown in previous Figure). Average width of the solar panel around the wall=29m and the average building diameter=9m.

For 25 solar panels, total plan area available $=\frac{\pi}{4} * (29^2 - 9^2)$=596.9*25m^2 =14922m^2 =15,000 m^2 (say)

Plus, total peripheral area around the circular tower (top 500m height) = (3.1415/4)*9^2*500 =31,807 m^2 =30,000 m^2 (say),

Thus total area = 45,000 m^2 (say),

C/s dimensions of one solar panel= 2m*1m

No. of panels= 45000/2=22,500

Capacity of one panel=375 kW

Assuming efficiency 75%, solar energy can be obtained=0.75*375*22,500 = **6.328 MW**

Alternately, for solar panel of size 2.07m long x 1.39m wide and 45mm thick with 600 W power capacity,

No. of panels required = 45000/2.8773 = 15,640 = 15,000 (say)

Assuming efficiency as 75%, solar energy can be obtained=0.75x600x15, 000 = **6.75 MW**

4.2 Approximate Cost Comparison in INR for Viability Analysis:

The cost of solar power systems to install 1MW solar power plant by investing INR 4-5 crore excluding cost of land of approx 5 acre. Total cost will be around INR 8 crore per MW including land cost.

Instead of wasting greeneries, use of roof top will be advantageous for installing solar panels.

The approx cost of Thermal power systems to install 1MW power plant is INR 10 crore.

Cost of Nuclear Power plant in India to be around Rs 27-30 crore per megawatt.

Approx. construction Cost of 1 KM such Tower = INR 6000 per Ton of RCCx 11,526 Ton = Rs 70,000,000/- for 6.3 MW, i.e 1.2 crore per MW

Thus, 1.2 Crore (construction cost) + 1.8 crore (Erection cost & land cost) +5 crore (installation cost) = Total INR 8.0 crore per MW.

Land required will be very less, approx 0.5 acre per MW.

5.0 Calculation of Wind Load (Taken as per is Code)

Along wind speed considering dynamic effect,
Basic wind speed=39m/s for place Bangalore from IS- 875 part-3, Cl. 6.2, 2015
Risk co-efficient K1=1.06, Terrain and height factor=k2
Topography factor k3=1, Importance factor k4=1, Terrain category=4
Design wind speed=Vz=Vb*K1*K2*K3*K4
Wind pressure=Pz=0.6Vz^2
H=1000m a=b=60m
h/a=16.67>5
For dynamic wind load 10.2 IS 875 part-3
Cf=2.3, Z0,4=2m, Roughness factor=2*izi=0.5484
Gv=4 for terrain category 4

Gust factor= $G = 1+r\sqrt{[g_v^2 B_z(1+g)^2 + \frac{H_s g_R^2 SE}{\beta}]}$

Fa=0.499 Lh=70*(h/10)^0.25   N=fa*Lh/Vh,dVh,d=$K_{2,h}$ *Vb

$B_s=1/(1+\sqrt{(0.26(h-s)^2} + 0.46bsh\text{^}2)/Lh$

Lh=70(h/10)^0.25 for terrain category 4

$M_a = \sum F_z Z$, $F_z = C_{f,z} A_z \bar{p}_d G$

$$B_s = \frac{1}{1+\frac{\sqrt{0.26(h-s)^2+0.46b_{sh}^2}}{L_h}}$$

$$= 70\left(\frac{h}{10}\right)^{0.25} \text{ for terrain category 4}$$

$$\Phi = \frac{g_v I_{hj}\sqrt{B_s}}{2}, \quad H_s = 1+\left(\frac{s}{h}\right)^2$$

$$S = \frac{1}{\left[1+\frac{3.5 f_a h}{\bar{V}_{h,d}}\right]\left[1+\frac{4 f_a b_{0h}}{\bar{V}_{h,d}}\right]}, \qquad E = \frac{\pi N}{(1+70.8N^2)^{\frac{5}{6}}}$$

$$N = \frac{f_a L_h}{\bar{V}_{h,d}}, \qquad g_R = \sqrt{[2\ln(3600 f_a)]}$$

Wind load calculations are done at different heights at an interval of 10m in a tabular form but not shown here due to paucity of space.

6.0 Staad Modelling:

Structural analysis of 1 km high tall tower is done using STAAD.PRO for Wind Load & Dynamic Seismic load as per IS Code in addition to Dead Load, Live Load and Temperature Load (for variation between top & bottom surface of the tower) and Design of structural elements has been done using Working stress Method as per IS Code for safer side.

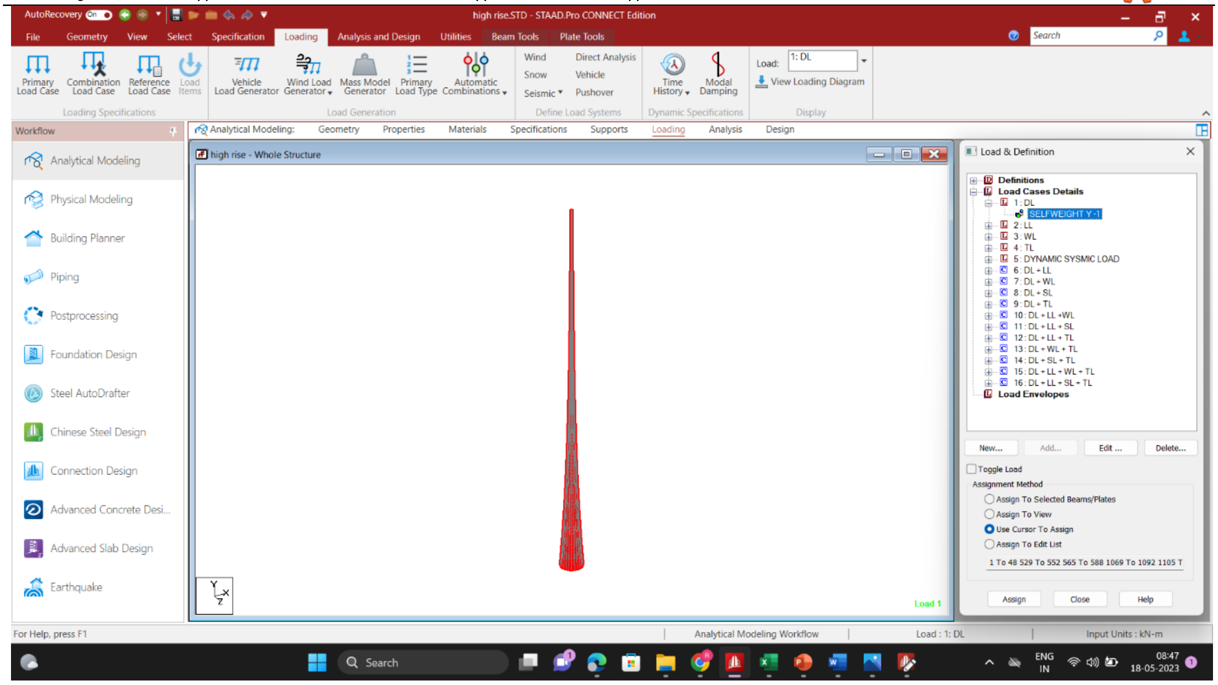


Fig.3: Dead Load

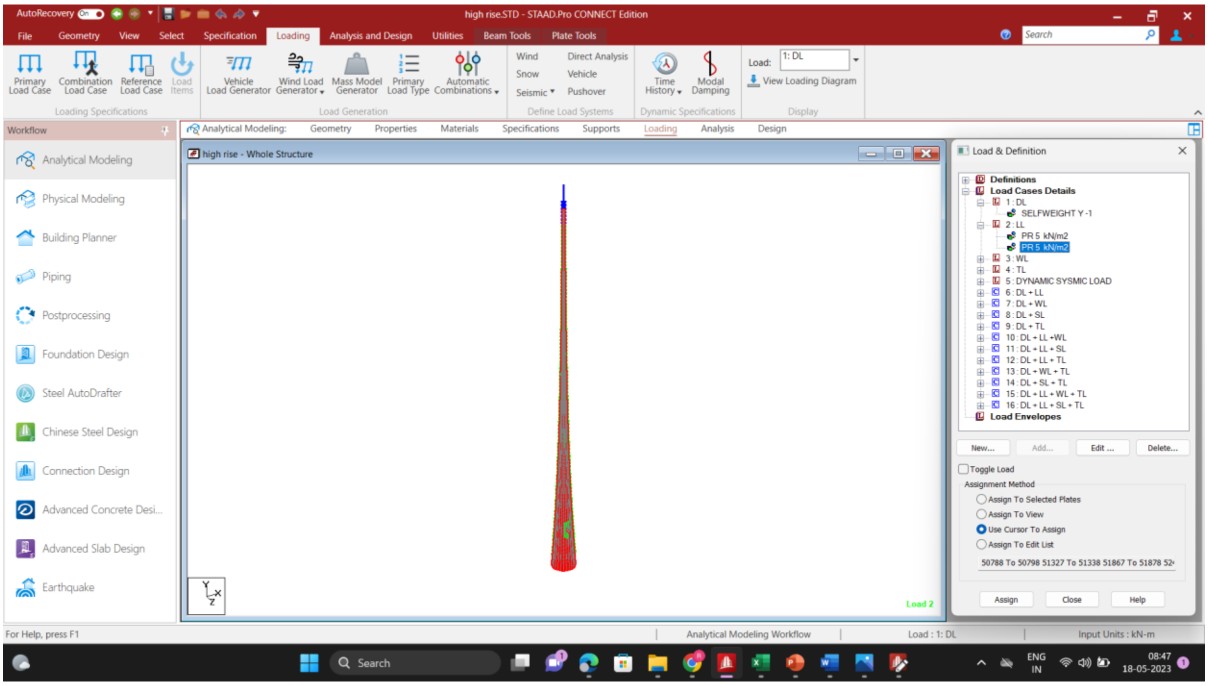


Fig.4; Live Load

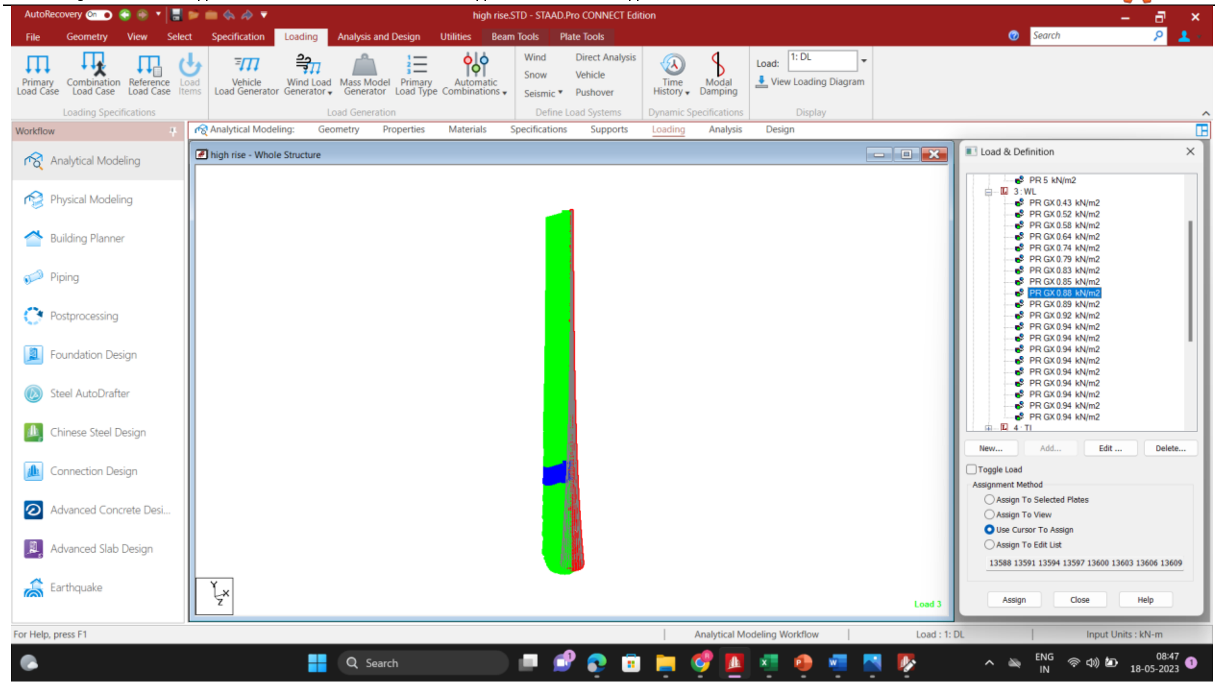


Fig.5: Wind Load

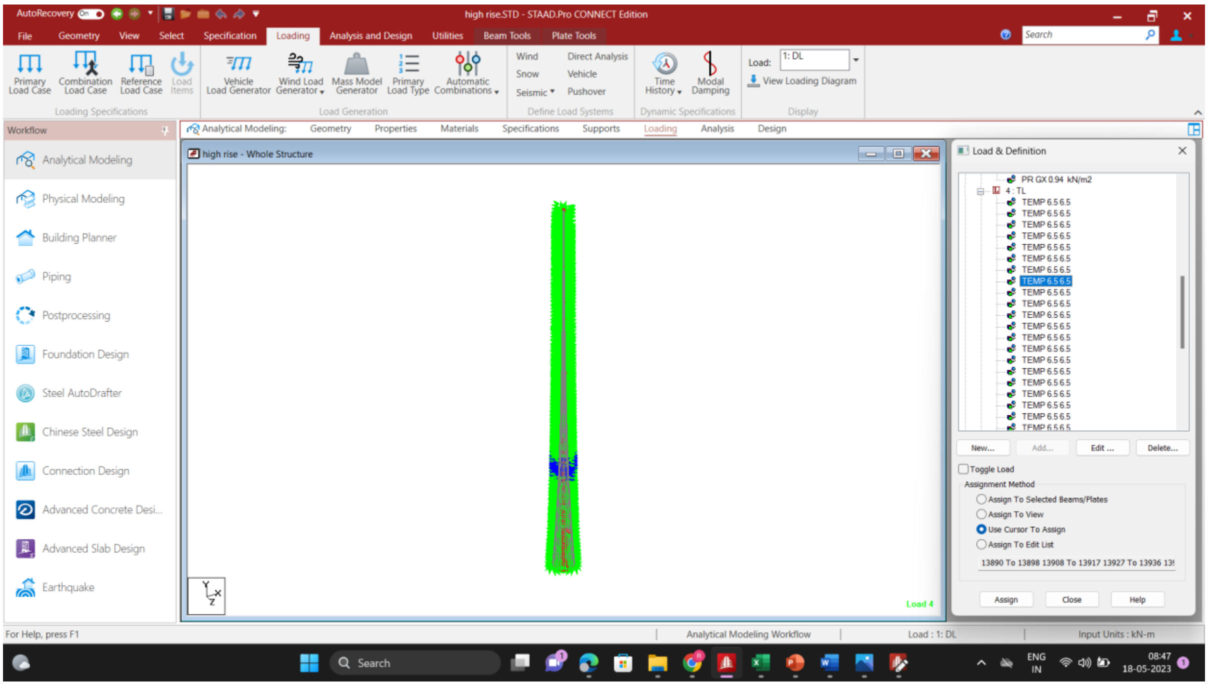


Fig.6: Temperature Load

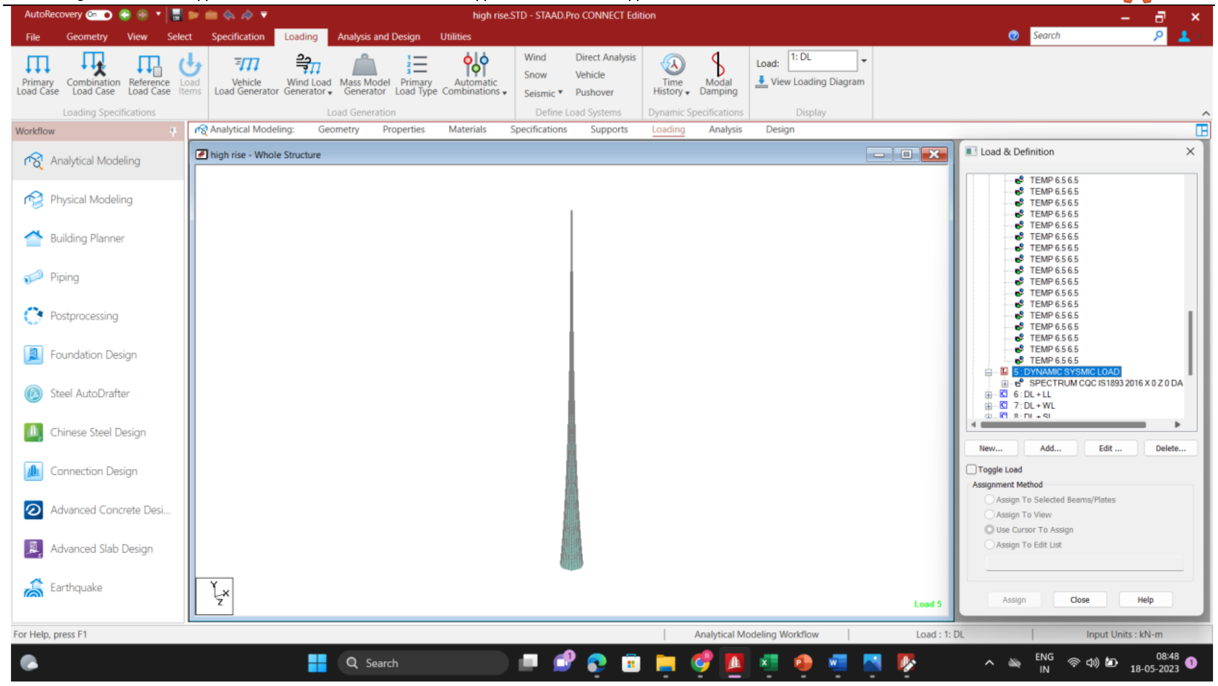
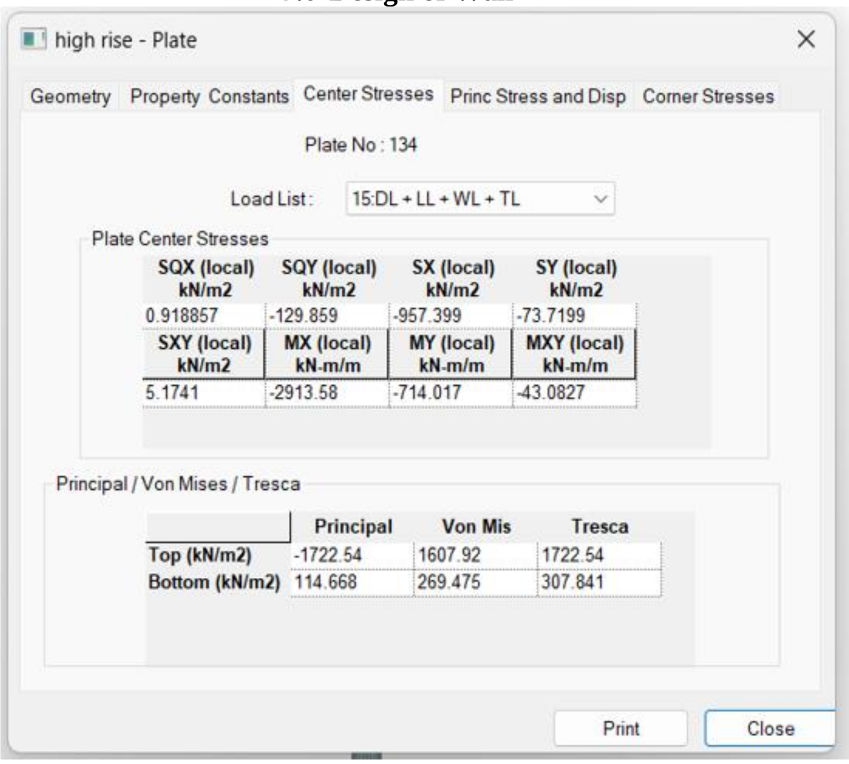


Fig.7: Dynamic Seismic Load

Among the different load cmbinatio DL+LL+WL+TL is the most critical load combination for the tower. So, we have designed components taking moments and applied load during this load combination. We have used Fe500 steel bars and M50 grade concrete

7.0 Design of Wall



high rise - Plate

Geometry | Property Constants | Center Stresses | Princ Stress and Disp | Corner Stresses

Plate No : 134

Load List: 15:DL + LL + WL + TL

Plate Center Stresses

SQX (local) kN/m2	SQY (local) kN/m2	SX (local) kN/m2	SY (local) kN/m2
0.918857	-129.859	-957.399	-73.7199
SXY (local) kN/m2	**MX (local) kN-m/m**	**MY (local) kN-m/m**	**MXY (local) kN-m/m**
5.1741	-2913.58	-714.017	-43.0827

Principal / Von Mises / Tresca

	Principal	Von Mis	Tresca
Top (kN/m2)	-1722.54	1607.92	1722.54
Bottom (kN/m2)	114.668	269.475	307.841

Print | Close

From the output files, it has been observed that the Maximum bending moment on the structure =2913.58 kNm per m width of wall

Now, $K=\frac{280}{280+3\times 275}=0.25$

As, $M = \sigma_{st} A_{st}\, jd$

$A_{st} = 2913.58 \times \frac{10^6}{275\left(1-\frac{.25}{3}\right)\times 4757.5}$=2429 mm^2

Providing 25 mm dia. main reinforcement the number of longitudinal reinforcement, spacing needed=π/4*625/2429*10^3=202 mm

So, provide 25mm dia @200mm c/c distance

Transverse reinforcement

Lateral tie:

Diameter of bar dia=Max $(\emptyset \frac{main}{4}$= 6.25mm, 8mm, 6mm)

Spacing = min (16φ=400mm, 300mm)

Provide 8 mm lateral tie @300mm c/c distance.

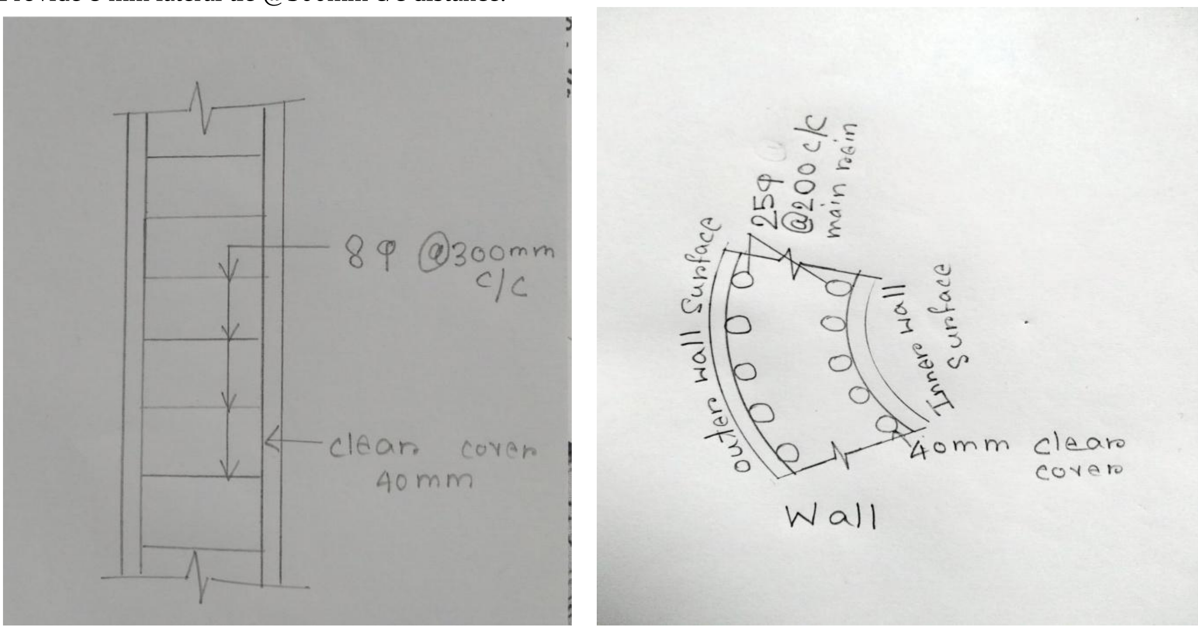


Figure 8: Wall reinforcement detailing

8.0 Raft Foundation Design

Design maximum bending moment in longitudinal direction=759 kN-m

Width of raft foundation=9m

So, perimeter width, the moment will be=759/9*1=84 kN-m

Effective depth required for moment criteria $M = \frac{1}{2} * \sigma_{cbc} * k * j * d^2 * b$

j=1- 0.25/3=0.92

D= $\sqrt{(84 * 10^6 * 2)/(16 * 0.25 * 0.92)}$ = 980mm

Taking effective depth =1000 mm

A_{st}=$\frac{\sigma_{cbc} * K_b * b * d}{2*\sigma st}$=$\frac{16*0.25*1000*1000}{2*275}$=7272 mm^2/m width

We provide two-way reinforcement.

Hence, in each face reinforcement required will be=7272/2=3636 mm^2

Providing 16Φ dia main reinforcement @100 mm c/c distance both ways bottom and top

P_t =0.1%, A_{st} = 1000 mm^2

Transverse reinforcement

Cantilever projection = (9-4.78)/2=2.11 m

Upward pressure =31.6/9=3.5KN/m

Bending moment @face of wall=1.75 KN-m

Providing minimum reinforcement $A_{st,min}$ =1000 mm^2

12mm dia @300mm c/c distance

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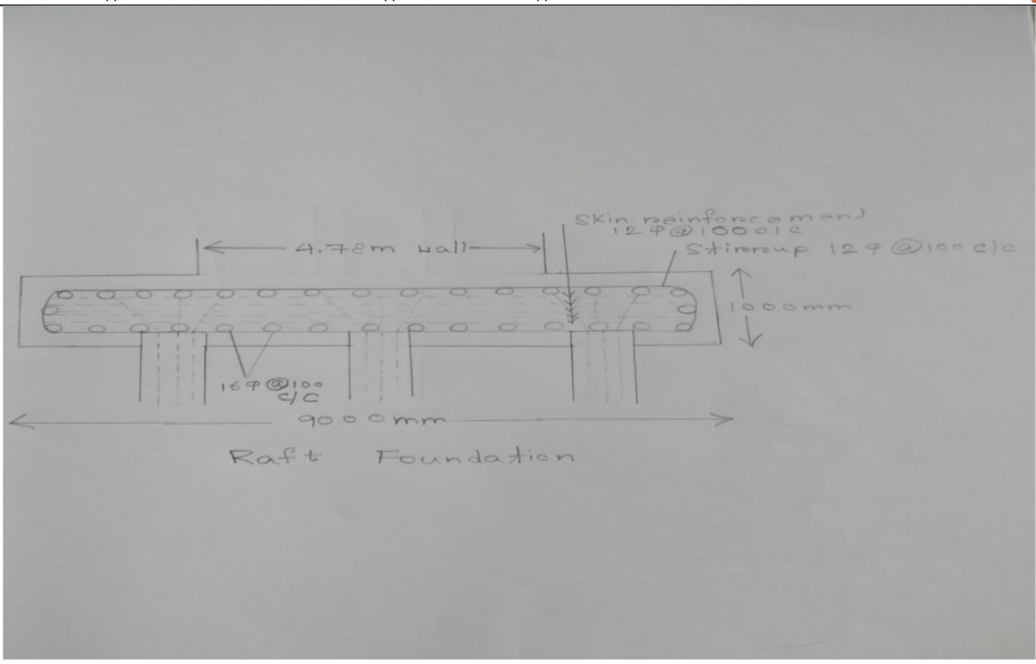

Figure 9: Raft foundation reinforcement detailing

8.1 Punching shear check

Total vertical load=112934 ton

Perimeter= $\pi * 62.11 + \pi * 52.22$=359 m

Nominal shear stress=112934*10*10^3/(359*1000)*10^6=0.0031MPa

Punching shear strength=0.25$\sqrt{50}$=1.76 MPa>0.0031MPa safe

Nominal shear stress<punching shear stress ….ok

8.2 Pile design

Let us provide 90 piles in 3 layers.

Therefore,

Load on each pile =11516/90=127 ton

Bearing capacity of the rock =900kN/m^2

c/s area of each pile=1270/900=1.4m^2

Hence, provide 1.5m dia pile @3m c/c distance

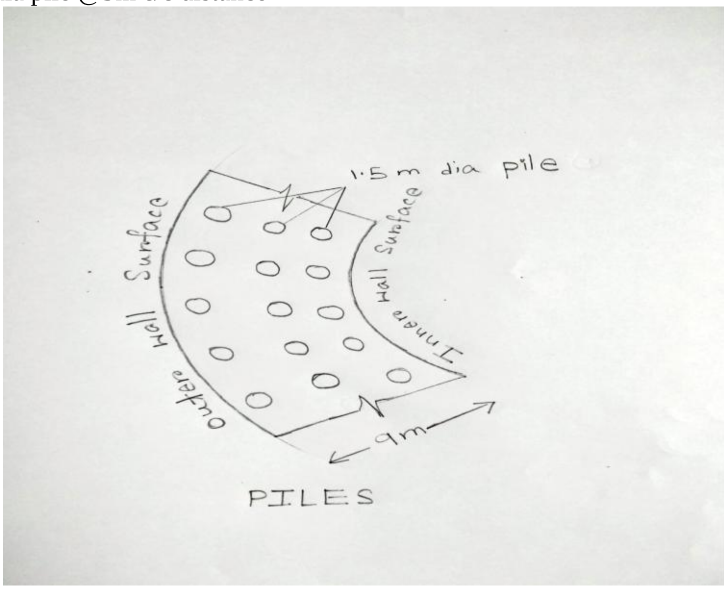

Figure 10: Pile arrangement for piled raft foundation

9.0 Conclusion

1) In this project, it has been discussed about an ambitious idea of capturing the uninterrupted solar power as an alternative of present system in India by constructing 1 km & above high rise tall towers.
2) This concept may be applicable in other countries but it will be essential for India in future as present coal fired thermal power plant is outdated for pollution aspect in most of the advanced countries. Nuclear power plant is not possible for present socio-economic-political reasons in India. Wind energy and hydro power available is not sufficient for India as a whole.
3) Present system of collecting solar energy requires large plan area in ground level or at top of roof of buildings but this is climate dependent (i.e not suitable in cloudy or rainy seasons). Hence, Construction of such towers may be essential in future for getting uninterrupted solar power supply.

10.0 References

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