UNIT-5 (Part-2)

Machine Foundation

→ In some cases, the foundations are subjected to dynamic loads.

→ These loads may result from various causes such as vibratory motion of machines, movement of vehicles, impact of hammer, earthquakes, winds, waves, mine explosions etc.

→ The dynamic loads transmitted to the foundation and their effect on the strata below can be determined using the principles of soil dynamic & theory of vibrations. The analysis is however, very complex.

⇒ Basically there are three types of machines.

1) Machines which produce a periodic unbalanced force, such as reciprocating engines and compressor. The speed of such machines is generally less than 600 r.p.m

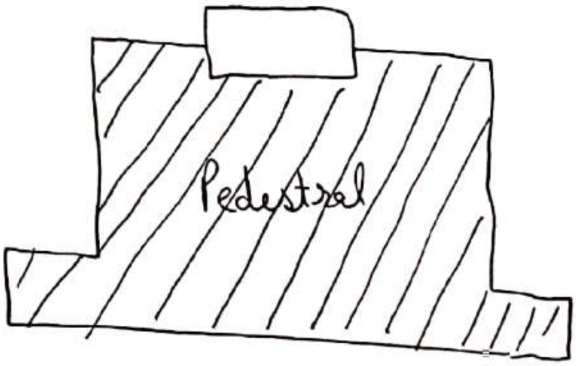
2) Machines which produce impact loads, such as forge hammer. In these machines, the dynamic force attains a peak value in very short time. The speed is usually between 60 to 150 blows per minute.

3) High speed machines, such as turbines and rotary compressor. The speed of such machines is very high, even more than 3000 r.p.m.

** Types of Machine Foundations:

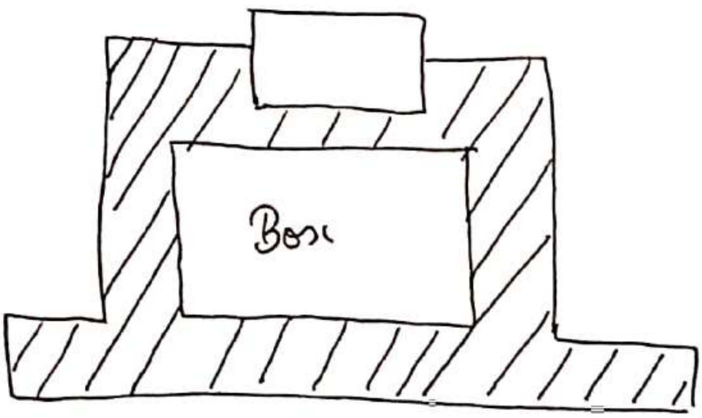
The following 4 types of machine foundation commonly used:

1) Block Type: This type of machine foundation consists of a pedestral resting on a footing. The foundation has a large mass and a small natural frequency.



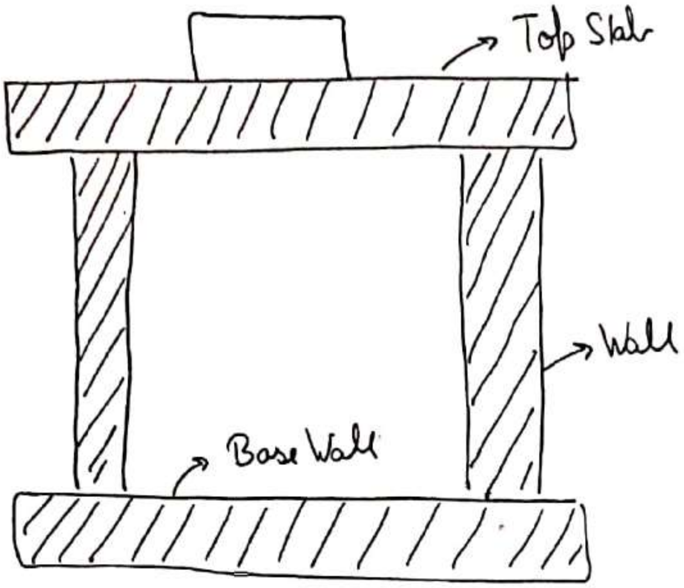
⇐ Block Type

2) Box Type: The foundation consists of a hollow concrete block. The mass of the foundation is less than that in the block type & the natural frequency is increased.

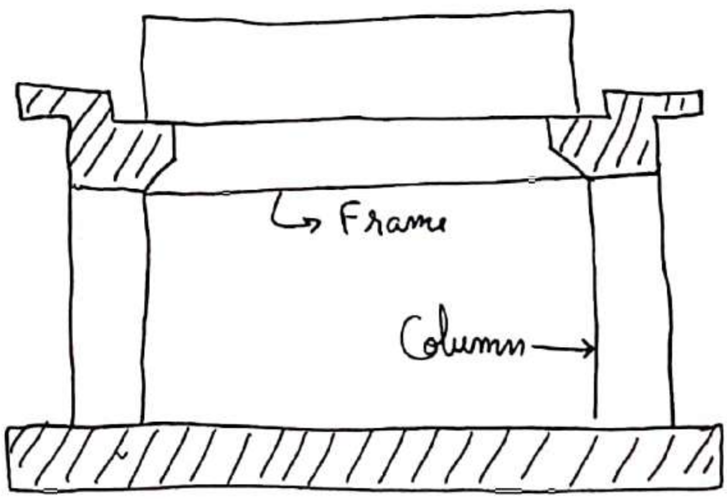


Box type

3) <u>Wall type</u>: A wall type of foundation consists of a pair of walls having a top ~~slab~~ slab. The machine rests on the top slab.



4) <u>Framed Type</u>: This type of foundation consists of vertical columns having a horizontal frame at their tops. The machine is supported on the frame.



Suitability of various types: Machines which produce periodical and impulsive forces at low speed are generally provided with a block type foundation.

Framed type foundations are generally used for the machine working at high speeds and for those of the rotating type.

Some machines which induce very little dynamic forces, such as lathes, need not to be provided with machine foundation. Such machines may be directly bolted to the floor.

* Basic Definitions:

1) Vibration (or oscillation): It is time-dependent, repeated motion of translational or rotational type.

2) Periodic Motion: It is the motion which repeats itself periodically in equal time intervals.

3) Period (T): The time period in which the motion repeats itself is called the period of motion or simply period.

4) Cycle: The motion completed in the period is called cycle of motion.

5) Frequency (f): The number of cycles of motion in a unit of time is known as the frequency of vibration. It is expressed in hertz (i.e cycles per second)
The period (T) and the frequency (f) are inter-related as:

$$\boxed{T = 1/f}$$

Circular frequency (ω) is in radians per second.

6) Free Vibration: Free vibrations occur under the influence of forces inherent in the system itself, without any external force. However to start free vibrations, some external force or natural disturbance is required. Once started, the vibration continue without an external force.

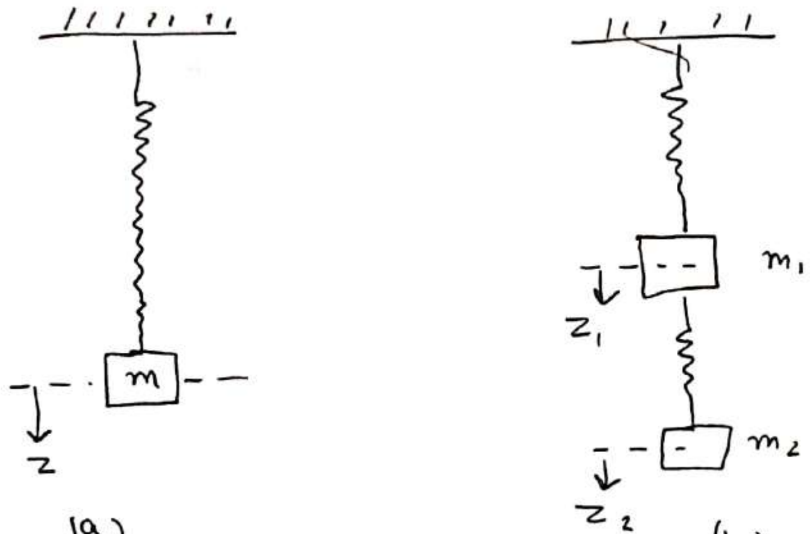
7) Forced Vibration: Forced vibrations occurs under the influence of continuous external force.

8) Natural frequency: The system under free vibrations vibrates at a frequency known as natural frequency. The natural frequency is the characteristic of the system.

9) Resonance: When the frequency of the exciting force is equal to one of the natural frequencies of the system, the amplitudes of motion become excessively large. This condition is known as resonance.

10) <u>Damping</u>: The resistance to motion which develops due to friction and other causes is known as damping.

11) <u>Degree of freedom</u>: The number of <u>independent co-ordinates</u> required to describe the motion of a system is called degree of freedom.



(a) (b)

Fig (a) shows a system with one degree of freedom and (b) shows a system with two degree of freedom.

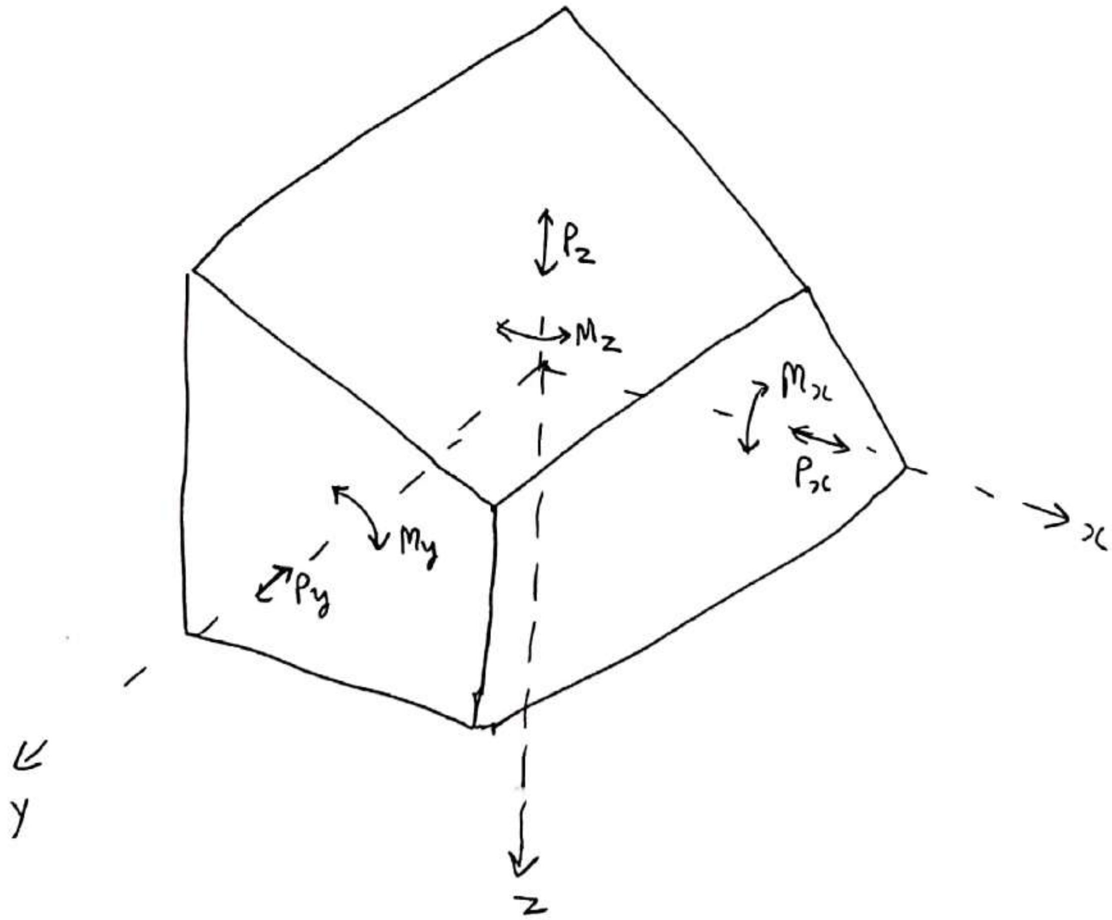
→ An elastic rod has an infinite degree of freedom. However, for convenience, the rod is divided into segments. The degree of freedom is made finite by considering the masses of these segments.

* Degree of freedom of a Block foundation :

A rigid block has 6 degree of freedom. Any displacement can be resolved into 6 independent displacements as under:

(1) Translation along X-axis (2) Translation along Y-axis
(3) Translation along Z-axis (4) Rotation about X-axis
(5) Rotation about Y-axis (6) Rotation about Z-axis

→ Translation along Z-axis & rotation about Z-axis can occur independently of any other ~~moth~~ motion. However, translations & rotation about X & Y axis are coupled, as these cannot occur independent of one another.



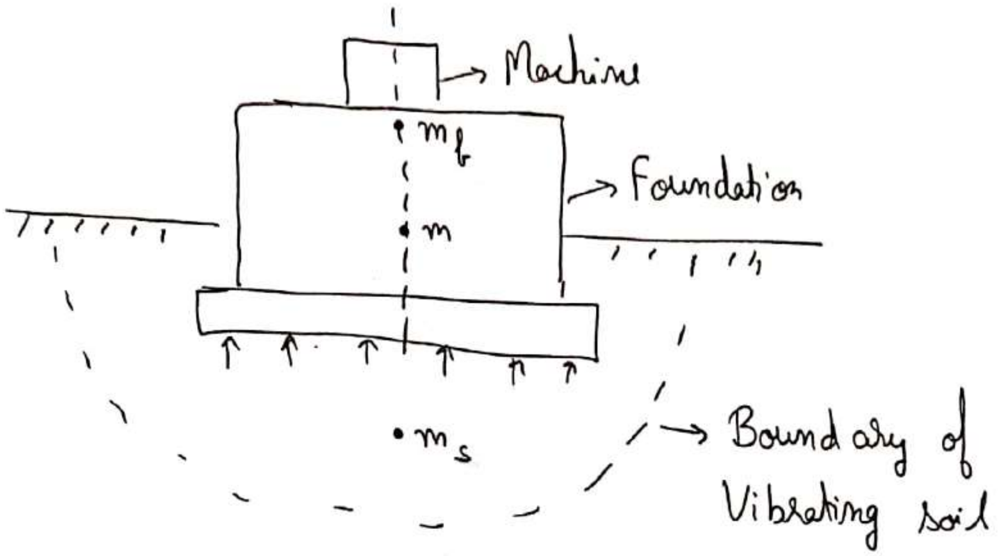
** Design of Machine Foundation :

A good machine foundation should satisfy the following criteria.

1) Like ordinary foundations, it should be safe against shear failure caused by superimposed loads and also the settlements should be within the safe limits.
2) There should be no possibility of resonance. The natural frequency of foundation should be either greater than or smaller than operating frequency of the machine.
3) The amplitudes under service conditions should be within the permissible limits for the machine.
4) The combined centre of gravity of the machine and the foundation should be on the vertical line passing through centre of gravity of the base plane.
5) Machine foundation should be taken to a level lower than the level of the foundation of the adjacent buildings and should be properly separated.
6) The vibrations induced should neither be annoying to the persons nor detrimental to other structure.
7) The depth of water table should be at least one-fourth of the width of the foundation below the base plane.

** Vibration Analysis of a Machine foundation :

→ Although a machine foundation has 6 degree of freedom, it is assumed to have a single degree of freedom for a simplied analysis.



→ m_f (mass) of the system lumps together the mass of the machine and mass of ~~machine~~ foundation. The total mass m_f acts at the centre of gravity of the system.

→ The mass is under the supporting action of the soil. The elastic action can be lumped together into a single elastic spring with a stiffness 'k'.

→ Likewise, all the resistance to motion is ~~lumpin~~ lumped into the damping coefficient c.

→ Thus the machine foundation reduces ~~to~~ a single mass having one degree of freedom.

Determination of parameters:

For vibration analysis of a machine foundation, the parameter m, c and k are required. These parameters can be determined as under:

1) **Mass (m)**: When a machine vibrates, some portion of the supporting soil mass also vibrates. The vibrating soil mass is known as the participating mass or in phase soil mass.

Therefore the total mass of system is equal to mass of foundation block and machine (m_f) and the mass (m_s) of the participating soil. Thus

$$\boxed{m = m_f + m_s}$$

There is no rational method to determine the magnitude of m_s. Value of m_s generally varies b/w zero & m_f.

2) **Spring Stiffness (k)**: The spring stiffness depends upon the type of soil, embedment of the foundation block, the contact area and the contact pressure distribution.

The following methods are commonly used.

a) **Laboratory Test**: A triaxial test with vertical vibrations is conducted to determine Young's Modulus 'E'. The modulus of rigidity (G) is determined by conducting the test under torsional vibration, and E is obtained indirectly from relation; $E = 2G(1+\mu)$; μ = poisson ratio

Stiffness (k) is : $\boxed{K = AE/L}$ A = area of cross-section, L = Length of specimen

b) <u>Barkan's Method</u>: The stiffness can also be obtained from the value of E using following relation given by Barkan:

$$k = \frac{1.13E}{1-\mu^2}\sqrt{A}$$

A = base area of machine i.e area of contact.

(c) <u>Resonance test</u>: Resonance frequency (f_n) is obtained using a vibrator of mass m set up on a steel plate supported on ground. Stiffness, k is obtained as

$$f_n = \frac{\omega_n}{2\pi}$$

$$f_n = \frac{1}{2\pi}\sqrt{k/m}$$

$$k = 4\pi^2 f_n \cdot m$$

3) <u>Damping Constant 'c'</u>: Damping is due to dissipation of vibration energy, which occurs mainly because of the following reasons:

(i) Internal friction loss due to hysterisis and viscous effects.

(ii) Radiational loss due to propagation of waves through soil.

The Damping factor D for an underdamped system can be determined in the laboratory. Vibration response is plotted and logrithmic decrement δ is found from the plot as,

$$\delta = \log(z_2/z_1)$$

where z_1 & z_2 are amplitudes of two consecutive cycles of an amplitude response curve.

The damping factor D & the logarithmic decrement δ are related:

$$\delta = \frac{2\pi D}{\sqrt{1-D^2}}$$

* Determination of natural frequency:

Natural frequency of system is given by :

$$\omega_n = \sqrt{k/m}$$

ω_n → radian per secion
K = equivalent spring constt.
m = mass of machine, foundation & participating soil.

Also :

$$f_n = \frac{1}{2\pi}\sqrt{k/m}$$

f_n = cycles per second.

⇒ Barken gave the following relation for natural frequency:

$$\omega_n = \sqrt{\frac{C_u A}{m}}$$

C_u = Coeff. of elastic uniform compression
A = Contact area of foundation with soil.

Q. Determine the natural frequency of a machine foundation having a base area 2m x 2m & mass 15 Kg including mass of machine. Take $C_u = 4 \times 10^7$ kN/m^3

⇒ $$\omega_n = \sqrt{\frac{C_u A}{m}}$$

$$\omega_n = \sqrt{\frac{4 \times 10^7 \times 2 \times 2}{15 \times 10^3}}$$

$$= 103.28 \text{ rad / sec}$$

$$f = \frac{\omega_n}{2\pi}$$

$$= \frac{103.28}{2\pi} = 16.43 \text{ hertz}$$

Q. Determine coeff. of uniform comp. if a vibration test on a block 1m x 1m x 1m gave resonance frequency of 30Hz in the vertical direction. Mass of oscillator used was 60 kg.

⇒ Mass of foundation = (1 x 1 x 1) 2400

= 2400

Total mass = 2400 + 60

= 2460 kg

$$\Rightarrow \quad \omega_n = \sqrt{\frac{C_u A}{m}}$$

$$f = \frac{1}{2\pi}\sqrt{\frac{C_u A}{m}}$$

$$30 = \frac{1}{2\pi}\sqrt{\frac{C_u \times 1 \times 1}{2460}}$$

$$C_u = 8.74 \times 10^7 \ N/m^3$$

$$= 8.74 \times 10^4 \ kN/m^3$$