RAMA UNIVERSITY

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FACULTY OF RNGINEERING AND TECHNOLOGY (DEPARTMENT OF CIVIL ENGINEERING)

CONSTRUCTION TECHNOLOGY

B. Tech (IInd YEAR/ IIIrd SEM)

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FROST HEAVE

- Frost heave is an upward swelling of soil due to the formation of ice during freezing conditions. It usually occurs when the freezing temperature penetrates the soil and turns the present moisture into ice thereby generating an upward movement in the soil.

- The size of ice mass increases because of the continuous supply of moisture through capillary action. Soil weight might restrain the influence of ice and generate ice lenses. Nonetheless, ice lenses can move the soil layer upward.

- Frost heave inflicts considerable damage to roads, channels, foundations and subsequently, the superstructure. In order to prevent the detrimental effects of frost heave, it is necessary to understand how it works and identify the basic elements which lead to its occurrence. After that, proper measures can be set up to prevent it.

Frost can damage pavements and building structures in two ways:

1. heaving of the frozen ground, caused by ice lenses forming in the soil, and collapse of the ground, caused by the thaw of these same ice lenses. The amount of frost heave can be tremendous.

2. In one case, a seven-story building heaved 2 to 3 inches. Vertical ground movements of 4 to 8 inches are common and as much as 24 inches have been reported. Variations in the amount of heave, due to different soil and water conditions, can crack structures easily. Walls, slabs, footings, and pavements all can be damaged.

WORKING OF FROST HEAVE

- As freezing temperature penetrates into the soil, it converts the soil’s moisture into ice. When moisture at freezing area solidifies, water from other parts of soil would move toward freezing area through capillary action. This leads to the increase in the size of ice mass. Soil weight and other objects above would restrain ice size growth and consequently, ice lenses are formed.

- When freezing temperature further penetrates into the soil, it leaves ice lenses behind. These ice lenses continue to grow towards the area that loses temperature which is toward soil surface.

- The ice lenses are capable of thrusting the soil layer upward. It creates cracks in the soil and causes damages to foundations and subsequently to the superstructure. It is reported that, when moisture converts to ice, its size increases by 9%.

- Fine grain frost-susceptible soil, moisture that continuously supplies water to ice lenses, and freezing temperature are the basic elements of frost heave action.

- When temperature declines, the ice melts and the structure lows back to its location under its weight. When freezing and thawing process repeats, it would severely deteriorate and possibly collapse.

WORKING OF FROST HEAVE

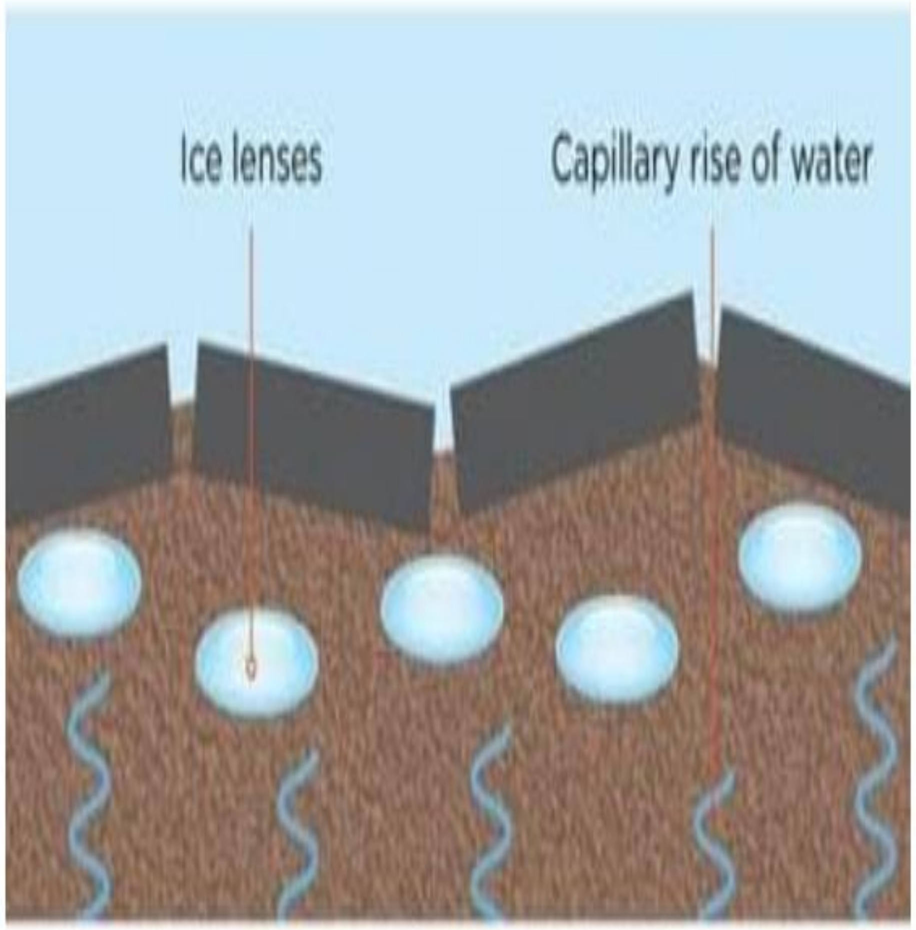

Fig. 1: Ice lenses and Capillary Rise of Water

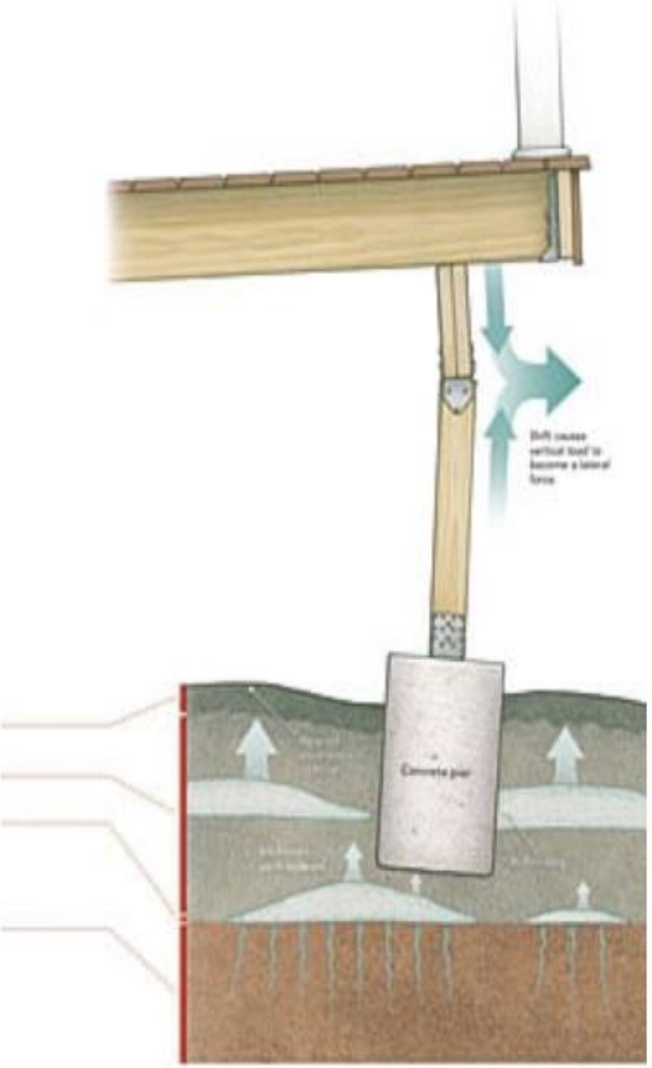

Fig. 2: How Frost Heave Works

EFFECTS OF FROST HEAVE

- Destruction of channels in freezing season.
- Decline in load carrying capacity of subgrade.
- Undulations and considerable damages to the pavement
- Damaged foundations and slabs.

Fig. 5: Pavements Cracks due to Frost Heave

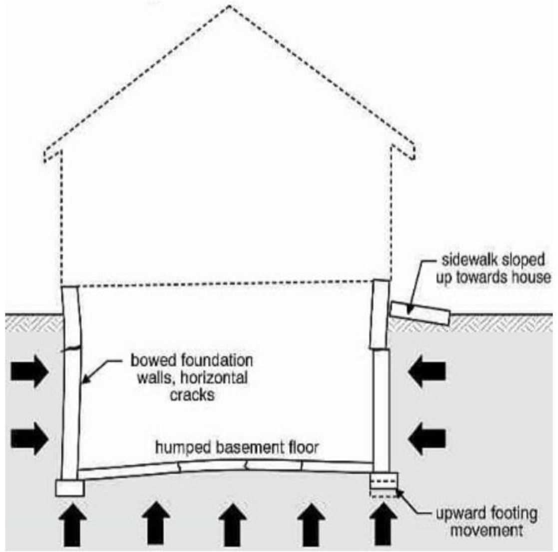

Fig. 3: Effect of Frost Heave on Buildings

Fig. 4: Frost Heave damaged Concrete

PREVENTION OF FROST HEAVE

Prevention

Generally, frost heave can be prevented by eliminating one of its basic elements which include fine grains soil, frost temperature, and water. There are several measures which can be considered to avoid frost heave :

- Provision of frost heave prevention systems such as hydronic heating system.
- Extend foundation such as piers below frost line.
- Provide backfill materials such as gravel around foundation so as to encourage water drainage.
- Use sleeve to avoid ice from gripping the concrete.
- Construct footing that withstands upward movement.
- For road construction, replace fine grain frost susceptible soil with coarse granular soil.
- Use capillary breaker so as to prevent movement of water toward freezing front and consequently decline frost heave influence.
- Stabilize the soil.

SAFE BEARING CAPACITY OF SOIL

- The safe bearing capacity qc of soil is the permissible soil pressure considering safety factors in the range of 2 to 6 depending on the type of soil, approximations and assumptions and uncertainties. This is applicable under service load condition and, therefore, the partial safety factors λ f for different load combinations are to be taken from those under limit state of serviceability

- Normally, the acceptable value of qc is supplied by the geotechnical consultant to the structural engineer after proper soil investigations. The safe bearing stress on soil is also related to corresponding permissible displacement / settlement.

- Gross and net bearing capacities are the two terms used in the design. Gross bearing capacity is the total safe bearing pressure just below the footing due to the load of the superstructure, self weight of the footing and the weight of earth lying over the footing. On the other hand, net bearing capacity is the net pressure in excess of the existing overburden pressure.

- Thus, we can write Net bearing capacity = Gross bearing capacity - Pressure due to overburden soil,

- While calculating the maximum soil pressure q, we should consider all the loads of superstructure along with the weight of foundation and the weight of the backfill. During preliminary calculations, however, the weight of the foundation and backfill may be taken as 10 to 15 per cent of the total axial load on the footing, subjected to verification afterwards.

DEPTH OF FOUNDATION

- All types of foundation should have a minimum depth of 50 cm as per IS 1080-1962. This minimum depth is required to ensure the availability of soil having the safe bearing capacity assumed in the design.

- Moreover, the foundation should be placed well below the level which will not be affected by seasonal change of weather to cause swelling and shrinking of the soil. Further, frost also may endanger the foundation if placed at a very shallow depth.

- Rankine formula gives a preliminary estimate of the minimum depth of foundation and is expressed as

$$d = (q_c/\lambda)\{(1 - \sin\phi)/(1 + \sin\phi)\}^2$$

where d = minimum depth of foundation

qc = gross bearing capacity of soil

λ = density of soil

φ = angle of repose of soil

- Though Rankine formula considers three major soil properties qc, λ and φ , it does not consider the load applied to the foundation.

- However, this may be a guideline for an initial estimate of the minimum depth which shall be checked subsequently for other requirements of the design.

DESIGN CONSIDERATIONS

a. MINIMUM NOMINAL COVER (CL. 26.4.2.2 OF IS 456)

- The minimum nominal cover for the footings should be more than that of other structural elements of the superstructure as the footings are in direct contact with the soil. Clause 26.4.2.2 of IS 456 prescribes a minimum cover of 50 mm for footings. However, the actual cover may be even more depending on the presence of harmful chemicals or minerals, water table etc.

b. THICKNESS AT THE EDGE OF FOOTINGS (CLS. 34.1.2 AND 34.1.3 OF IS 456)

- The minimum thickness at the edge of reinforced and plain concrete footings shall be at least 150 mm for footings on soils and at least 300 mm above the top of piles for footings on piles, as per the stipulation in cl.34.1.2 of IS 456. For plain concrete pedestals, the angle α between the plane passing through the bottom edge of the pedestal and the corresponding junction edge of the column with pedestal and the horizontal plane shall be determined from the following expression (cl.34.1.3 of IS 456)

$$\tan\alpha \le 0.9\{(100\, q_a/f_{ck}) + 1\}^{1/2} \qquad (11.3)$$

where q_a = calculated maximum bearing pressure at the base of pedestal in N/mm^2, and

f_{ck} = characteristic strength of concrete at 28 days in N/mm^2.

c. BENDING MOMENTS (CL. 34.2 OF IS 456)

1. It may be necessary to compute the bending moment at several sections of the footing depending on the type of footing, nature of loads and the distribution of pressure at the base of the footing. However, bending moment at any section shall be determined taking all forces acting over the entire area on one side of the section of the footing, which is obtained by passing a vertical plane at that section extending across the footing (cl.34.2.3.1 of IS 456).

2. The critical section of maximum bending moment for the purpose of designing an isolated concrete footing which supports a column, pedestal or wall shall be: (i) at the face of the column, pedestal or wall for footing supporting a concrete column, pedestal or reinforced concrete wall, and

3. halfway between the centre-line and the edge of the wall, for footing under masonry wall. This is stipulated in cl.34.2.3.2 of IS 456.

4. For round or octagonal concrete column or pedestal, the face of the column or pedestal shall be taken as the side of a square inscribed within the perimeter of the round or octagonal column or pedestal (see cl.34.2.2 of IS 456.

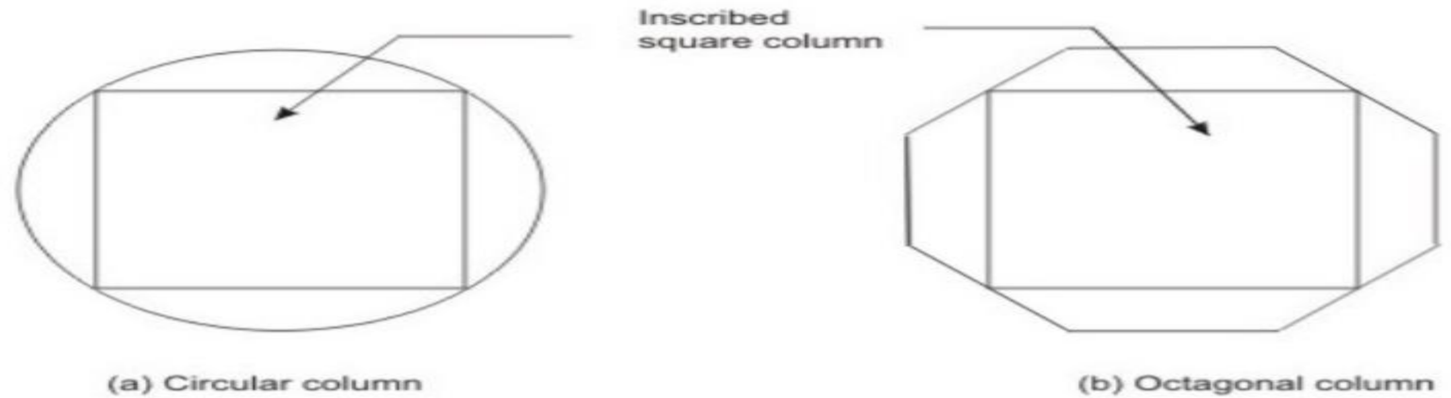

Fig. 11.28.13: Equivalent square columns (cl 34.2.2 of IS 456:2000)

d. Shear force (cl. 31.6 and 34.2.4 of IS 456)

- Footing slabs shall be checked in one-way or two-way shears depending on the nature of bending. If the slab bends primarily in one-way, the footing slab shall be checked in one-way vertical shear. On the other hand, when the bending is primarily two-way, the footing slab shall be checked in two-way shear or punching shear.

- **The respective critical sections and design shear strengths are given below:**

1. One-way shear (cl. 34.2.4 of IS 456) One-way shear has to be checked across the full width of the base slab on a vertical section located from the face of the column, pedestal or wall at a distance equal to :

I. effective depth of the footing slab in case of footing slab on soil, and

II. half the effective depth of the footing slab if the footing slab is on piles.

The design shear strength of concrete without shear reinforcement is given in Table 19 of cl.40.2 of IS 456.

2. Two-way or punching shear (cls.31.6 and 34.2.4)

- Two-way or punching shear shall be checked around the column on a perimeter half the effective depth of the footing slab away from the face of the column or pedestal.

- The permissible shear stress, when shear reinforcement is not provided, shall not exceed $k_s \tau_c$, where $k_s = (0.5 + \beta_c)$, but not greater than one, β_c being the ratio of short side to long side of the column, and $\tau_c = 0.25(f_{ck})^{1/2}$ in limit state method of design, as stipulated in cl.31.6.3 of IS 456.

- Normally, the thickness of the base slab is governed by shear. Hence, the necessary thickness of the slab has to be provided to avoid shear reinforcement.

THANK YOU