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ATTACHMENT (1)- Dynamic Analysis

ATTACHMENT (2)- Engineering Data

1.0 GENERAL

1.1 Scope

This calculation report is relevant to the design of C.A.BLOWER Foundation (551-B-1001/2001/3001/4001)

1.2 Definitions

Project	**:**	
Company	**:**	SATORP(Saudi Aramco Total Refining and Petrochemical Company)
Contractor	**:**	
Location	**:**	Industrial Site of Jubail 2, The West Coast of Arabian Gulf, Saudi

2.0 REFERENCE CODES, STANDARD AND PROJECT DOCUMENTS

2.1 Industry Codes and Standards

ACI-318-02	Building Code Requirements for Reinforced Concrete
ASCE 7-05	Minimum Design Loads for Buildings and Other Structures

2.2 Company References

JERES-M-001	Civil and Structural Design Criteria
JERES-Q-001	Criteria for Design and Construction of Concrete Structures
JERES-Q-005	Concrete Foundations
JERES-Q-007	Foundations and Supporting Structure for Heavy Machinery
JERES-Q-010	Cement Based, Non-Shrink Grout for Structural and Equipment Grouting
JERES-Q-011	Epoxy Grout for Machinery Support
JERMS-H-9106	Epoxy Coating of Steel Reinforcing Bars

2.3 Saudi Arabian Standard Organization

SASSO SSA 2	Steel Bars for the Reinfocement of Concrete
SASSO SSA 224	Steel Fabric for Reinforcement of Concrete

2.4 Project Documents

SA-JER-PUAAA-SKEC-468002	Design Criteria for Civil and Structure
SA-JER-PUAAA-SKEC-588001	Geotechnical Investigation Report
SA-JER-PUAAA-SKEC-468001	Geotechnical & Foundation Design Basis

2.5 Reference Document

Design of Structures and Foundations for Vibrating Machines by Suresh C. Arya

3.0 MATERIALS AND UNITS

3.1 Materials

3.1.1 Concrete

- Cement

1) Below Grade (up to 150 mm above grade)
Type - V Portland cement (JERES-Q-001 and ASTM 150) or
Type - I Portland cement (JERES-Q-001 and ASTM 150) + Silica Fume 7%

2) Above Grade (from 150 mm above grade)
Type - I Portland cement (JERES-Q-001 and ASTM 150)

- Specified Compressive Cylinder Strength at 28 Days

1) f'_c = 35 Mpa for basins and water retaining structures
2) f'_c = 28 Mpa for foundations, walls and pavings

- Unit Weight for Reinforced Concrete

1) W_c = 24 kN/m^3

- Modulus of elasticity

1) E_c = 24800 Mpa (f'c = 28 Mpa)
2) E_c = 27800 Mpa (f'c = 35 Mpa)

3.1.2 Reinforcing Bar

1) Reinforcing steel bars shall conform to SASO SSA 2, hot-rolled, high tensile, deformed steel.
2) Characteristic Strength (ACI 318M)
   - f_y = 422 Mpa

3) Modulus of Elasticity
   - E_s = 200,000 Mpa

3.1.3 Anchor Bolt

1) Threaded Anchor Bolts : ASTM A36/A36M or ASTM F1554, Gr. 36
   - Headed Bolts : ASTM A307 Grade A
   - Washers : ASTM F436/F436M
   - Nuts : ASTM A563 Grade A, Heavy Hex or ASTM A 563M
2) High Strength Anchor Bolts
   - Anchor Bolts : ASTM A193/A193M Gr. B7 or ASTM F1554, Gr. 105
   - Washers : ASTM F436/F436M
   - Heavy Hex Nuts : ASTM A194/A194M or ASTM A563, DH
3) Min. Anchor Bolt Diameter : 20 mm
4) For Corrosion Allowance : Anchor Bolt Diameter + 3 mm.

3.1.4 Grout for Machinery Support

When type of grout is not specified by the equiment Manufacturer,
cenmentitious grout shall be used for any of the following

1) Non-Shrink Grout for Structural and Equipment
   - Equipment with driver horsepower < 500 (373 kW)
   - RPM of Equipment < 3600 RPM
   - Total weight of Equipment < 2270 kg

2) Epoxy Grout for Machinery Support
   - Equipment with driver horsepower ≥ 500 (373 kW)
   - RPM of Equipment ≥ 3600 RPM
   - Total weight of Equipment ≥ 2270 kg

3.2 Units of Measurements

The Metric units shall be used :

- Force : kN
- Length : meter
- Temperature : Degree centigrade

4.0 PUMP FOUNDATION DESIGN ASSUMPTION

4.1 Foundation Grouping for Vibrating Machinery

4.1.1 Centrifugal Rotating Machinery (JERES-Q-007 Section 5.1.1)

1) Horsepower ≥ 500 — The foundatiom shall be designed for the expected dynamic forces using dynamic analysis procedures

2) Horsepwoer < 500 — The foundation weight shall be 3 times the total machinery weigh

UNIT	ITEMS	FDN. TYPE	MACHINE TYPE	RATING	POWER	DYNAMIC ANALYSIS
UNIT 551	51-B-1001/2001/3001/400	Rigid Block	Rotating	1167 kW	1587 HP	YES

4.2 General Design Requirements

4.2.1 Clean, simple outlines shall be used for foundations. Beams and columns shall be of a uniform rectangular shape. Block foundations should be rectangular.

4.2.2 The height of the machine support above grade shall be the minimum to accommodate suction and discharge piping arrangements.

4.2.3 The minimum thickness of the concrete foundations

- $0.60 + L / 30$ (meters)

Where, L = Length of foundation parallel to the machine bearing axis in meters

4.2.4 The width of the foundation

- B ≥ 1.5 × Vertical distance from the base to the machine centerline

Where, B = Width of foundation in meters

4.2.5 For deformed bars

1) The reinforcement in each direction shall not be less than 0.0018 times the gross area perpendicular to the direction of reinforcement

2) Minimum tie size in pers shall be 12 mm

4.2.6 Allowable Eccentricities for Concrete Foundations with Horizontal Shaft Machinery

1) The horizontal perpendicular to the machine bearing axis, between of gravity of the machine foundation system and the centroid of the cosil contact area (< 0.05 × B)

2) The horizontal parallel to the machine bearing axis, between of gravity of the machine foundation system and the centroid of the cosil contact area (< 0.05 × L)

4.2.7 Allowable Soil Bearing Pressures

1) For High-tuned foundati : Soil bearing pressures shall not exceed **50%** of the allowable bearing pressure permitted for static loads

2) For Low-tuned foundati : Soil bearing pressures shall not exceed **75%** of the allowable bearing pressure permitted for static loads

Where,

High-tuned System = A high-tuned system is a machine support/foundation system in which the operating frequency (range) of the machinery is below all natural frequencies of the system

Low-tuned System = A low-tuned system is a machine support/foundation system in which the operating frequenct (range) of the machinery is above all natural frequencies of the system

4.2.8 Permissible Frequency Ratios

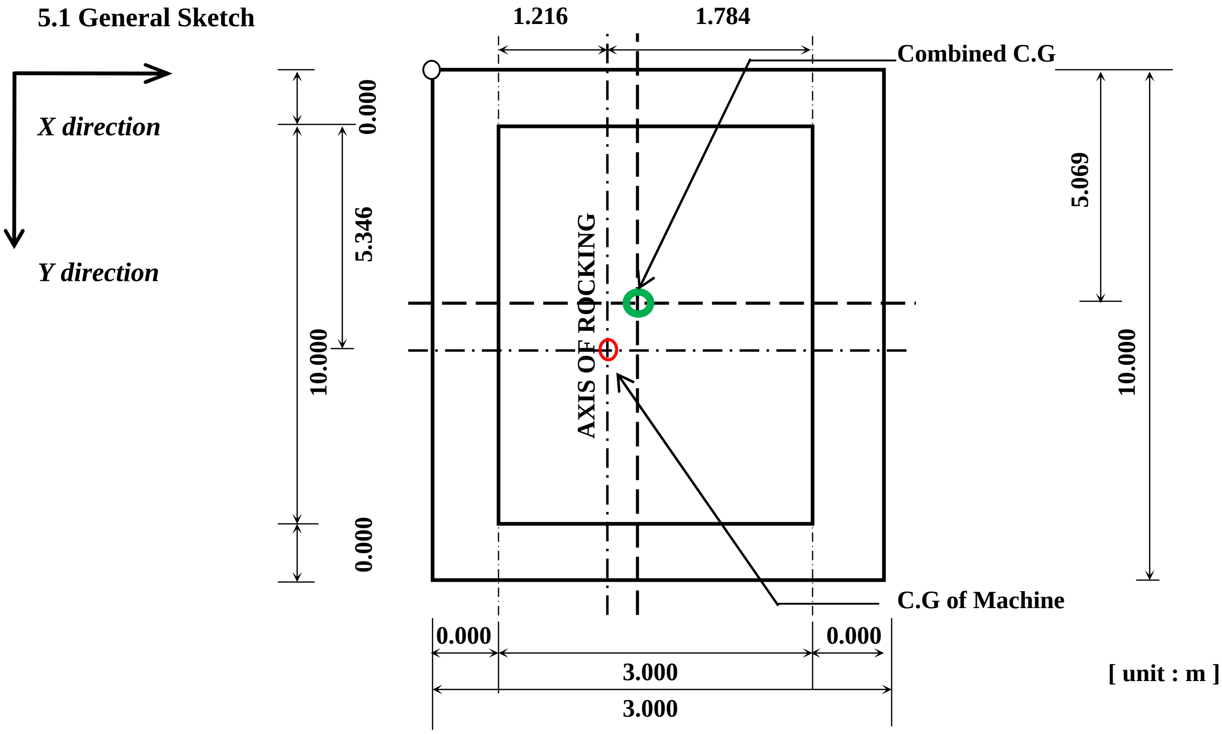
To avoid the danger of excessive vibration, the ratio between the operating frequency of the machi
f, and each natural frequency of the machine foundation system, f(n) shall not lie in the range of
0.7 to 1.3.

4.2.9 Permissible Vibration

If Manufacturer's vibration criteria are not available, the maximum velocity of movement
during steady-state normal operation shall be limited to 0.12 inch per second for centrifugal machi

5.0 BLOWER FOUNDATION (551-B-1001/2001/3001/4001)

5.1 General Sketch



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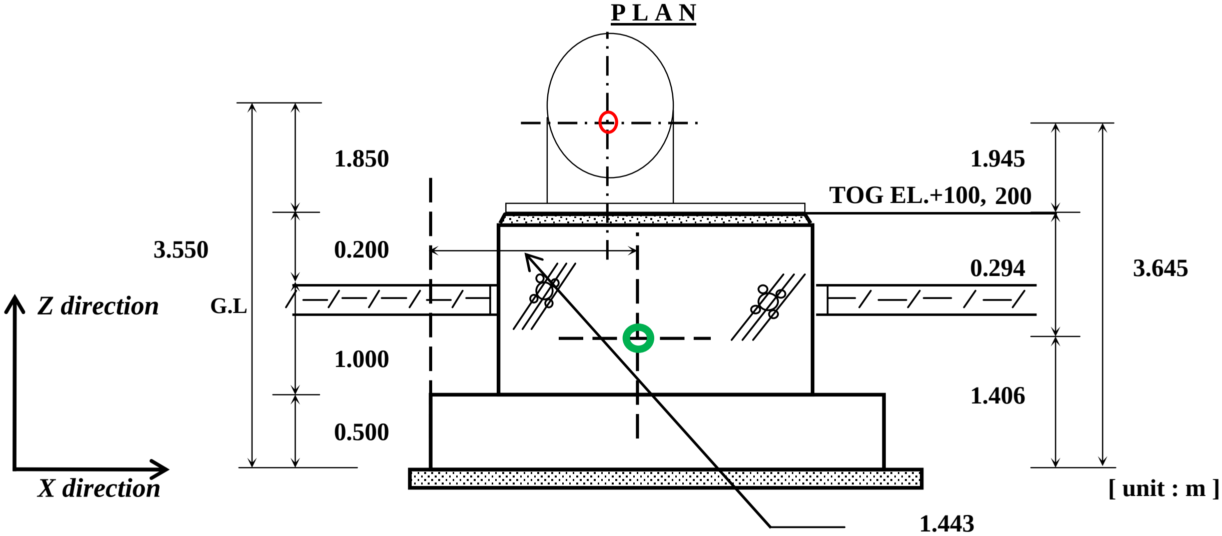


S E C T I O N

5.2 The Soil and Foundation Parameters

Allowable Soil Beraing	200.000	kN/m²
Shear Modulus, G	82579.233	kN/m²
Soil Internal damping Ratio	0.040	
Poisson's Ratio, υ	0.321	
Unit Weight (Soil)	17.000	kN/m³
Unit Weight (Con'c)	24.000	kN/m³

5.3 Foundation Data

Item No.	551-B-1001/2001/3001/4001	
Footing Width (FL)	3.000	m
Footing Length (FB)	10.000	m
Footing Height (FH)	0.500	m
Pedestal Width (PL)	3.000	m
Pedestal Length (PB)	10.000	m
Pedestal Height (PH)	1.200	m
Ground Level (G.L.)	0.200	m
Height (h)	1.700	m
Thickness of Grout	0.025	m

5.4 Equipment Data

Weight of C.A.BLOWER (W_c)	13.000	ton	=	127.530	kN
Weight of Motor (W_m)	9.400	ton	=	92.214	kN
Weight of Base Plate (W_b)	2.600	ton	=	25.506	kN
Weight of Silencer (W_s)	6.000	ton	=	58.860	kN
Total Weight (W_t)	31.000	ton	=	304.110	kN

5.5 Machine Data

(1) For values for Equipment

R.P.M	C.A.BLOWER - 2242	rpm	MOTOR - 1490	rpm
Rotor Weight	C.A.BLOWER - 3.670	ton		ton
Unbalanced Force	C.A.BLOWER - 0.072	ton		ton

(2) For dimensions of Equipment & Foundation

C.G from machines bottom to Machine center	1.945	m
C.G of Shaft from machines bottom ($C.G_{shaft}$)	1.850	m
C.G from Pedestal Edge to Machine Center (X-direction) (E_{dx})	1.216	m
C.G from Pedestal Edge to Machine Center (Y-direction) (E_{dy})	5.346	m

6.0 CHECK FOR BLOWER FOUNDATION DESIGN

6.1 The Mass Ratio of Blower Foundation

(1) Foundation Weight

Pedestal (W_{cp})	864.000 kN
Footing (W_{cf})	360.000 kN

W_c = [(FL × FB × FH) + (PL × PB × PH)] × Unit Weight (Con'c)
= [(3.000 m × 10.000 m × 0.500 m) + (3.000 m × 10.000 m × 1.200 m)] × 24.000
= 1224.000 kN

(2) Machine Weight

W_m = Weight of Blower + Weight of Motor + Weight of Base Plate + Weight of Silencer
= 127.530 + 92.214 + 25.506 + 58.860
= 304.110 kN

(3) Mass Ratio

R = W_c / W_m > **3.0**
= 1224.000 / 304.110 > **3.0**
= 4.025 > **3.0**

OK!!

6.2 The Minumum Thickness of Concrete Foundation

- Thickness (= FH + PH) ≥ 0.6 + FB / 30 (m)

Item No.	Length (= FB) (m)	Thickness (= FH + PH) (m)	0.6 + FB / 30 (m) (m)	
551-B-1001/2001/3001/4001	10.000	1.700	0.933	**OK!!**

6.3 The Width of Concrete Foundation

- FL ≥ 1.5 × Vertical Distance from The Base to the Machine Centerline

Item No.	Length (= FL) (m)	1.5 × C.G (m)
51-B-1001/2001/3001/400	3.000	2.775

OK!!

6.4 Allowable Soil Bearing Pressure (Static)

$Q = \dfrac{W_t}{Area}$ [kN/m²]

= 1,528.110 / 30.000

= 50.937 kN/m²

Item No.	Q = 0.750 × Qa (kN/m²)	Q (kN/m²)
51-B-1001/2001/3001/400	150.000	50.937

OK!!

Where,

Q_a = 0.750 × Q_{as} [kN/m²]

= 0.750 × 200.000

= 150.000 kN/m²

Low-tuned Foundations

Q_{as} = Allowable soil capacity for static case.

= 200.000 kN/m²

W_t = W_c + W_m [kN]

= 1,224.000 + 304.110

= 1528.110 kN

M_x = 0.25 W_m × (FH + PH + G.I [kN-m] (JERES-Q-007 Section 9.3)

= 0.250 × 304.110 × (0.500 + 1.200 + 1.850)

= 269.898 kN-m

A = FB × FL [m²]

= 10.000 × 3.000

= 30.000 m²

6.5 Allowable Eccentricities for Concrete Foundations

W_t = W_c + W_m = 1528.110 kN

X' = [(304.110 × 1.216) + (864.000 × 1.500) + (360.000 × 1.500)] / 1,528.110 = 1.443 m

Eccentricity(X-dir) = (1.500 - 1.443) ×100 / 3.0(= 1.884 < 5.000 %

OK!!

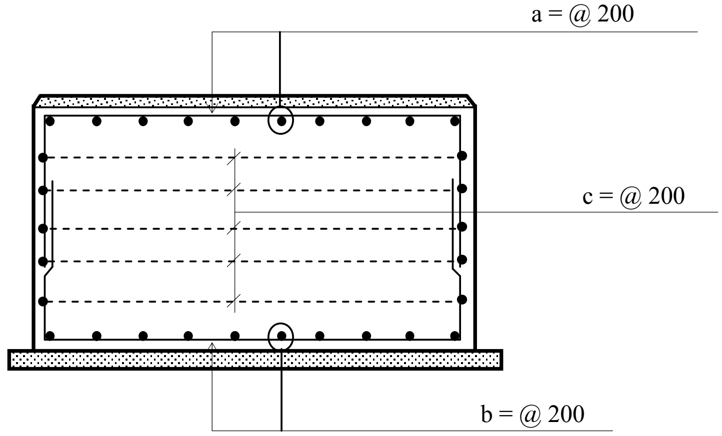
Y' = [(304.110 × 5.346) + (864.000 × 5.000) + (360.000 × 5.000)] / 1,528.110 = 5.069 m

Eccentricity(Y-dir) = (5.000 - 5.069) ×100 / 10.(= 0.689 < 5.000 %

OK!!

Z' = [(304.110 × 3.645) + (864.000 × 1.100) + (360.000 × 0.250)] / 1,528.110 = 1.406 m

6.6 Rebar Check



Item No.	Rebar Dia.			Req'd A_S = 0.0018 × b × (H / 2)		Use A_S
	a	b	c	Top (mm²)	Bottom (mm²)	(mm²)
551-B-1001/2001/3001/4001	D20	D20	D12	1350.000	1350.000	5024.000

OK!!

DYNAMIC ANALYSIS					
Design of Structures and Foundations for Vibrating Machines					
For Block Foundation (Centrifugal Machinery)					
Job Name:		Subject:			
Job Number:		Originator:	TYP	Checker:	

1.0 Machine Data

R.P.M	Blower	2242 rpm	Rotor Weight	Blower	=	0.600 ton
	Motor	1490 rpm		Motor	=	0.000 ton
Unbalanced Force	Blower =	0.405 ton		Motor	=	0.000 ton
Moment by U.F	Blower =	1.437 ton-m		Motor	=	0.000 ton-m

1.1 Centrifugal Force (F_o)

		For Blower			For Motor	
1) F_0	=	$(W_r / g) \times e \times w^2$		=	$(W_r / g) \times e \times w^2$	
	=	64,750.000 / 981.0 × 0.00588 × 234.78		=	0.000 / 981.0 × 0.00721 × 234.780²	
	=	21384.054	N	=	0.000	N
	=	21.384	kN	=	0.000	kN
Where,						
g	=	981	cm/sec²	=	981	cm/sec²
w	=	(RPM × 2 × π / 60)		=	(RPM × 2 × π / 60)	
	=	2,242 × 2 × π / 60		=	1,490 × 2 × π / 60	
	=	234.780	rad/sec	=	234.780	rad/sec
e	=	$\alpha \times \sqrt{(12000 / RPM)} \times 0.0025$	(cm)	=	$\alpha \times \sqrt{(12000 / RPM)} \times 0.0$	(cm)
(Maximum)	=	$\alpha \times \sqrt{(12000 / RPM)}$	(mil)	=	$\alpha \times \sqrt{(12000 / RPM)}$	(mil)
1.000 (mil)	=	1.000 × $\sqrt{(12000 / 2,242)}$		=	1.000 × $\sqrt{(12000 / 1,490)}$	
	=	2.314	(mil)	=	2.838	(mil)
	=	0.00588	cm	=	0.00721	cm

		Weight of Rotor of Blower			Weight of Rotor of Motor	
W_r	=	$(W_{c(rotor)} + W_s) \times$ 1.000		=	$(W_{m(rotor)}) \times$ 0.000	
	=	6.600	ton	=	0.000	ton
	=	64.750	kN	=	0.000	kN

W_c	=	Weight of C.A.BLOWER	=	13.000	ton	=	127.530	kN
W_m	=	Weight of Motor	=	9.400	ton	=	92.214	kN
W_b	=	Weight of Base Plate	=	2.600	ton	=	25.506	kN
W_s	=	Weight of Silencer	=	6.000	ton	=	58.860	kN

		For Blower			For Motor	
2) F_0	=	Factor × W × $(rpm / 1000)^{1.5}$		=	Factor × W × $(rpm / 1000)^{1.5}$	
	=	0.001 × 600.408 × (2242 / 1000)^1		=	0.001 × 0.000 × (1490 / 1000)^1.5	
	=	2.016	kN	=	0.000	kN
	=	0.205	ton	=	0.205	ton

Where,

Factor	=	0.001 for SI units	W	=	Total mass of the rotating
	=	0.1 for imperial units	FD	=	Steady state dynamic force

		For Blower			For Motor	
3) F_0	=	404.689	kg	=		kg
	=	0.405	ton	=		ton
	=	3.970	kN	=		kN

Apply for → 3) Fo

Vertical Dynamic Force	$F_{v(blower)}$	=	3.970	kN
	$F_{v(motor)}$	=	0.000	kN
	$F_{v(blower + motor)}$	=	3.970	kN
Horizontal Dynamic Force	$F_{h(blower)}$	=	3.970	kN
	$F_{h(motor)}$	=	0.000	kN
	$F_{h(blower + motor)}$	=	3.970	kN
Rocking Dynamic moment	$M_{r(blower)}$	=	[Verti. $Force_{(blower)}$]× (From Base to C.G) = $F_{V(blower)}$ × (h + C.G.	
			[3.970]× (1.700 + 1.850)	
			14.094	kN-m
	$M_{r(motor)}$	=	[Verti. $Force_{(motor)}$]× (From Base to C.G) = $F_{V(motor)}$ × (h + C.G.)	
			[0.000]× (1.700 + 1.850)	
			0.000	kN-m

1.2 Calculation of center of gravity of machine & fdn.

W_p	=	13.000 ton	=	127.530	kN				
W_m	=	9.400 ton	=	92.214	kN				
W_b	=	2.600 ton	=	25.506	kN				
W_w	=	6.000 ton	=	58.860	kN				
W_E	=	31.000 ton	=	304.110	kN	W_E / g	=	31.000	kN-sec²/m
W_{cp}	=	88.073 ton	=	864.000	kN	W_{cp} / g	=	88.073	kN-sec²/m
W_{cb}	=	36.697 ton	=	360.000	kN	W_{cb} / g	=	36.697	kN-sec²/m
W_F	=	124.771 ton	=	1224.000	kN	W_F / g	=	124.771	kN-sec²/m

W = 155.771 ton = 1528.110 kN W / g = 155.771 kN-sec²/m

I_o = I (Machine) + I (Foundation)

= $W_e k^2_M + \sum [W_F / 12 (a^2_i + b^2_i) + W_F k^2_{Fi}]$

= [31.000 × (1.700 + 1.945)²] + [(88.073) / 12 × (3.000² + 1.200²)]

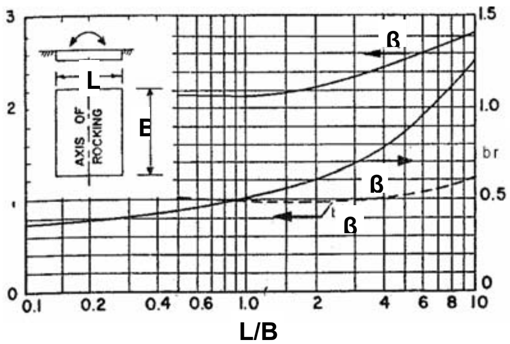
+ [(88.073) × (0.600 + 0.500)²] + [(36.697) / 12 × (3.000² + 0.500²)] + [(36.697) × (0.250)²]

= 625.640 kN-m²

Where,

W_E	=	Total Machine Weight
W_F	=	Foundation Weight
W	=	Total Static Load (Total Machine Weight + Foundation Weight)
g	=	981.000 cm/sec²
I_o	=	SUM [m_i ($A_i^2 + B_i^2$) / 12 + $m_i K_i^2$]

1.3 Coefficients B_v, B_h, and B_r for Rectangular Footings



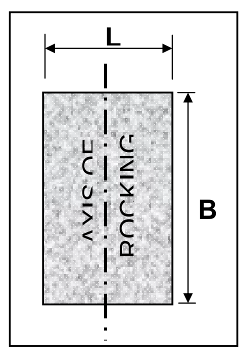
Coefficents β_v, β_h and β_r for rectangular footings

L	=	3.000	m
B	=	10.000	m

	L / B	Coefficients
Vertical (β_v)	**0.300**	**2.150**
Horizontal (β_h)	**0.300**	**1.017**
Roking (β_r)	**0.300**	**0.408**

2.0 Vertical Excitation Analysis

2.1 Spring Constant



(1) Equivalent radius (r_{0v}) for Rectangular Foundation

$$r_{ov} = \sqrt{(FB \times FL / \pi)}$$

$$= \sqrt{\frac{10.000 \times 3.000}{\pi}}$$

$$= 3.090 \text{ m}$$

(2) Embedment factor for Spring Constant

$$\eta_v = 1 + 0.6 \times (1 - \upsilon) \times (h / r_{ov})$$

$$= 1 + 0.6 \times (1 - 0.321) \times (1.500 / 3.090)$$

$$= 1.198$$

Effective Embedment height
= Height(h) - Ground Level(G.L.)
= 1.700 - 0.200
= 1.500

(3) Spring Constant Coefficient

$$\beta_v = 2.150$$

(4) Equivalent Spring Constant for Rectangular Foundation

$K_v = G / (1 - \upsilon) \times \beta_v \times \sqrt{FB \times FL} \times \eta_v$

$= \dfrac{82579.233}{1 - 0.321} \times 2.150 \times \sqrt{10.000 \times 3.000} \times 1.198$

$= 1715667.000$ kN/m

2.2 Damping Ratio

(1) Effect of Depth of Embedment on Damping Ratio

$\alpha_v = [1 + 1.9 (1 - \upsilon) \times h / r_{ov}] / \sqrt{\eta_v}$

$= [1 + 1.9 \times (1 - 0.321) \times 1.500 / 3.090] / \sqrt{1.198}$

$= 1.486$

(2) Mass Ratio

$B_v = (1 - \upsilon) / 4 \times W / (\gamma \times r_{ov}^3)$

$= \dfrac{(1 - 0.321)}{4} \times \dfrac{155.771}{1.733 \times 3.090^3}$

$= 0.517$

(3) Effective Damping Coefficient

This is not available for Vertical Mode

(4) Geometrical Damping Ratio

$D_v = 0.425 / \sqrt{B_v} \times \alpha_v$

$= 0.425 / \sqrt{0.517} \times 1.486$

$= 0.878$

(5) Internal Damping

$D_{vi} = 0.040$ Consider the Internal Damping

(6) Total Damping Ratio

$D_{vt} = D_v + D_{vi}$

$= 0.878 + 0.040$

$= 0.918$

2.3 Frequency Check

(1) Natural Frequency

$F_{nv} = 60 / (2 \times \pi) \times \sqrt{(K_v / m)}$

$= 60 / (2 \times \pi) \times \sqrt{(1{,}715{,}667.000 / 155.771)}$

$= 1002.178$ rpm

(2) Resonance Frequency (rpm)

$F_{rv} = F_{nv} \times \sqrt{[1 - (2 \times D_{vt}^2)]}$

$= 1{,}002.178 \times \sqrt{[1 - (2 \times 0.918^2)]}$

Not Apply

$\therefore\ 2 \times D_{vt}^2$

$= 2 \times 0.918^2$

$= 1.685 > 1.00$

RESONANCE NOT POSSIBLE!!! (There is no need to analysis Vibration)

(3) Frequency Ratio

(JERES-Q-007, Section 10.1)

When f / f(n) < 0.7, f / f(n) > 1.3, O.K!!!

For Blower

$r_{v(blower)} = \dfrac{f_{v(blower)}}{F_{nv}} = \dfrac{2242.000}{1002.178} = 2.237$

OK!!!

For Motor

$r_{v(motor)} = \dfrac{f_{v(motor)}}{F_{nv}} = \dfrac{1490.000}{1002.178} = 1.487$

OK!!!

(4) Magnification Factor

For Blower

$M_{v(blower)} = 1 / \sqrt{(1 - r_{v(blower)}^2)^2 + (2 D_{vt} \times r_{v(blower)})^2}$

$= 1 / \sqrt{(1 - 2.237^2)^2 + (2 \times 0.918 \times 2.237)^2} = 0.174$

$= 0.174 < 1.500$

OK!!!

For Motor

$M_{v(motor)} = 1 / \sqrt{(1 - r_{v(motor)}^2)^2 + (2 D_{vt} \times r_{v(motor)})^2}$

$= 1 / \sqrt{(1 - 1.487^2)^2 + (2 \times 0.918 \times 1.487)^2} = 0.335$

$= 0.335 < 1.500$

OK!!!

(5) Transmissibility Factor

For Blower

$T_{v(blower)} = M_{v(blower)} \times \sqrt{1 + (2\ D_{vt} \times r_v)^2}$

$= 0.174 \times \sqrt{1 + (2 \times 0.918 \times 2.237)^2}$

$= 0.736$

For Motor

$T_{v(motor)} = M_{v(motor)} \times \sqrt{1 + (2\ D_{vt} \times r_v)^2}$

$= 0.335 \times \sqrt{1 + (2 \times 0.918 \times 1.487)^2}$

$= 0.974$

(6) Vibration Amplitude

For Blower

(For the normal operating speed - 2242 rpm)

$V_{(blower)} = M_{v(blower)} \times F_{v(blower)} / K_v$

$= \dfrac{0.174 \times 3.970}{1715667.000}$

$= 4.026E-07$ m

(For the normal operating speed - 1490 rpm)

$V_{rocking(blower)}$

$= R_{(blower)} \times (FL / 2)$

$= 0.0000005 \times (3.000 / 2)$

$= 7.714E-07$ m

For Motor

(For the normal operating speed - 2242 rpm)

$V_{(motor)} = M_{v(motor)} \times F_{v(motor)} / K_v$

$= \dfrac{0.335 \times 0.000}{1715667.000}$

$= 0.000E+00$ m

(For the normal operating speed - 1490 rpm)

$V_{rocking(motor)}$

$= R_{(motor)} \times (FL / 2)$

$= 0.0000000 \times (3.000 / 2)$

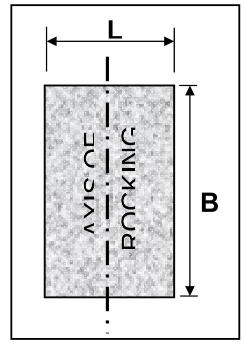
$= 0.000E+00$ m

Total Vertical Amplitude

$V_{total} = V_{(blower)} + V_{rocking(blower)} + V_{(motor)} + V_{rocking(motor)}$

$= 1.174E-06$ m

3.0 Horizontal Excitation Analysis



3.1 Spring Constant

(1) Equivalent radius (r_{0h}) for Rectangular Foundation

$$r_{oh} = \sqrt{(FB \times FL / \pi)}$$

$$= \sqrt{\frac{10.000 \times 3.000}{\pi}}$$

$$= 3.090 \quad m$$

(2) Emebedment factor for Spring Constant

Effective Embedment height
= Height(h) - Ground Level(G.L.)
= 1.700 - 0.200
= 1.500

$$\eta_h = 1 + 0.55 \times (2 - \upsilon) \times (h / r_{oh})$$

$$= 1 + 0.55 \times (2 - 0.321) \times (1.500 / 3.090)$$

$$= 1.448$$

(3) Spring Constant Coefficient

$$\beta_h = 1.017$$

(4) Equiavelent Spring Constant for Rectangular Foundation

$$K_h = 2 \times (1 + \upsilon) \times G \times \beta_h \times \sqrt{FB \times FL} \times \eta_h$$

$$= 2 \times (1 + 0.321) \times 82{,}579.233 \times 1.017 \times \sqrt{10.000 \times 3.000} \times 1.448$$

$$= 1760211.961 \quad kN/m$$

3.2 Damping Ratio

(1) Effect of Depth of Embedment on Damping Ratio

$$\alpha_h = [1 + 1.9 (2 - \upsilon) \times h / r_{oh}] / \sqrt{\eta_h}$$

$$= [1 + 1.9 \times (2 - 0.321) \times 1.500 / 3.090] / \sqrt{1.448}$$

$$= 2.118$$

(2) Mass Raito

$$B_h = (7 - 8\upsilon) / [32 \times (1 - \upsilon)] \times W / (\gamma \times r_{oh}^3)$$

$$= \frac{(7 - 8 \times 0.321)}{32 \times (1 - 0.321)} \times \frac{155.771}{1.733 \times 3.090^3}$$

$$= 0.621$$

(3) Effective Damping Coefficient

This is not avilable for Horizontal Mode

(4) Geometrical Damping Ratio

$D_h = 0.288 / \sqrt{B_h \times \alpha_h}$

$= 0.288 / \sqrt{0.621 \times 2.118}$

$= 0.774$

(5) Internal Damping

$D_{hi} = 0.040$ Consider the Internal Damping

(6) Total Damping Ratio

$D_{ht} = D_h + D_{hi}$

$= 0.774 + 0.040$

$= 0.814$

3.3 Frequency Check

(1) Natural Frequency

$F_{nh} = 60 / (2 \times \pi) \times \sqrt{(K_h / m)}$

$= 60 / (2 \times \pi) \times \sqrt{1{,}760{,}211.961 / 155.771}$

$= 1015.000$ rpm

(2) Resonance Frequency (rpm)

$F_{rh} = F_{nh} \times \sqrt{[1 - (2 \times D_{ht}^2)]}$

$= 1{,}015.000 \times \sqrt{[1 - (2 \times 0.814^2)]}$

Not Apply

$\therefore 2 \times D_{ht}^2$

$= 2 \times 0.814^2$

$= 1.325 > 1.0$

RESONANCE NOT POSSIBLE!!! (There is no need to analysis Vibration)

(3) Frequency Ratio

(JERES-Q-007, Section 10.1)
When f / f(n) < 0.7, f / f(n) > 1.3, O.K!!!

For Blower

$r_{h(blower)} = \dfrac{f_{h(blower)}}{F_{nh}} = \dfrac{2242.000}{1015.000} = 2.209$

OK!!!

For Motor

$r_{h(motor)} = \dfrac{f_{h(motor)}}{F_{nh}} = \dfrac{1490.000}{1015.000} = 1.468$

OK!!!

(4) Magnification Factor

For Blower

$M_{h(blower)} = 1 / \sqrt{(1 - r_{h(blower)}^2)^2 + (2 D_{ht} \times r_{h(blower)})^2}$

$= 1 / \sqrt{(1 - 2.209^2)^2 + (2 \times 0.814 \times 2.209)^2} = 0.189$

$= 0.189 < 1.50$

OK!!!

For Motor

$M_{h(motor)} = 1 / \sqrt{(1 - r_{h(motor)}^2)^2 + (2 D_{ht} \times r_{h(motor)})^2}$

$= 1 / \sqrt{(1 - 1.468^2)^2 + (2 \times \quad \times 1.468)^2} = 0.377$

$= 0.377 < 1.50$

OK!!!

(5) Transmissibility Factor

For Blower

$T_{h(blower)} = M_{h(blower)} \times \sqrt{1 + (2 D_{ht} \times r_{h(blower)})^2}$

$= 0.189 \times \sqrt{1 + (2 \times 0.814 \times 2.209)^2}$

$= 0.705$

For Motor

$T_{h(motor)} = M_{h(motor)} \times \sqrt{1 + (2 D_{ht} \times r_{h(motor)})^2}$

$= 0.377 \times \sqrt{1 + (2 \times 0.814 \times 1.468)^2}$

$= 0.977$

(6) Vibration Amplitude

For Blower

(For the normal operating speed - 2242 rpm)

$H_{(blower)} = M_{h(blower)} \times F_{h(blower)} / K_h$

$= \dfrac{0.189 \times 3.970}{1760211.961}$

$= 4.263E-07$ m

(For the normal operating speed - 1490 rpm)

$H_{rocking(blower)}$

$= R_{(blower)} \times (h + C.G.)$

$= 0.0000005 \times (1.700 + 1.850)$

$= 1.826E-06$ m

For Motor

(For the normal operating speed - 2242 rpm)

$H_{(motor)} = M_{h(motor)} \times F_{h(motor)} / K_h$

$= \dfrac{0.377 \times 0.000}{1760211.961}$

$= 0.000E+00$ m

(For the normal operating speed - 1490 rpm)

$H_{rocking(motor)}$

$= R_{(motor)} \times (h + C.G.)$

$= 0.0000000 \times (1.700 + 1.850)$

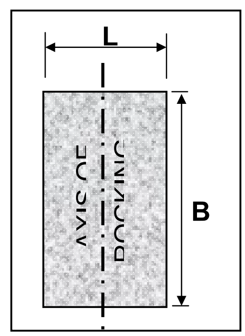
$= 0.000E+00$ m

Total Horizontal Amplitude

$H_{total} = H_{(blower)} + H_{rocking(blower)} + H_{(motor)} + H_{rocking(motor)}$

$= 2.252E-06$ m

4.0 Rocking Excitation Analysis



4.1 Spring Constant

(1) Equivalent (r_{0r}) for Rectangular Foundation

$r_{or} = [(FB \times FL^3) / (3 \times \pi)]$^(¼)

$= \left[\dfrac{[(10.000 \times 3.000^3)]}{3 \times \pi} \right]$^(¼)

$= 2.314$ m

(2) Embedment factor for Spring Constant

$\eta_r = 1 + 1.2 \times (1 - \upsilon) \times (h / r_{or}) + 0.2 \times (2 - \upsilon) \times (h / r_{or})^3$

$= 1 + 1.2 \times (1 - 0.321) \times (1.500 / 2.314) + 0.2 \times (2 - 0.321) \times (1.500 / 2.314)^3$

$= 1.620$

Effective Embedment height
= Height(h) - Ground Level(G.L.)
= 1.700 - 0.200
= 1.500

(3) Spring Constant Coefficient

β_r = 0.408

(4) Equivalent Spring Constant for Rectangular Foundation

$K_r = G / (1 - \upsilon) \times \beta_r \times FB \times FL^2 \times \eta_r$

$= \dfrac{82579.233}{(1 - 0.321)} \times 0.408 \times 10.000 \times 3.000^2 \times 1.620$

$= 7234608.000$ kN/m

4.2 Damping Ratio

(1) Effect of Depth of Embedment on Damping Ratio

$\alpha_r = \dfrac{1 + 0.7 \times (1 - \upsilon) \times (h / r_{or}) + 0.6 \times (2 - \upsilon) \times (h / r_{or})^3}{\sqrt{\eta_r}}$

$= \dfrac{1 + 0.7 \times (1 - 0.321) \times (1.500 / 2.314) + 0.6 \times (2 - 0.321) \times (1.500 / 2.314)^3}{\sqrt{1.620}}$

$= 1.244$

(2) Mass Ratio

$B_r = 3 \times (1 - \upsilon) / 8 \times I_o / (\rho \times r_{or}^5)$

$= \dfrac{3 \times (1 - 0.321)}{8} \times \dfrac{625.640}{1.733 \times 66.277}$

$= 1.387$

(3) Effective Damping Coefficient

n_r = 1.251

(4) Geometrical Damping Ratio

$D_r = 0.15 \times \alpha_r / [(1 + n_r \times B_r) \times \sqrt{(n_r \times B_r)}]$

$= \dfrac{0.15 \times 1.244}{(1 + 1.251 \times 1.387) \times \sqrt{(1.251 \times 1.387)}}$

$= 0.052$

(5) Internal Damping

D_{ri} = 0.040

(6) Total Damping Ratio

$D_{rt} = D_r + D_{ri}$
$= 0.052 + 0.040$
$= 0.092$

4.3 Frequency Check

(1) Natural Frequency

$F_{nr} = 60 / (2 \times \pi) \times \sqrt{(K_r / I_0)}$
$= 60 / (2 \times \pi) \times \sqrt{[7{,}234{,}608.000 / 625.640]}$
$= 1027.000$ rpm

(2) Resonance Frequency

$F_{rr} = F_{nr} \times \sqrt{[1 - (2 \times D_{rt}^2)]}$
$= 1{,}027.000 \times \sqrt{[1 - (2 \times 0.092^2)]}$
$= 1018.270$ rpm

$\therefore\ 2 \times D_{rt}^2$
$= 2 \times 0.092^2$
$= 0.017 < 1.00$

RESONANCE COULD BE POSSIBLE!!! (It is necessary to analysis Vibration)

(3) Frequency Ratio

(JERES-Q-007, Section 10.1)
When f / f(n) < 0.7, f / f(n) > 1.3, O.K!!!

For Blower

$r_{r(blower)} = \dfrac{f_{r(blower)}}{F_{nr}}$
$= \dfrac{2242.000}{1027.000}$
$= 2.183$

OK!!!

For Motor

$r_{r(motor)} = \dfrac{f_{r(motor)}}{F_{nr}}$
$= \dfrac{1490.000}{1027.000}$
$= 1.451$

OK!!!

(4) Magnification Factor

For Blower

$M_{r(blower)} = 1 / \sqrt{(1 - r_{r(blower)}{}^2)^2 + (2\,D_{rt} \times r_{r(blower)})^2}$

$= 1 / \sqrt{(1 - 2.183^2)^2 + (2 \times 0.092 \times 2.183)^2} = 0.264$

$= 0.264 < 1.500$ **OK!!!**

For Motor

$M_{r(motor)} = 1 / \sqrt{(1 - r_{r(motor)}{}^2)^2 + (2\,D_{rt} \times r_{r(motor)})^2}$

$= 1 / \sqrt{(1 - 1.451^2)^2 + (2 \times 0.092 \times 1.451)^2} = 0.880$

$= 0.880 < 1.500$ **OK!!!**

(5) Transmissibility Factor

For Blower

$T_{r(blower)} = M_{r(blower)} \times \sqrt{1 + (2\,D_{rt} \times r_{r(blower)})^2}$

$= 0.264 \times \sqrt{1 + (2 \times 0.092 \times 2.183)^2}$

$= 0.285$

For Motor

$T_{r(motor)} = M_{r(motor)} \times \sqrt{1 + (2\,D_{rt} \times r_{r(motor)})^2}$

$= 0.880 \times \sqrt{1 + (2 \times 0.092 \times 1.451)^2}$

$= 0.911$

(6) Vibration Amplitude

Moment Arm	=	(h + C.G.)
	=	(1.700 + 1.850)
	=	3.550

For Blower

$R_{(blower)} = M_{r(blower)} \times F_{r(blower)} / K_r$

$= \dfrac{0.264 \times (3.970 \times 3.550)}{7234608.000}$

$= 5.143E-07$ rad

For Motor

$R_{(motor)} = M_{r(motor)} \times F_{r(motor)} / K_r$

$= \dfrac{0.880 \times (0.000 \times 3.550)}{7234608.000}$

$= 0.000E+00$ rad

5.0 Amplitude Check

5.1 Total Amplitude

(1) Vertical Amplitude

V_{total} = Vertical Vibration Amplitude + Rocking Vibration Amplitude × (FL / 2)
= 1.174E-06 m
= 0.00012 cm
= 0.000046 in

(2) Horizontal Amplitude

H_{total} = Horizontal Vibration Amplitude + Rocking Vibration Amplitude × (h + C.G.)
= 2.252E-06 m
= 0.00023 cm
= 0.000089 in

(3) Maximum Velocity

Where,
Velocity = 0.120 in/sec
= 0.003 m/sec
"Machine" is the imposed frequency of the rotating equipment.
RPM = 2242 (For Pump)
= 1490 (For Motor)

Blower	Motor
$= \dfrac{\text{Velocity}}{2 \times \pi \times \text{Machine(rpm)}}$	$= \dfrac{\text{Velocity}}{2 \times \pi \times \text{Machine(rpm)}}$
$= \dfrac{0.003\ \text{m/sec}}{2 \times \pi \times 37.367}$	$= \dfrac{0.003\ \text{m/sec}}{2 \times \pi \times 24.833}$
= 0.0013 cm	= 0.0020 cm
= 0.00051 in	= 0.00077 in

∴ $\text{Max}(V_{total}, H_{total}) < A_t$ **OK!!!**

5.2 Vibration Velocity

Vmax = $2 \times \pi \times f \times (\text{Amplitude})$

(1) Vertical Velocity

For Blower

$V_{v(blower)} = [V_{(blower)} + V_{rocking(blower)}] \times [2 \times \pi \times (F_{v(blower)} / 60)]$

$= [0.00000040 + 0.00000077] \times [2 \times \pi \times (2{,}242 / 60)]$

$=$ 2.756E-04 m/s **OK!!!**

For Motor

$V_{v(motor)} = [V_{(motor)} + V_{rocking(motor)}] \times [2 \times \pi \times (F_{v(motor)} / 60)]$

$= [0.00000000 + 0.00000000] \times [2 \times \pi \times (1{,}490 / 60)]$

$=$ 0.000E+00 m/s **OK!!!**

$V_{v(total)} = \sqrt{V_{v(blower)}^2 + V_{v(motor)}^2}$

$= \sqrt{0.00027565^2 + 0.00000000^2}$

$=$ 2.756E-04 m/s **OK!!!**

(2) Horizontal Velocity

For Blower

$V_{h(blower)} = [H_{(blower)} + H_{rocking(blower)}] \times [2 \times \pi \times (F_{h(blower)} / 60)]$

$= [0.00000043 + 0.00000183] \times [2 \times \pi \times (2{,}242 / 60)]$

$=$ 5.287E-04 m/s **OK!!!**

For Motor

$V_{h(motor)} = [H_{(motor)} + H_{rocking(motor)}] \times [2 \times \pi \times (F_{h(motor)} / 60)]$

$= [0.00000000 + 0.00000000] \times [2 \times \pi \times (1{,}490 / 60)]$

$=$ 0.000E+00 m/s **OK!!!**

$V_{h(total)} = \sqrt{V_{v(blower)}^2 + V_{v(motor)}^2}$

$= \sqrt{0.00052873^2 + 0.00000000^2}$

$=$ 5.287E-04 m/s **OK!!!**

6.0 Soil Bearing Check (Static + Dynamic)

6.1 Transmissibility Force

(1) Transmissibility Vertical Force

$P_{v(blower)}$ = $[T_{v(blower)} \times F_{v(blower)}]$
= $[0.736 \times 3.970]$
= 2.922 kN

$P_{v(blower)}$ = $[T_{v(motor)} \times F_{v(motor)}]$
= $[0.974 \times 0.000]$
= 0.000 kN

$P_{v(total)}$ = $[T_{v(blower)} \times F_{v(blower)}] + [T_{v(motor)} \times F_{v(motor)}]$
= $[0.736 \times 3.970] + [0.974 \times 0.000]$
= 2.922 kN

(2) Transmissibility Horizontal Force

$P_{h(blower)}$ = $[T_{h(blower)} \times F_{h(blower)}]$
= $[0.705 \times 3.970]$
= 2.801 kN

$P_{h(motor)}$ = $[T_{h(motor)} \times F_{h(motor)}]$
= $[0.977 \times 0.000]$
= 0.000 kN

$P_{h(total)}$ = $[T_{h(blower)} \times F_{h(blower)}] + [T_{h(motor)} \times F_{h(motor)}]$
= $[0.705 \times 3.970] + [0.977 \times 0.000]$
= 2.801 kN

(3) Transmissibility Moment

P_r = $[T_{r(blower)} \times M_{r(blower)}] + [T_{r(motor)} \times M_{r(motor)}]$
= $[0.285 \times 14.094] + [0.911 \times 0.000]$
= 4.010 kN-m

6.2 Total Transmissibility Moment

P_{tr} = $P_r + [P_{v(total)} \times (P_L / 2 - E_{dx})] + [P_{h(total)} \times (C.G_{shaft} + h)]$
= $4.010 + [2.922 \times (3.000 / 2 - 1.216)] + [2.801 \times 3.550]$
= 14.782 kN-m

6.3 Soil Beraing Pressure (Static + Dynamic, Static)

(1) Fatigue Factor (ξ) 1.500 [Foundations and Supporting Structures for Heavy Machinery]
Design of Structures and Foundations for Vibrating N (8)

(2) $Q_{all} = 0.750 \times Qa = 150.000$ kN/m²

(3) $P_{sta+dyn}$

$$= \frac{W_t}{Area} \pm \frac{\xi \times P_{v(total)}}{Area} \pm \frac{\xi \times P_{h(total)} \times (C.G_{shaft} + h) \times 6}{B \times L^2} \pm \frac{\xi \times P_r \times 6}{B \times L^2}$$

$$= \frac{1528.110}{3.000 \times 10.000} \pm \frac{1.500 \times 2.922}{3.000 \times 10.000} \pm \frac{1.500 \times 2.801 \times (3.550) \times 3.000}{10.000 \times 3.000^2} \pm \frac{1.500 \times 4.010 \times 6}{10.000 \times 3.000^2}$$

= 51.981 or 49.893 kN/m²

= 5.299 or 5.086 ton/m²

$$= \frac{W_t}{Area} \pm \frac{\xi \times P_{v(total)}}{Area} \pm \frac{\xi \times P_{tr} \times 6}{B \times L^2}$$

$$= \frac{1528.110}{3.000 \times 10.000} \pm \frac{1.500 \times 2.922}{3.000 \times 10.000} \pm \frac{1.500 \times 14.782 \times 6}{10.000 \times 3.000^2}$$

= 52.561 or 49.313 kN/m²

= 5.358 or 5.027 ton/m²

Q_{all} = 150.000 kN/m²

$P_{sta+dyn}$ = 52.561 kN/m²

$\therefore$ Q_{all} > P_{dyn} **OK!!!**