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DESIGN AND ANALYSIS OF INDUSTRIAL EQUIPMENT FOUNDATIONS

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Abstract— In Industrial Sector like Oil & Gas, Refinery & Power plants different types of Equipment's play a major role for process requirement. Majority of Equipment's are categorized into Horizontal Vessels, vertical vessels, Exchangers, large storage tanks, pumps, turbo generators etc. These are further classified into Static Equipment's and Dynamic Equipment's based on rotations and vibrations. The Sizing of the Equipment's shall be designed based on process requirement, location and Elevation shall be decided by Piping discipline and Equipment details will be decided by Mechanical Discipline. Equipment Foundations design is major challenge for Structural Engineers to withstand process loads and Environments loads for different load combinations in terms of safety and economy. In order to carryout Foundation design for different loads and load combinations for optimum design several research carried out by using Finite Element Analysis with different software like SAP, ANSYS, STAAD Pro etc. Stack like structures are chimneys, Vertical Vessels which are having Height to Diameter ratio (H/D) is more than 20 are self-standing Equipment's and the Foundations are independent Foundations. Most of the Vertical Equipment's foundations are Octagonal in shape for Constructability point of view and economy point of view. In the present project, Equipment Foundations coming in Industrial Sector are studied and a Chimney Foundation has been analysed by using STAAD.pro software and Designed by using Internationals codes as per American code of institute and Saudi Arabian Best Practise(SABP-Q-003) Foundation is modelled as 4-noded rectangular mesh in 3D model and Stresses arrived from Analysis by using STAAD Pro are compared with Allowable stress based on codal provisions and Reinforcement is designed accordingly.

Keywords: Horizontal Vessels, Vertical Vessels, Static Equipment, Dynamic Equipment, Independent Foundations, Chimney Foundation.

I. INTRODUCTION

1.1 GENERAL: Foundations are substructures that are constructed below the ground level which support the superstructures above the ground level. The main function of the footing or foundation is to

- Transmit the load safely and effectively coming on to it to the underlying soil without exceeding the "safe bearing capacity of the soil".
- Ensuring that the settlements of the structure are within the permissible limits.
- In addition to that, the foundation should provide adequate safety against possible instability due to overturning, sliding and uplift.
- The design is carefully done so that foundation has to provide adequate steel to resist tensile forces and at the same time it should be verified that more steel than required should not be placed as it gives brittle failure.

1.2 TYPES OF FOUNDATIONS: Foundations are categorized as

(A) Shallow Foundations
(B) Deep Foundations

1.3 TYPES OF EQUIPMENT FOUNDATIONS:

- VERTICAL VESSELS FOUNDATIONS
- HORIZONTAL VESSELS FOUNDATIONS
- PACKAGE EQUIPMENT FOUNDATIONS
- MACHINERY EQUIPMENT FOUNDATIONS

VERTICAL VESSELS FOUNDATIONS:-

Vertical vessels are process equipment placed vertically on either foundation at grade either in a concrete or steel structure. This equipment can be either uniform in diameter or may have varying diameters. They can be short and stubby or tall and slim. This type of equipment is treated like a cantilever fixed at the bottom on a pedestal and free to thermally grow vertically.

FIG 1.1 Construction of Vertical Vessel Foundation (Octagonal)

HORIZONTAL VESSELS FOUNDATIONS:-

Horizontal Vessels mainly includes Heat Exchangers & Drums. Foundation Type is similar for both of them. A heat exchanger is a device used to transfer heat from one fluid to another while preventing the two from intermingling.

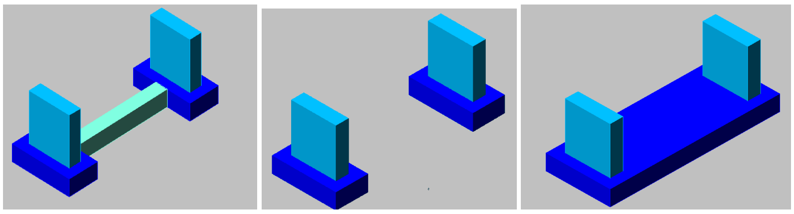


FIG 1.2 Types of Horizontal Vessel Foundations

PACKAGE EQUIPMENT FOUNDATIONS:-

Packaged Equipment are those in which only governing load is the DEAD LOAD. No significant vibrations are imparted. Foundations for Package Equipment are referred as SKID FOUNDATIONS. Skid Foundations are only checked for the Stability. Weight Check, rebar volume check and thickness check is not required for package equipment.

MACHINERY EQUIPMENT FOUNDATIONS:-

These are of two types. They are

- ❖ Reciprocating Machinery
- ❖ Rotating Machinery

1.4 AIM OF THE PROJECT:-

The main aim of this project is to Study different types of loads coming on to the Foundation and to take appropriate type and shape of foundation for cost effective, durable, stable will be carried out.

Procedure for Analysis and Design of Foundations will be formulated for Octagonal Foundation, which is supporting stack structures like chimneys etc.

1.5 SCOPE OF THE PROJECT:-

This research studies about different types of Equipment foundations in present Industrial Sector and their behaviour with different loads like Operating Loads, Environmental loads etc.

Study of International Standards and form a Methodology for Simplified and Optimum Analysis and Design. The design of Vertical Vessel Foundation (Octagonal Type) is discussed. Structural modelling in STAAD.PRO and analysis of the results are presented.

Stack structure like chimney is studied and Octagonal shape of the foundation considered. Foundation Serviceability like Sliding, Overturning, and Soil Bearing Capacity are calculated manually and spread sheet developed for the same. Analysis is done by using STAAD Pro software, Loads are taken from Equipment Vendor Data and the software results are compared with Manual design.

II METHOLOGY

2.1 STABILITY CHECK:-

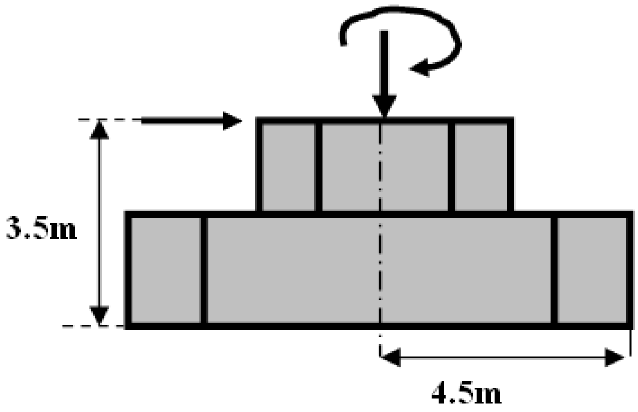


FIG 2.1 Free Body Diagram of Octagonal Foundation

The dimensions of the foundation are assumed and checks are carried out with those, if all the checks are O.K. Then those dimensions are taken as final size of the foundation.

2.2 Calculation of octagonal foundation properties:-

Area (A)	= 0.8284272 x B^2	= 67.10m^2
Length of side (S)	= 0.4142136 x B	= 3.73m
Length of Diameter (Ld)	= 1.0823922 x B	= 9.74m
Sec. Mod. Diameter (Ze)	= 0.1011422 x B^3	= 73.73m^3
Sec. Mod. Flat (Zf)	= Ze x Ld/B	= 79.79m^3

2.3 Sample calculations:-

Weight of base slab Wf	= 0.8284272*9^2*1.8*25
	= 3019.62kN
Weight of pedestal Wp	= 0.8284272*4^2*1.7*25
	= 563.33kN
Weight of overburden soil Wob	= 0.8284272*(9^2-4^2)*(3.5-1.8-0.2)*17
	= 1373 kN
P for Bearing pressure check (P)	= Wf+Wp+Wob+Do
	= 3019.62+563.33+1373+700
	= 5655.95kN
Ps for Sliding & Overturning check (Ps)	= Wf+Wp+Wob+Do
	= 3019.62+563.33+1373+700
	= 5655.95kN
Moment acting at bottom of foundation	= $M_{ow}+V_{ow}xD_{ov}$
	= 7000+250*3.5
	= 7875kNm

Shear force acting at bottom of foundation = (V_{ow}) = 250kN

2.4 Check for Bearing pressure:-

p1 =Direct stress = P/A = 5655.95/67.1 = 84.29 kN/m^2
p2 = Bending stress = M/Ze = 7875/73.73 = 106.81 kN/m^2
When the total octagonal area is not in compression, then soil bearing pressure shall be calculated using Figure B (for diagonal) of SABP-Q-003 and by using following formula :
As per equation 11 of SABP-Q-003 Bearing pressure = L x p1

When the total octagonal area is in compression, then soil bearing pressure shall be calculated by using following formula:
Bearing pressure = p1 + p2
Check for tension (if Direct stress < Bending stress) then tension otherwise total area is in compression.
Coefficient (L) taken from Figure B for diagonal of SABP-Q-003 = 2.46
Coefficient (K) taken from Figure B for diagonal of SABP-Q-003 = 0.184

As p1<p2 tension induced in foundation, therefore calculating bearing pressure using eq. 1

Bearing pressure = 84.29*2.46 = 207.35kN/m^2

F.O.S. against bearing pressure = 256.1/207.35 = 1.24

Minmum F.O.S. = 1

Check for bearing pressure is **O.K**

2.5 Check for Sliding:-

Sliding force (Vow) = 250kN

Resisting friction =μ x Total vertical load for Sliding check (Ps)
=2262.38kN

F.O.S. against sliding = Resisting friction /sliding force
= 9.0

Min F.O.S. = 1.5

Check for Sliding **O.K**

2.6 Check for Overturning:-

Overturning moment = $M_{ow} + V_{ow} \times D_{ov}$
= 7875 kN

Total vertical load for OT check (Ps) = Wf+Wp+Wob+Do
= 5655.95kN

Eccentricity (e) = Overturning moment / Ps
= 1.39m

F.O.S. against overturning = B / 2e
= 3.2

Min F.O.S. = 1.5

Check for overturning is **O.K**

Here the dimensions are safe for all the checks hence these are analysed using STAAD.PRO software for base pressure for comparison.

III ANALYSIS USING STAAD.PRO

3.1 INTRODUCTION OF STAAD.PRO:-

STAAD or STAAD.PRO is a structural analysis and design computer program originally developed by Research Engineers Internationals at YORBA LINDA a city in CALIFORNIA in 1997.In recent years it has become a part of integrated structural analysis and design. Additionally STAAD.PRO has added direct links to RAM connection and STAAD.Foundations to provide engineers working with those applications which handle design post processing that is not handled by STAAD.PRO itself.

3.2 PURPOSE OF STAAD.PRO:-

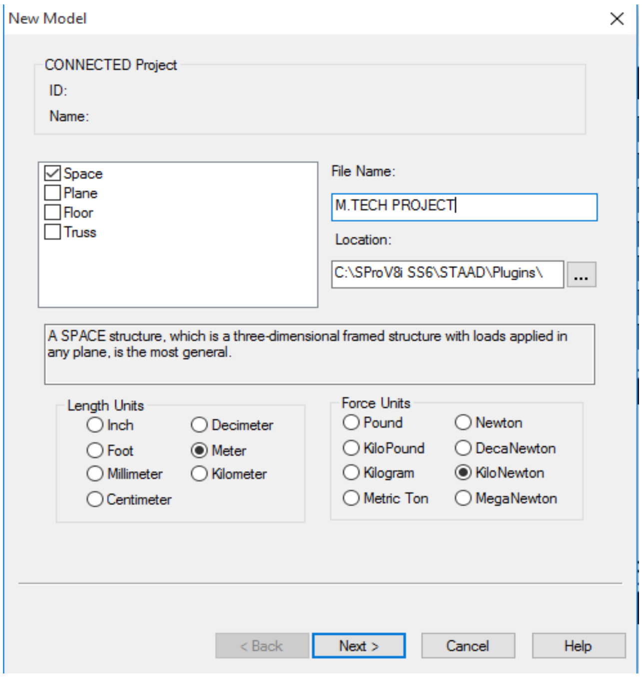
STAAD.PRO is a general purpose structural analysis and design program with applications primarily in the building industry such as commercial buildings, highway structures, industrial structures, dams, retaining walls, turbine foundations, culverts and other embedded structures etc. The program hence consists of the following facilities to enable this task.

1. Graphical model generation utilities as well as text editor based commands for creating the mathematical model. Beams and columns are represented using lines.
2. Analysis engines are performing linear elastic and delta analysis, finite element analysis, frequency extraction, and dynamic response (spectrum, time history, steady state etc.).
3. Design engines for checking code and optimization of steel, timber, aluminium members.
4. Reinforcement calculations for concrete beams, columns, slabs and shear walls.
5. Design of shear and moment connections for steel members.
6. Result viewing, result verification and report generation tools for examining displacement diagrams, bending moment, shear force diagrams, beam, plate, and solid stress contours etc.
7. Peripheral tools for import and export of data from and to vary widely accepted formats, links with other popular software's for areas like reinforced and prestressed concrete slab design, footing design, steel connection design etc.

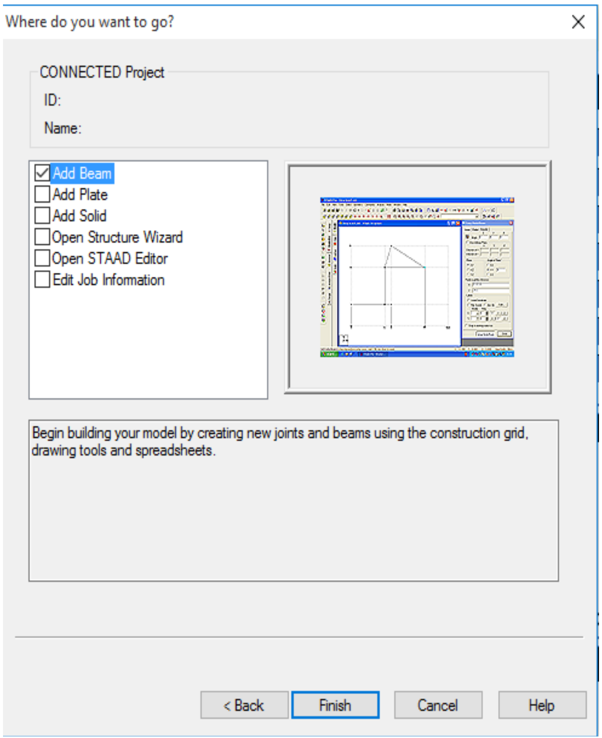
3.3 MODELING USING STAAD.PRO:-

STEPS IN MODELING THROUGH STAAD.PRO:-

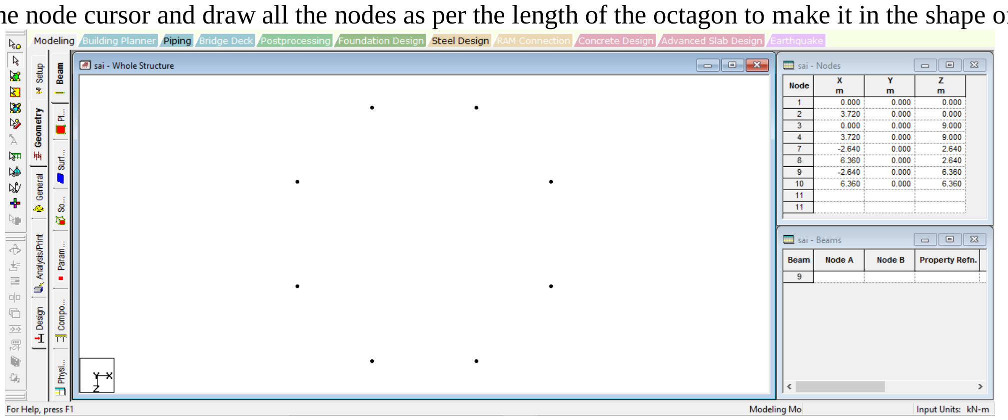
1) Open STAAD Program.
2) Click on the SPACE button as the model is in three dimensions and check the units of the model as Length in meter and Force in Kilo Newton.



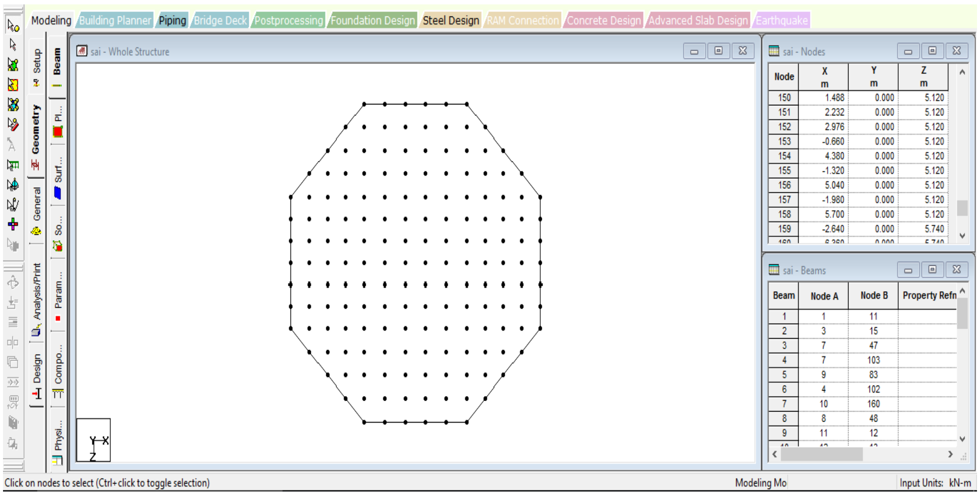
3) Click the NEXT button to move to next window. Press ADD BEAM and then FINISH buttons to open a STAAD PROGRAM



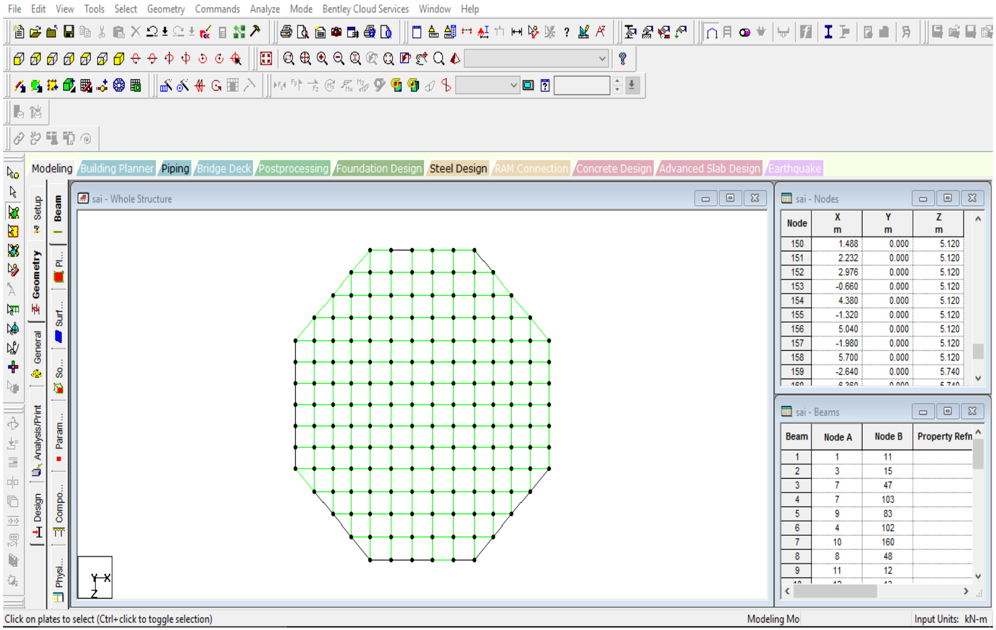
4) Select the node cursor and draw all the nodes as per the length of the octagon to make it in the shape of octagon.



5) Divide this into small number of suitable parts by adding nodes inside the octagon.



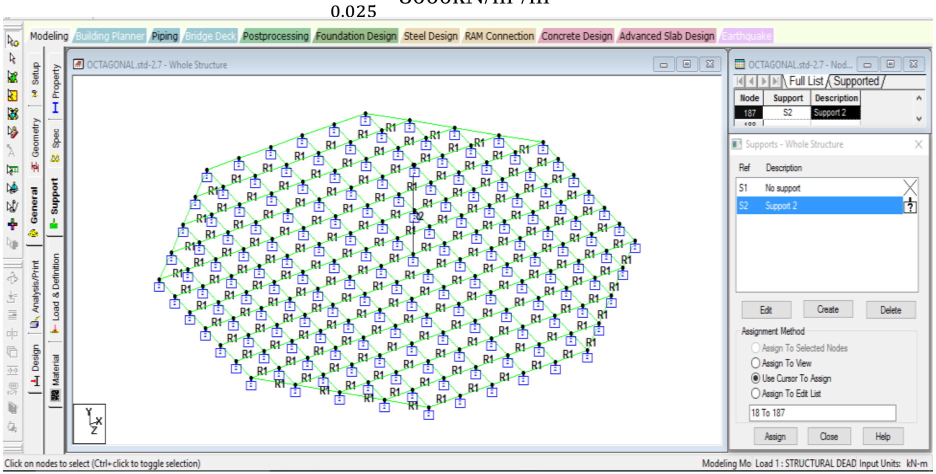
6) Add four nodded plates to the entire nodes to make form a mesh. To make it symmetrical structures add three nodded plates at the edges of the plates.



7) Click on SUPPORTS> CREATE> FOUNDATIONS> ELASTIC MAT> Y.
Enter Sub grade modulus as 8000kN/m^2/m.
As the base pressure is 200kN/m^2

The subgrade modulus is calculated as = $\frac{\text{basepressure}}{0.025}$

$$= \frac{200}{0.025} = 8000\text{kN/m}^2\text{/m}$$



8) Take the centre node and copy it in positive Y direction to 1.7m and add a beam to it to form the pedestal.

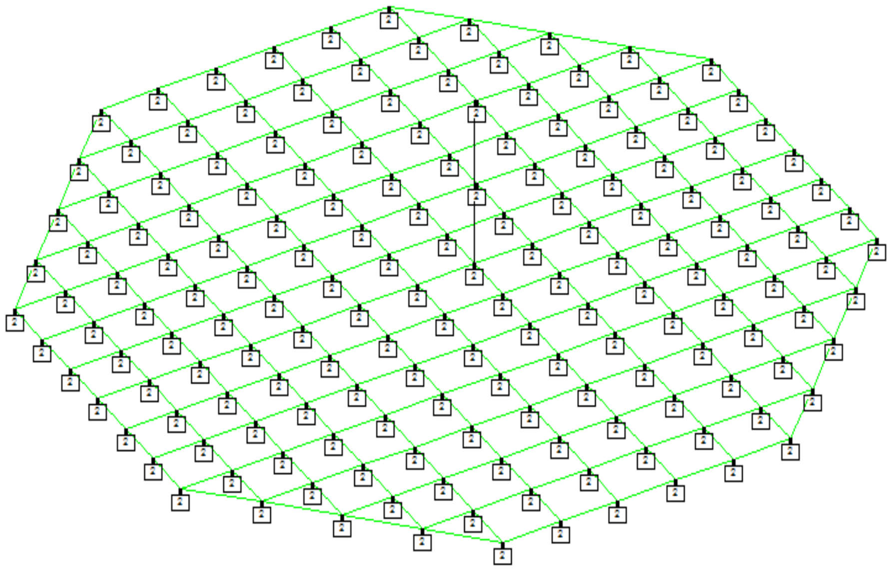
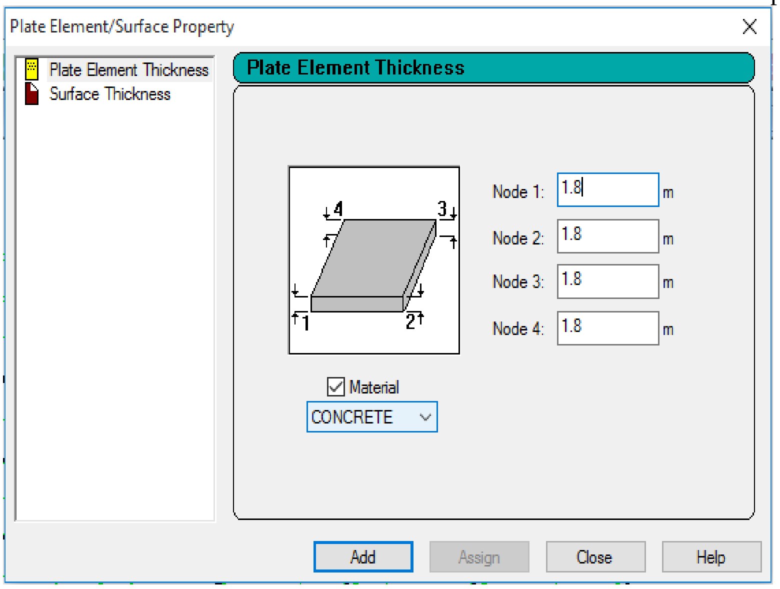
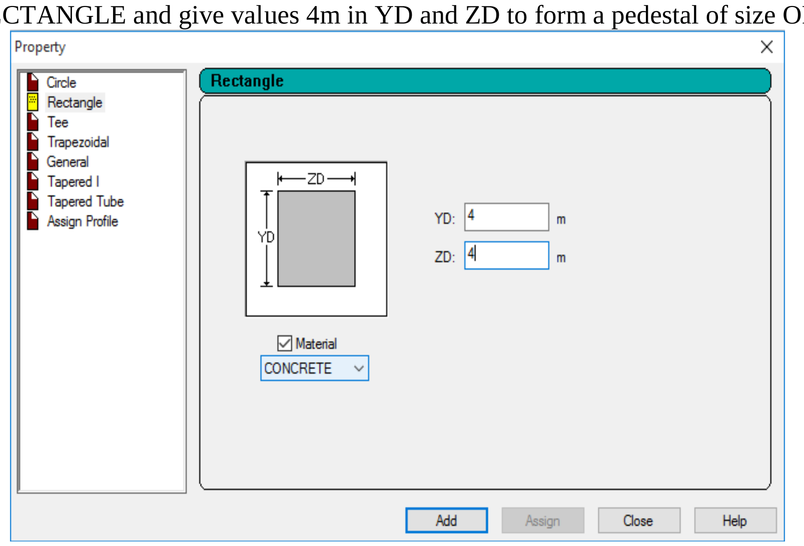


FIG 3.1 ISOMETRIC VIEW OF THE STRUCTURE

9) Click GENERAL> PROPERTY> THICKNESS and add 1.8m to the base plate



10) Click DEFINE> RECTANGLE and give values 4m in YD and ZD to form a pedestal of size OF 4m*4m.



11) The final three dimensional model of the octagon is as shown below with total thickness of 3.5m (base slab=1.8m+pedestal=1.7m).

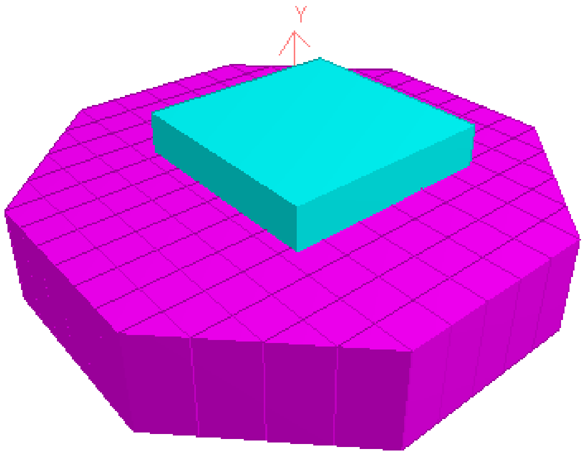


FIG 3.2 3-D VIEW OF OCTAGONAL FOUNDATION

12) Click on LOAD &DEFINITION and define primary loads as per the design criteria. Here we get 13 primary load cases.
13) Define load combinations for strength and serviceability conditions as per TABLE 3 of SABP-Q-003. Here we got 33 load combinations for both the conditions.

IV REINFORCEMENT DESIGN

4.1 Assumptions:

1. As perRef CL 4.2.2.2 of SABP-Q-003 Live load is not considered in design, as it will typically not control any part of foundation design
2. Water table is considered much below bottom of foundation.
3. Soil bearing is checked for maximum allowable along the diagonal.
4. Soil bearing pressure is used for footing design is computed on the flat.
5. Foundation behaves as a rigid unit
6. Net allowable soil pressure = 200 kN/m^2
7. Reinforced concrete design is done as per ACI 318-08.
8. All the required data used for design is taken as per vendor details and design is done for that data.

4.2 Calculation of Net Base Pressure for Foundation Design:-

For calculation of net pressure for foundation design load combination for strength design given in (Table-4 of SABP-Q-003) shall be used.

For calculation of moment /shear force at critical section, conservatively maximum pressure under the base slab is assumed as uniformly distributed pressure instead of actual triangular distribution pressure between maximum and minimum pressure

Sample Calculation:-

Effective depth of foundation (for main reinforcement) d = 1800-75-32*1.5
= 1.677m

Area of pedestal = 0.8284272*4^2
= 13.255 m^2

Size of equivalent square = sqrt(13.255)
= 3.641m

Projection of base slab beyond pedestal at one side = e+(B-Bp)/2
= 2.5m

Projection of base slab beyond pedestal on another side = (B-Bp)/2-e
= 2.5m

Projection of base slab beyond equivalent square pedestal at one side
= (B-Bp)/2-e
= 2.6795m

Projection of base slab beyond equiv. square pedestal at another side

= (9-2.5)/2-0
= 3.25m
Net Soil stress for foundation Design = 333.2kN/m^2
Max. Factored BM at face of equivalent square = 333.2*2.68^2*0.5
= 1196.59kN.m/m width
Factored Moment on top face (gf used=1.4)
=1.4((3.5-1.8-0.2)*17+(1.8*25))*2.68^2*0.5
= 354.45kN.m/m width
Max. Factored shear at distance def from pedestal = 333.2*(2.68-1.677)
= 334.2kN.m/m width
Max. Factored shear at face of the pedestal = 1850.29kN.m/m
Vertical load (Pu) = 1.2*(Wf+Wp+Wob+Wfp+Do)
= 1.2(3019.62+563.33+1373+700)
= 6787.14kN
Moment at bottom of foundation (Mu) = 1.6*(Mow+Vow*Dov)
= 1.6 (7000+250*3.5)
= 12600.0kN

pu1 =Direct stress = Pu/A
= 6787.14/67.1
= 101.2kN/m^2
pu2 = Bending stress = Mu/Zf
= 12600/79.79
= 157.9kN/m^2

When the total octagonal area is not in compression, then soil bearing pressure shall be calculated using Figure B (for Flat)

Bearing pressure = L x Pu/A Eq (3) (Ref eq 11 of SABP-Q-003)

When the total octagonal area is in compression, then soil bearing pressure shall be calculated by using following formula:

Bearing pressure = Pu/A + Mu /ZfEq (4)

Check for tension (if Direct stress < Bending stress) then tension otherwise total area is in compression.
"L" taken from Figure B (Considering flat width) of SABP-Q-003 = 3.02
"K" taken from Figure B (Considering flat width) of SABP-Q-003 = 0.32
As pu1<pu2 tension induced in foundation, therefore calculating bearing pressure using eq. 3
Gross bearing pressure = 101.15*3.02
=305.5kN/m^2
Net bearing pressure = Gross bearing pressure – Overburden pressure
Overburden pressure =1.2*(γs*(Dov-y-tf)+γc*tf)
= 1.2(17*(3.5-0.2-1.8)+25*1.8)
= 84.6kN/m^2
Therefore, net bearing pressure = 305.5-84.6
= 220.9kN/m^2
Effective depth of foundation (for main reinf.)def = 18000-75-32*1.5
= 1677mm

Moment shall be checked at the face of the equivalent square. Moment shall be calculated for a 1 meter-wide strip as a simple cantilever from the edge of the equivalent square

Area of pedestal = 0.8284272 X 4^2
= 13.25 m^2
Size of equivalent square = sqrt (13.25)
= 3.64m
Gross base press.at eq. square pedestal face = 305.5kN/m^2
Factored Moment at Edge of equivalent square pedestal = (305.5-84.6)*2.68^2*0.5
= 793.3 kN.m/m width
Gross base press.at pedestal face = 305.5kN/m^2
Shear force at pedestal Face = (305.5-84.6)*2.5
= 552.25 kN/m width
Gross base press at def from pedestal face = 305.5 kN/m^2
Shear force at dist. def from pedestal face = (305.5-84.6)*(2.5-1.677)
= 181.8kN.m/m width

4.3 Design of Base Slab:-

THIS DESIGN IS VALID ONLY AS PER ACI-318: 2008 CODE

As per Ref. Clause 10.2.7 ACI-318:08 basic equations for strength design are as follows:

$$\phi M_n \geqslant M_{ux}$$

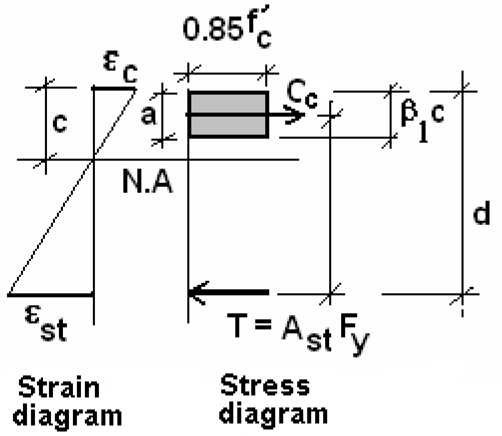
$$\phi M_n \geqslant M_{uy}$$

Where, Mn = Nominal moment capacity of section
Mu = Required moment capacity of the section

Note: Nominal moment strength calculation is based on the tension controlled section i.e, stress in steel Fs = Fy

As per Ref. Clause 10.2.7 ACI-318-08 the nominal moment strength is given as mentioned below:

$$M_n = A_{st} f_y \left[d - \frac{A_{st} f_y}{1.7 f'_c b} \right]$$



$$a = \frac{A_{st} F_y}{0.85 f'_c b} \qquad \varepsilon_{st} = \left[\frac{d-c}{c}\right] \varepsilon_c$$

FIG 4.1 Stress and Strain Diagram of Octagonal Foundation

As per Ref. Clause 102.1 to 10.2.7 ACI-318-08
Total compressive force =Cc = 0.85 $f'_c ab$
Where,

b	= Width of the section
a	= Depth of compression block
β_1	= Neutral axis depth factor
C	= Neutral axis depth of the section
Cc	= Total compressive force in the concrete
T	= Total tensile force in the steel
ε_c	= Strain in the extreme fibre of concrete
ε_{st}	= Strain in steel

BOTTOM REINFORCEMENT:-

Design bending moment (at bottom) Mub	= 1759.71 kN.m/m width
Design bending moment (at top) Mut	= 521.26 kN.m/m width
Strength reduction factor -1 for flexure Φfbt	= 0.9(Tension controlled)
Strength reduction factor -2 for flexure Φfbc	= 0.65 (Compression controlled)
Strength reduction factor for shear Φs	= 0.75
Strength reduction factor for bearing	= 0.65
Effective depth of the section	= 1.677 m
Maximum Ast required	= 0.18% of Ag
	= 0.18/100*(1000)(1.8*1000) = 3240mm^2/m

As per Ref. Clause 10.5.4 & 7.12.2.1 ACI-318M-08

Yield strength of reinforcement Fy = 422 N/mm^2
Characteristic Strength of concrete Fc = 28 N/mm^2
Reinforcement dia& spacing for baseslab = 32mm dia @ 100mm c/c
Maximum Spacing of Reinforcement = MIN (3*def or 450mm)

As per Ref Clause 10.5.4 ACI -318

< Maximum spacing, O.K
>Minimum spacing, O.K

Area of Reinforcement provided Astprov = 8042.48mm2/m
Percentage of reinforcement provided **ρ,**prov = 0.408%

(ρ,prov =100*Ast/b*def, where, b=1000mm)

As per Ref. Explanation of clause 10.2.7

Concrete Stress block depth factor β_1 = 0.850

(β_1= 0.85-(0.05/7)*(Fc-28))

Maximum permissible reinforcement **ρ,max** =1.8%

(ρ,max = 0.85*Fc* β_1*0.375/Fy)

As per Ref. Explanation of CL 9.3.2.2 ACI-318

Percentage of steel for balance failure **ρ,b** = 2.8% *(ρ,max= 0.63*ρ,b)*

Nominal moment strength Mn = 5449.62 kNm/m

Top Reinforcement:-

Design bending moment (at top) Mut = 521.26 kN.m/m width
Effective thickness of footing teff = 1.8m
As 50mm lean concrete is provided below footing

Tensile stress = 521.6*10^6*6/((1.8*1000)^2*1000)
= 0.97 N/mm2

As per Ref. Eq 16 of SABP-Q-003 Flexural strength of structural plain concrete =Ft = 5Φ(Fc)$^{0.5}$
Where,

Ft = flexural strength of structural plain concrete = 1.21 N/mm^2
Fc = compressive strength of concrete
Φ = strength reduction factor for structural plain concrete = 0.55
Effective depth of the section deff = 1.667m
Factored moment at the top face Mut = 521.26 kN.m/m
Minimum area of reinforcement Ast,min = 1620 mm^2/m

(half of the minimum of 0.18*Ag = 0.09%)

Rein dia& spacing for base slab ϕ_d **and Sp** = 32mm dia @ 200mm c/c

As per Ref Clause 10.5.4 ACI -318

< Maximum spacing, O.K
>Minimum spacing, O.K

Maximum Spacing of Reinforcement = MIN (3*def or 450mm)

Area of top reinforcement provided Ast,prov = 4021.2 mm^2/m
Nominal Moment strength of the sect Mn = 2785.31kN.m/m
Moment capacity of the section Mc = Φfb*Mn
= 2506.78 kN.m/m

>Mu = 521.26, OK, Section is safe

Check required for thickness for pedestal reinforcing embedment:

Development length of pedestal shall be calculated by using following formula, but should not be less than larger of 8db & 150mm

As per Ref CL 12.5.2 ACI-318-08,

$$\ell_{dh} = \left(\frac{0.24\psi_e f_y}{\lambda\sqrt{f'_c}}\right)d_b$$

ℓ_{dh} min = 8*dia of bar or 150mm = 256mm
As per Ref CL 12.5.1ACI-318-08
Modification factor for the density of concrete λ = 1for normal weight concrete
ψe = 1.2 for epoxy coated R/F
As per Ref. CL12.1.2 ACI-318-08
Value for $\sqrt{Fc}$ (for the grade of concrete used) $\sqrt{Fc}$ = 5.3 < 8.3Mpa
ℓ_{dh} Required = 0.24*1.2*422*32/1*5.29
= 735.2mm
Min thickness of base slab required for embedment length = 654mm
For 90°hook (Clear cover +2*dia of bottom bar+0.7* ℓ_{dh} required)
HENCE OK
As thickness provided > required for embedment
4.4 CHECK FOR SHEAR:-
As per Ref. CL 11.1.1 of ACI-318M-08 basic equation for design of cross-section subjected to shear is given below:
Vn≥ Vu
Check for one-way shear:-
As per Ref.CL 11.2.1.1 of ACI-318M-08Nominal shear strength of concrete alone is given by the equation:

$$V_c = 0.17\lambda\sqrt{f'_c}\, b_w d$$

As per Ref.CL 11.1.2 of ACI-318M-08

$$\left[\sqrt{f'_c}\right]_{max} = 8.3\text{Mpa}$$

Modification factor for the density of concrete λ = 1.00

for normal weight concrete

As per Ref.CL 11.1.2 ACI-318-08

Value of $\sqrt{f'_c}$ (for the grade of concrete used) $\sqrt{f'_c}$ = 5.292 < 8.3Mpa

Effective depth of the section def = 1.677m

Nominal shear resistance by concrete alone Vc = $\frac{0.17*1*5.292*1000*1.677*1000}{1000}$

= 1508.6 kN/m width

Reduced nominal shear stress = $\phi\tau_{vn}$

= 0.675 N/mm2

Reduced nominal shear resistance = ϕ_sVc= 0.75*1508.6

=1131.4 kN/m width

Projection of the base slab beyond pedestal = Lc = 1.1 m

(i) Check at a distance def from the face of the pedestal:-

Shear force at the critical section = 524.12 kN/m width

OK, Foundation is safe in shear

Shear stress at the section-1 = τvu_1= **Vu/bdef**= 0.358 N/mm

Check for punching (two-way) shear:-

Column type based on location Col = Interior Column

Width of pedestal (from input) Bp = 4m

Minimum perimeter for two-way action bo = 8*[0.41421*(Bp+def)]

Minimum perimeter for two-way action bo = 18.81 m

Two-way shear resistance can be taken as minimum of (a), (b), (c)

For octagonal/square pedestal the,

Ratio of longer side to shorter side β = 1

As per Ref.CL.11.11.2.1 of ACI-318M-08

Factor for depending on column location α_s = 40

As per Ref.CL.11.11.2.1 of ACI-318M-08Nominal shear strength of concrete for two-way action of a slab is given by the following equation:

Punching Shear :

a) $V_c = 0.17\left[1+\frac{2}{\beta}\right]\lambda\sqrt{f'_c}\,b_o d$

b) $V_c = 0.083\left[\frac{\alpha_s d}{b_o}+2\right]\lambda\sqrt{f'_c}\,b_o d$

c) $V_c = 0.33\,\lambda\sqrt{f'_c}\,b_o d$

a) Vc = 85135.701 kN

b) Vc = 77095.339 kN

c) Vc = 55087.806 kN

Minimum nominal punching strength Vpn = MIN(a,b,c) = 55087.806 kN

Reduced strength in punching shear Vp = Φs*Vpn = 41315.885 kN

Permissible punching shear stress Ʈp = Vp/(bo*d) = 1.31N/mm^2

Width of foundation base slab B = 9.00m

Cantilever length of base slab Lc = 1.1m

Total base area of base slab Af = 67.1m^2

Area within the punching shear perimeter Apc = 26.7 m^2

Tributary area for punching check Ap = Af-Apc = 40.40m^2

Total punching shear at the critical section Vup = Ap*(σbase)

= 13462.1 kN

Developed punching shear stress τ_{pd} = $V_{up}/(b_o*d)$

= 0.43N/ mm^2

4.5 Side Face Reinforcement:-

As per Ref. CL.10.6.7 of ACI-318M-08 When overall depth (tf) of base slab is greater than 900mm skin reinforcement need to be provided.

As (tf) is greater than 900mm skin reinforcement need to be provided.

As per Ref.EQ10.4 of ACI-318M-08 the spacing of reinforcement closest to the tension face shall not exceed minimum of

$$s = 380\left(\frac{280}{f_s}\right) - 2.5c_c$$

S = 110.70mm

Where, Cc = least distance from the surface of the skin reinforcement or prestressing steel to the side face.

Cc = 107mm

Provide skin R/F 20 Dia @110mm c/c

Design of pedestal:-

Diameter of dowels = 32mm

As per Ref Cl 4.5.5 of SABP-Q-003 Minimum pedestal reinforcement is as follows:

	Dowels		**Ties**		**Case applicable**
Minimum pedestal R/F	**Nos**	**Dia**	**Dia**	**Spacing**	
For octagons 1.83m to 2.6m	16	12	10	375	Not applicable
For octagons 2.6m to 3.66m	24	16	12	375	Not applicable
For octagons above 3.66m	@450 mm	16	12	375	Applicable

Provide 32 Dia 56 Nos. Vertical
Provide 12 Dia ties @ 375 mm C/C
<u>Top reinforcement in pedestal</u>
As per Ref. CL 4.5.6 of SABP-Q-003
Provide 12 Dia @ 300 mm C/C

V RESULTS

5.1 GENERAL:-

In the present chapter the design results are presented which is an outcome from the manual calculation done in the previous chapter. This chapter presents the results and discussions of the study. In the present project an octagonal shape foundation is designed whose size is 9.0m with an area of 67.1m^2. To decrease the cost of the project and to make it economical the shape of the foundation is taken as OCTAGONAL instead of SQUARE or RECTANGLE.
The area of the foundation is decreased by 18.2% as the area of the octagon is 82.8% of the area of the square. Hence the design is cost effective and economical for the given values of the loads.

5.2 BASE PLATE:-

The base plate size is designed depending upon the length of the vessel and loads coming on to it. As the vessel is 30m, the dead load coming on to the foundation is very high.
The size of the base plate is = 9.0m
The length of each side of octagon is = 3.73m
Thickness of the baseplate below ground level is = 1.8m
Area of the base plate is = 67.1m^2

5.3 PEDESTAL:-

The pedestal size is fixed based on the anchor bolt circle diameter of the vessel. As the bolt circle diameter of vessel is 3.3m, to our convenience and to have sufficient space to place it the pedestal size is taken as 4.0m, the thickness of the pedestal below the ground level is taken as 1.50m and above the ground is taken as 0.2m, so that the pedestal can take the loads coming on to it and to easily transfer the loads the below soil.

The size of the base plate is = 4.0m
The length of each side of octagon is = 1.66m
Total thickness of the pedestal = 1.7m
Thickness of the baseplate below ground level is = 1.5m
Thickness of the baseplate below ground level is = 0.2m
Area of the base plate is = $67.1m^2$

6.4 Net Allowable Bearing Capacity of Soil:- It is defined as the net pressure which can be applied safely without any shear failure.

As per the geotechnical report the Net Allowable Bearing Capacity of soil at the site

= $200kN/m^2$

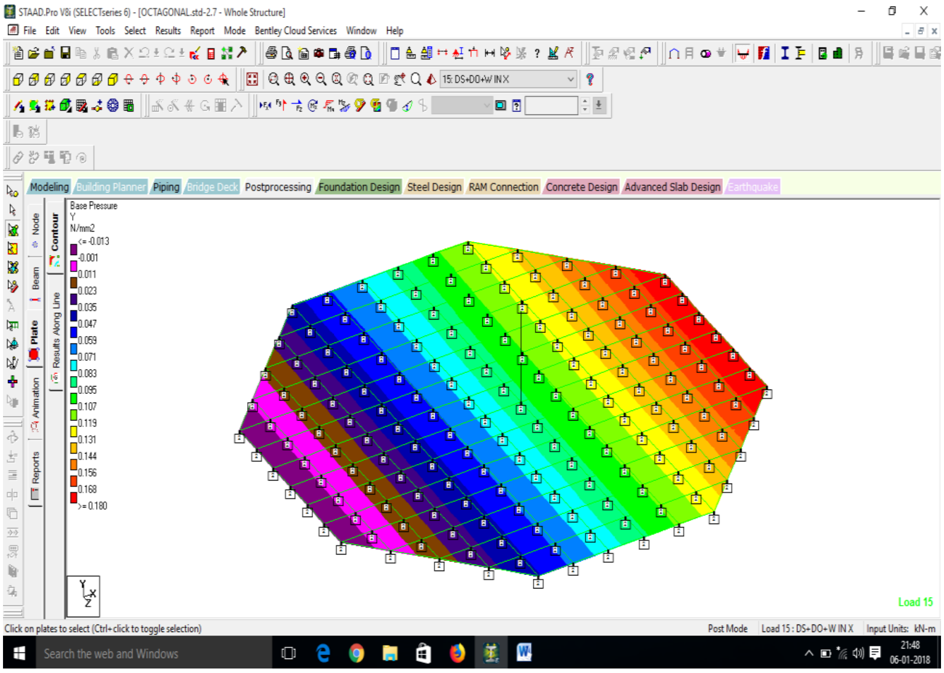


FIG 5.1 BASE PRESSURE

Here the max base pressure we got is $180kN/m^2$. Hence the foundation is safe.

VI CONCLUSIONS

The detail Study of Equipment Foundation coming in Industrial sector are Studied. Foundation for Stack Structure, Chimney from on-going project is carried out. Foundation is modelled as 4-noded rectangular Elements and Support system is developed with soil springs. Pedestal is modelled as Beam element and Loads coming from Vertical vessel are applied on top of the Pedestal.

Octagonal Foundation is considered as shape of Foundations as it has less area compared to Circular and Square Foundations and it has economy compared to Circular and Square Foundations has easy in constructability point of view for easy form work and Reinforcement. Various loads like Equipment operating load, Equipment Empty Load, Equipment Test load are taken from Mechanical Vendor Data Sheet. Environment loads Wind and Earthquake are calculated by using various relevant codes.

Load Combinations are arrived based on client specification and project Design basis. Foundation Safe load carrying capacity is checked with result arrived from STAAD Pro with Safe Carrying Capacity of soil taken from project Geo-technical Report.

Octagonal Foundation size is arrived by using serviceability load combinations and checked for Safe Bearing Capacity, Sliding, Overturning and uplift cases. The provided size is safe for all serviceability requirements.

Octagonal Foundation design is carried out by using Ultimate Limit State Method by using ACI 318. (American Concrete Institute) and adequate Reinforcement is provided for all Ultimate load combinations. Foundation Thickness is verified for Punching Shear and one-way shear. All manual design and STAAD Pro results are presented in Chapter 5 and Chapter 4 respectively. STAAD Pro Analysis and manual design are compared and coming within the limit.

VII REFERENCES

[1]. Mark Fintel and S.K. Gosh "Reinforced Concrete Designers Handbook", CBS Publication.
[2]. R.Park and T Pauley "Design of Reinforced Concrete Structure", John Wiley Publication.
[3]. Kong and Evans "Design of RCC and Pre-stressed Concrete", ELBS Publication.
[4]. J.E. Bolwes "Foundation Analysis and design", MC Graw Hill Publication.
[5]. Richart and Wood Prentice "Soil Dynamics & FoundationVibration", Hall Publication.
[6]. R.W. Clough and J Penzien "Dynamics of Structure", MC Graw Hill Publication.
[7]. American Code of Institute (ACI-318M-08) Building Code Requirement for Structural Concrete.
[8]. Structural Engineering Institute / American Society of Civil Engineers (SEI/ASCE 7-02) Minimum Design Loads for Buildings and Other Structures.
[9]. Saudi Arabian Engineering Standards (SAES-M-001) Structural Design Criteria for Non-Building Structures.
[10]. Saudi Arabian Engineering Standards (SAES-A-112) Metrological and Seismic Design Data.
[11]. Saudi Arabian Engineering Standards (SAES-A-204) Preparation of Structural Calculations.
[12]. Saudi Arabian Best Practise (SABP-Q-003) Vertical Vessel Foundation Design Guide.