Modelling of Turbo Generator Foundation using FEM to Study the Isolation Effect on the System

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Abstract - **Design of Frame Foundation is relatively a complex task compared to any other foundation. There are many parameters that influence machine-foundation response. The stiffness of Frame Structure plays a vital role in designing turbo generator foundation. Individual vibration characteristics of columns, beams, cantilever projections etc., besides being part of the system, have also been found to significantly influence the response. Design and analysis of turbo generator concrete pedestal with both basic principles and Finite Elements analytical method using SAP2000 program is presented to compare the results of the two methods. And the obtained results in this study used to determine how using base-isolators lead to a control of the dynamic properties of the foundation, and the results shows that isolators could resist up to90% of dynamic loads generated by turbo generator machines. This calculation was done also by mathematical and finite element methods to compare the results which shows a very good results.**

Keywords: Dynamic Analysis, Machine Foundations, Turbo Generators foundations, Isolators, Passive supplemental devices, Finite Element Modelling, dynamic response.

I. INTRODUCTION

Turbine generator is the power generation machinery used in power plants. It is the most vital and expensive equipment of a power plant. The turbo-generator foundation consists of turbine, generator and its auxiliaries which consists of top deck, columns and bottom raft. Heavy machinery with rotating masses requires a special support system that can resist the dynamic forces and resulting vibrations, Prakash & Puri (2006). A key ingredient to the successful foundation design for a turbo-generator is the control of the dynamic response of the foundation, in terms of the operation frequency and sustainability of dynamic loads, Jayarajan (2014). This Research highlightsthe usage of isolators to control the dynamic response of the foundation, through calculating the isolators effect with both manual and finite element model using SAP2000.

a) Objectiveand Scopeof Work

The main objective of this research is to study the following parameters:

- Dynamic analysis of turbo generator foundation by using basic principles computation method.
- Dynamic analysis of turbo generator foundation by finite element analysis method using SAP2000.
- Compare the results between basic principles and finite element model to figure out the differences between the two methods.
- Validation of Turbo Generator Frame Foundation Results Obtained by FEM.
- Usage of isolators in decreasing the transmitted dynamic loads of machines to foundationto control the dynamic properties of turbo generator foundation and representing it by both basic principles calculation and finite element analysis model.

II. DYNAMIC ANALYSIS OF TURBO GENERATOR FOUNDATION BY USING BASIC PRINCIPLES COMPUTATION METHOD

Design of turbine generator concrete frame foundation with using basic principles calculation method is presented to calculate the stiffness and frequencies of T.G machine Foundation.

1. Foundation Data

Foundation material properties are as follows:

Concrete Grade	M25
Mass density of concrete	2.50 t/m3
Elastic Modulus E	3.00E+07 kN/m2
Poisson's ratio	0.15
Shear Modulus G	1.30E+07 kN/m2
Top Deck L=13.80 m, B = 8.00m, Thickness =1.80 m	

Base RaftL=13.30 m, B = 8.00 m, Thickness =2.00 m, and the following figure 1 shows the turbine generator machine foundationgeometry (plan and elevation) used in this study.
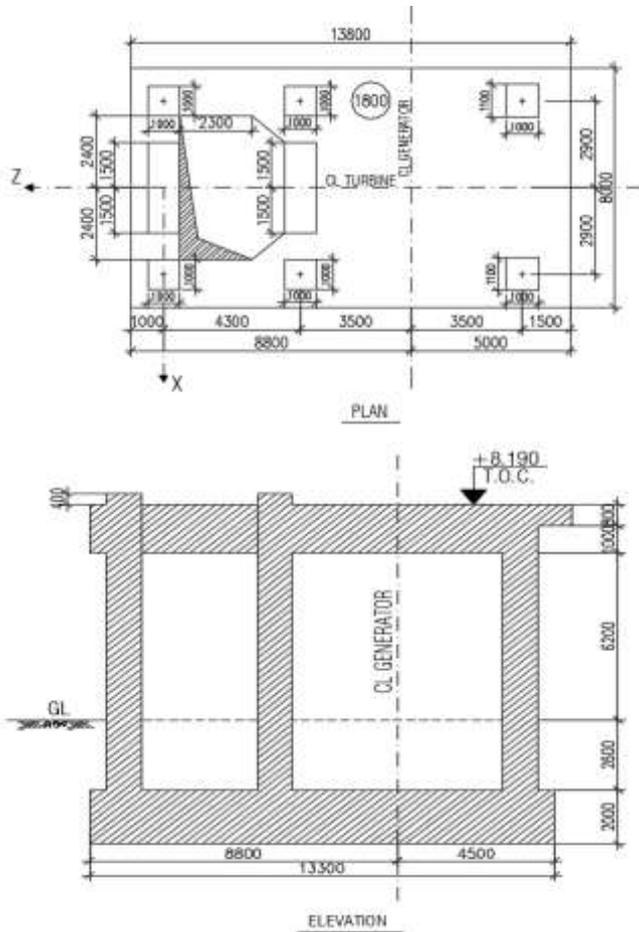

Figure 1: Turbo Generator Foundation Plan and Elevation

2. Frame Sizes

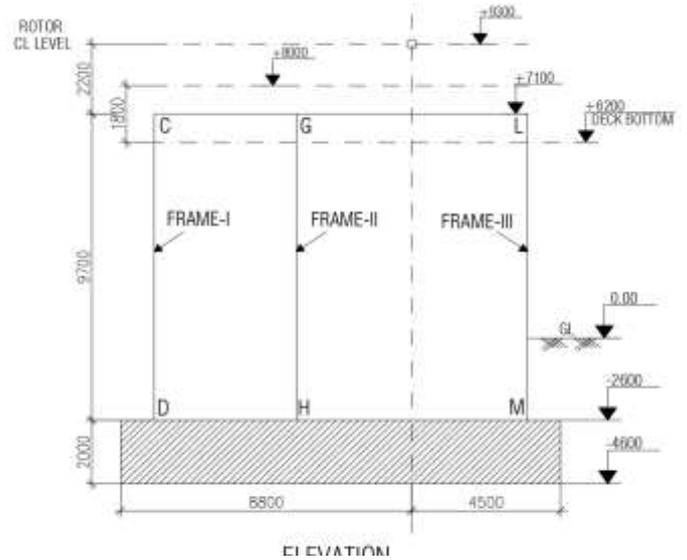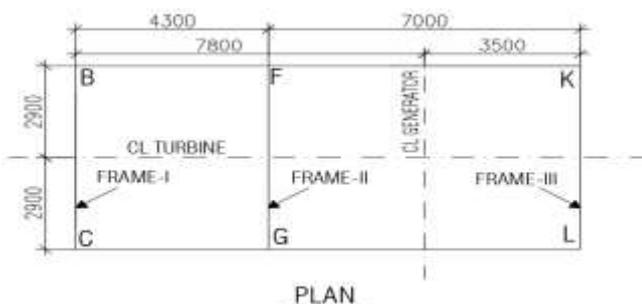| Frame number	Frame 1	Frame 2	Frame 3	
Frame Beam width	1	1	1	m
Frame Beam depth	1.8	1.8	1.8	m
Frame span	9.7	9.7	9.7	m
Beam Moment of Inertia	0.49	0.49	0.49	m^4
Column Moment of Inertia	0.08	0.08	0.11	m^4

Figure 2: Frames Plane and Elevation (Center Line)

3. Machine Load Data
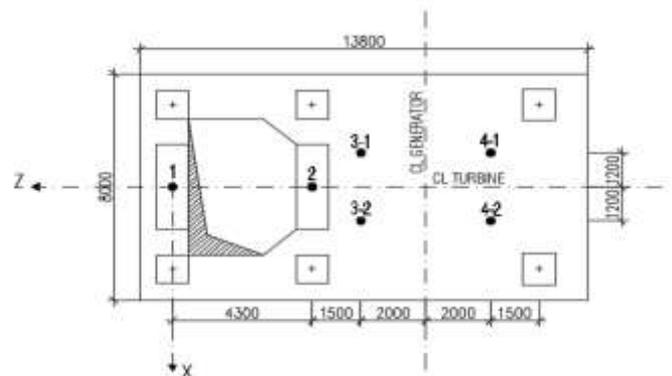
Figure 3: Machine Load Points

Load point	• 1	• 2	• 3	• 4Total (KN)
Total M/C WT	400	360	200	200 1160KN
Rotor WT Unbalance	25	35	70	70 200KN
Lateral/Vertical	5	7	15	15 42KN
Longitudinal	2	3	6	6 17KN
Blade loss force	3	11	—	— 14KN
Short Circuit Torque				2160 KN.m
Machine Speed				50 Hz

4. Machine Mass on Frames

Frame 1
Mass @ frame Beam center	W1=	400 KN
Total Mass on Frame 1		400 KN

Frame 2
Mass @ frame Beam center	W2=	360 KN
Mass W3 @ 1.7 m from Left column	W3=	100 KN
Mass W3 @ 1.7 m from Right column	W3=	100 KN

Total Mass on Frame 2		560 KN

Frame 3

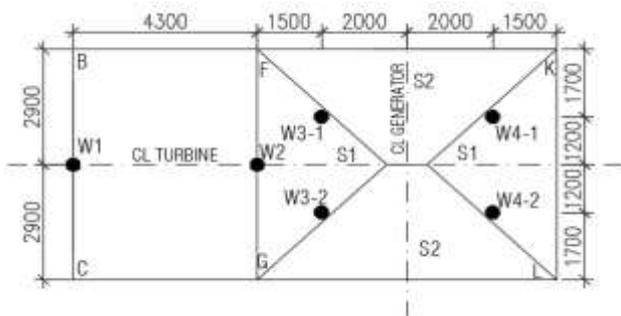| Mass @ frame Beam center		NIL
Mass W4 @ 1.7 m from Left column	W4=	100 KN
Mass W4 @ 1.7 m from Right column	W4=	100 KN
Total Mass on Frame 3		200 KN
Total Machine Mass		1160 KN

Figure 4: Machine Load @ Top Deck
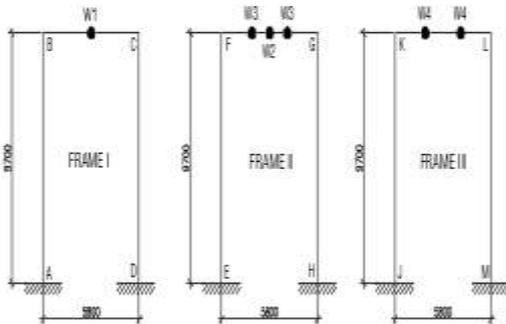
Figure 5: Machine Load on Frames
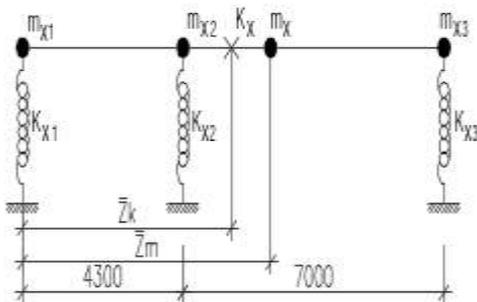
Figure 6: Eccentricity Center of Mass and Center of Stiffness

5. Design of T.G Foundation

a) Sizing of Foundation

- Top deck total weight (without cut-out) = 4874 KN
- Weight of Opening size @ turbine side (Trapezium shape) = 660 KN

- Net weight of top deck = 4874 − 660 = 4214 KN
- Weight ratio of top deck to machine = 4214 / 1160 = 3.63

b) Frame Lateral Stiffness

$$Kx = \frac{12EIc}{H^3} \, x \, \frac{1 + 6K}{2 + 3K}$$

Frame 1

$$Kx = \frac{12x3x10^7 x0.08}{9.7^3}\left(\frac{1 + 6x9.75}{2 + 3x9.75}\right) = 6.01x10^4 \text{ KN/m}$$

Frame 2

$$Kx = \frac{12x3x10^7 x0.08}{9.7^3}\left(\frac{1 + 6x9.75}{2 + 3x9.75}\right) = 6.01x10^4 \text{ KN/m}$$

Frame 3

$$Kx = \frac{12x3x10^7 x0.11}{9.7^3}\left(\frac{1 + 6x7.33}{2 + 3x7.33}\right) = 8.14x10^4 \text{ KN/m}$$

Total Lateral Stiffness

$$Kx = (6.01 + 6.01 + 8.14)x10^4 = 2.02x10^5 \text{ KN/m}$$

Center of Stiffness with Respect to Frame 1

$$Z_k = \frac{\left(6.01x4.3 + 8.14 \, x \, (4.3 + 7)\right)x10^4}{2.02x10^5} = 5.83 \, m$$

c) Dynamic Analysis

Lateral Vibration (along X)

Total lateral Natural Frequency

$$Px = \sqrt{(2.02x10^5)/598} = 18.38 \text{ rad/s} = 2.9 \text{ Hz}$$

Vertical Vibration (along Y)

Frame 1 (Vertical Natural Frequency)
Py = 169.4 rad/s = 26.9 Hz

Frame 2 (Vertical Natural Frequency)
Py = 140 rad/s = 22.4 Hz

Frame 3 (Vertical Natural Frequency)
Py = 162 rad/s = 25.8 Hz

III. DYNAMIC ANALYSIS OF TURBO GENERATOR MACHINE FOUNDATION BY FINITE ELEMENT ANALYSIS METHOD USING SAP2000

The TG Foundation has also been analyzed using Finite Element method using SAP2000 to compare the results betweenbasic principlesand finite element methods.

a) Modeling Procedure

Modeling procedure used in the finite element model using SAP2000 software is:

- The first element used is Shell element to simulate the table top foundation itself with concrete material and defined as Shell-Thick with 1.80 m.
- The second element is Frame element and it is defined as rigid link frame element by giving it a large modulus of elasticity and zero weight, to connect the loading points to the foundation horizontal center line to ensure adequate and smooth load transfer from the loading points to the foundation body. Rigid Frames are also used to connect the turbine supporting points to the turbine Centre of gravity and also to connect generator supporting points to generator center of gravity to ensure that the loading points are connected and acting as one body to simulate the equipment itself.
- The third element is the frame beam element to simulate beams and columns of frame foundation with the exact beams and columns dimensions.
- Foundation Basement can be simulated using shell element with springs or solid element but in this case, foundation will be simulated as fixed constraints under each columnbecause there is no need to calculate the stresses on the soil in this study. And the geometry of all foundation is presented in figures 7& 8.
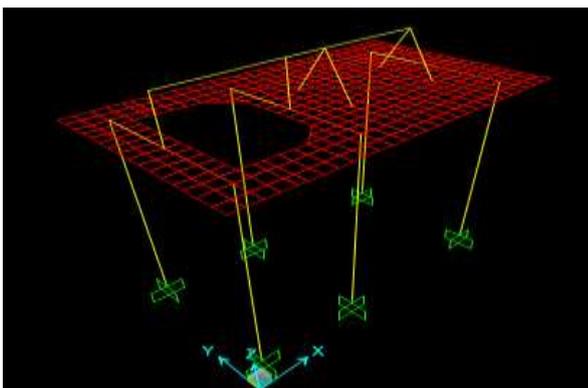

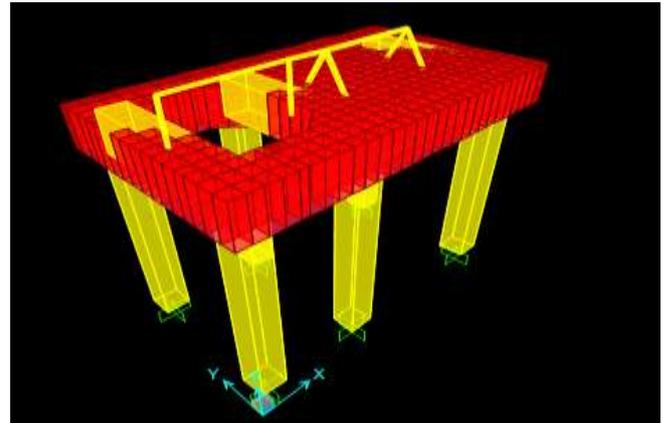**Figure 7: Model Geometry using Shell-Beam Element Method**

Figure 8: Model Geometry (Extruded View)

b) Material Properties

- Concrete Grade   M25
- Mass density of concrete   2.50 t/m3
- Elastic Modulus E   3.00E+07 kN/m2
- Poisson's ratio   0.15
- Shear Modulus G   1.30E+07 kN/m2

c) Load Definition

The loads on the foundation used in SAP2000 dynamic model are based on the loads used in basic principles calculation method to simulate the same model.

d) Time History Function Definition

According to DIN 4024-1(the German institute for standardization) the natural frequencies of the foundation with equipment must not occur within the following ranges:

For a 50 Hz application an exclusion ranges of 37.5 Hz to 64 Hz for the first natural frequency and 42.5 Hz to 56.5 Hz for higher natural frequencies.

A step of 2.5 Hz was selected to define time history frequencies which started from 37.5 Hz to 65 Hz for Steady state condition. And from 2.5 Hz to 37.5 Hz for startup and shut down condition.

e) Dynamic Load Cases

- Time History load cases definition: In phase and Out of phase cases are considered (at each frequency).
- Load Cases generation concept are as follows: Load cases are the basic cases with Arrival time of T = 0.0 and all load points starting their cycle at the same time.

Notes:

- All load combinations are generated with all Loads at the defined load points with positive sign and negative sign separately.
- The considered damping is the damping of the whole system (Equipment + Foundation system)
- Damping is assumed as 0.05.

f) Mass Source Definition

Mass Source = Equipment Own Weight (represented in mass joints) + Foundation Own Weight.

g) Load Combinations Generation

Dynamic analysis load combination is the envelope of all defined Time history load cases.

h) Analysis (Free Vibration Analysis)

Natural Frequencies for various modes is listed in Table I. First eight mode shapes are presented to show natural frequencies for transitional, torsional and vertical modes of vibration and to compare the results with basic principles calculation method

TABLE I
Frame natural frequencies (HZ)

Modal Periods And Frequencies						
OutputCase	StepType	StepNum	Period	Frequency	CircFreq	Eigenvalue
Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
MODAL	Mode	1	0.375295	2.6646	16.742	280.29
MODAL	Mode	2	0.366129	2.7313	17.161	294.5
MODAL	Mode	3	0.287812	3.4745	21.831	476.59
MODAL	Mode	4	0.04174	23.958	150.53	22659
MODAL	Mode	5	0.032601	30.674	192.73	37145
MODAL	Mode	6	0.031537	31.708	199.23	39693
MODAL	Mode	7	0.026669	37.497	235.6	55508
MODAL	Mode	8	0.02583	38.714	243.25	59170

From basic principles computation. It is seen that lateral translational frequency along X axis is 2.9 Hz as against 2.7 Hz which is showing the same result given by FE Analysis and that to ensure that the analysis is represent the actual system. Comparing vertical natural frequency, it is seen that lower vertical natural frequencies, obtained by basic principles computation, for Frames 1, 2 & 3 are 27, 22.4 & 25.8 Hz respectively and FE analysis gives vertical mode frequency as 23.957 Hz, which is in the same frequency range.

IV. VALIDATION OF TURBO GENERATOR FRAME FOUNDATION RESULTS OBTAINED BY FEM

After design turbo generator concrete pedestal with both basic principles and Finite Elements analytical method using SAP2000. The results are validated by comparison with previous published bookBhatia (2008) as shown in table II, because The obtained results in the previous study will be used for further works in the next section.

TABLE II
Validation Table showing Frame natural frequencies

Frame Natural Frequencies (Hz)			
Mode	Solid Model Analyzed by K.G. Bhatia example	Beam Plate Model Using SAP 2000	Observation
1	2.95	2.6646	Less than 10%
2	3.02	2.7313	Less than 10%
3	3.67	3.4745	Less than 10%
4	26.48	23.958	Less than 10%
5	32.36	30.674	Less than 10%
6	33.2	31.708	Less than 10%
7	35.57	37.497	Less than 10%
8	36.4	38.714	Less than 10%

The above table is the comparison between solid model analyzed by Bhatia (2008) and beam plate model analyzed by SAP2000 and the observation shows that results are in the same range and not exceed 10% between the two methods.

V. ISOLATION EFFECT ON TURBO-GENERATOR FRAME FOUNDATION

Isolation means reduction in the transmissibility of the exciting forces from the machine to the foundation and vice-versa. Vibration isolation devices have been used to achieve satisfactory performance. Isolation includes the following:

- Control of transmission of dynamic forces from machine to the foundation and thereby to the adjoining structures and equipment.
- Isolation of equipment from the vibration effects of the adjoining system.
- Isolation from external forces like Earthquake Shock, Blast, etc.
- Control vibrations on account of locating a machine at intermediate structural floors.
- Control vibrations on account of house a new (higher rating) machine on the foundation.
- Overcome uncertainty of dynamic soil parameters, and so on.

The complete knowledge of load-transfer mechanism from the machine to the foundation and the complete knowledge of excitation forces and associated frequencies are a must for the correct evaluation of machine performance and to correctly use the correct damping device.

Excitation dynamic forces are:

i. Internally generated forces by the machine itself, or
ii. Externally applied forces (that are applied directly to the machine, or transmitted through the foundation).

From the above points the following will be studied:

- Selection of suitable isolation system from machine and foundation parameters.
- Calculate the max vertical dynamic force experienced by one isolator.
- Compare the loads could be transmitted to the foundation with and without using isolators system

1. Isolators Selection

Isolators could be chosen as per required specification to adapt with system requirements.And there are many types of isolators available commercially such as:

- Mechanical Isolators (spring type with or without damping)
- Sheet / Pad type isolators

Isolator selection is depending on machine excitation frequency, isolation efficiency and overall mass of machine with inertia block, and there are many ways to arrive to the required specifications by selecting the reasonable isolators.Example of selection criteria for mechanical isolators and sheet/pad type isolators is given as under.

Machine and isolation parameters are as under:

Machine mass	m1	kg
Isolator Mass	m2	kg
Machine speed (rpm)	N	rpm
Excitation Frequency	ω	rad/sec
Target Transmissibility Ratio	TR	
Target Isolation Efficiency	Ƞ	
Required frequency Ratio For Ƞ,	β	
The required frequency of isolation system	f	Hz
For this f, required deflection of isolator	δ	mm

One can select the isolator to match this static deflection

a) Mechanical isolators (spring damper unit)

Let the isolator capacity (single isolator) be	R	N
Total mass of machine + isolator	m	kg

Number of isolators required (q = mg / R)	q	
Vertical stiffness of each isolator (Ky = R/δ)	Ky	N/mm
Lateral stiffness (specified by manufacturer) Kx		N/mm
Damping of isolator (specified by manufacturer)ζ		%

b) Sheet Pad Type isolators (Cork sheets, Rubber pads, etc.)

Elastic modulus of sheet isolator	EA	N/m2
Area of isolation block in contact with sheet/pad isolator	Ah	m2
Required Thickness of Sheet/Pad Isolator (t = $\frac{EsAh}{mg}\delta$)	t	mm

2. Study the effect of using vibration Isolation system on T.G foundation

In this section the effect of using vibration isolation system in turbo-generator machines is studied and compared with the results without isolators to understand the mechanism of isolators and also to study the maximum dynamic force could be transmitted by isolators.

In the beginning the center of stiffness of isolation (VL stiffness along Y-Direction) should be matched with overall center of mass of (machine + Inertia block) because presence of any eccentricity would result in reducing isolation effectiveness. Figure 9, shows machine mass points and coordinates with respect to origin.
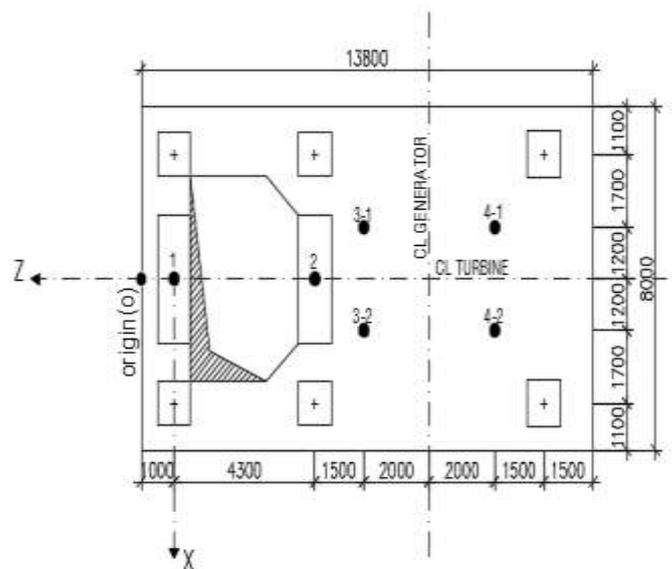

Figure 9: Machine mass points and coordinates with respect to origin

Considering origin at left side top of inertia block, so machine mass coordinates with respect to origin will be as follows:

Mass point	Machine weight (KN)	Coordinates with respect to origin (mm)		
#	W_{mi}	X_{mi}	Z_{mi}	Y_{mi}
1	400	0	-1000	1300
2	360	0	-5300	1300
3-1	100	-1200	-6800	1300
3-2	100	1200	-6800	1300
4-1	100	-1200	-10800	1300
4-2	100	1200	-10800	1300

$\bar{X}m = \frac{\Sigma(WmiXmi)}{\Sigma Wmi} = \frac{0}{1160} = 0$ mm

$\bar{Z}m = \frac{\Sigma(WmiZmi)}{\Sigma Wmi} = \frac{-5828000}{1160} = $ -5024.137 mm

$\bar{Y}m = 1300$ mm

Top Deck self-weight and its CG with respect to origin:

∴ CG of machine weight with respect to origin:
 $\bar{X}m = 0$, $\bar{Z}m = -5024.137$, $\bar{Y}m = 1300$

∴ CG of Top deck self-weight with respect to origin:
 $\bar{X} = 0$, $\bar{Z} = -7479$, $\bar{Y} = -900$

∴ Total mass of machine + Inertia block = 4214+1160=5374 kN

Overall Centroid:

Overall centroid represented by point C

Center of mass of machine-foundation in X-Z plane

$\bar{X} = \frac{Wm\,Xm + Wf\,Xf}{Wm + Wf} = \frac{(1160\,x0) + (4214\,x0)}{(1160 + 4214)} = 0$ mm

$\bar{Z} = \frac{Wm\,Zm + Wf\,Zf}{Wm + Wf} = \frac{(1160\,x-5024) + (4214\,x-7479)}{(1160 + 4214)} = $ -6949 mm

$\bar{Y} = \frac{Wm\,Ym + Wf\,Yf}{Wm + Wf} = \frac{(1160\,x1300) + (4214\,x-900)}{(1160 + 4214)} = $ -425 mm

Selection of isolator:

   Considering the target of isolation efficiency η = 90% with isolating damping 10% which means that $\zeta = 0.1$

∴From the following graph figure 10, (Isolation Efficiency VS. frequency ratio) Bhatia (2008), the frequency ratio is selected (β) = 3.6

Figure 10: Isolation Efficiency Ƞ vs. Frequency Ratio β for different Damping Values ζ

∴ Required isolator frequency(P)= $\frac{\omega}{\beta} = \frac{314.16}{3.6} = 87.26$ rad/s

As ω = $\frac{2\pi N}{60}$ = 314.16 rad/sec

∴ Required isolator deflection δ, calculated as follows:

∵ P = $\sqrt{\frac{g}{\delta}}$,

∴ $(P^2) = \frac{g}{\delta}$,   Then, $\delta = \frac{9810}{87.26^2} = 1.3$ mm

∵ Total wt. of machine foundation system W=5374 kN
Consider No. of isolators = 6 isolators

∴ Load per isolator = $\frac{5374}{6} = 896$ KN

   The nearest available isolator from (manufacture catalog) should be selected, gives isolator of capacity 900 kN & $\delta = 5$ mm

∴ Stiffness of isolator (Vertical) = Ky = $\frac{900}{5} = 180$ KN/mm

∴ Stiffness of isolator (Lateral) = Kx = Kz = 0.6 x 180 = 108 KN/mm

Check of isolator placement locations:

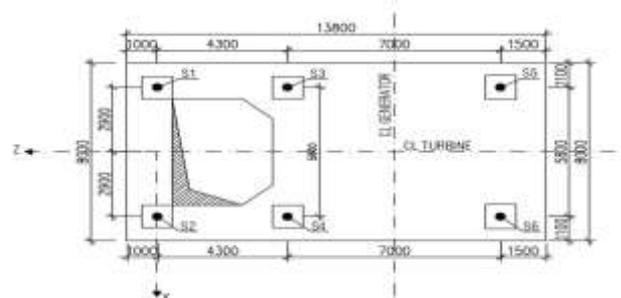| Isolator No.	Stiffness (KN/mm)	Coordination with respect to origin		
	K_{yi}	X_{ki}	Z_{ki}	Y_{ki}
S1	180	2900	-1000	-1800
S2	180	-2900	-1000	-1800
S3	180	2900	-5300	-1800
S4	180	-2900	-5300	-1800
S5	180	2900	-12300	-1800
S6	180	-2900	-12300	-1800

Figure 11: Isolation Number and Location

Center of isolators stiffness and its eccentricity with center of mass:

$$ex = \frac{0}{8000} = 0 \quad , \quad ez = \frac{-6949 - (6800)}{-13800} \times 100 = 0.05\%$$

And for good design, center of isolators stiffness should be not more than 0.05%, which we not exceed in our case study. So we don't need for relocate the isolators.

Dynamic Analysis:

Mass and mass moment of inertia at centroid (Center of mass):

i) Machine

Point	Mass (ton)	Coordinates WRT Origin (mm)			Centroid coordinates (mm)			Mass moment of inertia (t.m²)		
	mm_i	X_{mi}	Z_{mi}	Y_{mi}	$\bar{X}$	$\bar{Z}$	$\bar{Y}$	M_{mix}	M_{miz}	M_{miy}
1	40	0	-1000	1300	0	-6949	-425	1535	119	1415
2	36	0	-5300	1300	0	-6949	-425	205	107	98
3-1	10	-1200	-6800	1300	0	-6949	-425	30	44	14.6
3-2	10	1200	-6800	1300	0	-6949	-425	30	44	14.6
4-1	10	-1200	-10800	1300	0	-6949	-425	178	44	16.27
4-2	10	1200	-10800	1300	0	-6949	-425	178	44	16.27

∴ $m_m = \Sigma m_{mi} = 116$ ton, $m_{mx(machine)} = \Sigma M_{mix} = 2156$ t.m²,

$m_{mz(machine)} = \Sigma M miz = 401$ t.m², $m_{my(machine)} = \Sigma M miy = 1575$ t.m²

ii) Foundation (Top Deck)

Dimension and total weight of top deck foundation:

Dimensions	X (mm)	Z (mm)	y (mm)
	0	13800	1800
Total weight		421.4 ton	

C.G with respect to origin:

C.G with respect to origin		
X (mm)	Z (mm)	Y (mm)
0	-7479	-900

Overall centroid with respect to origin:

Overall centroid with respect to origin		
X (mm)	Z (mm)	Y (mm)
0	-6949	-425

Mass moment of inertia @ centroid:

Mass moment of inertia @ centroid		
$M_{mix \, (foundation)}$ (t.m²)	$M_{miz \, (foundation)}$ (t.m²)	$M_{miy \, (foundation)}$ (t.m²)
392	95	126.5

∴ $m_f = 421.4$ ton, $M_{mix \, (foundation)} = 392$ t.m2,

$M_{miz \, (foundation)} = 95$ t.m2, $M_{miy \, (foundation)} = 126.5$ t.m2

Total for Machine and Foundation (Mass and Mass Moment of Inertia)

m (total) = 421.4 + 116 = 537.4 t, M_{mx} = 2156 + 392 = 2548t.m2

Mmz = 402 + 95 = 497 t.m2, Mmy = 1575 + 126.5 = 1701.5t.m2

Stiffness

Stiffness computations are tabulated as under:

Isolator	Stiffness (KN/m)	Coordinates wrt Origin (mm)			Stiffness centroid (mm)			Stiffness (KNm/rad)		
	K_{yi}	X_{ki}	Z_{ki}	Y_{ki}	$\bar{X}_k$	$\bar{Z}_k$	$\bar{Y}_k$	$K_{\theta i}$	$K_{\Psi i}$	$K_{\phi i}$
S1	1.8x10⁵	2900	-1000	-1800	0	-6200	-1800	4.9x10⁶	3.8x10⁶	1.5x10⁶
S2	1.8x10⁵	-2900	-1000	-1800	0	-6200	-1800	4.9x10⁶	3.8x10⁶	1.5x10⁶
S3	1.8x10⁵	2900	-5300	-1800	0	-6200	-1800	1.46x10⁵	9.95x10⁵	1.5x10⁶
S4	1.8x10⁵	-2900	-5300	-1800	0	-6200	-1800	1.46x10⁵	9.95x10⁵	1.5x10⁶
S5	1.8x10⁵	2900	-12300	-1800	0	-6200	-1800	6.7x10⁶	4.9x10⁶	1.5x10⁶
S6	1.8x10⁵	-2900	-12300	-1800	0	-6200	-1800	6.7x10⁶	4.9x10⁶	1.5x10⁶

We get overall stiffness as:

Kx = 6.48 x 10⁵ KN/m   Ky = 1.08 x 10⁶ KN/m

Kz = 6.48 x 10⁵ KN/m   Kθ = 2.35 x 10⁷KNm/rad

KΨ = 1.94 x 10⁷ KNm/rad   Kϕ = 9 x 10⁶KNm/rad

Natural Frequency

$$Px = \sqrt{\frac{Kx}{m}} = \sqrt{\frac{6.48 \times 10^5}{537.4}} = 34.72 \text{ rad/sec}$$

$$Py = \sqrt{\frac{Ky}{m}} = \sqrt{\frac{1.08 \times 10^6}{537.4}} = 44.8 \text{ rad/sec}$$

$$Pz = \sqrt{\frac{Kz}{m}} = \sqrt{\frac{6.48 \times 10^5}{537.4}} = 34.72 \text{ rad/sec}$$

$$P\theta = \sqrt{\frac{K\theta}{Mmx}} = \sqrt{\frac{2.35 \times 10^7}{2548}} = 96 \text{ rad/sec}$$

$$P\Psi = \sqrt{\frac{K\Psi}{Mmy}} = \sqrt{\frac{1.94 \times 10^7}{1701.5}} = 106.7 \text{ rad/sec}$$

$$P\phi = \sqrt{\frac{K\phi}{Mmz}} = \sqrt{\frac{9 \times 10^6}{497}} = 134.5 \text{ rad/sec}$$

Amplitudes

Excitation frequency $(\omega) = \frac{2\pi N}{60} = 314.16$ rad/sec

Height of rotor center line from overall centroid:
S=1.3 – (-0.425) = 1.725m

Dynamic force at center line of rotor level

Fx = 42KN,   Fy = 42 KN

Mφ = Fxx s = 42 x 1.725 = 72.45 KN.m

Net Forces acting in centroid:

Fx = 42 KN,   Fy = 42 KN,   Mφ = 72.45 KN.m

Amplitude at centroid

i) Force Fx = 42 KN

Frequency ratio = βx = $\frac{\omega}{Px} = \frac{314.16}{34.72} = 9$

Amplitude: Xc = $\frac{Fx}{Kx}$ x $\frac{1}{|(1-\beta x^2)|} = \frac{42}{6.48 \times 10^5}$ x $\frac{1}{|(1-9^2)|}$

= $\frac{42}{6.48 \ x 9^5}$ x $\frac{1}{80}$ = 8.1 x 10^{-7}m

ii) Force Fy = 42 KN

Frequency ratio = βy = $\frac{\omega}{Py} = \frac{314.16}{44.8} = 7$

Amplitude: Yc = $\frac{Fy}{Ky}$ x $\frac{1}{|(1-\beta y^2)|} = \frac{42}{1.08 \times 10^6}$ x $\frac{1}{48}$ = 8.1 x 10^{-7}m

iii) Moment Mφ = 72.45 KN.m

Frequency ratio = βφ = $\frac{\omega}{P\phi} = \frac{314.16}{134.5} = 2.34$

Amplitude: φc = $\frac{M\phi}{K\phi}$x $\frac{1}{|(1-\beta\phi^2)|} = \frac{72.45}{9 \times 10^6}$ x $\frac{1}{4.475}$ = 1.054 x 10^{-6}rad

Amplitude at Foundation top deck

-Maximum amplitude along X

Height of top deck from joint c = 425 mm = 0.425 m

X$_f$ (max) = Xc + H x φc = 8.1 x 10^{-7} + |1.054 x 10^{-6} x 0.425|

= 1.257 x 10^{-6} = 1.26 microns

-Maximum amplitude along Y

Maximum top deck width along X   B=8m

Y$_f$ (max) = Yc + (B/2) x φc = 8.1 x 10^{-7} + (8/2) x 1.054 x 10^{-6}

= 5.026 x 10^{-6} = 5 microns

Max vertical dynamic force experienced by isolator

∵ Max isolator spacing along x = 5.8 m (see figure. 10)

∴Max vertical dynamic force experienced by one isolator (Placed along Z):

$\frac{Fy}{6} + \frac{1}{3}$ x$\frac{M\phi}{(\frac{5.8}{2})} = \frac{42}{6} + \frac{1}{3}$ x $\frac{72.54}{2.9}$ = 15.33 KN

∴Max vertical dynamic force transmitted by single isolator

F$_{Ty}$ = K$_{yi}$ x (Y$_c$ + φ$_c$ x X$_s$) =

1.8 x 10^5 x (8.1 x 10^{-7} + 1.054 x 10^{-6} x 2.9) = 0.695 KN = 695N

Transmissibility Ratio = $\frac{0.695}{15.33}$ = .0453

∴ Isolation efficiency η = (1- 0.0453) = 0.95 = 95% which meet our isolation requirements.

So we can represent the variance between max vertical dynamic force transmitted to columns with and without using isolators system and highlights it as under in table III:

TABLE III
Max Vertical Dynamic Force transmitted to column with and without using isolators (for single isolator)

Force Isolating	Max vertical dynamic force transmitted to columns	Ratio highlighting the effect of using isolator system
Without using isolators	7000 N	90% of dynamic force could be decreased using isolation system
With using isolators	695 N	

3. Study the effect of using vibration Isolation system on T.G foundation using Finite Element Analysis method

This part shows simulating the isolators on turbo generator machine foundation by using SAP2000 finite element analysis model as shown in figure 12. Isolation mount at each support location is represented by spring elements with same stiffness properties in X, Y &Z directions. Free vibration analysis yields natural frequencies and mode shapes were done. Steady state response and amplitudes have been computed for unbalance forces. Transient Response is obtained to simulate start-up and shut-down conditions. In this section we will present the finite element model results with using isolators to compare it with the previous basic principles calculation.
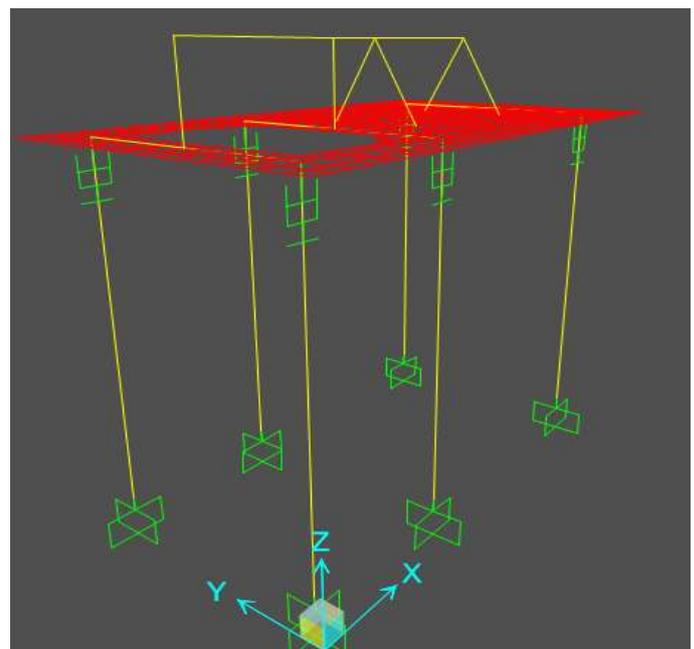

Figure 12: Simulating Isolators in sap model

a) Maximum Velocities at Foundation top deck along X&Z Results from SAP model

The following table III shows the maximum velocities at machine resting points on foundation top deck.

TABLE IV
Max Velocities at Foundation Top Deck

Joint Velocities - Absolute					
Joint	OutputCase	CaseType	StepType	U1	U3
Text	Text	Text	Text	mm/sec	mm/sec
P1	Envelope Dynamic Loads	Combination	Max	0.03262	0.25
P2	Envelope Dynamic Loads	Combination	Max	0.01859	0.47
P3-1	Envelope Dynamic Loads	Combination	Max	0.38	0.68
P3-2	Envelope Dynamic Loads	Combination	Max	0.38	0.68
P4-1	Envelope Dynamic Loads	Combination	Max	0.38	1.18
P4-2	Envelope Dynamic Loads	Combination	Max	0.38	1.18

b) Maximum Amplitudes at Foundation top deck along X&Z:

1. Max Amplitude in Lateral (X) direction = $(1.4 \times \frac{V}{2\pi f})$ as per ISO 10816.

$\therefore$ Max Amplitude in Lateral (X) direction = $1.4 \times \frac{1.18}{2\pi \times 50} = 5$ mic.

2. Max Amplitude in vertical (Z) direction = $(1.4 \times \frac{V}{2\pi f})$ as per ISO 10816.

$\therefore$ Max Amplitude in VL (Z) direction $= 1.4 \times \frac{0.38}{2\pi \times 50} = 1.6$ mic.

It is interesting to note that these results compare reasonably well with those obtained by basic principles computations. Which lead us to verify the good effect of isolators in deducting dynamic loads transmitted to turbine foundations.

VI. SUMMARY

The purpose of this paper is toperform a dynamic analysis of turbo generator foundation by using bothbasic principlesand finite element methodsto compares the results and figure out the differences between the two methods and also to figure out the differences between modelling the foundation with solid element and shell beam elements methods. And thenthese analysesused to study the effect of using the isolators in decreasing the transmitted dynamic loads of machines to foundation to control the dynamic properties of T.G foundation and this study represented by both basic principles calculation and finite element analysis.

VII. CONCLUSION

The analysis using basic principles computation shows the same result given by FE Analysis and that to ensure that the analysis is representing the actual system.

Comparison between solid model analyzed by Bhatia (2008) and beam plate model analyzed by SAP2000 was done and the observation shows that results are in the same range and not exceed 10% between the two methods.

Using isolators on turbo generator machine foundation shows the significant effect in decreasing the dynamic forces transmitted to the foundation and the analysis results of the system with using isolators shows that 90% of dynamic loads could be decreased by using isolators.

Simulating isolators using FEM gives an exact results compared with those obtained by basic principlescomputations, which means that FEM could simulate the exact system.And this is to verify the good effect of isolators in deducting dynamic loads transmitted to turbine foundations.

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