Q) Determine the natural frequency of a machine foundation having a base area 2m x 2m and a mass of 15 Mg, including the mass of the machine. Taking $C_u = 4 \times 10^4$ kN/m³

Sol?- Given data

Area = (2m x 2m)

Mass = 15 Mg

$C_u = 4 \times 10^4$ kN/m³

(C_u in N/m³, m in kg)

From equ^n $\omega_n = \sqrt{\frac{C_u A}{m}}$

$$\omega_n = \sqrt{\frac{4 \times 10^4 \times 10^3 \times (2 \times 2)}{15 \times 10^3}} = 103.28 \text{ rad/sec}$$

$$f_n = \frac{\omega_n}{2\pi} = \frac{103.28}{2\pi} = 16.43 \text{ cps (hetz)}$$

Q) Determine the coefficient of uniform compression if a vibration test on a block 1m x 1m x 1m gave a resonance frequency of 30 Hz, in the vertical direction. The mass of the oscillator used was 60 kg.

Soln. - Given data

Size = 1m x 1m x 1m

f = 30 Hz

m = 60 kg

mass of foundation block = (1m x 1 x 1) x 2400 = 2400 kg.

Total mass = 2400 + 60 = 2460 kg.

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

$f = \frac{1}{2\pi}\sqrt{\frac{C_u A}{m}} \Rightarrow 30 = \frac{1}{2\pi}\sqrt{\frac{C_u \times (1 \times 1)}{2460}}$

$\Rightarrow C_u = 8.74 \times 10^7 \text{ N/m}^3 = 8.74 \times 10^4 \text{ kN/m}^3$

3) The natural frequency of a machine foundation is 4 hertz. Determine its magnification at the operating frequency of 8 hertz. Take damping factor (D) as 0.30.

Sol?:- Given data

$f_n = 4$ hertz, $f = 8$ hertz

$D = 0.30$

Magnification (M) = ?

$\omega_n = 2\pi f_n$ $\left(f_n = \frac{\omega_n}{2\pi}\right)$

$\omega = 2\pi f$ $\left(f = \frac{\omega}{2\pi}\right)$

r = frequency ratio $= \omega/\omega_n = f/f_n = 8/4 = 2$ $\left(\frac{\omega}{2\pi} \times \frac{2\pi}{\omega_n} = \frac{f}{f_n}\right)$

$$M = \frac{1}{\sqrt{(1-r^2)^2 + 4D^2r^2}}$$

$$= \frac{1}{\sqrt{(1-2^2)^2 + 4\times(0.30)^2\times 2^2}}$$

$$= 0.31$$

4) The exciting force of a machine is 100KN. Determine the transmitted force if the natural frequency of the machine foundation is 3.0Hz. Take $D = 0.40$ and the operating frequency as 5 HZ.

Sol?:- Given data

Exciting force = 100KN.

Natural frequency = 3.0HZ = f_n

$D = 0.40$

operating frequency = 5HZ = f

$f/f_n = r$

$\Rightarrow 5/3 = r$

$$M = \frac{1}{(1-r^2)^2 + 4D^2r^2}$$

$$= \frac{1}{\sqrt{\left(1-\left(\frac{5}{3}\right)^2\right)^2 + 4\times(0.40)^2\times\left(\frac{5}{3}\right)^2}}$$

$$= 0.45$$

Transmitted force, $|F_T| = F_0 M \sqrt{1+(2\zeta r)^2}$

$$= 100 \times 0.45 \sqrt{1+\left(2\times 0.40\times\frac{5}{3}\right)^2}$$

$$= 75 \text{ kN}.$$

5) A foundation block of weight 30kN rests on a soil for which the stiffness may be assumed as 25 000 kN/m. The machine is vibrated vertically by an exciting force of $3.0 \sin(30t)$ kN. Find natural frequency, natural period, natural circular frequency and the amplitude of vertical displacement. The damping factor is 0.50.

Sol?

Given data

$\zeta = 0.50$

exciting force $= 3.0 \sin(30t)$

$= F_0 \sin \omega t$

Weight $= 30$kN.

stiffness $= 25000$ kN/m $= K$

$f_n = ?$, $T = ?$

$F_0 = 3.0$, $\omega = 30$ radian/second.

$$\omega_n = \sqrt{K/m} = \sqrt{\frac{25000}{(30\times10^3)/9.81}} = 90.42 \text{ rad/s}.$$

$f_n = \frac{1}{2\pi}\sqrt{k/m} = 14.39$ cycles/sec.

$T = \frac{1}{f_n} = 0.069$ second

$r = \frac{\omega}{\omega_n} = \frac{30}{90.42} = 0.33$

$$M = \frac{1}{\sqrt{(1-r^2)^2 + 4D^2r^2}}$$

$$= \frac{1}{\sqrt{(1-(0.33)^2)^2 + 4\times(0.5)^2\times(0.33)^2}}$$

$= 1.05$

static deflection $= \delta_{st} = (F_0/k)$

$= \frac{3.0\times100}{25000} = 0.012$ cm

Amplitude $= M\delta_{st}$

$= 1.05 \times 0.012$

$= 0.013$ cm.

Q.) A 2.50 Mg vertical compressor - foundation system is operated at 40 Hz. The soil at the site is medium stiff clay ($C_u = 4\times10^4$ kN/m^3). Determine the natural frequency and the magnification factor, assuming $m_s = 0.2m_f$. The base area is 2.5 m^2. Take $D = 0$.

Sol:- Given data

Total mass $= 2.5 + (0.2\times2.5) = 3.0$ Mg

$= 3\times10^3$ kg.

$\omega_n = \sqrt{\frac{C_uA}{m}} \Rightarrow f = \frac{1}{2\pi}\sqrt{\frac{C_uA}{m}} = \frac{1}{2\pi}\sqrt{\frac{4\times10^7\times2.5}{3\times10^3}}$

$= 29.06$ Hz

$$M = \frac{1}{\sqrt{(1-r^2)^2 + 4D^2r^2}} = \frac{1}{\sqrt{\left\{1-\left(\frac{40}{29.06}\right)^2\right\}^2 + 4\times0\times\left(\frac{40}{29.06}\right)^2}}$$

$= 1.12$

Q) A machine having a total weight of 20000 kN has an unbalance such that it is subjected to a force of magnitude 5000 kN at a frequency of 600 rpm what should be the spring constant for the supporting springs if the maximum force transmitted into the foundation due to the machine is to be 500 kN. Assume that the damping can be neglected.

(R.P.M – The no. of revolution a rotational device complete a minute used in to measure rotational speed or angular velocity)

Sol^n:- Given data

$w = 20000\,kN$

Force magnitude $= 5000\,kN = F_0 =$ exisiting force $=$ unbalanced force.

frequency $(\omega) = 600\,r.p.m.$

$K = ?$

Force transmitted $(F_T) = 500\,kN$.

Damping ratio $\frac{C}{C_c} = D = 0$

$$m = w/g = \frac{20000\,kN}{9.81} = \frac{20000 \times 1000}{9.81} = 2.0387 \times 10^6\,kg$$

$$F_T = F_0 M \sqrt{1 + 4D^2 r^2} =$$

$$M = \frac{1}{\sqrt{(1-r^2)^2 + 4D^2 r^2}} = \frac{1}{1-r^2}$$

$$500 = 5000 \times \frac{1}{1-r^2}$$

$(1\,kg = 1\,N/m\,sec^2)$

$$\Rightarrow 1 - r^2 = 10$$

$$\Rightarrow r = 3 = \frac{f}{f_n} = \frac{\omega}{\omega_n}$$

$\omega = 600\,r.p.m = 10\,r.p.s$

$$\frac{\omega}{\omega_n} = 3 \Rightarrow \frac{10}{3} = \omega_n = 3.33\,r.p.s$$

$$\omega_n = \sqrt{K/m} \Rightarrow = K = m.\omega_n^2 = 2.0387 \times 10^6 \times (3.33)^2 = 22.65 \times 10^6\,kg/sec^2$$

$K = 22.65 \times 10^6\,N/m$

Q.) Resonance occured at a frequency of 22 cycles per second in a vertical vibration test of a block 1m x 1m x 1m. Determine the coefficient of elastic uniform in compression of the soil given that the weight of the oscillator is 65 kg and that the force produced by it at 12 cycles per second is 100 kg. Also compute the amplitude in vertical dir at 12 cycles per second.

Soln:- Given data

$f_n = 22$ cycles/sec. $\quad f = 12$ cycles/sec.

Size = 1m x 1m x 1m

$A_z = ?$

$C_u = ?$

Mass of test block of concrete $= \frac{w}{g} = \frac{1 \times 1 \times 2.4 \times 1000}{9.81} = 244.65$ kg

mass of vibrator $= \frac{65}{9.81} = 6.63$ kg

$m = 6.63 + 244.65 = 251.28$ kg.

$\omega_n = \sqrt{\frac{C_u \cdot A}{m}} \Rightarrow C_u = \frac{\omega_n^2 \cdot m}{A} = \frac{(2\pi f_n)^2 \cdot m}{A}$

$f_n = \frac{1}{2\pi} \cdot \omega_n$

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

$= \frac{(2\pi 22)^2 \cdot 251.28}{1\ m^2}$

$= 14.801 \times 10^6$ kg/m^3

F_0 = Total load produced in vertical direction
= 100 kg.

$$r = \frac{f}{f_n} = \frac{12}{22} = 0.5455 \Rightarrow r^2 = 0.2975$$

$$\therefore \text{Amplitude } (A_z) = \frac{F_0}{m \omega_n^2 (1 - r^2)}$$

$$= \frac{100}{251.28 (44\pi)^2 [1 - 0.2925]}$$

$$= 2.96 \times 10^{-5} \text{ m} = 0.0296 \text{ m}.$$

Q) Using Barken's expression for natural frequency and the amplitude of vibrations, calculate the change in the percentage amplitude in terms of frequency ratio (r) if the soil mass participating in the vibration is 23% of m. also calculating this change for $r = 0.3$ & $r = 2$

Soln. — Given data

$r = 0.3$

$r = 2$

(i) $\omega_n = \sqrt{\frac{C_u \cdot A}{m}}$ (for the 1st case without soil participation)

$r = \frac{\omega}{\omega_n}$, $A_z = \frac{F_0}{m \omega_n^2 (1 - r^2)} = \frac{a}{1 - r^2}$

(ii) For the 2nd case (with soil participation)

$$\omega_n' = \sqrt{\frac{C_u A}{m}} = \sqrt{\frac{C_u \cdot A}{1.23\, m}} = \omega_n \sqrt{\frac{1}{1.23}}$$

$$A_z' = \frac{F_0}{(1.23 m)(\omega_n')^2 (1 - r'^2)} = \frac{F_0}{(1.23 m)\left(\frac{\omega_n^2}{1.23}\right)(1 - r'^2)}$$

$$= \frac{a}{1 - r'^2}$$

$\therefore$ % change $A_Z = \dfrac{A_Z' - A_Z}{A_Z}$

$= \dfrac{H^2 - r^2}{1 - r'^2} \times 100$

$r^2 = \left(\dfrac{w}{w_n}\right)^2$ and $r'^2 = \left(\dfrac{w}{w_n'}\right)^2 = \dfrac{w}{\left(\frac{w_n^2}{1.23}\right)} = 1.23\left(\dfrac{w}{w_n}\right)^2 = 1.23r^2$

% change in $A_Z = \dfrac{1.23r^2 - r^2}{1 - 1.23r^2} \times 100$

$= \dfrac{23r^2}{1 - 123r^2}$

when $r = 0.3$, % change in $A_Z = \dfrac{23(0.3)^2}{1 - 1.23(0.3)^2}$

$= 2.3\%$

when $r = 2$, % change in $A_Z = \dfrac{23(2)^2}{1 - 1.23(2)^2}$

$= -23.5\%$

Q. List the basic differences in analyzing a reciprocating machine foundation by two approaches.

2) Linear theory of elasticity :- (Elastic half space method)

-> This method is called the elastic half space method because the ground is assumed to be an elastic, homogeneous, isotropic, semi-infinite body which in the theory of elasticity is referred to as elastic half space.

-> The elastic half space theory can be used to determine the values of equivalent soil springs and damping then make use of theory of vibrations to determine the response of the foundation.

-> These are known as the elastic half space analogs.

-> The machine foundation is idealized as a mechanical oscillator with a circular base resting on the surface of ground.

-> The Boussinesq's solution for finding the stresses induced in soil due to a point load on the ground surface.

-> In the elastic half space method, the point load is assumed to be dynamic. By integrating the solution for a dynamic point load over a circular area, the stresses due to a circular machine foundation is calculate.

-> 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.

→ Using the theory the values 'K' and 'C' are calculated.

→ Soil properties that are required to determine K and C are the shear modulus (G), mass-density (ρ) and poisson's (μ).

→ According to the theory with the vertical-vibrations of a machine foundation of radius r_0.

$$K_z = \frac{4 G r_0}{1-\mu}$$

$$C_z = \frac{3.4 r_0^2}{1-\mu} \sqrt{\rho G}$$

Q:- what are the dynamic properties of soil?

=> Soil profile and dynamic soil properties :-

-> Satisfactory design of a machine foundation needs information on soil profile, depth of different layers, physical properties of soil & ground water level.

-> Dynamic shear modulus of soil is generally determined from laboratory or field tests.

-> This information can be obtained by usual sub surface exploration techniques. In addition one must determine dynamic shear modulus, material damping, Poisson's ratio and mass density of soil for dynamic analysis of the machine-foundation.

→ Material damping can be determined from vibration tests on soil columns in the laboratory.

→ Geometrical damping is estimated from elastic-half space theory and appropriate analogs.

Q:- Explain each term.

Coefficient of elastic uniform compression :- (C_u)

→ It is the ratio of external uniform pressure to the elastic part of the settlement.

Coefficient of elastic uniform shear (C_c)

→ It is the ratio of average shear stress at the foundation contact area to the elastic part of the displacement in sliding.

Coefficient of elastic non-uniform shear (C_ψ)

→ It is the ratio of external moment applied to the vertical axis to the product of polar moment of inertia of contact area of base of foundation and the angle of rotation of the foundation.

Coefficient of elastic non uniform compression (C_ϕ)

→ It is the ratio of external moment about a horizontal axis to the product of moment of inertia of contact area of base of the foundation about the same axis and the corresponding angle of rotation of the foundation uniform pressure to the elastic part of the settlement.

Q:- what do you mean by horizontal vibration test.

Horizontal vibration test :-

→ The value of coefficient of elastic uniform shear C_z can be determined by horizontal vibration test.

→ The mechanical oscillator is mounted on the block such that it generates horizontal simusoidal vibrations in the direction of the longitudinal axis of the block.

→ Three calibrated acceleration pickups are mounted on the block, one each at top, bottom and middle, along the vertical central line of the transverse face of the block so as to sense the horizontal vibrations.

→ The oscillator is excited in steps, starting from "at rest" conditions.

→ The signal from each pickup is amplified and recorded.

→ Further the same precedure that was used for vertical vibrations is adopted.

→ The amplitude of horizontal vibrations, A_x is obtained from

$$A_x = \frac{a_x}{4\pi^2 f^2}$$

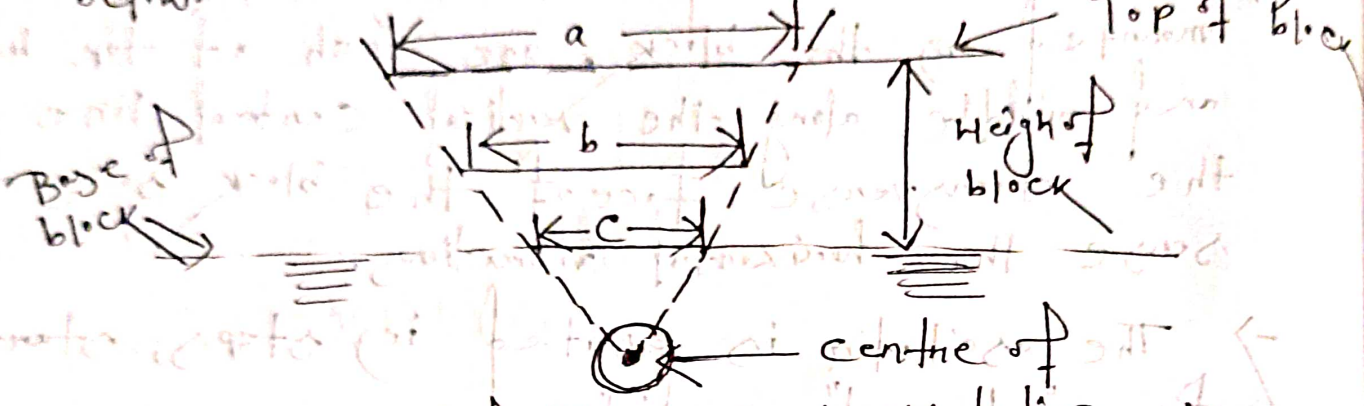
where, a_x = horizontal acceleration in the direction under consideration.

f = frequency in cps.

→ The amplitude, frequency plot is obtained from these observations and the natural frequency of horizontal vibrations is determined.

→ Further, the amplitude of vibration at the natural frequency of the system are obtained from the pick-ups at the three locations and plotted against the height of the block.

→ The natural frequency corresponds to the first mode or the lower natural frequency if the plot corresponds to the figure given below.



→ The coefficient of elastic uniform (shear) of the soil is given by the equation.

$$C_u = \frac{8\pi^2 \gamma f_{nx}^2}{(A_0 + I_0) + \sqrt{(A_0 + I_0)^2 - 4\gamma A_0 I_0}}$$

where, $\gamma = \frac{M_m}{M_{mo}}$ $\qquad A_0 = A/m$

f_{nx} = Horizontal resonant frequency of block soil system.

M_m = Mass moment of inertia of the block oscillator and motor about the horizontal axis passing through the centre of gravity of block and perpendicular to the direction of vibration.

Q:- what is vertical vibration test?

Vertical vibration test :-

→ The mechanical oscillator is mounted on the block such that it generates purely vertical sinusoidal vibrations and the line of action of vibratory forces passes through the centre of gravity of the block;

→ Two acceleration pick ups, duly calibrated are mounted on the block such that they ~~are~~ sense vertical motion of the block.

→ Choosing a suitable value of angle of setting of eccentric masses, the oscillator is made to run at a constant frequency.

→ The ~~angle~~ signals of acceleration pickups are recorded through amplifiers and per recorded on any other suitable recording/indicating device

→ The frequency of the oscillator is then increased and then process is repeated.

→ The same process is continued for other eccentricity settings.

→ In a forced vertical vibration test, the amplitude of vibration (A_z) at a given frequency, (f_z) is given by

$$A_z = \frac{a_z}{4\pi^2 f_z}$$

where, a_z = Acceleration in the vertical direction.

→ Amplitude vs. frequency curve is then plotted for each eccentricity value to obtain the natural frequency of soil block system.

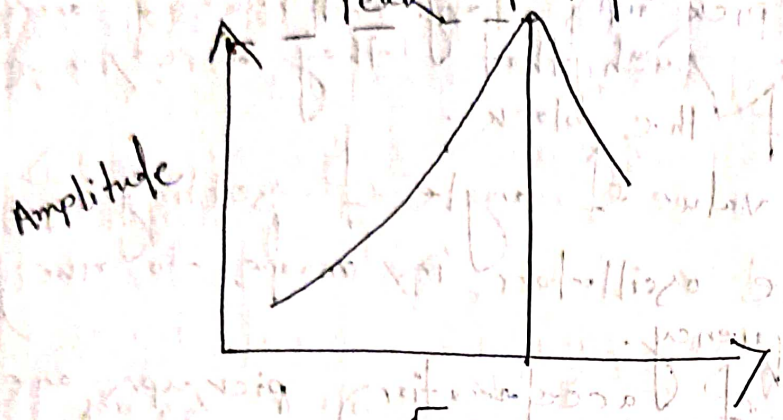
The coefficient of elastic uniform compression C_u, is given by

$$C_u = \frac{4\pi^2 f_{nz}^2 m}{A}$$

where, f_{nz} = Natural frequency of vibration of soil block system

m = mass of block, oscillator & motor

A = Contact area of block with soil



Amplitude vs. frequency curve

→ The value of C_u varies with the contact area of the base, Hence, the value of C_u obtained from test needs a correction due to contact area.

→ IS code recommends that for area larger than $1 m^2$, the value obtained for an area of $1 m^2$ may be used.

$$C_u = \frac{4\pi^2 f_{nz}^2 m}{A}$$

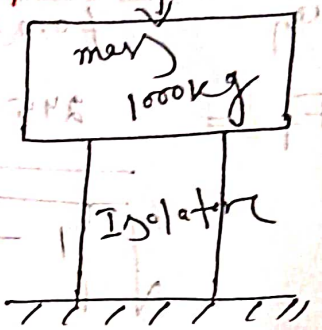
Q.) A machine of mass 1000kg is acted upon by an external force of 2450 N at 1500 rpm. To reduce the effect of vibration, isolators are provided having a static deflection of 2mm under machine weight and its damping factor is 0.2.

Determine :- (i) Amplitude of vibration of machine.

(ii) Force transmitted to the foundation

(iii) Speed at which the maximum amplitude of vibration would occur.

Sol:- Given data



$m = 1000kg$

$F_0 = 2450\ N$

$N = 1500$ rpm

$\Rightarrow \omega = \frac{2\pi N}{60}$

$= \frac{2\pi \times 1500}{60}$

$= 157.07$ rad/sec

static displacement (deflection) $(\delta) = 2mm$

$= 2 \times 10^{-3} m$

$D = 0.2$

X (or) $A_z = ?$

$F_T = ?$

$$F_T = F_0 \sqrt{\frac{1 + \left(2D\frac{\omega}{\omega_n}\right)^2}{\left\{1 - \left(\frac{\omega}{\omega_n}\right)^2\right\}^2 + \left(2D\frac{\omega}{\omega_n}\right)^2}}$$

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

spring force $F = Kx = K\delta = mg$

$K\delta = m \cdot g$

$$\Rightarrow K = \frac{mg}{\delta} = \frac{1000 \times 9.8}{2 \times 10^{-3}}$$

$$\boxed{K = 4.9 \times 10^{6}\ N/m}$$

$$\omega_n = \sqrt{K/m} = \sqrt{\frac{4.9 \times 10^{6}}{1000}} = 70.03\ rad/s$$

$$\frac{\omega}{\omega_n} = \frac{157.07}{70.03} = 2.24$$

$$F_T = \frac{2450\sqrt{1 + \{2(0.2)(2.24)\}^2}}{\sqrt{\{1 - (2.24)^2\}^2 + \{2(0.2)(2.24)\}^2}}$$

$$= 2450 \times 0.3259$$

$$\boxed{F_T = 798.6\ N}$$

Amplitude (X) or (A_z)

$$X = \frac{\left(\frac{F_0}{K}\right)}{\sqrt{\left\{1 - \left(\frac{\omega}{\omega_n}\right)^2\right\}^2 + \left(2\zeta\frac{\omega}{\omega_n}\right)^2}}$$

$$= \frac{2450 / 4.9 \times 10^{6}}{\sqrt{\{1 - (2.24)^2\}^2 + (2 \times 0.2 \times 2.24)^2}}$$

$$= 1.21 \times 10^{-4}\ m$$

$$= 0.121 \times 10^{-3}\ m$$

$$= 0.121\ mm$$

$\omega = \omega_n$

$= 70.03\ rad/s$

Q:- Explain degree of freedom system.

Degree of freedom of a block foundation :-

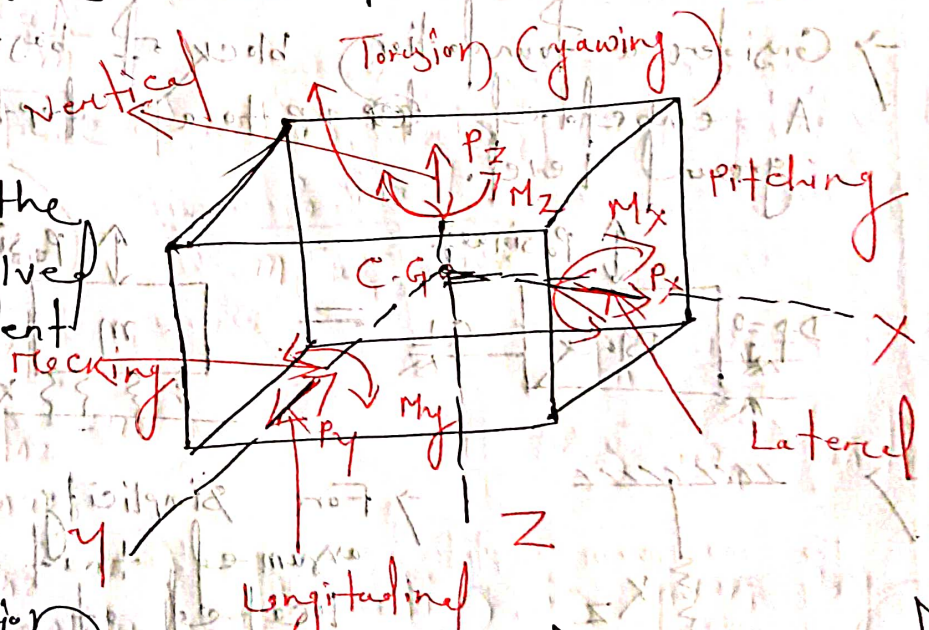
→ For a block foundation, under the action of unbalanced forces, the rigid block may undergo displacements or oscillations as below.

a) Translation along z-axis
b) Translation along x-axis
c) Translation along y-axis
d) Rotation along z-axis - yawing
e) Rotation along x-axis - pitching
f) Rotation along y-axis - Rocking.

→ The rigid block foundation is designed to have six degree of freedom. Thus it means any displacement or movement can be resolved into six independent displacement.

→ The rigid body displacement of the block can be resolved into six independent displacement as discussed.

→ out of these six types of motion, translation and rotation along vertical axis (z-axis) can occur independently of any other motion.



(Modes of vibration of a rigid block foundation)

Axes and Coordinates IS:2974 (Part-1-1982)

→ Translation about x-axis (or y-axis) and rotation about y-axis (or x-axis) are coupled motion.

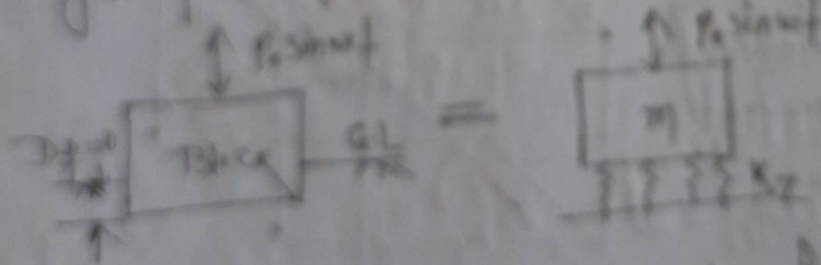
→ Thus analysis of block foundation requires consideration for four types of motion, i.e. out of these, two are independent and two are coupled.

→ For estimating the natural frequencies of vibration in the coupled modes, the natural frequency of the system in pure translation and pure rocking need to be determined.

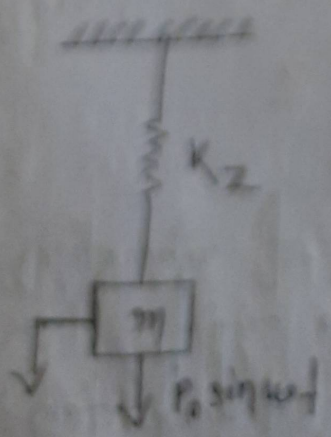
→ Further, as the state of stress below the foundation block in different modes is different, the corresponding spring constant has to be used.

Vertical vibrations of a block foundation

→ Consider a foundation block of base contact area 'A' embedded up to a depth D_f below the ground level.



→



→ For simplicity of analysis, it is assumed that the block is located at the ground level such that there is no embedment, that is $D_f = 0$

→ The subsoil is assumed to be replaced by an equivalent spring with spring constant

→ Translation about x-axis (or y-axis) and rotation about y-axis (or x-axis) are coupled motion.

→ Thus analysis of block foundation requires consideration for four types of motions. out of these, two are independent and two are coupled.

→ For estimating the natural frequencies of vibration in the coupled modes, the natural frequency of the system in pure translation and pure rocking need to be determined.

→ Further, as the state of stress below the foundation block in different modes is different, the corresponding spring constant has to be used.

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Q. Determination of Natural Frequency :-

→ The natural frequency of the foundation soil system can be determined using the theory of vibrating. The equation of motion, neglecting damping, is

$$m\frac{d^2z}{dt^2} + Kz = F_0 \sin\omega t$$

where, m = mass of machine, foundation & participating soil.

K = equivalent spring constant of the soil.

→ The natural frequency of the system is given by

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

where, ω_n is in radian per sec.

ω_n = circular natural frequency.

Also, $$f_n = \frac{1}{2\pi}\sqrt{K/m}$$

f_n = Natural frequency

f_n is in cycles per second.

Thus, $$f_n = \frac{1}{2\pi}\sqrt{\frac{K}{m_f + m_s}}$$

m_f = Mass of machine and foundation.

m_s = mass of the participating soil mass.

→ Barkan (1962) gave the following relation for the natural frequency

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

where, C_u = Coefficient of elastic uniform compression.

A = Contact area of foundation with soil.

$$K = C_u \times A$$

F_0 = exciting force.

→ The maximum amplitude is given by

$$Z_{max} = \frac{F_0}{m \cdot \omega_n^2 (1-r^2)}$$

→ The coefficient of elastic uniform compression (C_u) depends upon the type of soil.

$$C_u = 1.13 \frac{E}{(1-\mu^2)} \cdot \frac{1}{\sqrt{A}}$$

$$\frac{(C_u)_2}{(C_u)_1} = \left(\frac{A_1}{A_2}\right)^{1/2}$$

Q:- Explain 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).

In single degree of freedom system

$$C_c = 2\sqrt{km}$$

$$= 2\sqrt{m \cdot \omega_n^2 \cdot m}$$

$$= 2\sqrt{m^2 \cdot \omega_n^2}$$

$$\boxed{C_c = 2 m \omega_n}$$

$\omega_n^2 = k/m$

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

Q:- Explain resonant column test?

Resonant Column test :-

-> The resonant column test is used to obtain the elastic modulus E, shear modulus G and damping characteristics of soil at low strain amplitudes.

-> This test is based on the theory of wave propagation in prismatic rods. Either a cylindrically varying axial load or torsional load is applied to one end of the prismatic or cylindrical specimen of soil.

-> This in turn will propagate either a compression wave or a shear wave in the specimen of soil

-> In this technique the excitation frequency generating the wave is adjusted until the specimen experiences resonance. The value of the resonant frequency is used in getting the value of E and G depending on the type of excitation (axial or torsional)

-> The resonant column technique was used for testing of soils by many investigations.

-> several versions of torsional resonant column device using different end conditions to constraint the test specimen are available.

-> Some common end conditions used in developing the equipment are as follows.

1) Fixed-free
2) Spring base model
3) Fixed partially restrained

-> The vibration exciting device itself, without a specimen attached is a single degree of freedom system. Firstly remove the specimen cap and the additional rigid mass, connect the sine wave generator

to the vibration excitation device and vary the excitation frequency to determine the resonant frequency f_{n1} of the device.

→ The rotational spring constant, K_0 of the spring about the axis of specimen can be obtained using equation i.e

$$K_0 = \frac{4\pi^2 - J_A f_{n1}^2}{\left[1 - \left(\frac{f_{n1}}{f_{n1}}\right)^2\right]}$$

→ The value of mass polar moment of inertia of the rigid mass, J_0 can be computed.

$$J_0 = \frac{K_0}{4\pi f_{n0}^2}$$

→ Logarithmic decrement for apparatus δ_A as follows.

$$\delta_A = \frac{1}{n} \log_e \frac{A_1}{A_n}$$

where, A_1 = Amplitude of vibration for the 1st cycle.

A_2 = Amplitude of vibration for the nth cycle.

→ Damping constant is given by

$$D_A = \frac{\delta_A}{\pi} \sqrt{K_0 J_0}$$

Q:- Explain ultrasonic pulse test?

Ultrasonic pulse test :-

→ The theory of ultrasound is similar to that of audible sound. Sound is the result of mechanical disturbance of a material that is a vibration.

→ Ultrasonic pulses of either compression or shear waves can be generated and received by suitable piezoelectric crystals.

→ Using elastic theory, a relationship between the speed of propagation and wave amplitude of these waves and certain properties of the media through which they are travelling can be determined as follows.

$$E = \rho V_c^2 \frac{(1+\mu)(1-2\mu)}{1-\mu} \quad \text{---(1)}$$

$$G = \rho V_s^2 \quad \text{---(2)}$$

$$\mu = \frac{1 - \frac{1}{2}\left(\frac{V_c}{V_s}\right)^2}{1 - \left(\frac{V_c}{V_s}\right)^2} \quad \text{---(3)}$$

$$\delta = \frac{2.302}{n} \log_{10} \frac{A_o}{A_n} \quad \text{---(4)}$$

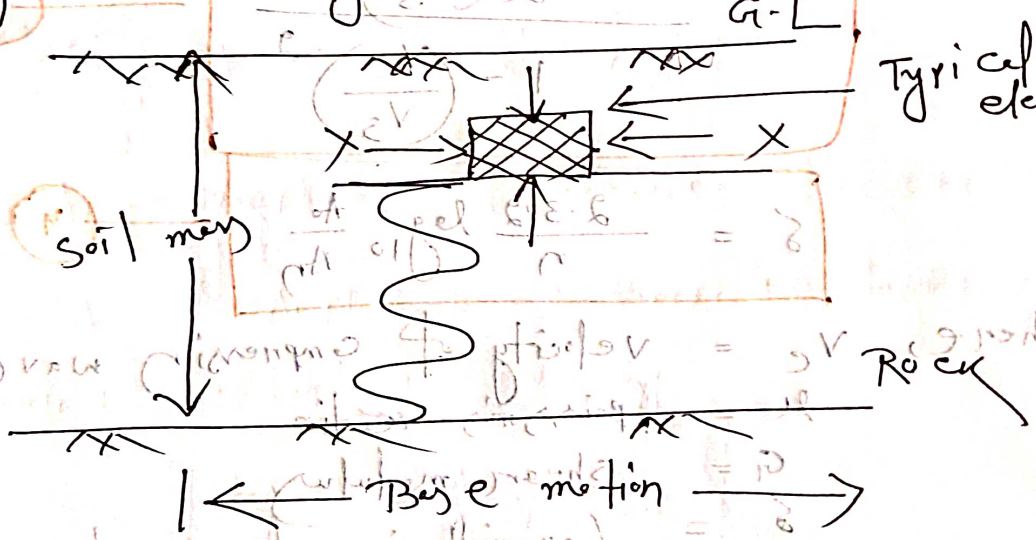
where, V_c = velocity of compression wave
μ = poissons ratio
G = shear modulus
δ = Logarithmic decrement
A_n = amplitude after 'n' oscillations.
V_s = velocity of shear wave
E = young's modulus
ρ = mass density = γ/g
A_o = initial value of amplitude.

→ In this test ultrasonic transmitters and receivers are attached to platens that can be placed at each end of a specimen with the distance separating them carefully measured.

→ The transmitters and receivers are made of piezoelectric materials which exhibit changes in dimensions when subjected to a voltage across their faces and which produce a voltage across their faces when distorted.

→ A high frequency electrical pulse applied to the transmitter causes it to deform rapidly and produce a stress wave that travels through the specimen towards the receivers.

→ The distance between the transmitters and receiver is divided by the time difference between the voltage pulse to obtain the wave-propagation velocity.



Q1- Explain shear wave?

Shear waves:

Differentiating $\rho \frac{\partial^2 v}{\partial t^2} = (\lambda+\mu)\frac{\partial \bar{e}}{\partial y} + \mu \nabla^2 v$ with respect to 'z' and $\rho \frac{\partial^2 w}{\partial t^2} = (\lambda+\mu)\frac{\partial \bar{e}}{\partial z} + \mu \nabla^2 w$ with respect to 'y' we get

$$\rho \frac{\partial^2}{\partial t^2}\left(\frac{\partial v}{\partial z}\right) = (\lambda+\mu)\frac{\partial \bar{e}}{\partial y \partial z} + \mu \nabla^2 \frac{\partial v}{\partial z} \quad \text{---(1)}$$

and $$\rho \frac{\partial^2}{\partial t^2}\left(\frac{\partial w}{\partial y}\right) = (\lambda+\mu)\frac{\partial \bar{e}}{\partial y \partial z} + \mu \nabla^2 \frac{\partial w}{\partial y} \quad \text{---(2)}$$

Subtracting eqn (1) from eqn (2), we get,

$$\rho \frac{\partial^2}{\partial t^2}\left(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}\right) = \mu \nabla^2 \left(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}\right) \quad \text{---(3)}$$

From eqn $2\bar{w}_x = \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}$, $\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z} = 2\bar{w}_x$, therefore,

$$\frac{\rho \partial^2 \bar{w}_x}{\partial^2 t^2} = \mu \nabla^2 \bar{w}_x$$

$$\frac{\partial^2 \bar{w}_x}{\partial t^2} = \frac{\mu}{\rho} \nabla^2 \bar{w}_x = v_s^2 \nabla^2 \bar{w}_x \quad \text{---(4)}$$

similar expressions can be obtained for $\bar{w}_y$ & $\bar{w}_z$ as below,

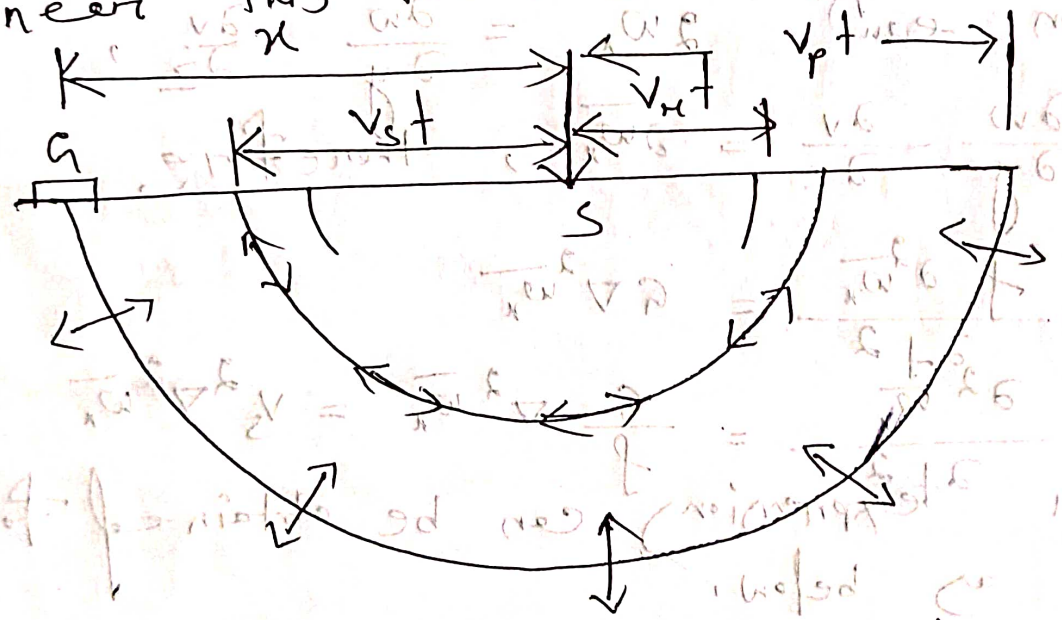
$$\frac{\partial^2 \bar{w}_y}{\partial t^2} = \frac{\mu}{\rho} \nabla^2 \bar{w}_y = v_s^2 \nabla^2 \bar{w}_y \quad \text{---(5)}$$

$$\frac{\partial^2 \bar{w}_z}{\partial t^2} = \frac{\mu}{\rho} \nabla^2 \bar{w}_z = v_s^2 \nabla^2 \bar{w}_z \quad \text{---(6)}$$

The above expressions indicate that the rotation is propagated with velocity V_s which is equal to $\sqrt{G/\rho}$. Shear wave is also referred as distortion wave or S-wave.

⇒ Wave propagation in elastic half space:-

→ In an elastic homogeneous ground, stressed suddenly at a point 's' near its surface. Three elastic waves travel outward at different ~~level~~ speed. Two are body waves i-e, they are propagated as spherical fronts affected only a minor extend by the free surface of the ground. and third is surface wave which is confined to the region near this free surface.



(pulse fronts of the P, S & R waves)

389. A vane shear test on a soil sample gives a moment of total resistance M. The shear stress at failure 'S' being more or less uniform at top, bottom and surface of cylinder of soil is given by (where H = height of vane, D = diameter of vane)

(a) $s = \dfrac{2M}{\pi D^2 H}$ (b) $s = \dfrac{2M}{\pi D^2 (H + D)}$

(c) $s = \dfrac{2M}{\pi D^2 \left(H + \dfrac{D}{3}\right)}$ (d) $s = \dfrac{2M}{\pi D H}$ **(IES 2008)**

390. Consider the following factor pertaining to flow through soil

1. Hydraulic gradient 2. Grain size
3. Void ratio
4. Cross sectional area of sample

Of these the factors affecting permeability include.

(a) 1 and 4 (b) 2 and 3
(c) 1, 2 and 3 (d) 2, 3 and 4

391. Which one of the following gives the correct decreasing order of the densities of a soil sample?

(a) Saturated, submerged, wet, dry
(b) Saturated, wet, submerged, dry
(c) Saturated, wet, dry, submerged
(d) Wet, saturated, submerged, dry

392. The upper limit of area ratio for which the amount of disturbance of soil sample can be considered to be small is

(a) 10 % (b) 15 % (c) 20 % (d) 25 %

393. Consider the following types of soil tests.

1. California bearing ratio
2. Consolidation
3. Unconfined compression

The soil tests required to be done in the case of undisturbed samples include

(a) 1, 2 and 3 (b) 1 and 2
(c) 1 and 3 (d) 2 and 3

394. In a typical deposit of submerged soil, the approximate depth at which the intergranular pressure is equal to 50 kN/m^2 is

(a) 2.5 m (b) 5 m
(c) 7.5 m (d) 10 m

395. In a saturated clay layer undergoing consolidation with single drainage at its top, the pore water pressure would be the maximum at its

(a) Top (b) Middle
(c) Bottom (d) Top as well as the bottom

396. A saturated clay stratum of thickness 10 m, bounded on top and bottom by medium coarse sand layers, has a coefficient of consolidation of 0.002 cm^2/s. If this stratum is subjected to loading, it is likely that it would under go 50% of its primary consolidation in

(a) 1136 days (b) 227 days
(c) 284 days (d) 568 days

397. A circular area of radius 'R' on the surface of a semi infinite soil mass is uniformly loaded with a loading intensity of 'q'. The vertical stress σ_z directly below its centre at a depth 'z' is given by **(IES 2009)**

(a) $\dfrac{q}{z}\dfrac{2}{\pi}\left[\dfrac{1}{1+(R/z)^2}\right]^2$ (b) $q\left[1-\dfrac{1}{1+(R/z)^2}\right]^{3/2}$

(c) $\dfrac{3q}{2\pi z^2}\left[\dfrac{1}{1+(R/z)^2}\right]^{5/2}$ (d) $\dfrac{q}{2\pi z}\left[\dfrac{1}{1+(R/z)^2}\right]^{3/2}$

398. Consider the following steps:

1. Driving sheet piles surrounding a vibration receiving structure.
2. Digging a trench around a source of vibration.
3. Placing rubber mountings between a machine causing vibration and its base.

Active isolation of vibration can be achieved by

(a) 1 and 2 (b) 1 and 3
(c) 2 and 3 (d) 3 alone

399. Consider the following statements regarding settlement of foundations:

1. Differential settlement of foundation leads to structural damage to the superstructure.
2. In non-cohesive soils, the major component of settlement is due to consolidation.
3. Lowering of ground water table contributes to settlement foundations.

Of these statements

(a) 1 and 2 are correct (b) 1 and 3 are correct
(c) 2 and 3 are correct (d) 1, 2 and 3 are correct

400. A normally consolidated clay layer settles by 25 mm when the effective stress is increased from 15 kPa to 30 kPa. If the effective stress is later increased further from 30 kPa to 60 kPa then the additional settlement would be

(a) 25 mm (b) 50 mm
(c) 75 mm (d) 100 mm

401. The stress distribution at a depth beneath a loaded area is determined using Newmark's influence chart which indicates an influence value of 0.005. The number of segments covered by the loaded area in the chart is 20 and the intensity of loading on the area is 10T/m^2. The intensity of stress distribution at that depth is

(a) 1 T/m^2 (b) 2 T/m^2
(c) 5 T/m^2 (d) 10 T/m^2

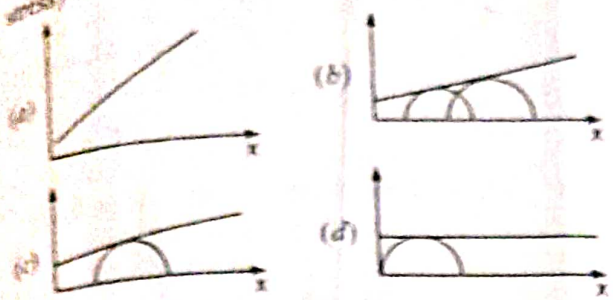
402. Consider the following field tests

1. Vertical pile load test
2. Cyclic pile load test
3. Lateral pile load test
4. Instrumented test pile

While estimating the load carrying capacity of a pile, the tests that can be used for separating the skin resistance from point resistance, would include.

(a) 1 and 3 (b) 1 and 4
(c) 2 and 3 (d) 2 and 4

Which one of the following diagrams correctly illustrates the Mohr's stress conditions of unconfined shear test on cohesive soil? (x-axis Normal stress, y-axis shear stress)



404. The mean unconfined compressive strength of a purely cohesive soil was found to be 50 kN/m^2. The ultimate bearing capacity of a square footing calculated by Terzaghi's concept (bearing capacity factor NC = 5.7) will be
(a) 185.25 kN/m^2 (b) 390.5 kN/m^2
(c) 285 kN/m^2 (d) 142.5 kN/m^2
(IES 2012)

405. A soil specimen having a cohesion c = 106 kN/m^2 and $\phi = 6°$ is tested in an unconfined compression test apparatus. The angle which the failure plane of the sample will make with the axis of the sample is
(a) 42° (b) 45°
(c) 48° (d) 51°

406. A CD triaxial test is performed on a clay soil. The given figures show two curves each for deviator stress vs axial strain 5 and volume change vs axial strain %. If the clay is over consolidated, then the results would be as in curves

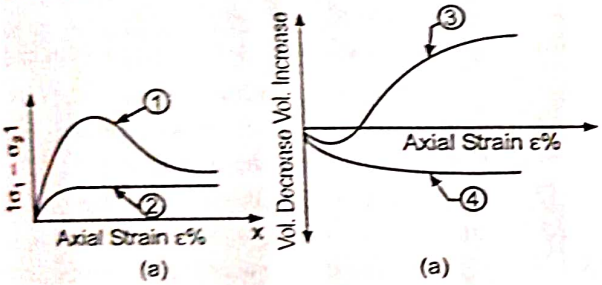


Fig. 8.39.

(a) 1 and 3 (b) 1 and 4
(c) 2 and 3 (d) 2 and 4

407. Given that for a soil backfill,
K_A = coefficient of active earth pressure
K_O = coefficient of earth pressure at rest, and
K_P = coefficient of passive earth pressure,
Which one of the following represents the correct relationship between K_A, K_O and K_P?
(a) $K_O = K_P/2$ (b) $K_O = (K_A + K_P)/2$
(c) $K_O = (K_P - K_A)/2$ (d) None of the above

408. A vertical retaining wall retains a c-ϕ backfill and carries a surcharge of uniform intensity 'q' per unit area. The depth Z_o from the top of the wall where the active earth pressure is zero is given by ($\alpha = 45° + \phi/2$ and γ = unit weight of the soil)
(a) $\frac{q}{\gamma}$ (b) $\frac{2c}{\gamma}\tan\alpha - \frac{q}{\gamma}$
(c) $\frac{2c}{\gamma}\tan\alpha + \frac{q}{\gamma}$ (d) $\frac{2c}{\gamma}\tan\alpha$

409. A cantilever sheet pile derives its stability from
(a) Lateral resistance of soil
(b) Self weight (c) The deadman
(d) The anchor rod

410. Deflection of a sheet pile in a braced cut
(a) Increases from top to bottom
(b) Decreases from top to bottom
(c) Increases from top and then decreases
(d) Decreases from top and then increases

411. A particular soil sample is subjected to test for the determination of permeability coefficient in two separate constant head permeameters, whose specifications are as under:

	Permeameter A	Permeameter B
Diameter of sample	D	2 D
Length of sample	2 L	L

If the tests on both the permeameters are conducted with equal head of water applied on the samples, then the ratio of amount of water discharged through the permeameters A and B during a period of one hour will be
(a) 4.000 (b) 1.000 (c) 0.250 (d) 0.125

412. The standard compaction curve obtained from a laboratory test is shown in the figure. The dotted compaction curve of the same soil (shown in the figure) will be obtained if

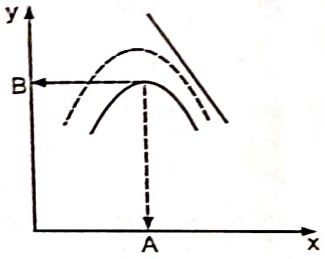


Fig. 8.40.

(a) Compactive effort is decreased
(b) Moisture content is reduced with same compactive effort
(c) Moisture content is increased with same compactive effort
(d) Compactive effort is increased

413. The foundation soil under the toe of a dam has a void ratio 'e'. The specific gravity of the soil solid is G. Factor of safety against piping is to be taken as 2.5. The maximum permissible upward exit gradient is given by
(a) $i = 2.5\left(\frac{G-1}{1+e}\right)$ (b) $i = 2.5\left(\frac{1+e}{G-1}\right)$
(c) $i = 0.4\left(\frac{1+e}{G-1}\right)$ (d) $i = 0.4\left(\frac{G-1}{1+e}\right)$

414. Given that
ω_n = natural frequency of foundation soil system,
C_u = coefficient of elastic uniform compression of soil,
A = contact area of foundation with soil, and
m = mass of machine plus foundation, natural frequency of foundation soil system for analysis of machine foundation shall be determined by Barken's method by using the equation:

(a) $\omega_n = C_u \frac{A}{m}$ (b) $\omega_n = C_u \sqrt{\frac{A}{m}}$

(c) $\omega_n = \frac{A}{m}\sqrt{C_u}$ (d) $\omega_n = \sqrt{\frac{C_u A}{m}}$

415. The given diagram relates to design features of samplers affecting soil disturbance. The area ratio of the soil sample is given by

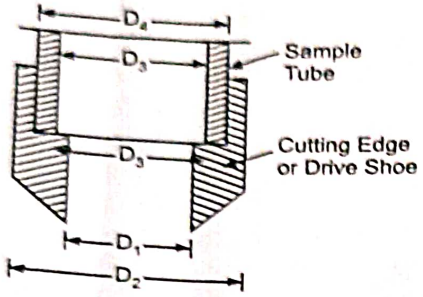


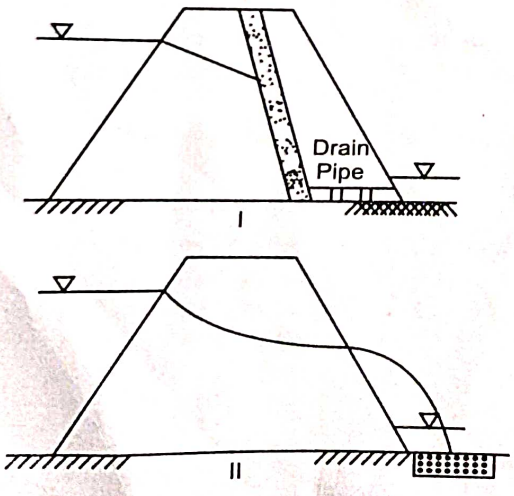
Fig. 8.41.

(a) $\frac{D_2^2 - D_3^2}{D_2^2}$ (b) $\frac{D_2^2 - D_1^2}{D_1^2}$

(c) $\frac{D_2^2 - D_4^2}{D_4^2}$ (d) $\frac{D_3^2 - D_1^2}{D_1^2}$

416. Which one of the following parameters can be used to estimate the angle of internal friction of sandy soil?
(a) Particle size
(b) Roughness of particle
(c) Particle size distribution
(d) Density index

417. Phreatic lines for different types of drainage/ filter arrangements are shown in figure.



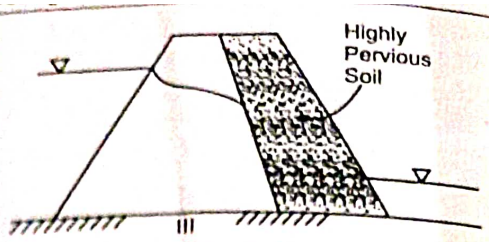


Fig. 8.42.

The phreatic line is correctly shown in figure.
(a) I and II (b) I and III
(c) II alone (d) II and III

418. Given that the effective angle of internal friction of a soil is 10°, the angle between the failure plane and the major principal plane will be
(a) 17.5° (b) 27.5°
(c) 40° (d) 50°

419. On analysis of particle size distribution of a soil, it is found that $D_{10} = 0.1$ mm, $D_{30} = 0.3$ mm and $D_{60} = 0.8$ mm. The uniformity coefficient and coefficient of curvature, as given by the particle size distribution curve, are respectively
(a) 3 and 3
(b) 2.67 and 1.25
(c) 2.67 and 3
(d) 8 and 1.125

420. In which one of the following situations would one use shear parameters obtained from consolidated quick test with pore pressure measurements?
(a) Foundation on silty sands
(b) Excavation in saturated clays
(c) Pervious dams and slope stability
(d) Determination of earth pressures in saturated clays

421. Consider the following limitations:
1. Can be performed only on purely cohesionless soils.
2. Plane of failure is predetermined.
3. There is virtually no control on drainage.
4. Non-uniform distribution of stresses.
5. Principal stresses in the sample cannot be determined.

The limitations inherent in direct shear test include:
(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 3, 4 and 5 (d) 1, 2 and 5

422. A sample of clay and a sample of sand have the same specific gravity and void ratio. Their permeabilities would differ because
(a) Their porosities would be different
(b) Their degrees of saturation would be different
(c) Their densities would be different
(d) The size ranges of their voids would be different.

423. During seepage through an earth mass, the direction of seepage is
(a) Parallel to the equiponential lines
(b) Perpendicular to the stream lines
(c) Perpendicular to the equiponential lines
(d) Along the direction of gravity.

Consider the following assumptions:
1. Failure occurs on a plane surface.
2. Wall is smooth but not necessarily vertical.
3. Failure wedge is a rigid body.

Coulomb's theory of earth pressure is based on assumptions
(a) 1, 2 and 3 (b) 1 and 2
(c) 1 and 3 (d) 2 and 3

425. Consider the following statements:
Clays which exhibit high activity
1. Contain montmorillonite
2. Contain kaolinite.
3. Have a high silt content.
4. Have a high plasticity index.
5. Have a low plasticity index.

Of these statements
(a) 1, 3 and 5 are correct
(b) 2, 3 and 5 are correct
(c) 2 and 4 are correct
(d) 1 and 4 are correct

426. In a compaction test on a soil sample, if the compaction energy is decreased (γ_d = maximum dry density, OMC = optimum moisture content).
(a) γ_d will increase with increase in OMC
(b) γ_d will decrease with increase in OMC
(c) γ_d will decrease with decrease in OMC
(d) γ_d will increase with decrease in OMC

427. For stability analysis of slopes of purely cohesive soils, the critical centre is taken to lie at the intersection of
(a) The perpendicular bisector of the slope and the locus of the centre
(b) The perpendicular drawn at one third slope from the toe and the locus of the centre
(c) The perpendicular drawn at two third slope from the toe and the locus of the centre
(d) Directional angles.

428. A completely saturated normally consolidated clay is tested in a triaxial test under consolidated undrained condition. The value of pore pressure coefficient at failure, A_f is given by ($\Delta\sigma_3$ = change in cell pressure; $\Delta\sigma_1$ = change in axial stress: Δ_u = corresponding change in pore pressure)

(a) $A_f = \left(\frac{\Delta u - \Delta\sigma_1}{\Delta u - \Delta\sigma_3}\right)$ (b) $A_f = \left(\frac{\Delta u - \Delta\sigma_1}{\Delta\sigma_1 - \Delta\sigma_3}\right)$

(c) $A_f = \left(\frac{\Delta u - \Delta\sigma_3}{\Delta u - \Delta\sigma_1}\right)$ (d) $A_f = \left(\frac{\Delta u - \Delta\sigma_3}{\Delta\sigma_1 - \Delta\sigma_3}\right)$

429. The water table at a location is at the ground surface and the saturated unit weight of the soil is 20 kN/m^3. If, due to heavy precipitation, the water level rises to 2 m above the ground level, the increase in the vertical effective stress at a point 2 m below the ground surface will be
(a) 40 kN/m^2 (b) 20 kN/m^2
(c) 10 kN/m^2 (d) Zero

430. The time 't' required for attaining a certain degree of consolidation of a clay layer is proportional to
(a) H^2 and C_v (b) H^2 and $1/C_v$
(c) $1/H^2$ and C_v (d) $1/H^2$ and $1/C_v$

431. Which one of the following correctly defines the term 'Activity' of clays?
(a) $\frac{\text{Plasticity index}}{\text{Percentage of clay}}$
(b) $\frac{\text{Plastic limit}}{\text{Liquidity index}}$
(c) $\frac{\text{Unconfined compression strength}}{\text{Cohesion}}$
(d) $\frac{\text{Unconfined compression strength of remoulded sample}}{\text{Unconfined compression strength of undisturbed sample}}$

432. The difference between maximum void ratio and minimum void ratio of a sand sample is 0.30. If the relative density of this sample is 66.6% at a void ratio of 0.40, then the void ratio of this sample at its loosest state will be
(a) 0.40 (b) 0.60
(c) 0.70 (d) 0.75

433. Given that for an overconsolidated clay soil deposit, the pressure under which the deposit has been fully consolidated in the past is 125 kN/m^2 and the present overburden pressure is 75 kN/m^2, the overconsolidation ratio of the soil deposit is
(a) $\frac{75}{125}$ (b) $\frac{50}{75}$
(c) $\frac{125}{75}$ (d) $\frac{200}{75}$

81. (d)	82. (c)	83. (d)	84. (a)	85. (c)	86. (b)	87. (d)	88. (b)	89. (b)	90. (c)
91. (b)	92. (b)	93. (d)	94. (b)	95. (b)	96. (c)	97. (a)	98. (c)	99. (c)	100. (d)
101. (a)	102. (a)	103. (c)	104. (c)	105. (c)	106. (c)	107. (d)	108. (b)	109. (c)	110. (c)
111. (b)	112. (b)	113. (c)	114. (a)	115. (d)	116. (c)	117. (c)	118. (d)	119. (d)	120. (c)
121. (d)	122. (b)	123. (d)	124. (c)	125. (b)	126. (a)	127. (c)	128. (a)	129. (c)	130. (c)
131. (b)	132. (c)	133. (b)	134. (c)	135. (a)	136. (b)	137. (b)	138. (b)	139. (c)	140. (d)
141. (b)	142. (c)	143. (c)	144. (b)	145. (c)	146. (b)	147. (d)	148. (a)	149. (c)	150. (a)
151. (b)	152. (b)	153. (a)	154. (b)	155. (b)	156. (b)	157. (b)	158. (d)	159. (b)	160. (d)
161. (c)	162. (c)	163. (a)	164. (c)	165. (b)	166. (c)	167. (a)	168. (c)	169. (b)	170. (b)
171. (b)	172. (a)	173. (d)	174. (b)	175. (a)	176. (b)	177. (c)	178. (c)	179. (b)	180. (c)
181. (c)	182. (c)	183. (c)	184. (c)	185. (b)	186. (c)	187. (d)	188. (d)	189. (d)	190. (a)
191. (b)	192. (d)	193. (d)	194. (b)	195. (b)	196. (a)	197. (a)	198. (d)	199. (d)	200. (c)
201. (d)	202. (d)	203. (c)	204. (c)	205. (d)	206. (b)	207. (d)	208. (c)	209. (b)	210. (d)
211. (b)	212. (c)	213. (a)	214. (d)	215. (b)	216. (b)	217. (d)	218. (c)	219. (b)	220. (a)
221. (b)	222. (c)	223. (c)	224. (b)	225. (c)	226. (c)	227. (a)	228. (d)	229. (a)	230. (c)
231. (d)	232. (d)	233. (c)	234. (c)	235. (b)	236. (c)	237. (c)	238. (d)	239. (a)	240. (b)
241. (b)	242. (b)	243. (b)	244. (a)	245. (d)	246. (a)	247. (c)	248. (a)	249. (c)	250. (a)
251. (c)	252. (b)	253. (c)	254. (a)	255. (b)	256. (d)	257. (b)	258. (a)	259. (b)	260. (a)
261. (b)	262. (d)	263. (c)	264. (c)	265. (c)	266. (d)	267. (b)	268. (b)	269. (a)	270. (b)
271. (b)	272. (a)	273. (a)	274. (c)	275. (d)	276. (c)	277. (b)	278. (b)	279. (c)	280. (c)
281. (c)	282. (d)	283. (c)	284. (c)	285. (d)	286. (d)	287. (a)	288. (d)	289. (c)	290. (a)
291. (b)	292. (a)	293. (c)	294. (a)	295. (b)	296. (a)	297. (d)	298. (b)	299. (a)	300. (c)
301. (d)	302. (a)	303. (a)	304. (c)	305. (d)	306. (c)	307. (c)	308. (b)	309. (b)	310. (c)
311. (b)	312. (c)	313. (a)	314. (c)	315. (b)	316. (b)	317. (a)	318. (b)	319. (a)	320. (a)
321. (b)	322. (d)	323. (d)	324. (c)	325. (b)	326. (a)	327. (b)	328. (b)	329. (b)	330. (b)
331. (b)	332. (a)	333. (b)	334. (c)	335. (d)	336. (a)	337. (b)	338. (c)	339. (d)	340. (b)
341. (a)	342. (d)	343. (c)	344. (d)	345. (a)	346. (a)	347. (c)	348. (b)	349. (b)	350. (d)
351. (b)	352. (c)	353. (a)	354. (b)	355. (d)	356. (d)	357. (a)	358. (c)	359. (b)	360. (a)
361. (c)	362. (c)	363. (c)	364. (a)	365. (b)	366. (a)	367. (b)	368. (d)	369. (c)	370. (a)
371. (c)	372. (a)	373. (d)	374. (c)	375. (c)	376. (d)	377. (a)	378. (c)	379. (a)	380. (a)
381. (d)	382. (d)	383. (b)	384. (a)	385. (a)	386. (d)	387. (d)	388. (c)	389. (c)	390. (b)
391. (b)	392. (a)	393. (d)	394. (b)	395. (c)	396. (c)	397. (b)	398. (c)	399. (b)	400. (a)
401. (a)	402. (d)	403. (d)	404. (a)	405. (a)	406. (a)	407. (a)	408. (b)	409. (a)	410. (a)
411. (d)	412. (d)	413. (d)	414. (d)	415. (b)	416. (d)	417. (a)	418. (d)	419. (d)	420. (a)
421. (b)	422. (d)	423. (c)	424. (c)	425. (d)	426. (b)	427. (d)	428. (d)	429. (b)	430. (b)
431. (a)	432. (b)	433. (c)							

TRUE OR FALSE TYPE QUESTIONS

The measure of soil compaction is its wet density.

The void ratio of soil can exceed unity.

Between bearing capacity and settlement, the proportioning of a footing in sand is more often governed by settlement.

The bulb of pressure under a strip footing forms in the direction of its length.

Friction piles are also called 'floating piles'.

As the angle of internal friction of the soil increases, the active earth pressure increases and the passive earth pressure decreases.

7. Flow lines and equipotential lines in a flow net are orthogonal to each other.

8. Effective stresses in a sand layer below a lake do not alter as the lake level fluctuates.

9. Water pressure is atmospheric at all points on a phreatic line. Phreatic line is, therefore, an equipotential line.

10. Fifty per cent of the consolidation at a site subjected to a stress level of 200 kPa occured in two months. If the site had been loaded to 400 kPa, fifty per cent of the consolidation would occur in four months.

11. The problem of slope stability analysis assuming circular slip surfaces and considering equilibrium of the soil body as a whole is statically determinate.

61. (d)	62. (d)	63. (c)	64. (b)	65. (d)	66. (b)	67. (d)	68. (d)	69. (b)	70. (c)
71. (c)	72. (d)	73. (d)	74. (b)	75. (b)	76. (c)	77. (d)	78. (b)	79. (b)	80. (d)
81. (d)	82. (c)	83. (d)	84. (d)	85. (c)	86. (b)	87. (d)	88. (b)	89. (b)	90. (c)
91. (b)	92. (b)	93. (d)	94. (b)	95. (b)	96. (c)	97. (d)	98. (c)	99. (c)	100. (d)
101. (a)	102. (d)	103. (c)	104. (b)	105. (c)	106. (c)	107. (d)	108. (b)	109. (c)	110. (c)
111. (b)	112. (b)	113. (b)	114. (d)	115. (d)	116. (c)	117. (c)	118. (d)	119. (d)	120. (c)
121. (d)	122. (b)	123. (d)	124. (c)	125. (d)	126. (d)	127. (c)	128. (a)	129. (c)	130. (c)
131. (b)	132. (c)	133. (b)	134. (c)	135. (b)	136. (b)	137. (a)	138. (b)	139. (b)	140. (d)
141. (b)	142. (c)	143. (c)	144. (b)	145. (c)	146. (b)	147. (d)	148. (a)	149. (c)	150. (a)
151. (b)	152. (b)	153. (a)	154. (b)	155. (b)	156. (b)	157. (b)	158. (d)	159. (b)	160. (d)
161. (c)	162. (c)	163. (a)	164. (c)	165. (b)	166. (c)	167. (a)	168. (c)	169. (b)	170. (b)
171. (b)	172. (d)	173. (d)	174. (b)	175. (a)	176. (b)	177. (c)	178. (c)	179. (b)	180. (c)
181. (c)	182. (c)	183. (c)	184. (c)	185. (b)	186. (c)	187. (d)	188. (d)	189. (d)	190. (a)
191. (b)	192. (d)	193. (d)	194. (b)	195. (b)	196. (a)	197. (c)	198. (d)	199. (d)	200. (c)
201. (d)	202. (d)	203. (c)	204. (c)	205. (d)	206. (b)	207. (d)	208. (c)	209. (b)	210. (d)
211. (b)	212. (c)	213. (a)	214. (d)	215. (b)	216. (b)	217. (d)	218. (c)	219. (b)	220. (a)
221. (b)	222. (c)	223. (c)	224. (b)	225. (c)	226. (c)	227. (a)	228. (d)	229. (a)	230. (c)
231. (d)	232. (d)	233. (c)	234. (c)	235. (b)	236. (c)	237. (c)	238. (d)	239. (a)	240. (b)
241. (b)	242. (b)	243. (b)	244. (a)	245. (d)	246. (a)	247. (c)	248. (a)	249. (c)	250. (a)
251. (c)	252. (b)	253. (c)	254. (a)	255. (b)	256. (d)	257. (b)	258. (a)	259. (b)	260. (a)
261. (b)	262. (d)	263. (c)	264. (c)	265. (c)	266. (d)	267. (b)	268. (b)	269. (a)	270. (b)
271. (b)	272. (d)	273. (a)	274. (c)	275. (d)	276. (c)	277. (b)	278. (b)	279. (c)	280. (c)
281. (c)	282. (d)	283. (c)	284. (c)	285. (d)	286. (d)	287. (a)	288. (d)	289. (c)	290. (a)
291. (b)	292. (a)	293. (c)	294. (a)	295. (b)	296. (a)	297. (d)	298. (b)	299. (a)	300. (c)
301. (d)	302. (a)	303. (a)	304. (c)	305. (d)	306. (c)	307. (c)	308. (b)	309. (b)	310. (c)
311. (b)	312. (c)	313. (a)	314. (c)	315. (b)	316. (b)	317. (a)	318. (b)	319. (a)	320. (a)
321. (b)	322. (d)	323. (d)	324. (c)	325. (b)	326. (a)	327. (b)	328. (b)	329. (b)	330. (b)
331. (b)	332. (a)	333. (b)	334. (c)	335. (d)	336. (a)	337. (b)	338. (c)	339. (d)	340. (b)
341. (a)	342. (d)	343. (c)	344. (d)	345. (a)	346. (a)	347. (c)	348. (b)	349. (b)	350. (d)
351. (b)	352. (c)	353. (a)	354. (b)	355. (d)	356. (d)	357. (a)	358. (c)	359. (b)	360. (a)
361. (c)	362. (c)	363. (c)	364. (a)	365. (b)	366. (a)	367. (b)	368. (d)	369. (c)	370. (a)
371. (c)	372. (a)	373. (d)	374. (c)	375. (c)	376. (d)	377. (a)	378. (c)	379. (a)	380. (a)
381. (d)	382. (d)	383. (b)	384. (a)	385. (a)	386. (d)	387. (d)	388. (c)	389. (c)	390. (b)
391. (b)	392. (a)	393. (d)	394. (b)	395. (c)	396. (c)	397. (b)	398. (c)	399. (b)	400. (a)
401. (a)	402. (d)	403. (d)	404. (a)	405. (a)	406. (a)	407. (a)	408. (b)	409. (a)	410. (a)
411. (d)	412. (d)	413. (d)	414. (d)	415. (b)	416. (d)	417. (a)	418. (d)	419. (d)	420. (a)
421. (b)	422. (d)	423. (c)	424. (c)	425. (d)	426. (b)	427. (d)	428. (d)	429. (b)	430. (b)
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381. (*d*)	**382.** (*d*)	**383.** (*b*)	**384.** (*a*)	**385.** (*a*)	**386.** (*d*)	**387.** (*d*)	**388.** (*c*)	**389.** (*c*)	**390.** (*b*)
391. (*b*)	**392.** (*a*)	**393.** (*d*)	**394.** (*b*)	**395.** (*c*)	**396.** (*c*)	**397.** (*b*)	**398.** (*c*)	**399.** (*b*)	**400.** (*a*)
401. (*a*)	**402.** (*d*)	**403.** (*d*)	**404.** (*a*)	**405.** (*a*)	**406.** (*a*)	**407.** (*a*)	**408.** (*b*)	**409.** (*a*)	**410.** (*a*)
411. (*d*)	**412.** (*d*)	**413.** (*d*)	**414.** (*d*)	**415.** (*b*)	**416.** (*d*)	**417.** (*a*)	**418.** (*d*)	**419.** (*d*)	**420.** (*a*)
421. (*b*)	**422.** (*d*)	**423.** (*c*)	**424.** (*c*)	**425.** (*d*)	**426.** (*b*)	**427.** (*d*)	**428.** (*d*)	**429.** (*b*)	**430.** (*b*)
431. (*a*)	**432.** (*b*)	**433.** (*c*)							