CHAPTER-VII-DESIGN OF MACHINEFOUNDATIONS

INTRODUCTION

- Machine foundations, being of a special kind, fall into a separate class of their own.
- For example, the general criteria for ensuring stability of a machine foundation are rather different from those for other foundations.
- Also the design approach and methods of analysis are totally different in view of the dynamic nature of the forces.
- The types of machine foundations are also different.

TYPES OF MACHINES

Machines may be classified as follows, based on their dynamic effects and the design criteria:

(i) Those producing periodical forces reciprocating machines or engines, such as compressors.

(ii) Those producing impact forces forge hammers and presses.

(iii) High speed machines such as turbines and rotary compressors.

(iv) Other miscellaneous kinds of machines.

Based on their operating frequency, machines may be divided into three categories:

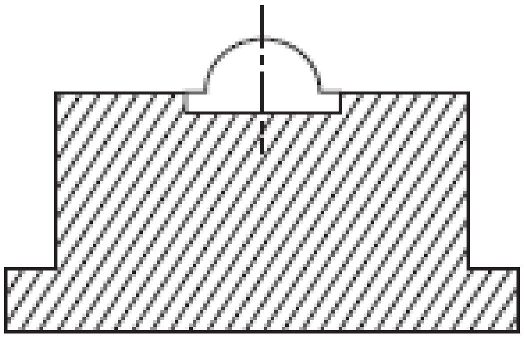
(a) Low to medium frequency machines up to 500 rpm:

(b) Medium to high frequency machines—300 to 1000 rpm.

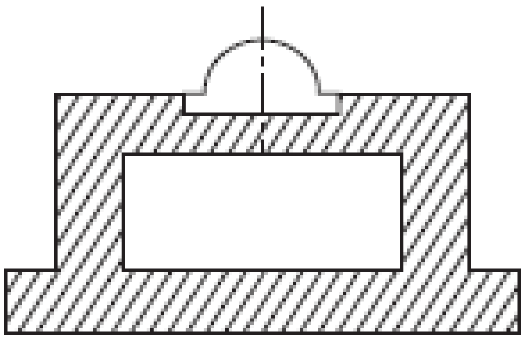
(c) Very high frequency machines-greater than 1000 rpm:

TYPES OF MACHINE FOUNDATIONS

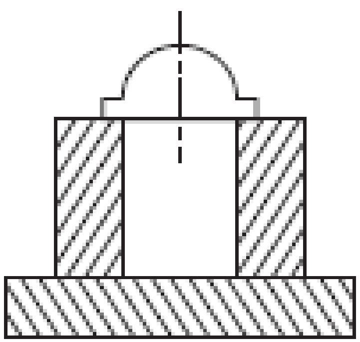
Machine foundations are generally classified as follows, based on their structural form:



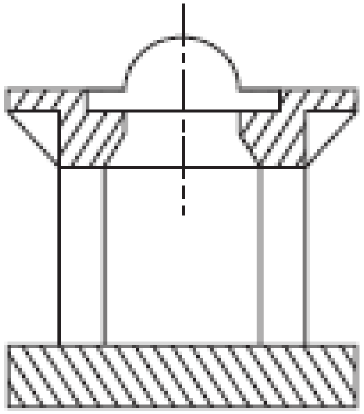
(a) Block-type



(b) Box or caisson type



(c) Wall type



(d) Framed-type

Types of machine foundations

I–BLOCK-TYPE FOUNDATIONS

- It consisting of a pedestal of concrete on which the machine rests.

II–BOX OR CAISSON TYPE FOUNDATIONS

- It consisting of a hollow concrete block.

III–WALL-TYPE FOUNDATIONS

- It consisting of a pair of walls which support the machinery on their top.

IV–FRAMED-TYPE FOUNDATIONS

- It consisting of vertical columns supporting on their top a horizontal frame work which forms the seat of essential machinery.

General Criteria for Design of Machine Foundations

The following criteria should be satisfied by a machine foundation:

(i) The foundation should be able to carry the superimposed loads without causing shear failure. The bearing capacity under dynamic loading conditions is generally considered to be less than that for static loading, the reduction factor ranging from 0.25 to 1.0.

(ii) The settlement should be within permissible limits.

(iii) The combined centre of gravity of machine and foundation should be, to the extent possible, in the same vertical line as the centre of gravity of the base line.

(iv) Resonance should be avoided; hence the natural frequency of the foundation-soil system should be far different from the operating frequency of the machine. (For low-speed machines, the natural frequency should be high, and vice-versa). The operating frequency should be high, and vice-versa). The operating frequency must be either less than 0.5 times or greater than 1.5 times the resonant frequency so as to ensure adequate margin of safety.

(v) The amplitude under service conditions should be within the permissible limits, generally prescribed by the manufacturers.

(vi) All rotating and reciprocating parts of the machine should be so balanced that the unbalanced forces and moments are minimized. (This, of course, is the responsibility of the mechanical engineers).

(vii) The foundation should be so planned as to permit subsequent alteration of natural frequency by changing the base area or mass of the foundation, if found necessary subsequently.

Design Approach for Machine Foundation

- The dimension of machine foundations are fixed according to the operational requirements of the machine.
- The overall dimensions of the foundation are generally specified by the manufacturers of the machine.
- If there is choice to the foundation designer, the minimum possible dimensions satisfying the design criteria should be chosen.
- Once the dimensions of the foundation are decided upon, and site conditions are known, the natural frequency of the foundation-soil system and the amplitudes of motion under operating conditions have to be determined.
- The requirements specified in the previous subsection should be satisfied to the extent possible for a good design. Thus, the design procedure is one of ‘trial and error’.

The specific data required for design vary for different types of machines.However,certain general requirements of data may given as follows:

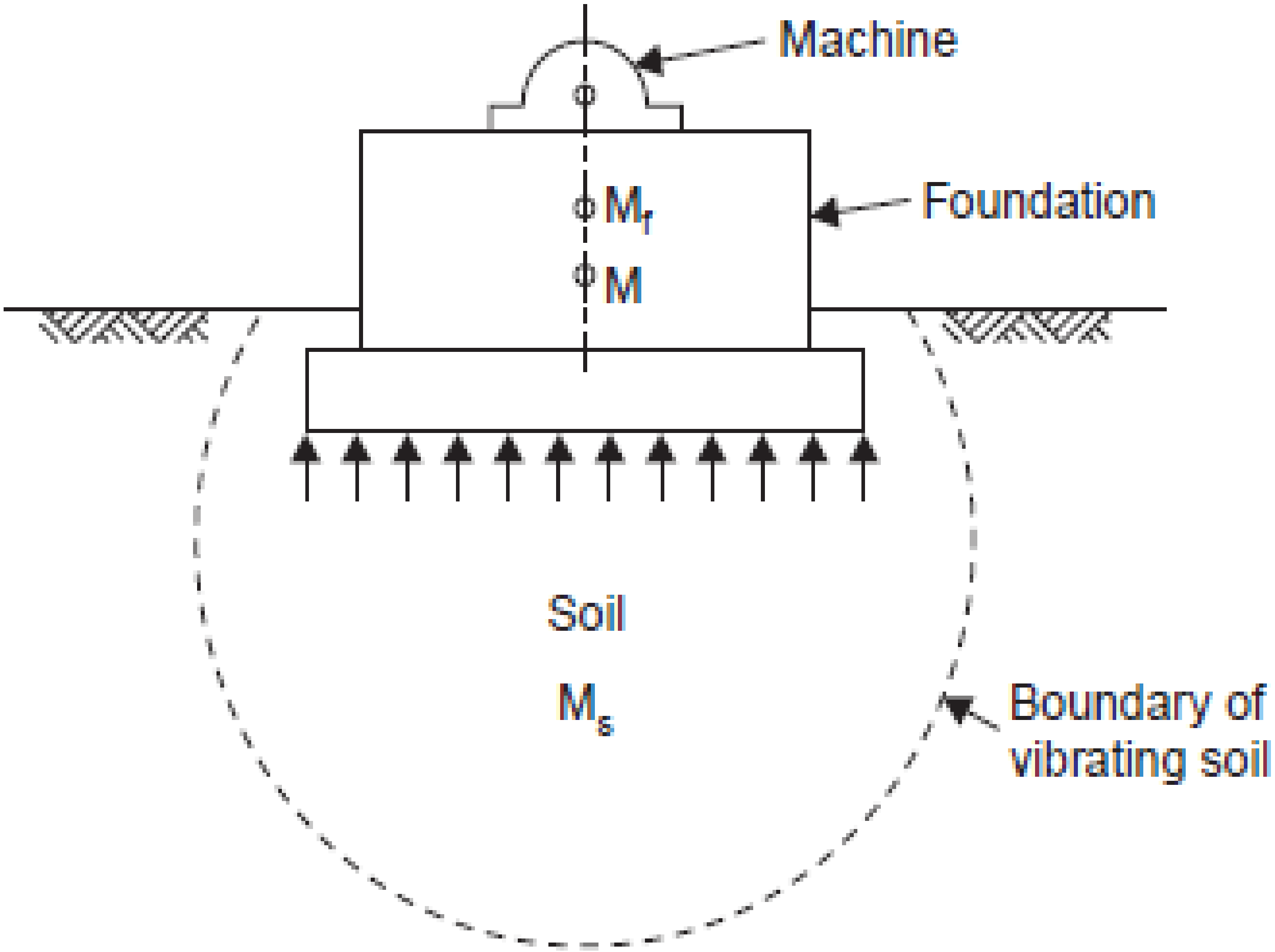
(i) Loading diagram, showing the magnitudes and positions of static and dynamic loads exerted by the machine.

(ii) Power and operating speed of the machine.

(iii) Line diagram showing openings, grooves for foundation bolts, details of embedded parts, and so on.

(iv) Nature of soil and its static and dynamic properties, and the soil parameters required for the design.

Vibration Analysis of a Machine Foundation



Machine foundation-soil system

- Although the machine foundation has six-degree freedom, it is assumed to have single degree of freedom for convenience of simplifying the analysis Fig. shows a machine foundation supported on a soil mass.
- Mf is the lumped mass of the machine and of the foundation, acting at the centre of gravity of the system.
- Along with Mf, a certain mass, Ms, of soil beneath the foundation will participate in the vibration.
- The combined mass M (the sum of Mf and Ms) is supposed to be lumped at the centre of gravity of the entire system

CONSTRUCTION ASPECTS OF MACHINE FOUNDATIONS

1.Concrete

- M 150 concrete should be used for block foundations are M 200 concrete for framed foundations.
- The concreting should preferably be done in a single operation.
- The location of construction joints should be judiciously chosen.
- Proper treatment of the joints with a suitable number of dowels and shear keys is required.
- Cement grout with no-shrinkable additive should be used under the machine bed-plate and for pockets of anchor-bolts.

2. Reinforcement

- Reinforcement should be used on all surfaces, openings, cavities, etc., required to be provided in the machine foundation.
- In block-type foundation, reinforcements should be used in the three directions.
- The minimum reinforcement should be 250N/cum of concrete.
- The reinforcement usually consists of 16 to 25mm bars kept at 200 to 300mm spacing in both directions, and also on the lateral faces.
- The concrete cover should be a minimum of 75mm at bottom and 50mm on sides and at top. Around all openings, steel reinforcement equal to 0.5 to 0.75% of cross-sectional area of the opening shall be provided, in the form of a cage.

3. Expansion Joints

- Machine foundations should be separated from adjoining structural elements by expansion joints to prevent transmission of vibration.

4. Connecting Elements

- ❖ Base plates and anchor bolts are used to fix machines to the foundation. For this purpose, concreting should be stopped at the level of the base plate.
- ❖ This gap will be filled later by cement mortar. A 150mm × 150 mm hole is generally sufficient for bolt holes.
- ❖ A minimum clearance of 80mm should be provided from the edge of the bolt hole to the nearest edge of the foundation.
- ❖ The length of a bolt to be concreted is generally 30 to 40 times the diameter. Bolt holes should be invariably filled with concrete.
- ❖ Concreting the spaces under the machines should be done with extreme care using 1:2 mortar mix.
- ❖ Machines should not be operated for at least 15 days after under-filling, since vibrations are harmful to fresh mortar. The edges of the foundation should be protected by providing a border of steel angles.

5. Spring Absorbers

- ❖ Spring absorbers are commonly used for providing isolation in machine foundations.
- ❖ These can be installed by using either ‘supported system’ or ‘suspended system’.
- ❖ In the former, the springs are placed directly under the machine or the foundation; in the latter, the foundation is suspended from springs located at or close to the floor level.
- ❖ In the suspended system, access to the springs becomes easy for future maintenance or replacement.
- ❖ For well-balanced machines, relatively smaller springs are adequate; in such cases, the supported system may be used.
- ❖ For machines with large exciting forces, heavy springs will be required; in this case, the suspended system is preferred.

6. Provision for Tuning

- When the necessary margin of safety cannot be realized in design to avoid resonance, it is desirable to give due provision in the construction for tuning the foundation at a later stage.
- By "tuning" is meant changing the natural frequency of the foundation system if found necessary at a later stage.
- To facilitate subsequent enlargement of the foundation, dowels should be let projecting.
- It has been suggested that hollows be left in the foundation block which may be subsequently concreted, if required, to increase the mass of the foundation with the same base area.

Example : 1: Determine the natural frequency of a machine foundation which has a base area of 2.20 m × 2.20 m and a weight of 155 kN including the weight of the machine. Take the value of the coefficient of elastic uniform compression as 4.4×10^4 kN/m^3.

$$\omega_n = \sqrt{\frac{c_u . A}{M}}$$

Substituting $C_u = 4.4 \times 10^4$ kN/m^3,

$A = 2.20 \times 2.20$ m^2,

and $M = \dfrac{155}{9.81}$ kN sec^2/m,

$$\omega_n = \sqrt{\frac{4.4 \times 10^4 \times (2.20)^2}{(155 / 9.81)}} \text{ rad/s}$$

$= 116.1$ rad/s

∴ Natural frequency, $f_n = \dfrac{\omega_n}{2\pi} = \dfrac{116.1}{2\pi}$ = **18.5 cps (Hz)**

Example 2: Determine the coefficient of elastic uniform compression if a vibration test on a concrete block of 1 m cube gave a resonant frequency of 36 Hz in vertical vibration. The weight of the oscillator used was 500 N. Take the unit weight of concrete as 24.0 kN/m^3.

Weight of the block = 1 x 1 x 1 x 24.0 = 24 kN

∴ Total weight including that of the oscillator = 24.5 kN

$$\omega_n = \sqrt{\frac{C_u . A}{M}}$$

Substituting $A = 1\ m^2$,

$$M = \frac{24.5}{9.31}\ kN.\ sec^2/m \quad \text{and} \quad \omega_n = 2\pi \times 36\ rad/s,$$

$$72\pi = \omega_n = \sqrt{\frac{C_u \times 1}{24.5 / 9.81}}$$

whence

$$C_u = (72\pi)^2 \times \frac{24.5}{9.81}\ kN/m^3$$

$$= 1.277 \times 10^5\ kN/m^3$$

Example 3: Determine the natural frequency of a machine foundation of base area 2m × 2m and weight 150 kN, assuming that the soil mass participating in the vibration is 20% of the weight of foundation. Take C_u = 36,000 kN/m^3.

Weight of foundation = 150 kN

Weight of soil mass participating in the vibration = 20% of 150 kN = 30 kN

Total weight = 150 + 30 = 180 kN

$$f_n = \frac{1}{2\pi}\sqrt{\frac{C_u.A}{M}}$$

Substituting C_u = 36,000 kN/m^3, A = 4 m^2,

and $$M = \frac{180}{9.81} \text{ kN sec}^2/\text{m},$$

$$f_n = \frac{1}{2\pi}\sqrt{\frac{36{,}000 \times 4 \times 1}{(180/9.81)}} \text{ cps}$$

$$= 14.1 \text{ Hz}$$