Research Paper Engineering

Analysis and Design of Machine Foundation

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ABSTRACT

Foundations for various machines are like any other foundation as far as the transfer of static loads is concerned. In addition of static loads, machine also produced dynamic loads. Thus, dynamic loads are not short lived but act over a large period of time. During transfer of these dynamic loads, frequency of vibrations of machine and the soil foundation system as well as dynamic displacement is of great importance. The dynamic force generated depends upon the type of the machine and its operating mechanism and operating frequency. Observations from extensive tests conducted on machine foundation models and prototypes as well as failure investigations conducted on various machine foundations suggest the need for improvement in the design procedures to ensure better performance of machines.

Keywords :

Introduction:
The basic criteria in the design of machine foundation is that,

a) The dynamic forces of machines are transmitted to the soil through the foundation in such way that all kinds of harmful effects are eliminated and the amplitude of vibration of the machine as well as that of the foundation are well within the specified limits
b) Foundation is structurally safe to withstand all static and dynamic forces generated by the machines.

Observations from extensive tests conducted on machine foundation models and prototypes as well as failure investigations conducted on various machine foundations suggest the need for improvement in the design procedures to ensure better performance of machines. These include:

a) More comprehensive evaluation of site soil data
b) Better understanding of machine data and its use in foundation design
c) Improvement in the design philosophy that suggests
i) Improvement in the modeling technique
ii) Improvement in analysis technique
iii) Improvement in structural design process iv) Improvement in construction technology

Vibration isolation techniques have also been used to reduce vibrations in the machines. Vibration isolation leads to reduction in the transmissibility of the exciting forces from the machine to the foundation and vice-versa resulting in minimization of machine failures and reduction in downtime on account of high vibrations.

The significant aspects of soil properties, which influence soil structure interaction, are: soil mass participation in vibration of foundations, effect of embedment of foundation, applicability of Hooke's law to soil and dynamic parameters.

❖ Forced vibrations:
If the system indicated in Figure 1 is subjected to a harmonic exciting force

$P_0 \sin \omega_m t$. There can be two cases depending on the type of excitation-

(a) amplitude of excitation being constant and (b) amplitude proportional to the square of the circular operating frequency ω_m

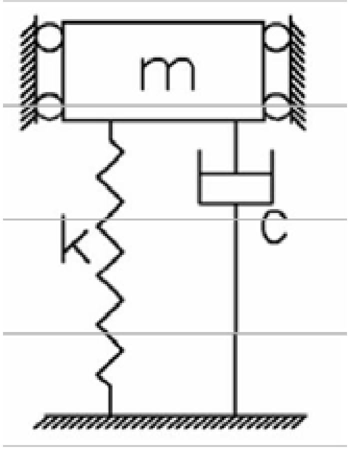

Figure 3 :Single Degree Freedom System of excitation being

a) ***Constant Force Excitation:*** In this case, the amplitude of exciting force (P_0) is constant and independent of forcing frequency.

The equation of motion of a damped single degree of freedom system subjected to forced excitation can be expressed as

$$m\ddot{z} + C\dot{z} + k z = P_0 \sin \omega_m t$$

where P_0 is the amplitude of exciting force under steady – state forced excitation, the system has a tendency to vibrate at the operating frequency ω_m.

If transient part corresponding to free vibrations is neglected , the solution of under steady state conditions can be given as

$$z = a_d * \sin(\omega_m t + \alpha)$$

where a_d is amplitude and α is the phase difference between the exciting force and displacement.

b) **Rotating Mass Type Excitation**:
In this case, the exciting force P in the case of reciprocating or unbalanced rotating mass type excitation is of the form

$P= m_e e \omega_m^2 \sin \omega_m t$

Where, m_e is the reciprocating or unbalance rotating mass , e=eccentricity of unbalanced mass in the case of rotating type

machines,

ω_m=frequency of motion

For this type of forced excitation ,the equation of motion for a single degree of freedom system is expressed as

$m\ddot{z} + c\dot{z} + kz = (m_e e \omega_m^2)\sin \omega$

❖ **General criteria for design of Machine Foundations:**

- It should be safe against shear failure caused by superimposed loads and also settlements should be within the safe limits. The soil pressure should normally not exceed 80% of the allowable pressure for static loading.
- There should be no possibility of resonance. The natural frequency should be either greater than or smaller than the operating frequency of the machine.
- The amplitudes under service conditions should be within permissible limits for the machine.
- The combined center of gravity of the machine and the foundation should be on the vertical line passing through the centre of gravity of the base plane.
- All rotating and reciprocating parts of machine should be so well balanced as to minimize unbalanced forces or moments.
- Where possible, foundation should be planned in such a manner as to permit subsequent alteration of natural frequency.
- Machine foundation should be taken to a level lower than the level of the foundation of the adjacent buildings and should be properly separated.
- Any steam or hot air pipes, embedded in foundation must be properly isolated.
- The vibrations induced should neither be annoying to the persons nor detrimental to other structures.
- The depth of the ground water table should be at least one fourth of the width of the foundation below the base plane.

❖ **Degree of freedom of a block foundation:**
The block foundation is regarded as rigid when compared with the flexibility of soil over which it rests. As such it is subjected to rigid body displacements – translation and rotations. The block foundation has six degree of freedom with three translation modes along x,y, z axis and three rotation modes along x, y, z axis as shown in fig.

i) Translation along x-axis ii) Translation along y-axis

iii) Translation along z-axis (vertical vibrations)

iv) Rotation along x-axis (rocking vibrations)

v) Rotation along y-axis (pitching vibrations)

vi) Rotation along z-axis (yawing torsion vibrations)

❖ **Method of Analysis:**

- Linear elastic spring method
- Elastic half space method
- Impedance function method

Linear elastic spring method:
Some general features of this approach:

1) As the name implies this approach considers the soil as spring

2) The damping in the system is neglected, leading to conservative solutions.

3) It is considered that the total mass of the system includes, in addition to the mass of the foundation and the machine, mass of the in- phase soil assumed to vibrate together with the machine-foundation system.
4) Different modes of vibration, either independently or in coupled mode can be analyzed in this approach. Analysis consists of determining the natural frequency or frequencies in free vibration and amplitudes of motions in forced vibration.
5) Each mode of vibration is analyzed by an appropriate mass- spring model, neglecting damping.

Elastic half space method:
In this method a better representation of a foundation soil system than mass spring model provide more realistic analysis with the help of theory of elasticity but this method is more complicated. In this method, the machine foundation is represented by a finite circular base resting on ground, which is termed elastic half space. The soil is assumed to be an elastic, homogeneous, isotropic, semi-infinite solid and the theory is applicable to cases where foundation vibrations are low. The equivalent soil spring and damping values depend upon the;

i) Type of soil and its properties
ii) Geometry and layout of the foundation
iii) Nature of the foundation vibrations occasioned by unbalanced dynamic loads.

Impedance function method:
The dynamic response of a foundation may Gazetas calculated by the impedance function method. The dynamic impedance is a function of the foundation soil system and the nature and type of exciting loads and moments. The dynamic impedance is defined as the ratio between force R and the resulting steady state displacement U at the centroid of the base of massless foundation.

Steps for Analysis of Block Foundation:
Step-1 : To get the data from the geotechnical report

SOIL PARAMETER:

- Soil density ρ (kN/m^2)
- Maximum allowable ground bearing capacity q_a(kN/m^2)
- Shear modulus G(MN/m^2)
- Poisson's ratio ξ
- Depth of embedment(m)

Step-2 : To get vendor data from vendor document and vendor drawing

<u>**MACHINE DATA**</u>

a) FREQUENCIES

- Operational speed (compressor & turbine)
- Minimum speed
- Maximum speed

b) Weight(kg)

- Equipment

- Compressor
- Baseframe compressor+pipework
- Turbine
- Baseframe turbine+pipework

c) Speeds:
- Compressor
- Turbine

d) Unbalanced Forces:
For compressor and turbine;

Axial F_{xx}(N) Horizontal F_{yy}(N)

Vertical F_{zz}(N)

Moments are calculated only for soil pressure check

Step 3: Calculate combined Center of gravity:
Calculate combined Foundation and machinery centroid

Step - 4 : Dynamic Analysis for various modes is to be performed to get check for Frequency ratio, Amplitude, Magnification factor and Soil base pressure.

❖ Design criteria as per IS: 2974 (Part:1)-1982:
- The foundation structure of machine shall be isolated at all levels from the main building and from other foundations as far as possible.
- Overhanging cantilevers where unavoidable shall be designed to ensure rigidity against vibration.
- All machine foundations shall satisfy two fundamental criteria;

that resonance does not occur between the frequencies of the pulsating loads and natural frequency of foundation/soil system and also the amplitude of vibration does not exceed safe limits. Design criteria based on frequency and amplitude limits can be classed as follows: a) Limits set by the possibility of damage or uneconomic wear to machinery or associated equipment or both,

b) Limits set by the possibility of damage to building structures,
c) Limits of structural borne vibrations to ensure comfort of person, and d) Limits set by possibility of disturbance of ground resulting in unacceptable settlement of foundation.

❖ Minimum Reinforcement in Block Foundations:
- Minimum reinforcement in the concrete block shall be not less than 25 kg/m3.

For machines requiring special design considerations of foundations, like machines pumping explosive gases the reinforcement shall be not less than 40 kg/m3.

- The minimum reinforcement in the block shall usually consist of 12 mm bars spaced at 200/250 mm centre to centre extending both vertically and horizontally near all the faces of the foundation block.
- The following points shall be considered while arranging the reinforcements:

a) The ends of mild steel (if used) shall always be hooked irrespective of whether they are designed for tension or compression,
b) Reinforcement shall be used at all faces,
c) If the height of foundation block exceeds one metre, shrinkage reinforcement shall be placed at suitable spacing in all three directions, and
d) Reinforcement shall be provided around all pits and openings and shall be equivalent to 0.50 to 0.75 percent of the cross-sectional area of the opening.

Conclusion:
In analysis and design of Block foundation, eccentricity check, resonance check, amplitude check, horizontal peak velocity check, ground bearing pressure check is required to be performed as to have safe foundation of machine which is critical aspect of design.