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80 SOIL MECHANICS AND FOUNDATIONS

$$A = -\frac{F_0 \cos \phi}{(k - m\omega^2) + i c \omega} \quad \dots(28.23 \text{ a}) \quad B = \frac{F_0 (k - m\omega^2)}{(k - m\omega^2)^2 + (c\omega)^2} \quad \dots(28.23 \text{ b})$$

Substituting these in Eq. 28.20 (a), we get the solution in the form

$$z = \frac{-F_0 \cos \phi}{(k - m\omega^2) + i c \omega} \cos \omega t + \frac{F_0 (k - m\omega^2)}{(k - m\omega^2)^2 + (c\omega)^2} \sin \omega t \quad \dots(28.24)$$

The equation represents the component due to forced vibrations with the period of  $T = \frac{2\pi}{\omega}$ . The frequency in vibrations (in cycles per second) is given by

$$f = \frac{\omega}{2\pi} \quad \dots(28.25 \text{ a})$$

The natural frequency of vibration,  $\omega_n$  defined earlier, is given by

$$\omega_n = \sqrt{\frac{k}{m}} \quad \text{radians/sec} \quad \dots(28.25 \text{ b})$$

and

$$f_n = \frac{\omega_n}{2\pi} = \frac{1}{2\pi} \sqrt{\frac{k}{m}} \quad \dots(28.25 \text{ c})$$

Substituting in Eq. 28.24,

$$\frac{-F_0 \cos \phi}{(k - m\omega^2) + i c \omega} = z \sin \phi \quad \dots(28.26 \text{ a}) \quad \text{and} \quad \frac{F_0 (k - m\omega^2)}{(k - m\omega^2)^2 + (c\omega)^2} = z \cos \phi \quad \dots(28.26 \text{ b})$$

we get

$$z = z_0 \sin \phi \cos \omega t + z_0 \cos \phi \sin \omega t = z_0 \sin(\omega t + \phi) \quad \dots(28.27)$$

where the angle  $\phi$  is termed as the phase angle between the exciting force and the motion of vibrating mass.

Noting that these terms represent a pair of vectors which must be added to obtain the displacement, the solution for the displacement due to the forced vibrations of Eq. 28.24 becomes

$$z = \sqrt{A^2 + B^2} F_0 \sin(\omega t + \phi) \quad \dots(28.28)$$

Substituting the values of  $A$  and  $B$ , and noting from Eq. 28.12 that

$$c_1 = 2 \sqrt{m k} = 2k \sqrt{\frac{m}{k}} = \frac{2k}{\omega_n} \quad \dots(28.29 \text{ a}) \quad \text{or} \quad k = \frac{m \omega_n^2}{2} \quad \dots(28.29 \text{ b})$$

we get

$$z = \frac{F_0}{k} \frac{1}{\sqrt{\left(\frac{2m\omega^2}{k} + 1 - \left(\frac{\omega}{\omega_n}\right)^2\right)^2 + \left(\frac{c}{k}\right)^2}} \sin(\omega t + \phi) \quad \dots(28.30 \text{ a})$$

or

$$z = \frac{F_0}{k} \frac{1}{\sqrt{\left(2 \frac{\omega}{\omega_n} \frac{k}{k}\right)^2 + \left(1 - \left(\frac{\omega}{\omega_n}\right)^2\right)^2}} \sin(\omega t + \phi) \quad \dots(28.30 \text{ b})$$

The maximum deflection  $z_{max}$  is thus given by