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6.1 The Mass Ratio of Blower Foundation  
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6.4 Allowable Soil Bearing Pressure  
6.5 Allowable Eccentricities for Concrete Foundation  
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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 : SATORP (Saudi Aramco Total Refining and Petrochemical Company)
Company : SATORP (Saudi Aramco Total Refining and Petrochemical Company)
Contractor : 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 Reinforcement 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/m³

- 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 equipment Manufacturer, cementitious 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 $\geq$ 500 (373 kW)
   - RPM of Equipment $\geq$ 3600 RPM
   - Total weight of Equipment $\geq$ 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

1) Horsepower ≥ 500 The foundation shall be designed for the expected dynamic forces using dynamic analysis procedures
2) Horsepower < 500 The foundation weight shall be 3 times the total machinery weight

<table>
<thead>
<tr>
<th>UNIT</th>
<th>ITEMS</th>
<th>FDN. TYPE</th>
<th>MACHINE TYPE</th>
<th>RATING</th>
<th>POWER</th>
<th>DYNAMIC ANALYSIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNIT 551</td>
<td>51-B-1001/2001/3001/400</td>
<td>Rigid Block</td>
<td>Rotating</td>
<td>1167 kW</td>
<td>1587 HP</td>
<td>YES</td>
</tr>
</tbody>
</table>

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

- \( 0.60 + \frac{L}{30} \) (meters)

Where, \( L = \) Length of foundation parallel to the machine bearing axis in meters
4.2.4 The width of the foundation

- \( B \geq 1.5 \times \text{Vertical distance from the base to the machine centerline} \)

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 mm 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 \( ( < 0.05 \times B) \)

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 \( ( < 0.05 \times L) \)

4.2.7 Allowable Soil Bearing Pressures

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

2) For Low-tuned foundation: 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 frequency (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 machine, \(f\), 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
5.2 The Soil and Foundation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allowable Soil Bearing</td>
<td>200.000</td>
<td>kN/m²</td>
</tr>
<tr>
<td>Shear Modulus, G</td>
<td>82579.233</td>
<td>kN/m²</td>
</tr>
<tr>
<td>Soil Internal damping Ratio</td>
<td>0.040</td>
<td></td>
</tr>
<tr>
<td>Poisson's Ratio, ν</td>
<td>0.321</td>
<td></td>
</tr>
<tr>
<td>Unit Weight (Soil)</td>
<td>17.000</td>
<td>kN/m³</td>
</tr>
<tr>
<td>Unit Weight (Con'c)</td>
<td>24.000</td>
<td>kN/m³</td>
</tr>
</tbody>
</table>

5.3 Foundation Data

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

5.4 Equipment Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of C.A.BLOWER (Wc)</td>
<td>13.000 ton</td>
<td>127.530 kN</td>
</tr>
<tr>
<td>Weight of Motor (Wm)</td>
<td>9.400 ton</td>
<td>92.214 kN</td>
</tr>
<tr>
<td>Weight of Base Plate (Wb)</td>
<td>2.600 ton</td>
<td>25.506 kN</td>
</tr>
<tr>
<td>Weight of Silencer (Ws)</td>
<td>6.000 ton</td>
<td>58.860 kN</td>
</tr>
<tr>
<td>Total Weight (Wt)</td>
<td>31.000 ton</td>
<td>304.110 kN</td>
</tr>
</tbody>
</table>

5.5 Machine Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>R.P.M</td>
<td>C.A.BLOWER - 2242 rpm</td>
</tr>
<tr>
<td>Rotor Weight</td>
<td>C.A.BLOWER - 3.670 ton</td>
</tr>
<tr>
<td>Unbalanced Force</td>
<td>C.A.BLOWER - 0.072 ton</td>
</tr>
</tbody>
</table>

(1) For values for Equipment
(2) For dimensions of Equipment & Foundation

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C.G from machines bottom to Machine center</td>
<td>1.945 m</td>
</tr>
<tr>
<td>C.G of Shaft from machines bottom (C.G_{shaft})</td>
<td>1.850 m</td>
</tr>
<tr>
<td>C.G from Pedestal Edge to Machine Center (X-direction) (E_{dx})</td>
<td>1.216 m</td>
</tr>
<tr>
<td>C.G from Pedestal Edge to Machine Center (Y-direction) (E_{dy})</td>
<td>5.346 m</td>
</tr>
</tbody>
</table>

6.0 CHECK FOR BLOWER FOUNDATION DESIGN

6.1 The Mass Ratio of Blower Foundation

(1) Foundation Weight

\[ W_c = [(FL \times FB \times FH) + (PL \times PB \times PH)] \times \text{Unit Weight (Con'c)} \]
\[ = [(3.000 \times 10.000 \times 0.500) + (3.000 \times 10.000 \times 1.200)] \times 24.000 \]
\[ = 1224.000 \text{ kN} \]

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

(2) Machine Weight

\[ W_m = \text{Weight of Blower} + \text{Weight of Motor} + \text{Weight of Base Plate} + \text{Weight of Silencer} \]
\[ = 127.530 + 92.214 + 25.506 + 58.860 \]
\[ = 304.110 \text{ kN} \]

(3) Mass Ratio

\[ R = \frac{W_c}{W_m} > 3.0 \]
\[ = \frac{1224.000}{304.110} > 3.0 \]
\[ = 4.025 > 3.0 \]

OK!!

6.2 The Minimum Thickness of Concrete Foundation

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

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Length (= FB) (m)</th>
<th>Thickness (= FH + PH) (m)</th>
<th>0.6 + FB / 30 (m) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>551-B-1001/2001/3001/4001</td>
<td>10.000</td>
<td>1.700</td>
<td>0.933</td>
</tr>
</tbody>
</table>

OK!!
6.3 The Width of Concrete Foundation

- $FL \geq 1.5 \times \text{Vertical Distance from The Base to the Machine Centerline}$

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Length ($= FL$) ($m$)</th>
<th>$1.5 \times C.G$ ($m$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>51-B-1001/2001/3001/400</td>
<td>3.000</td>
<td>2.775</td>
</tr>
</tbody>
</table>

6.4 Allowable Soil Bearing Pressure (Static)

$$Q = \frac{W_t}{\text{Area}} \ [\text{kN/m}^2]$$

$$= \frac{1,528.110}{30.000}$$

$$= 50.937 \ [\text{kN/m}^2]$$

Where,

- $Q_a = 0.750 \times Q_a \ [\text{kN/m}^2]$  
  $$= 0.750 \times 200.000$$
  $$= 150.000 \ [\text{kN/m}^2]$$

- $Q_{as} = \text{Allowable soil capacity for static case.}$  
  $$= 200.000 \ [\text{kN/m}^2]$$

- $W_t = W_c + W_m \ [\text{kN}]$  
  $$= 1,224.000 + 304.110$$
  $$= 1,528.110 \ [\text{kN}]$$

- $M_x = 0.25 \times (FH + PH + G.I) \ [\text{kN-m}]$  
  $$= 0.25 \times 304.110 \times (0.500 + 1.200 + 1.850)$$
  $$= 269.898 \ [\text{kN-m}]$$

- $A = FB \times FL \ [\text{m}^2]$  
  $$= 10.000 \times 3.000$$
  $$= 30.000 \ [\text{m}^2]$$

---

OK!!

Low-tuned Foundations
6.5 Allowable Eccentricities for Concrete Foundations

\[ W_t = W_c + W_m = 1528.110 \text{ kN} \]

\[ X' = \frac{(304.110 \times 1.216) + (864.000 \times 1.500) + (360.000 \times 1.500)}{1528.110} = 1.443 \text{ m} \]

Eccentricity(X-dir) = (1.500 - 1.443) × 100 / 3.0 = 1.884 < 5.000 %  \[ \text{OK!!} \]

\[ Y' = \frac{(304.110 \times 5.346) + (864.000 \times 5.000) + (360.000 \times 5.000)}{1528.110} = 5.069 \text{ m} \]

Eccentricity(Y-dir) = (5.000 - 5.069) × 100 / 10.0 = 0.689 < 5.000 %  \[ \text{OK!!} \]

\[ Z' = \frac{(304.110 \times 3.645) + (864.000 \times 1.100) + (360.000 \times 0.250)}{1528.110} = 1.406 \text{ m} \]

6.6 Rebar Check

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Rebar Dia.</th>
<th>Req'd ( A_s ) = 0.0018 \times b \times (H / 2)</th>
<th>Use ( A_s ) (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>551-B-1001/2001/3001/4001</td>
<td>D20 D20 D12</td>
<td>1350.000 1350.000</td>
<td>5024.000</td>
</tr>
</tbody>
</table>

\[ a = @ 200 \]
\[ b = @ 200 \]
\[ c = @ 200 \]
## Dynamic Analysis

### Design of Structures and Foundations for Vibrating Machines

#### For Block Foundation (Centrifugal Machinery)

### 1.0 Machine Data

<table>
<thead>
<tr>
<th>R.P.M</th>
<th>Blower</th>
<th>Motor</th>
<th>Rotor Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blower</td>
<td>2242 rpm</td>
<td>1490 rpm</td>
<td><strong>Blower = 0.600 ton</strong></td>
</tr>
<tr>
<td>Motor</td>
<td>1490 rpm</td>
<td></td>
<td><strong>Motor = 0.000 ton</strong></td>
</tr>
</tbody>
</table>

**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 ($F_0$)

**1) $F_0$**

For Blower:

\[
F_0 = \left(\frac{W_r}{g}\right) \times e \times w^2
\]

For Motor:

\[
F_0 = \left(\frac{W_r}{g}\right) \times e \times w^2
\]

Where,

\[
g = 981 \text{ cm/sec}^2
\]

\[
w = \left(\text{RPM} \times 2 \times \frac{\pi}{60}\right)
\]

\[
e = \alpha \times \left(\frac{12000}{\text{RPM}}\right) \times 0.0025 \text{ cm}
\]

Where, $\alpha = 1.000$ (mil)

\[
1.000 \text{ (mil)}
\]

\[
W_r = \left(\text{W}_{c, \text{rotor}} + W_s\right) \times 1.000
\]

\[
6.600 \text{ ton}
\]

\[
64.750 \text{ kN}
\]

\[
W_c = \text{Weight of C.A.BLOWER} = 13.000 \text{ ton} = 127.530 \text{ kN}
\]

\[
W_m = \text{Weight of Motor} = 9.400 \text{ ton} = 92.214 \text{ kN}
\]

\[
W_b = \text{Weight of Base Plate} = 2.600 \text{ ton} = 25.506 \text{ kN}
\]

\[
W_s = \text{Weight of Silencer} = 6.000 \text{ ton} = 58.860 \text{ kN}
\]

**2) $F_0$**

For Blower:

\[
F_0 = \text{Factor} \times W \times \left(\frac{\text{rpm}}{1000}\right)^{1.5}
\]

\[
= 0.001 \times 600.408 \times \left(2242 / 1000\right)^{1.5}
\]

\[
= 2.016 \text{ kN}
\]

\[
= 0.205 \text{ ton}
\]

For Motor:

\[
F_0 = \text{Factor} \times W \times \left(\frac{\text{rpm}}{1000}\right)^{1.5}
\]

\[
= 0.001 \times 0.000 \times \left(1490 / 1000\right)^{1.5}
\]

\[
= 0.000 \text{ kN}
\]

\[
= 0.205 \text{ ton}
\]
Where,

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

### 3) \( F_0 \)

<table>
<thead>
<tr>
<th>For Blower</th>
<th>For Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_{b} ) = 404.689 kg</td>
<td>kg</td>
</tr>
<tr>
<td>= 0.405 ton</td>
<td>ton</td>
</tr>
<tr>
<td>= 3.970 kN</td>
<td>kN</td>
</tr>
</tbody>
</table>

Vertical Dynamic Force

- \( F_{b} \) = 3.970 kN
- \( F_{m} \) = 0.000 kN
- \( F_{b} \) = 3.970 kN

Horizontal Dynamic Force

- \( F_{h} \) = 3.970 kN
- \( F_{h} \) = 0.000 kN
- \( F_{h} \) = 3.970 kN

Rocking Dynamic moment

- \( M_r(blower) \) = \([\text{Verti. Force}_{b}(\text{From Base to C.G})] \times (h + \text{C.G.})\)
  = \([3.970] \times (1.700 + 1.850)\)
  = 14.094 kN-m

- \( M_r(motor) \) = \([\text{Verti. Force}_{m}(\text{From Base to C.G})] \times (h + \text{C.G.})\)
  = \([0.000] \times (1.700 + 1.850)\)
  = 0.000 kN-m

### 1.2 Calculation of center of gravity of machine & fdn.

<table>
<thead>
<tr>
<th></th>
<th>( W_p )</th>
<th>( W_m )</th>
<th>( W_b )</th>
<th>( W_w )</th>
<th>( W_E )</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.000 ton</td>
<td>9.400 ton</td>
<td>2.600 ton</td>
<td>6.000 ton</td>
<td>31.000 ton</td>
<td>127.530 kN</td>
</tr>
<tr>
<td>36.697 ton</td>
<td>36.697 ton</td>
<td>36.697 ton</td>
<td>36.697 ton</td>
<td>36.697 ton</td>
<td>127.530 kN</td>
</tr>
<tr>
<td>1224.000 kN</td>
<td>864.000 kN</td>
<td>360.000 kN</td>
<td>604.000 kN</td>
<td>1224.000 kN</td>
<td>1224.000 kN</td>
</tr>
</tbody>
</table>

- \( W \) = 155.771 ton = 1528.110 kN
- \( W \) = 1528.110 kN
- \( W \) = 155.771 kN-sec²/m

- \( I_o \) = I (Machine) + I (Foundation)
- \( I_o \) = \( W_k \) + \( W_k \) + \( W_k \) = \( \frac{W}{g} \)
- \( I_o \) = \( 625.640 \) kN-m²
Where,

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

1.3 Coefficients \( B_v, B_h, \) and \( B_r \) for Rectangular Footings

<table>
<thead>
<tr>
<th>( L/B )</th>
<th>Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical ( (\beta_v) )</td>
<td>0.300</td>
</tr>
<tr>
<td>Horizontal ( (\beta_h) )</td>
<td>0.300</td>
</tr>
<tr>
<td>Roking ( (\beta_r) )</td>
<td>0.300</td>
</tr>
</tbody>
</table>

2.0 Vertical Excitation Analysis

2.1 Spring Constant

(1) Equivalent radius \( (r_{ov}) \) for Rectangular Foundation

\[ r_{ov} = \sqrt{\frac{F_B \times F_L}{\pi}} \]
\[ = \sqrt{\frac{10,000 \times 3,000}{\pi}} \]
\[ = 3.090 \text{ m} \]

(2) Embedment factor for Spring Constant

\[ \eta_v = 1 + 0.6 \times (1 - \nu) \times \left( \frac{h}{r_{ov}} \right) \]
\[ = 1 + 0.6 \times (1 - 0.321) \times \left( \frac{1.500}{3.090} \right) \]
\[ = 1.198 \]

(3) Spring Constant Coefficient

\[ \beta_v = 2.150 \]
(4) Equivalent Spring Constant for Rectangular Foundation

\[ K_v = \frac{G}{(1 - \nu)} \times \beta_v \times \sqrt{FB \times FL \times \eta_v} \]
\[ = \frac{82579.233}{1 - 0.321} \times 2.150 \times \sqrt{10.000 \times 3.000 \times 1.198} \]
\[ = 1715667.000 \text{ kN/m} \]

2.2 Damping Ratio

(1) Effect of Depth of Embedment on Damping Ratio

\[ \alpha_v = \frac{[1 + 1.9 (1 - \nu) h / \eta_v]}{\eta_v} \]
\[ = \frac{[1 + 1.9 \times (1 - 0.321) \times 1.500 / 3.090]}{1.198} \]
\[ = 1.486 \]

(2) Mass Ratio

\[ B_v = \frac{(1 - \nu) / 4 \times W / (\gamma \times \eta_v^2)}{1 - 0.321} \times \frac{155.771}{1.733 \times 3.090^3} \]
\[ = 0.517 \]

(3) Effective Damping Coefficient

This is not available for Vertical Mode

(4) Geometrical Damping Ratio

\[ D_v = \frac{0.425 / B_v \times \alpha_v}{\eta_v} \]
\[ = \frac{0.425 / 0.517 \times 1.486}{0.878} \]
\[ = 0.878 \]

(5) Internal Damping

\[ D_{vi} = 0.040 \text{ Consider the Internal Damping} \]

(6) Total Damping Ratio

\[ D_{vt} = D_v + D_{vi} \]
\[ = 0.878 + 0.040 \]
\[ = 0.918 \]
2.3 Frequency Check

(1) Natural Frequency

\[ F_{nv} = \frac{60}{(2 \times \pi) \times \left( \frac{K_v}{m} \right)} \]
\[ = \frac{60}{(2 \times \pi) \times \left( \frac{1,715,667.000}{155.771} \right)} \]
\[ = 1002.178 \text{ rpm} \]

(2) Resonance Frequency (rpm)

\[ F_{rv} = F_{nv} \times \left[ 1 - (2 \times Dvt^2) \right] \]
\[ = 1002.178 \times \left[ 1 - (2 \times 0.918^2) \right] \]
\[ \therefore 2 \times Dvt^2 \]
\[ = 2 \times 0.918^2 \]
\[ = 1.685 > 1.00 \]

**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

\[ r_v(\text{blower}) = \frac{f_v(\text{blower})}{F_{nv}} \]
\[ = \frac{2242.000}{1002.178} = 2.237 \]
\[ \text{OK!!!} \]

For Motor

\[ r_v(\text{motor}) = \frac{f_v(\text{motor})}{F_{nv}} \]
\[ = \frac{1490.000}{1002.178} = 1.487 \]
\[ \text{OK!!!} \]

(4) Magnification Factor

For Blower

\[ M_v(\text{blower}) = 1 / \sqrt{(1 - r_v(\text{blower})^2 + (2 \times D_{vt} \times r_v(\text{blower}))^2) \]
\[ = 1 / \sqrt{(1 - 2.237^2) + (2 \times 0.918 \times 2.237)^2} \]
\[ = 0.174 < 1.500 \]
\[ \text{OK!!!} \]

For Motor

\[ M_v(\text{motor}) = 1 / \sqrt{(1 - r_v(\text{motor})^2 + (2 \times D_{vt} \times r_v(\text{motor}))^2) \]
\[ = 1 / \sqrt{(1 - 1.487^2) + (2 \times 0.918 \times 1.487)^2} \]
\[ = 0.335 < 1.500 \]
\[ \text{OK!!!} \]
(5) Transmissibility Factor

For Blower

\[ T_v(blower) = M_v(blower) \times \sqrt{1 + (2 \times D_v \times r_v)^2} \]

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

\[ = 0.736 \]

For Motor

\[ T_v(motor) = M_v(motor) \times \sqrt{1 + (2 \times D_v \times r_v)^2} \]

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

\[ = 0.974 \]

(6) Vibration Amplitude

For Blower

(For the normal operating speed - 2242 rpm)

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

\[ = 0.0000005 \times (3.000 / 2) \]

\[ = 4.026E-07 \text{ m} \]

(For the normal operating speed - 1490 rpm)

\[ V_{(rocking(blower))} = R_{(blower)} \times (FL / 2) \]

\[ = 0.0000005 \times (3.000 / 2) \]

\[ = 7.714E-07 \text{ m} \]

For Motor

(For the normal operating speed - 2242 rpm)

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

\[ = 0.0000000 \times (3.000 / 2) \]

\[ = 0.000E+00 \text{ m} \]

(For the normal operating speed - 1490 rpm)

\[ V_{(rocking(motor))} = R_{(motor)} \times (FL / 2) \]

\[ = 0.0000000 \times (3.000 / 2) \]

\[ = 0.000E+00 \text{ m} \]

Total Vertical Amplitude

\[ V_{total} = V_{(blower)} + V_{(rocking(blower))} + V_{(motor)} + V_{(rocking(motor))} \]

\[ = 1.174E-06 \text{ m} \]
3.0 Horizontal Excitation Analysis

3.1 Spring Constant

(1) Equivalent radius ($r_{oh}$) for Rectangular Foundation

$$r_{oh} = \frac{FB \times FL}{\pi} = \frac{10.000 \times 3.000}{\pi} = 3.090 \text{ m}$$

(2) Embedment factor for Spring Constant

$$\eta_h = 1 + 0.55 \times (2 - \nu) \times \left(\frac{h}{r_{oh}}\right) = 1 + 0.55 \times (2 - 0.321) \times \left(\frac{1.500}{3.090}\right) = 1.404$$

(3) Spring Constant Coefficient

$$\beta_h = 1.017$$

(4) Equivalent Spring Constant for Rectangular Foundation

$$K_h = 2 \times (1 + \nu) \times G \times \beta_h \times \frac{FB \times FL \times \eta_h}{\pi} = 2 \times (1 + 0.321) \times 82,579.233 \times 1.017 \times \frac{10.000 \times 3.000 \times 1.404}{\pi} = 1760211.961 \text{ kN/m}$$

3.2 Damping Ratio

(1) Effect of Depth of Embedment on Damping Ratio

$$\alpha_h = \left[1 + 1.9 \times \left(\frac{2 - \nu}{r_{oh}}\right)\right] / \eta_h = \left[1 + 1.9 \times \left(\frac{2 - 0.321}{3.090}\right) \times 1.500 / 3.090\right] / 1.448 = 2.118$$

(2) Mass Ratio

$$B_h = \frac{(7 - 8\nu) / [32 \times (1 - \nu)] \times W / (\gamma \times r_{oh}^3)}{(7 - 8 \times 0.321) \times \frac{155.771}{32 \times (1 - 0.321) \times 1.733 \times 3.090^3}} = 0.621$$
(3) Effective Damping Coefficient

This is not available for Horizontal Mode

(4) Geometrical Damping Ratio

\[
D_h = \frac{0.288}{B_h \times \alpha_h} \\
= \frac{0.288}{0.621 \times 2.118} \\
= 0.774
\]

(5) Internal Damping

\[
D_{hi} = 0.040 \quad \text{(Consider the Internal Damping)}
\]

(6) Total Damping Ratio

\[
D_{ht} = D_h + D_{hi} \\
= 0.774 + 0.040 \\
= 0.814
\]

3.3 Frequency Check

(1) Natural Frequency

\[
F_{nh} = \frac{60}{2 \times \pi} \times \sqrt{\left(\frac{K_h}{m}\right)} \\
= \frac{60}{2 \times \pi} \times \sqrt{\frac{1,760,211.961}{155.771}} \\
= 1015.000 \quad \text{rpm}
\]

(2) Resonance Frequency (rpm)

\[
F_{rh} = F_{nh} \times \sqrt{\left[1 - (2 \times D_{ht}^2)\right]} \\
= 1,015.000 \times \sqrt{\left[1 - (2 \times 0.814^2)\right]} \\
\text{Not Apply}
\]

\[
\therefore 2 \times D_{ht}^2 \\
= 2 \times 0.814^2 \\
= 1.325 > 1.0
\]

**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!!

\[
\begin{align*}
\text{For Blower} & \quad r_h(\text{blower}) = \frac{f_h(\text{blower})}{f_{nh}} \\
& = \frac{2242.000}{1015.000} \\
& = 2.209 \\
\text{For Motor} & \quad r_h(\text{motor}) = \frac{f_h(\text{motor})}{f_{nh}} \\
& = \frac{1490.000}{1015.000} \\
& = 1.468 \\
\end{align*}
\]

OK!!!

(4) Magnification Factor

\[
\begin{align*}
\text{For Blower} & \quad M_h(\text{blower}) = \frac{1}{\sqrt{(1 - r_h(\text{blower}))^2 + (2 D_{ht} \times r_h(\text{blower}))^2}} \\
& = \frac{1}{\sqrt{(1 - 2.209)^2 + (2 \times 0.814 \times 2.209)^2}} \\
& = 0.189 < 1.50 \\
\text{For Motor} & \quad M_h(\text{motor}) = \frac{1}{\sqrt{(1 - r_h(\text{motor}))^2 + (2 D_{ht} \times r_h(\text{motor}))^2}} \\
& = \frac{1}{\sqrt{(1 - 1.468)^2 + (2 \times 0.814 \times 1.468)^2}} \\
& = 0.377 < 1.50 \\
\end{align*}
\]

OK!!

(5) Transmissibility Factor

\[
\begin{align*}
\text{For Blower} & \quad T_h(\text{blower}) = M_h(\text{blower}) \times \sqrt{1 + (2 D_{ht} \times r_h(\text{blower}))^2} \\
& = 0.189 \times \sqrt{1 + (2 \times 0.814 \times 2.209)^2} \\
& = 0.705 \\
\text{For Motor} & \quad T_h(\text{motor}) = M_h(\text{motor}) \times \sqrt{1 + (2 D_{ht} \times r_h(\text{motor}))^2} \\
& = 0.377 \times \sqrt{1 + (2 \times 0.814 \times 1.468)^2} \\
& = 0.977 \\
\end{align*}
\]
(6) Vibration Amplitude

For Blower
(For the normal operating speed - 2242 rpm)
\[ H_{\text{blower}} = \frac{M_{h(\text{blower})} \times F_{h(\text{blower})}}{K_h} \]
\[ = \frac{1760211.961}{0.189 \times 3.970} \]
\[ = 4.263 \times 10^{-7} \text{ m} \]
(For the normal operating speed - 1490 rpm)
\[ H_{\text{rocking(blower)}} = R_{(\text{blower})} \times (h + \text{C.G.}) \]
\[ = 0.0000005 \times (1.700 + 1.850) \]
\[ = 1.826 \times 10^{-6} \text{ m} \]

For Motor
(For the normal operating speed - 2242 rpm)
\[ H_{\text{motor}} = \frac{M_{h(\text{motor})} \times F_{h(\text{motor})}}{K_h} \]
\[ = \frac{0.377 \times 0.000}{1760211.961} \]
\[ = 0.000 \times 10^{-6} \text{ m} \]
(For the normal operating speed - 1490 rpm)
\[ H_{\text{rocking(motor)}} = R_{(\text{motor})} \times (h + \text{C.G.}) \]
\[ = 0.0000000 \times (1.700 + 1.850) \]
\[ = 0.000 \times 10^{-6} \text{ m} \]

Total Horizontal Amplitude
\[ H_{\text{total}} = H_{(\text{blower})} + H_{\text{rocking(blower)}} + H_{(\text{motor})} + H_{\text{rocking(motor)}} \]
\[ = 4.263 \times 10^{-7} + 1.826 \times 10^{-6} + 0.000 \times 10^{-6} + 0.000 \times 10^{-6} \]
\[ = 2.252 \times 10^{-6} \text{ m} \]

4.0 Rocking Excitation Analysis

4.1 Spring Constant

(1) Equivalent \(r_{or}\) for Rectangular Foundation
\[ r_{or} = \left( \frac{[FB \times FL^3] / (3 \times \pi)^{1/4}}{[10.000 \times 3.000^3] / 3 \times \pi} \right)^{1/4} \]
\[ = 2.314 \text{ m} \]

(2) Embedment factor for Spring Constant
\[ \eta_r = 1 + 1.2 \times (1 - u) \times (h / r_{or}) + 0.2 \times (2 - u) \times (h / r_{or})^3 \]
\[ = 1 + 1.2 \times (1 - 0.321) \times (1.500 / 2.314) + 0.2 \times (2 - 0.321) \times (1.500 / 2.314)^3 \]
\[ = 1.620 \]

Effective Embedment height
\[ = \text{Height(h) - Ground Level(G.L.)} \]
\[ = 1.700 - 0.200 \]
\[ = 1.500 \]
(3) Spring Constant Coefficient

\[ \beta_r = 0.408 \]

(4) Equivalent Spring Constant for Rectangular Foundation

\[ K_r = \frac{G}{(1 - \nu)} \times \beta_r \times FB \times FL^2 \times \eta_r \]
\[ = \frac{82579.233}{(1 - 0.321)} \times 0.408 \times 10.000 \times 3.000^2 \times 1.620 \]
\[ = 7234608.000 \text{ kN/m} \]

4.2 Damping Ratio

(1) Effect of Depth of Embedment on Damping Ratio

\[ \alpha_r = \frac{1 + 0.7 \times (1 - \nu) \times (h / r_{or}) + 0.6 \times (2 - \nu) \times (h / r_{or})^3}{\eta_r} \]
\[ = \frac{1 + 0.7 \times (1 - 0.321) \times (1.500 / 2.314) + 0.6 \times (2 - 0.321) \times (1.500 / 2.314)^3}{1.620} \]
\[ = 1.244 \]

(2) Mass Ratio

\[ B_r = 3 \times (1 - \nu) / 8 \times I_o / (\rho \times r_{or}^5) \]
\[ = \frac{3 \times (1 - 0.321)}{8} \times \frac{625.640}{1.733 \times 66.277} \]
\[ = 1.387 \]

(3) Effective Damping Coefficient

\[ n_r = 1.251 \]

(4) Geometrical Damping Ratio

\[ D_r = 0.15 \times \alpha_r / [(1 + n_r \times B_r) \times (n_r \times B_r)] \]
\[ = 0.15 \times 1.244 \]
\[ = 0.052 \]

(5) Internal Damping

\[ D_{ri} = 0.040 \]
(6) Total Damping Ratio

\[ D_t = D_i + D_n \]
\[ = 0.052 + 0.040 \]
\[ = 0.092 \]

4.3 Frequency Check

(1) Natural Frequency

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

(2) Resonance Frequency

\[ F_{rr} = F_{nr} \times \left( 1 - 2 \times D_t^2 \right) \]
\[ = 1,027.000 \times \left( 1 - 2 \times 0.092^2 \right) \text{ rpm} \]

\[ \therefore 2 \times D_t^2 \]
\[ = 2 \times 0.092^2 \]
\[ = 0.017 < 1.00 \]

**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

\[ r_t(blower) = \frac{f_t(blower)}{F_{nr}} \]
\[ = \frac{2242.000}{1027.000} \]
\[ = 2.183 \]

**OK!!!**

For Motor

\[ r_t(motor) = \frac{f_t(motor)}{F_{nr}} \]
\[ = \frac{1490.000}{1027.000} \]
\[ = 1.451 \]

**OK!!!**
(4) Magnification Factor

For Blower
\[ M_r(blower) = \frac{1}{\sqrt{1 - (r_{r(blower)})^2} + (2 \times D_t \times r_{r(blower)})^2} \]
\[ = \frac{1}{\sqrt{1 - 2.183^2} + (2 \times 0.092 \times 2.183)^2} = 0.264 \]
\[ < 1.500 \]

For Motor
\[ M_r(motor) = \frac{1}{\sqrt{1 - (r_{r(motor)})^2} + (2 \times D_t \times r_{r(motor)})^2} \]
\[ = \frac{1}{\sqrt{1 - 1.451^2} + (2 \times 0.092 \times 1.451)^2} = 0.880 \]
\[ < 1.500 \]

(5) Transmissibility Factor

For Blower
\[ T_r(blower) = M_r(blower) \times \sqrt{1 + (2 \times D_t \times r_{r(blower)})^2} \]
\[ = 0.264 \times \sqrt{1 + (2 \times 0.092 \times 2.183)^2} \]
\[ = 0.285 \]

For Motor
\[ T_r(motor) = M_r(motor) \times \sqrt{1 + (2 \times D_t \times r_{r(motor)})^2} \]
\[ = 0.880 \times \sqrt{1 + (2 \times 0.092 \times 1.451)^2} \]
\[ = 0.911 \]

(6) Vibration Amplitude

For Blower
\[ R(blower) = \frac{M_r(blower) \times F_r(blower)}{K_r} \]
\[ = \frac{0.264 \times 3.970 \times 3.550}{7234608.000} \]
\[ = 5.143E-07 \text{ rad} \]

For Motor
\[ R(motor) = \frac{M_r(motor) \times F_r(motor)}{K_r} \]
\[ = \frac{0.880 \times 0.000 \times 3.550}{7234608.000} \]
\[ = 0.000E+00 \text{ rad} \]
5.0 Amplitude Check

5.1 Total Amplitude

(1) Vertical Amplitude

\[ V_{total} = \text{Vertical Vibration Amplitude} + \text{Rocking Vibration Amplitude} \times \left(\frac{\text{FL}}{2}\right) \]

= 1.174E-06 m
= 0.00012 cm
= 0.000046 in

(2) Horizontal Amplitude

\[ H_{total} = \text{Horizontal Vibration Amplitude} + \text{Rocking Vibration Amplitude} \times (h + \text{C.G.}) \]

= 2.252E-06 m
= 0.00023 cm
= 0.000089 in

(3) Maximum Velocity

Where,

\[ \text{Velocity} = \frac{\text{Machine}}{2 \times \pi} \text{in/sec} = \frac{\text{m/sec}}{0.003} \]

"Machine" is the imposed frequency of the rotating equipment.

RPM

= 2242 (For Pump)
= 1490 (For Motor)

\[ \text{Blower Velocity} = \frac{2 \times \pi \times \text{Machine(rpm)}}{0.003 \text{ m/sec}} \]

= 2 × π × 37.367
= 0.0013 cm
= 0.00051 in

\[ \text{Motor Velocity} = \frac{2 \times \pi \times \text{Machine(rpm)}}{0.003 \text{ m/sec}} \]

= 2 × π × 24.833
= 0.0020 cm
= 0.00077 in

\[ \therefore \text{Max}(V_{total}, H_{total}) < A_t \quad \text{OK!!!} \]
5.2 Vibration Velocity

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

(1) Vertical Velocity

For Blower

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

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

$$= 2.756 \times 10^{-4} \text{ m/s}$$

OK!!!

For Motor

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

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

$$= 0.000 \text{ m/s}$$

OK!!!

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

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

$$= 2.756 \times 10^{-4} \text{ m/s}$$

OK!!!

(2) Horizontal Velocity

For Blower

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

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

$$= 5.287 \times 10^{-4} \text{ m/s}$$

OK!!!

For Motor

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

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

$$= 0.000 \text{ m/s}$$

OK!!!

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

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

$$= 5.287 \times 10^{-4} \text{ m/s}$$

OK!!!
6.0 Soil Bearing Check (Static + Dynamic)

6.1 Transmissibility Force

(1) Transmissibility Vertical Force

\[ P_v(blower) = [T_v(blower) \times F_v(blower)] \]
\[ = [0.736 \times 3.970] \]
\[ = 2.922 \text{ kN} \]

\[ P_v(motor) = [T_v(motor) \times F_v(motor)] \]
\[ = [0.974 \times 0.000] \]
\[ = 0.000 \text{ kN} \]

\[ P_v(total) = [T_v(blower) \times F_v(blower)] + [T_v(motor) \times F_v(motor)] \]
\[ = [0.736 \times 3.970] + [0.974 \times 0.000] \]
\[ = 2.922 \text{ kN} \]

(2) Transmissibility Horizontal Force

\[ P_h(blower) = [T_h(blower) \times F_h(blower)] \]
\[ = [0.705 \times 3.970] \]
\[ = 2.801 \text{ kN} \]

\[ P_h(motor) = [T_h(motor) \times F_h(motor)] \]
\[ = [0.977 \times 0.000] \]
\[ = 0.000 \text{ kN} \]

\[ P_h(total) = [T_h(blower) \times F_h(blower)] + [T_h(motor) \times F_h(motor)] \]
\[ = [0.705 \times 3.970] + [0.977 \times 0.000] \]
\[ = 2.801 \text{ kN} \]

(3) Transmissibility Moment

\[ P_r = [T_r(blower) \times M_r(blower)] + [T_r(motor) \times M_r(motor)] \]
\[ = [0.285 \times 14.094] + [0.911 \times 0.000] \]
\[ = 4.010 \text{ kN-m} \]

6.2 Total Transmissibility Moment

\[ P_u = P_r + [P_v(total) \times (P_L / 2 - F_{dx})] + [P_h(total) \times (C.G_{shaft} + h)] \]
\[ = 4.010 + [2.922 \times (3.000 / 2 - 1.216)] + [2.801 \times 3.550] \]
\[ = 14.782 \text{ kN-m} \]
6.3 Soil Bearing Pressure (Static + Dynamic, Static)

(1) Fatigue Factor (ξ) 

Design of Structures and Foundations for Vibrating Machinery

(2) \( Q_{all} = 0.750 \times Q_a = 150,000 \) kN/m²

(3) \( P_{sta+dyn} = \) 

\[
\frac{W_i}{\text{Area}} \pm \frac{\xi \times P_{(total)}}{\text{Area}} \pm \frac{\xi \times P_{(total)} \times (C.G_{shaft} + h) \times 6}{B \times L^2} \pm \frac{\xi \times P_t \times 6}{B \times L^2} \\
= \frac{1528.110}{3.000 \times 10.000} \pm \frac{1.500 \times 2.922}{3.000 \times 10.000} \pm \frac{1.500 \times (3.550) \times 3.000}{10.000 \times 3.000^2} \pm \frac{1.500 \times 4.010 \times 6}{10.000 \times 3.000^2} \\
= 51.981 \text{ or } 49.893 \text{ kN/m²} \\
= 5.299 \text{ or } 5.086 \text{ ton/m²}
\]

\[
\frac{W_i}{\text{Area}} \pm \frac{\xi \times P_{(total)}}{\text{Area}} \pm \frac{\xi \times P_{n} \times 6}{B \times L^2} \\
= \frac{1528.110}{3.000 \times 10.000} \pm \frac{1.500 \times 2.922}{3.000 \times 10.000} \pm \frac{1.500 \times 14.782 \times 6}{10.000 \times 3.000^2} \\
= 52.561 \text{ or } 49.313 \text{ kN/m²} \\
= 5.358 \text{ or } 5.027 \text{ ton/m²}
\]

\( Q_{all} = 150,000 \) kN/m²

\( P_{sta+dyn} = 52.561 \) kN/m²

\( \therefore Q_{all} > P_{dyn} \) [OK!!]