



MACHINE FOUNDATION

INTRODUCTION

- In addition to the static loads due to weight of the machine and the foundation itself, the machine foundations are subjected to dynamic loads.
- The nature of dynamic load depends upon the type of machine.

In general machine can be grouped into three categories:

- Reciprocating machines
- Impact machines
- Rotary machines

Reciprocating machines

- These machine produce periodic, unbalanced force, e.g., reciprocating engines and compressors.
- The unbalanced force in such machines varies sinusoidally.
- The operating speeds of such machines are usually less than 600 rpm.

Impact machines

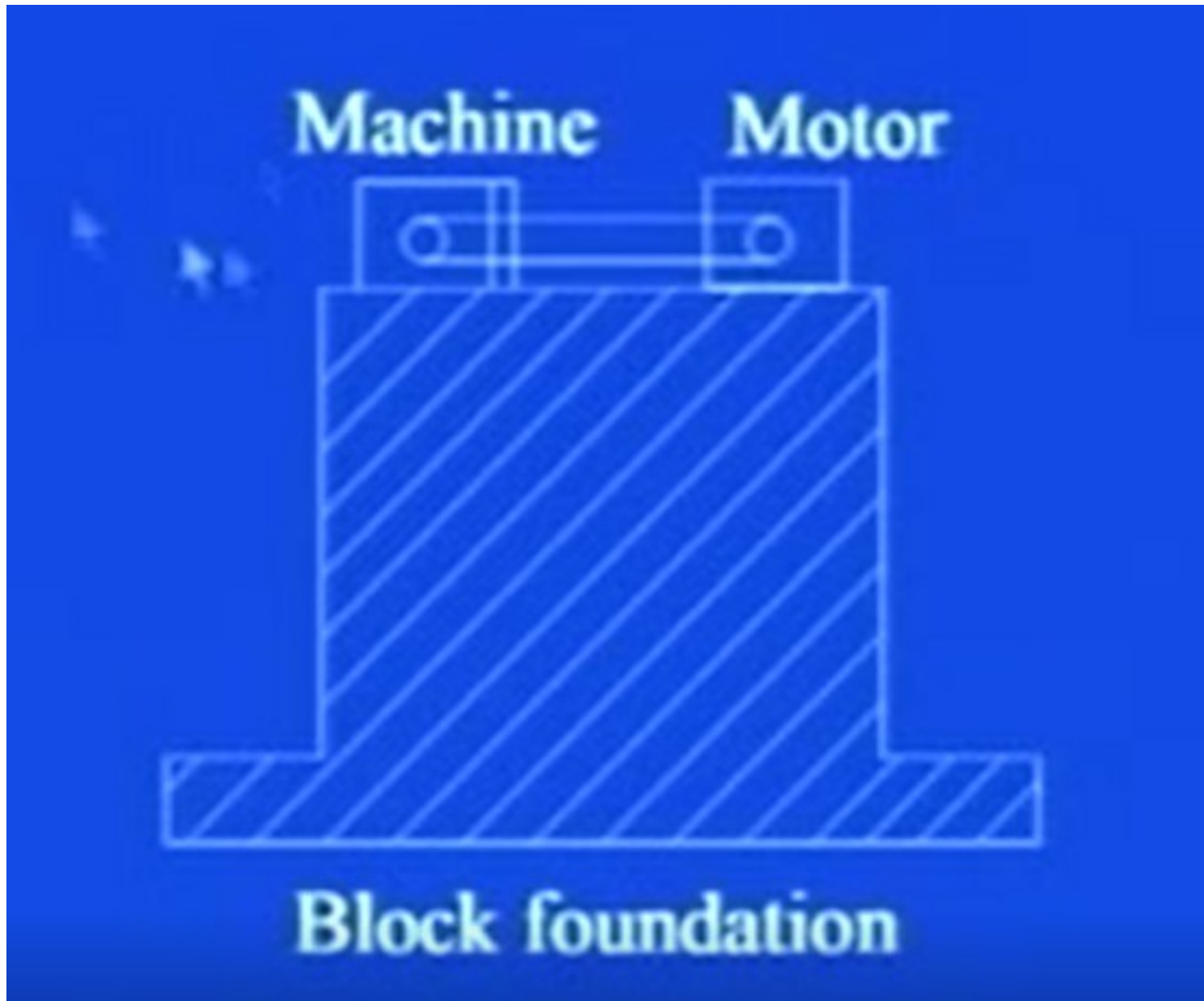
- Machines that produce impact loads, e.g., forge hammers, form this group of machines.
- In such machines, dynamic load builds up in a very short period of time and then dies out completely.
- The speed of operation of these machines is 60 to 150 blows per minute.

Rotary machines

- Medium and high speed machines, e.g., turbo-generators and rotary compressors.
- Operating speed vary from 1500 to 10000 rpm.

Suitable type of foundation

- The type of foundation that is suitable for a machine depends on the type of machine.
- For the reciprocating machines, block foundation is usually provided.
- A block foundation consists of a pedestal integrated with footing.
- A block foundation has a large mass and hence a smaller natural frequency.



Suitable type of foundation

- If a relatively lighter foundation is preferred (as the mass of foundation reduces, its natural frequency increases), a box or a caisson type of foundation may be provided.

Machine

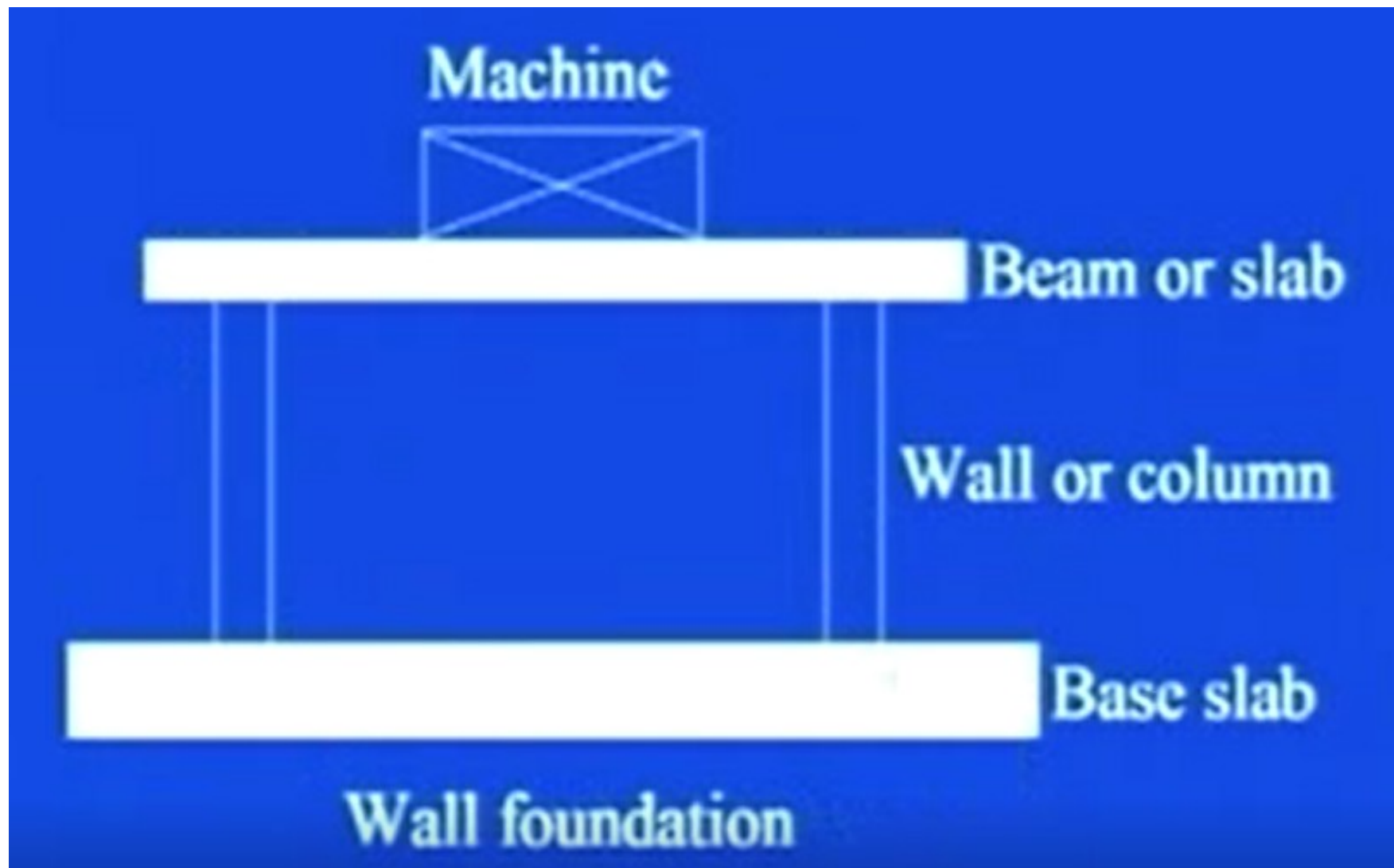
Motor



Box or caisson foundation

Suitable type of foundation

- Foundations for steam turbines are usually complex.
- These consist of a system of wall columns and beam slabs.
- Each element of such foundation is quite flexible.



TERMINOLOGY

Vibration

- Time dependent, repeating motion of translational or rotational type of any body possessing mass and elasticity is termed as vibration.
- The vibratory motion of a body can be of three types, namely, periodic, random or transient.

Amplitude

The maximum displacement of a vibrating body from its mean position or position of static equilibrium.

Period

The time period in which the motion repeats itself.

Cycle

The motion completed in one period is the cycle of motion.

Damping

It is the resistance to motion due to friction and / or other causes.

Viscous damping

When the damping force is proportional to the velocity of the system.

Degree of freedom

Number of independent coordinates required to define a vibratory system.

Free vibration

Vibration of a system when it is displaced from its equilibrium position and left to vibrate.

Natural frequency

The frequency at which a system vibrates under the effect of forces inherent in the system.

Operating frequency

The frequency at which a machine is operating.

Aperiodic

When there is non-regularity of the system in crossing its equilibrium position during motion.

Steady state

When a system is under a sinusoidal forced vibration and the response of the system is also sinusoidal.

Transient

When a system is subjected to a sudden velocity.

Resonance

When the frequency of the exciting force (operating frequency of the machine) equals the natural frequency of the foundation-soil system, the condition of resonance is reached. At resonance, the amplitude of a vibrating system is the maximum.

DESIGN CRITERIA FOR SATISFACTORY ACTION OF A MACHINE FOUNDATION

For satisfactory performance of a machine foundation, the foundation should satisfy the following criteria:

Under static loads:

1. The foundation should be safe against shear failure of soil.
2. The foundation should not settle more than a certain permissible value.

Under dynamic loads:

- 1. There should be no resonance, i.e., the natural frequency of the foundation-soil system should either be larger than or smaller than the operating frequency of the machine.**
- 2. The amplitudes of vibration under the operating frequency of the machine should be within permissible limits.**

Under dynamic loads:

3. The vibrations should not be annoying to the persons or detrimental to other machines and structures. Richart (1962) developed some criteria for vertical vibrations, which can be taken as a guide for determining permissible limits of frequency and amplitude.

The background features abstract, overlapping geometric shapes in various shades of blue, ranging from light sky blue to deep navy blue. These shapes are primarily located on the left and right sides of the frame, creating a modern, architectural feel. The central area is a plain, light grayish-white, providing a high-contrast space for the text.

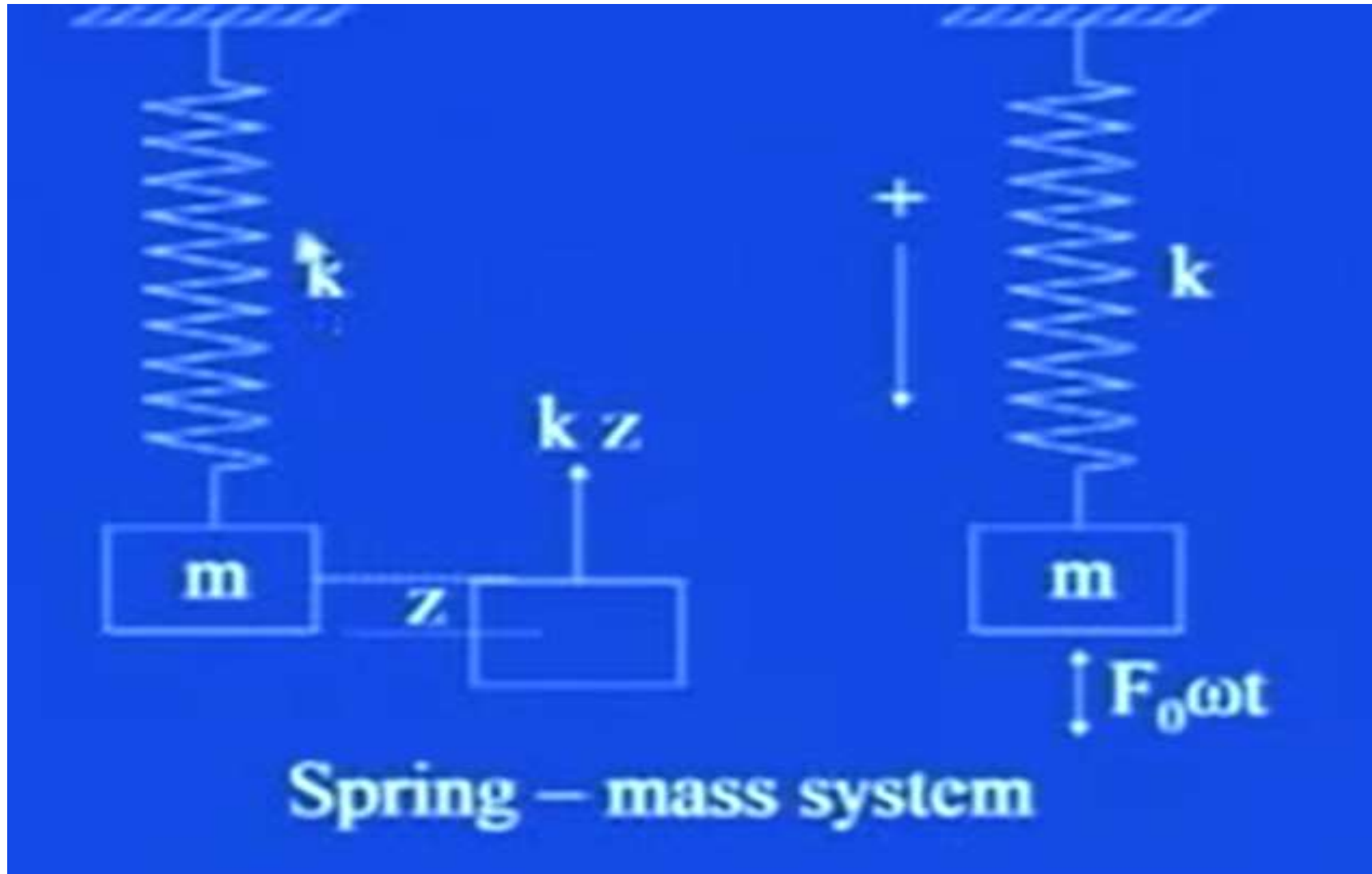
MACHINE FOUNDATION

THEORY OF LINEAR WEIGHTLESS SPRING

Simple continuous system can be represented by an equivalent spring.

Single degree freedom system – free vibration

- For a spring-mass system with mass m and spring stiffness k , if the mass is displaced by a distance z , the force acting on the mass is kz .
- Considering downward displacement and force as positive, the equation of motion can be written as



Single degree freedom system – free vibration

$\Sigma \text{ forces} = \text{mass} \times \text{acceleration}$

$$\text{or, } m\ddot{z} + kz = 0 \quad (1)$$

Let the solution of above equation be

$$z = A \sin(\omega_n t + \alpha) \quad (2)$$

where, A and α are constants of integration and ω_n is the circular natural frequency (radians/sec).

From equation (2),

$$\frac{dz}{dt} = \dot{z} = A\omega_n \cos(\omega_n t + \alpha) \quad (3)$$

$$\frac{d^2z}{dt^2} = \ddot{z} = -A\omega_n^2 \sin(\omega_n t + \alpha) \quad (4)$$

From equation (1), (3) and (4),

$$m\omega_n^2 = k$$

$$\omega_n = (k / m)^{1/2}$$

If f_n is the natural frequency in cycles per second,

$$f_n = \omega_n / 2\pi, \text{ or, } f_n = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$$

The natural time period, T_n is given by,

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

Single degree freedom system – forced vibration

If the spring-mass system is acted upon by an exciting force , $F_0 \sin \omega t$, the equation of motion will be

$$m\ddot{z} + kz = F_0 \sin \omega t \quad (5)$$

Let $z = A_z \sin \omega t$, substituting the value of z and \ddot{z} in equation (5),

$$m (-A_z \omega^2 \sin \omega t) + k A_z \sin \omega t = F_0 \sin \omega t$$

Upon simplification,

$$A_z = F_0 / (k - m\omega^2) \quad (6)$$

Equation (6) can be written as

$$A_z = \frac{F_0 / k}{\left(1 - \frac{m\omega^2}{k}\right)}$$

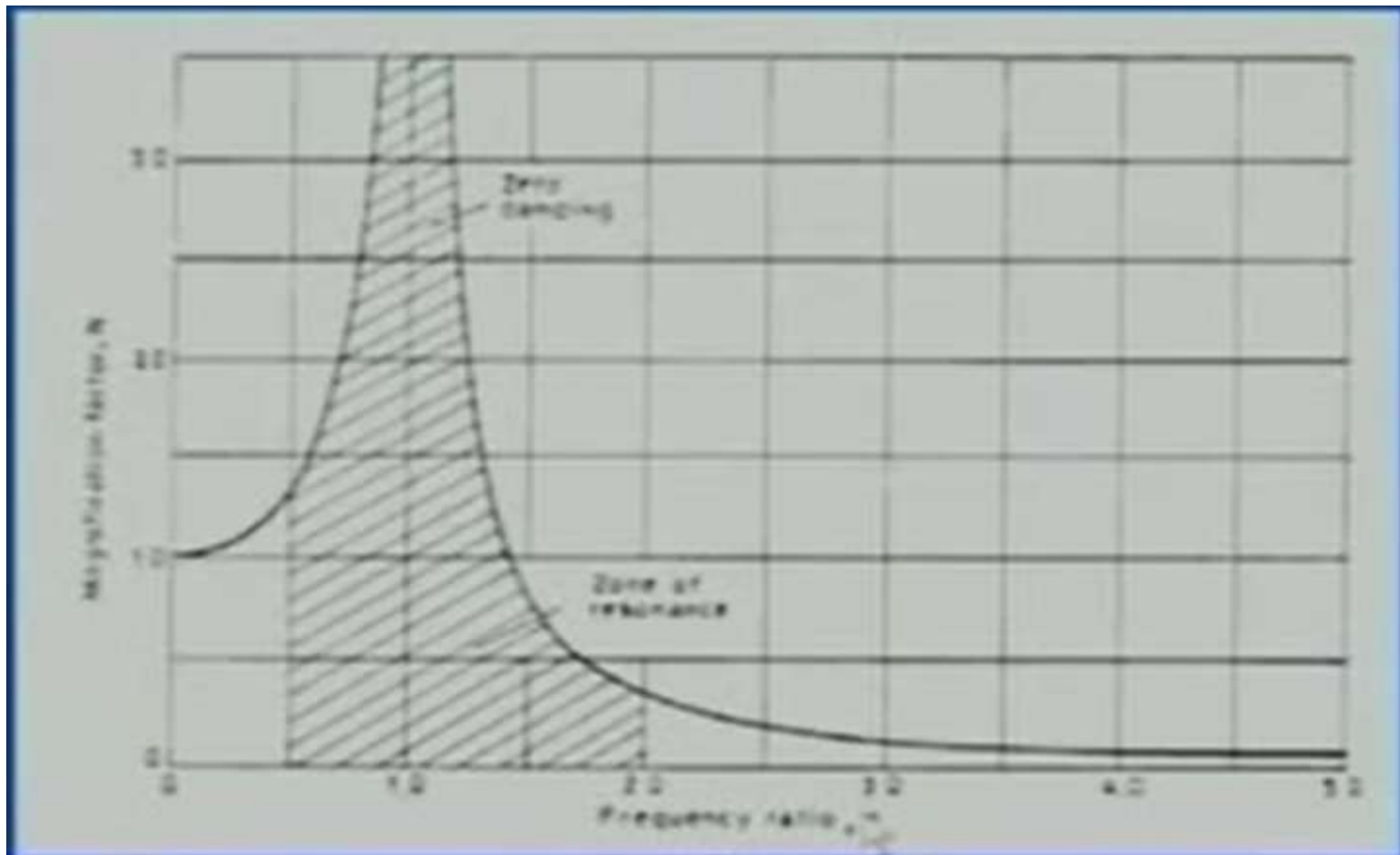
Substituting F_0/k by δ_{st} , i.e., the static deflection if the force F_0 were to be applied statically and $k/m = \omega_n^2$

$$A_x = \frac{\delta_{st}}{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right]} \quad (7)$$

Replacing ω/ω_n by r , i.e., frequency ratio and A_z/δ_{st} by N , i.e., magnification factor, equation (7) can be rewritten as

$$N = \frac{1}{1 - r^2} \quad (8)$$

The above equation holds good where no damping takes place. For different values of r , the corresponding values of N can be worked out and plotted.



Frequency ratio vs. magnification plot for zero damping

Effect of damping

Let viscous damping be present in the free vibration of a single degree freedom system such that the damping force F_d is given by

$$F_d = c \dot{z} \quad (9)$$

where, c is the damping coefficient.

The equation of motion is

$$m\ddot{z} + c\dot{z} + kz = 0 \quad (10)$$

Effect of damping

The solution of equation (10) is

$$z = A \cdot \exp \left(-i \frac{\omega_{nd} t}{\sqrt{1 - \xi^2}} \right) \sin(\omega_{nd} t + \alpha)$$

where, A and α are constants to be determined from initial boundary conditions. The circular natural frequency in the damped case, ω_{nd} is given by

$$\omega_{nd} = \omega_n \sqrt{1 - \xi^2}$$

where, ξ is damping coefficient, the ratio of actual damping to critical damping.

Critical damping

- If in a system, the amount of damping is increased, it stops oscillating and comes to rest after some time. Damping corresponding to the case when the system returns to its equilibrium position without oscillation in a minimum time, is defined as critical damping,

C_c

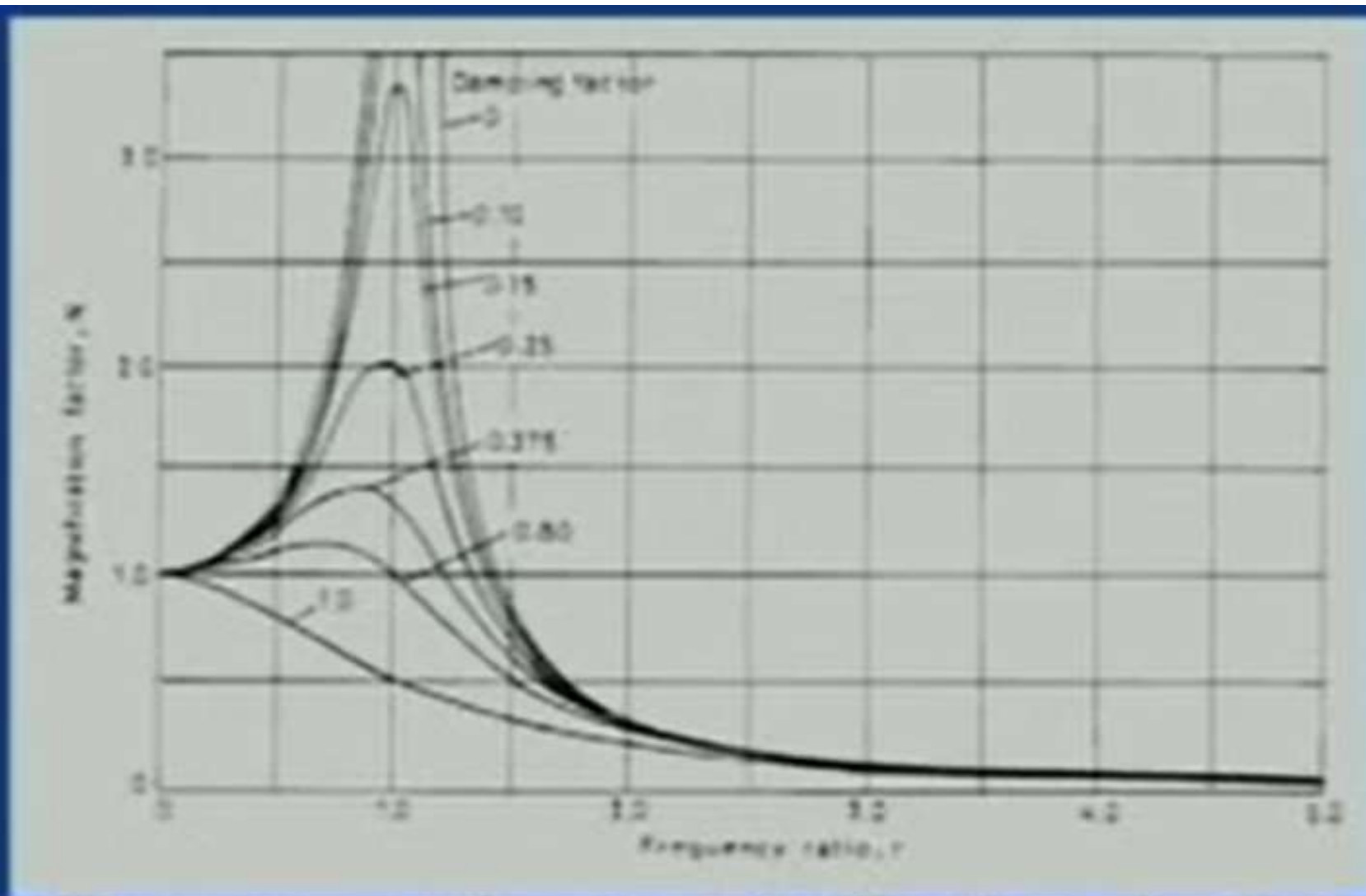
Critical damping

- In a single degree freedom system,

$$C_c = 2 (k m)^{1/2} = 2 m \omega_n$$

Taking into account damping in a forced vibration system, the equation for magnification factor, N gets modified to

$$N = \frac{1}{\left[(1-r^2)^2 + (2\xi r)^2 \right]^{1/2}}$$



Frequency ratio vs. magnification plot for different magnitude of damping factor

Critical damping

- At resonance ($r = 1$), the amplitudes become infinite even with a very small amount of damping.
- Further away from resonance, damping reduces the amplitude of vibration by only a small amount.