Expansive Soil
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Lecture 26
Foundation on Expansive Soil

Hello, everyone. Welcome back to the course Expansive Soil. Today, I will start a new module. This will be the module 8th and the title of this module will be the Application of Expansive Soil. This module will have two lectures. The first one will be the foundation on expansive soil. And the second one will be the application of expansive soil for various geotechnical engineering. And this will be the lecture number twenty-third.

(Refer Slide Time: 00:54)

So, when we design for a foundation, then we need to take care of two things. The depth of the expansive soil. Particularly designing the foundation in an expansive soil is quite bit tricky. So, here, when we design, we need to take care of the zone for which there will be an expansiveness of the soil occurs.

If you could recall, in the earlier classes, I have explained about the depth of the expansive behaviour zone. So, that is known the active zone. If you see the change in the water content profile along with the depth, we could see that with increase in the depth from the ground surface, the water content profile will vary. And depending on the season, particularly for wet season or dry season, this profile will be different.

So, when you look into the water content profile of soil with depth, the water content profile will vary. Mostly it at ground surface, it will be quite low during dry season. Similarly, during the wet season, it will be quite high, but with increasing the depth, the water content will keep on changing, but after reaching a certain value, the water content will not change. If we compare the water content profile for dry and wet season, we could see the variation in the water content with depth is quite different.

But once we reach to a certain level up to here, there will be no much variation in the water content with depth occur. So, this zone is known as active zone. And if an expansive soil present over here, then the expansiveness of the soil will occur only during this portion. If you could recall, I told you that the expansive behaviour of the soil will be a problem when there will be change in the water content.

So, in this case, there will be no change in the water content, therefore, there will be no effect of expansive soil behaviour on this soil. But if we look into, if we go above this, above this line or in between the ground surface and active zone, the expansive soil will create a problem in the active zone only. So, therefore, when we design a foundation, we need to first determine what will be the active zone. And we also say this one as an unstable zone.

So, first point while designing a foundation in an expansive soil will be to determine what will be the active zone or what will be the unstable zone? Then the zone below this one is known as stable zone because the water content will remain constant. So, there will be no variation of expansive soil or no effect of expansive soil on foundation at this zone will occur.

So, therefore, the first point in designing a foundation in an expansive soil to determine the unstable zone or the active zone.

(Refer Slide Time: 04:02)

When we design a foundation on an expansive soil, we need to take care of the following things. First, we need to increase the structural load to counterbalance the swelling pressure, then to reduce the heave of expansive soil and third to provide the foundation to a deeper stable soil. As long as possible, we should try to avoid constructing a foundation on an expansive soil, but all the time we cannot avoid.

So, if we have to design a foundation, then we have to take care of these three things, that is to in increase the structural load so that the swelling pressure will be counterbalanced. If we design a foundation, the swelling pressure will try to push this foundation in upward direction or try to push the structure in the upward direction. So, if we provided a load, which can counterbalance this swelling pressure, then the effect of the swelling will not be significant.

Then to reduce the expansive behaviour of the soil. So, we can do that with different techniques, which we have learned in the previous classes like soil treatment methods, like lime stabilization, cement stabilization, or mechanical methods. These are the different methods by which we can reduce the expansive behaviour of the soil or we can do one thing, we can go for a foundation to a deeper stable soil.

So, if this is a soil profile and this is the active zone, then the foundation should be extended beyond this active zone or unstable zone. And the foundation should be located at stable zone so, that the effect of expansiveness of the soil will have no bearing on the foundation.

(Refer Slide Time: 05:59)

So, when we design a foundation or when we take a foundation, particularly say, for example, a deep foundation, like a pile foundation, there will be some uplifting force as well as there will be some resisting force. Say, for example, if we take a pile foundation like this, suppose this is the active zone or unstable zone, this is the stable zone. That means the soil in this zone will only experience some swelling characteristics, let this length be L_1 and let this length be L_2.

Now, when we calculate the uplift force on this foundation, due to the swelling behaviour of the soil, the soil will try to push this pile in the upward direction. So, this will be the uplifting force. If you look into this diagram, this will be the uplifting force and this will only act in this zone, that is the active zone. So, this uplift force depends on the pile diameter, it depends on the length of the pile.

Suppose if this is L_1, this is L_1 and let this pile diameter is d then it depends on the pile diameter. It depends on the length of the pile. It depends on the cohesion under undrained condition that is c_u. And also it depends on the coefficient of uplift between the concrete and the soil. That means the force of adhesion between the soil and the concrete at the point of contact between the soil and concrete.

So, generally, this can be taken as 0.15, depending on the soil and the material of this pile. So, the uplifting force will be Q_{up} will be;

Uplift force = $Q_{up} = \pi d \alpha_u c_u L_1$

d = Diameter of pile shaft

α_u = Coefficient of uplift between concrete and soil = 0.15

c_u = Cohesion under undrain condition

And the resisting force will come from this stable zone. That means if we look into the stable zone here, the resistance against the uplifting will be provided by the shaft friction in the stable zone.

So, the resisting force Q R_1 in the stable zone will be equals to;

Resisting force = $Q_{R1} = \pi d \alpha c_u L_2$
d = Diameter of pile shaft
α= Adhesion factor under compression loading
c_u = Cohesion under undrain condition
L_2 = Length of the pile in the stable zone

So, this is the L_2. So, this is the case when we use slender pile or pile like this one without any bell.

But sometimes, or in many cases for an expansive soil, we need to use the belled pier or the bulb piles. In the belled piles, we provide bells like this one can have one bell or two bells depending on the soil, and also depending on the design load. So, let, in this case, we are providing a single bell to this belled pile or single bulb to this belled pile.

Now, when we see this uplifting force, as well as the resisting force, the uplift force again will come because of the upliftment or uplifting force caused due to the swelling of the soil in this zone that will be equals to Q_{up} will be equals to;

Uplift force = $Q_{up} = \pi d \alpha_u c_u L_1$

This resisting force will be made of two components. One will be Q_{R1} that will be because of the friction between the pile length of L_2. And the second will be coming because of this bearing over here at this point. So, the resisting force Q_R will be equals;

$Q_R = Q_{R1} + Q_{R2}$

For this case

Where, $Q_{R1} = \pi d \alpha c_u L_2$

Now, when you calculate the Q_{R2}, this resisting force, which comes because of the bearing of pile bulb on the soil at this point, we need to calculate the annular area.

That means the area between the pile bulb and the outer layer of the pile shaft. That is the annular area. So, this annular area will be equals;

Annular area = $\frac{\pi}{4}\left(d_b^2 - d^2\right)$

Where, d_b is the diameter of bulb and d is the diameter of this pile shaft.

Resisting force = $Q_{R2} = \frac{\pi}{4}\left(d_b^2 - d^2\right)(cN_c + \gamma L_2)$

Where,

N_c = Bearing capacity factor

c = Cohesion of the soil at the bulb of the pile

γ= Unit weight of the soil

L_2 = Length of soil

Now, depending on the ratio, L_2/d_b, the value of N_c can change. Say for example, when this ratio is equals to 1.7, the N_c value will be equals to 4. When the ratio is equals to 2.5, it will be equals to 6. And when it will be greater than 5, then the value will be 9. So, depending on the values of the ratio between L_2/d_b, the values of N_c will change. And then the total uplift force will be equals to the resisting force for a stable foundation.

So, these are the different forces, which acts on a pile foundation when, if the pile is located in an expansive soil.

(Refer Slide Time: 12:12)

So, when we design a foundation in an expansive soil, there are few methods by which we can design it. The first one is the increasing the load of the structure. So, as I told you, if this is a foundation, the foundation will be subjected to an uplift pressure because of the swelling of the soil. So, this is the frictional resistance.

In this case, the pile is located in an unstable zone, that is the active zone. If it is located in a stable zone, then Q_b will not be there, only the frictional resistance will act. So, to counteract this frictional force arises due to the swelling of the soil, we need to increase the load of the footing, or we need to increase the load of the structure, which comes to the footing. But to do this, we need to have a larger structure, which may not be economical.

So, therefore, this method is not economical. So, in this method, we need to increase the load of the structure to counterbalance the swelling pressure of the soil. But this is not an economical method.

(Refer Slide Time: 13:25)

In the second option, we need to reduce the heave of the expansive soil. Suppose in this case, a foundation is located in an expansive soil. So, in this case, we need to reduce the expansiveness behaviour of the soil located here. Say, in this case, what we can do is there are different way by which we can achieve this. First option is by providing a foundation, surrounded with granular fill.

So, in this case, what we have to do is, we need to excavate a trench and we need to excavate the trench up to 20 to 30 centimetres below the base of the footing. So, we need to extra excavate the soil, which will be more than 20 to 30 centimetre below the depth the foundation layer.

Then in this zone, we need to provide some drainage material, which will be made of sand and gravel. So, this mixture of sand and gravel or the granular fill will be provided here. Now, once we provide this granular fill, then we need to construct the RCC foundation and then we need to construct the foundation over here.

And we need to keep some space, air gap, here to allow the soil to swell if there is swelling occurs. So, in this method, the excavation will be carried out up to a depth of 20 to 30 centimetre below the foundation level. The drainage material, such as mixture of sand and gravel will be provided at the bottom level. Then RCC foundation will be constructed over this granular fill. This granular material will act as a cushion layer to absorb the swelling of the soil.

So, whenever the swelling occurs, that swelling will be taken care of by this granular material. So, therefore, the amount of effect of swelling on this foundation will be minimal. But this type of foundation need to be constructed in dry season when the soil has shrunk to its lowest level. And also this kind of foundation is generally applicable for the soil with low to medium level of expansiveness, or soil exhibiting a low to medium level up expansive characteristics.

(Refer Slide Time: 15:56)

The second option by treating the soil. So, there are various method by which we can reduce the swelling capacity of the soil, like adding lime or cement or bitumen or fly-ash. So, by adding those materials, we can reduce the expansiveness behaviour of the soil. So, if we encounter any kind of expansive soil, then first the soil need to be treated using this method. Once the soil is stabilized, then the soil will be compacted and then the foundation will be laid over this soil. Generally, this kind of treatment is carried out to low to medium level of swelling of the soil.

(Refer Slide Time: 16:38)

So, next method is the CNS technology, which is quite widely used in India and also around the world. In this method, a layer of cohesive non-swelling soil, known as CNS, of sufficient depth is provided over the expansive soil. So, suppose if this is an expansive soil layer, a layer of CNS soil of sufficient depth will be provided over this expansive soil. Then the self-weight of this layer will counter-react the swelling pressure of the soil and higher is the expansiveness of the soil, the higher will be the thickness of this CNS layer.

So, depending on the expansive or swelling pressure of this soil, the thickness of this CNS layer will be different. As per as Indian standard is concerned, if the swelling pressure is in between 50 to 150 kN/m^2, the thickness of the CNS layer will be like 75 to 85 centimetres. If the swelling pressure is between 200 to 300 kN/m^2, it will be 90 to 100 centimetres.

If it is between three 350 to 500 kN/m^2, it will be a 105 to 125 centimetre. So, this is quite ideally used and again, this can be used for many application, mostly the structure loaded with light load.

(Refer Slide Time: 18:06)

The other method, which is most widely used for highly loaded structure is to provide a foundation to deeper stable soil. The deeper stable soil means, as I told you, there are two zones exist. One is active zone, the zone in which there will be a fluctuation in the water content with depth during wet and summer season.

So, there will be a problem to an expansive soil behaviour only at this zone. So, that is why, this is known as unstable zone. And below that active zone, there will be stable zone. The soil at this zone will mostly be stable. It will not go any expansive or shrinkage due to wetting or drying of the soil. So, when the soil is in top unstable zone, it will absorb moisture and the soil will expand.

Due to this heaving effect, an upward force will act, which will push the shaft in the upward direction. So, that will be the uplifting force. This upward force will try to pull this pile out of its position. So, this uplift force will try to push this pile in the upward direction. Now, this uplifting force will be resisted by the downward load Q, and also the resisting force provided by the friction between the pile and the soil in the stable zone, that is Q_{R1} and also the bearing between the soil and the bulb diameter that is Q_{R2} as I explained earlier.

(Refer Slide Time: 19:42)

Let is consider a pile of length;

$L = L_1 + L_2 + L_3$

Out of this length, L_1 length is located in unstable zone. L_2 is the length of the soil, which is located in the stable zone between the bulb and the stable zone, that is L_2. And L_3 is the length of the soil or length of the bulb in the stable zone. Now the uplifting force, which has been acting on the pile;

$$\text{Uplift force} = Q_{up} = \pi d c_a L_1$$

Where, c_a is a unit adhesion between the soil and shaft.

So, this adhesion between the soil and shaft will try to push this in the upward direction, so, that is why we need to take c_a. The different codes has provided different c_a value depending on the soil type and depending on the material, which is used in the pile. Then comes the total resisting force Q_R, which will be made up resisting force caused by the skin friction on the shaft of length L_2, which will be Q_{R1} plus the reaction provided by the soil bulb within the annular surface A_r.

So, this is the annular surface A_r.

$$\text{Annular area} = A_r = \frac{\pi}{4}\left(d_b^2 - d^2\right)$$

So, if we take this total area, and if we subtract this area, then we will get the annular area this.

Then,

$$Q_{R1} = \pi.d.L_2.c_a$$

$$Q_{R2} = q_d \frac{\pi}{4}.\left(d_u^2 - d^2\right)$$

Now this q_d, which comes from the bearing capacity equation,

$$q_d = c_b N_c = 9c_b$$

c_b = Cohesion of soil at the bulb level

As I told you, the values of c_b depends on L_2/d_b. Let us assume this c_b is equals to 9, So, the cohesion of the soil at this level is the c_b.

So, once we know this c_b value, L_1, L_2 and d_u and d, we can find out what will be the total uplifting force, what will be total resisting force.

(Refer Slide Time: 22:16)

And then we can calculate the stability of the pile. Let consider two scenarios. In the first case, we will not take the weight Q and will use a factor of safety 1.2. You can take any factor of safety in this case, let is it be 1.2.

So,

$$\text{Factor of safety} = \frac{Q_R}{Q_{up}} = 1.2$$

$$Q_{up} = \frac{Q_R}{1.2}$$

The resisting force has two components Q_{R1} and Q_{R2}.

So, $Q_R = Q_{R1} + Q_{R2}$

$$Q_{up} = \frac{Q_R}{1.2} = \frac{Q_{R1} + Q_{R2}}{1.2}$$

Now we will replace,

$$Q_{up} = \pi d c_a L_1$$

$$Q_{R1} = \pi d c_a L_2$$

$$Q_{R2} = 9c_b \frac{\pi}{4}\left(d_b^2 - d^2\right)$$

So,

$$Q_{up} = \frac{Q_R}{1.2} = \frac{Q_{R1} + Q_{R2}}{1.2}$$

$$\pi.d.L_1.c_a = \frac{\pi.d.L_2.c_a + 9.c_b.\frac{\pi}{4}\left(d_b^{\,2} - d^2\right)}{1.2} \qquad (1)$$

Now consider the top pile load Q with a factor of safety 2.

$$\text{Factor of safety } = \frac{Q_R}{Q_{up} - Q} = 2.0$$

$$\frac{Q_R}{2.0} = Q_{up} - Q$$

And again, Q_R is made of two components Q_{R1} and Q_{R2}.

$$\frac{Q_R}{2.0} = \frac{Q_{R1} + Q_{R2}}{2.0}$$

Now, again, if you replace Q_{up}, Q_{R1}, and Q_{R2}, then we will get;

$$\pi.d.L_1.c_a - Q = \frac{\pi.d.L_2.c_a + 9.c_b.\frac{\pi}{4}\left(d_b^{\,2} - d^2\right)}{2}$$

Where, c_a is the adhesion between the shaft and the soil, c_b is the cohesion of the soil at the bulb.

Now will replace the value of L1 from equation 1. So, when we replace the, the value of L1 from equation one, we will get,

$$Q + \frac{1}{2}\left[\pi.d.L_2.c_a + 9.c_b.\frac{\pi}{4}.\left(d_b^{\,2} - d^2\right)\right] = \frac{1}{1.2}\left[\pi.d.L_2.c_a + 9.c_b.\frac{\pi}{4}.\left(d_b^{\,2} - d^2\right)\right]$$

Here we are replacing the values of this one over there. So, here we know the Q load. We know the d, L_2, So, accordingly we can design the pile. So, for any factor of safety, we can see whether the pile foundation is safe or not. Or if we know the Q values we can calculate, or we can design the pile by choosing different L_2, L_1, d, and d_b. So, this way we can design a pile for a deep foundation.

(Refer Slide Time: 25:34)

There is another method by which we can provide a pile foundation in an expansive soil. In this case, what we will do is we will first drill an oversized hole into the ground, and then we will put the pile and the area between the pile and the cut will be filled with non-expansive particularly soft compressible soil or material. Straw, or saw dust can be used as a filler material.

So, in this method, an oversized pile hole will be drilled. The space between the pile and the soil will be filled with soft and composable material to reducing the uplifting pressure. So, here, this material will act a cushion between the soil and the pile. So, therefore, the uplifting pressure will get reduced. So, this method will then reduce the uplifting pressure. But one of the demerits of this method is this method will reduce the total load bearing capacity. As some of the portion of the soil will be resisting this upward, uplift pressure by providing a frictional resistance. But when we provide a soft material over here, then the frictional resistance, which will be opposing this uplift pressure will also get reduced. So, because of that, the total load bearing capacity of the pile will be reduced. And this is most commonly used when upper expansive layer of the soil is underlain by non-expansive soil. And also this is applicable for a low to medium swelling soil.

(Refer Slide Time: 27:18)

When we design a pile, we do some common error, which we should avoid. First one is we go for an excessive pile diameter. As I told you, one of the method of counterbalance the swelling pressure is to increase the load. So, in that case, what we do is we increase the diameter to get the enough dead load to counter-react the swelling pressure. But this is not all the time economical.

Instead of that, we should go for a longer pile of small diameter, because if we go for a shorter pile with larger diameter, the uplifting pressure will be more as the surface area of the pile will be more. And also if the pile is of short length, then the uplifting pressure will also be acting at the bottom of the footing.

The next is insufficient pile length. The possibility of a pile to remain in the unstable zone will remain high if the length of the pile is kept short. If we take a soil and if this is a unstable zone, and this is a stable zone, if we keep the pile of short length, then the entire length of the pile will remain in unstable zone.

So, now this pile will be subjected to the uplift pressure from the side, as well as from the bottom. So, therefore, we have to be sure that the pile of sufficient length should be provided and pile should go into the stable zone as well. The other common error, what we do is by providing a non-uniform pile diameter. Sometimes during the construction, extra concrete materials we just pour.

So, this extra concrete material can act as a part of pile. And if the soil is an expansive type, then there will be an uplifting pressure acting over this extra pile area or extra portion of the pile. So, this uplifting pressure will generate additional uplifting pressure on the pile. Similarly, if we design a pile of this shape, then also there will be an uplifting pressure acting on the surface of the pile.

So, therefore, the pile should be of uniform diameter, and we need to avoid the presence of this mushroom type of structures on the side of pile.

(Refer Slide Time: 29:48)

Sometimes we need to provide a shallow foundation to an expansive soil. But we need to remember that the shallow foundation should not be used in expansive soil, except when the soil is of low expansion type or when the soil will have a low expansion potential. But when we provide a shallow foundation to an expansive soil, we need to take care of three design criteria.

The first one is, the structure should be designed to be stiff enough to provide rigidity in case of heaving. That means the structure should be stiff enough such that in case of a heaving, then it should not get cracked. Then the second one is the foundation to be designed to isolate the structure from the expansive soil. And the third is the soil should be stabilized to produce the less expansion.

So, we need to take care of these three things while designing a shallow foundation in an expansive soil. A stiffened mat foundation or reinforced slab on grade foundations are primarily used to provide rigidity to withstand expansive soil heave and a deep foundation system is used primarily to isolate the structure from the expansive soil.

(Refer Slide Time: 31:05)

If we are providing a shallow foundation to an expansive soil, then we need to take care of this standard procedure. The first one is the soil has to be stabilized by going for any improvement methods. As I discussed in the previous classes, we need to compact the soil on the wet side of the OMC. If we look into the dry density and water content curve, this part is known as dry OMC and this part is known as wet of OMC. And if we compact the soil on the dry of OMC the soil will exhibit a higher swelling characteristics. If we compare the soil on the wet of OMC, the swelling tendency of the soil will decrease. So, therefore, we need to compact the soil on the wet side of the OMC.

Then control the expansion. For example, allow the soil to expand in the cavities of the footing or structure. Say for example, if we provide a footing with this kind of cavity, like this, then the soil will expand to these cavities. Therefore, the expansion will be only limited to this cavity portion and it will not increase or lift the structure. All this expansion behaviour of the soil will be arrested within this cavity. So, the other that is control the expansion. That means allowing the soil to expand in the cavities.

Control the soil water. The main problem with the expansiveness behaviour is water. If there is a source of water, or if the water is getting ingress into the soil, then the soil expansive characteristic will increase, or the soil will expand. If we isolate the structure such that the water cannot ingress or cannot enter into the soil, then the swelling of this soil can be controlled. So, therefore, we can control the movement of the water into this layer located below the foundation.

Or, providing a granular blanket of 0.3 to 1 meter to control the capillary water or loading the structure to a sufficient load to counter the swelling pressure and providing vertical and horizontal barriers. So, these vertical and horizontal barriers can prevent the ingress of the water into the soil just below the foundation.

So, these are the different standard procedures for shallow foundation providing in an expansive soil.

(Refer Slide Time: 33:36)

There are different types of foundation, which we can provide as a shallow foundation in an expansive soil. So, these are the continuous footing. In continuous footing also we can provide voids. As I discussed in the previous slide, if we provide the voids, then the expansiveness behaviour of the soil will get only to this or will occur only on this cavity portion. So, therefore, there will be no more impact or not much impact of expansive behaviour on this footing.

We can go with the isolated pad. We need to provide different pads, which is located at sufficient distance apart such that the effect of the swelling on this structure will be minimum.

Or we can go with the reinforced mat.

(Refer Slide Time: 34:25)

In the continuous footing. This is most commonly used for light loaded structure and cannot be used for a high expansive soil. So, only applicable for soil which has a medium to low value expansiveness. And it can be used with the swelling potential less than 1 percent or the swelling pressure less than 3000 psf. So, only for this kind of soil, continuous footing can be applied.

And also in order to apply a higher dead load pressure on the expansive soil, we need to reduce the thickness of this footing. That is we need to reduce this thickness such that the pressure exerted by the foundation on the soil will be more as the pressure is equals to F by A, that means the pressure is inversely proportional to A. So, if we reduce the A, then it will exert a higher pressure on the soil, or it will exert a higher pressure to counter-react the swelling pressure.

Next is a pad foundation. So, in pad foundation, So, this is the pad foundation, this is isolated pads. In the pad foundation, it will be consisting of series of individual footing pads placed on the upper soil and spanned by grade beams. And it can be provided where the soil poses moderate soil potential and have high bearing capacity. And also the individual pads should be sufficient exerted pressure higher than the swelling pressure of the soil. So, in this case, we can provide the pad foundation and also the pressure coming from this pad will be more than the swelling pressure of the soil. And this pad should be located to a far distance so that the effect will be minimum.

(Refer Slide Time: 36:15)

Another type of footing we can provide is waffle slab. This is the type of waffle slab. Mostly it is provided at a shallow depth or mostly on the ground surface as well. This is also known as a ribbed slab foundation, and it is a structure. If we look in from the top, it will be a planar structure. But if we look from the bottom, it will have number of voids like this. So, these are the voids.

So, a waffle slab foundation also known as ribbed slab foundation is just structure that is plain at the top and is a grid like system at the bottom. So, this grid like system are known as the ribs. Here, we can see this is the waffle slab, and this is the voids. So, this is known as ribs. This waffle slab will be very highly stiff and rigid in nature. And mostly the thickness of this waffle slab will be between 14 to 20 inches.

So, when we provide a waffle slab here, the soil, this will be the slab resting on the soil. Say for example, if the soil undergoes any kind of swelling, that swelling will be take place within this waffle zone or the void zone, that means at this zone. So, therefore, the impact of the swelling will be less on the footing. The ribs support the structure while the waffle voids allow the soil to expand.

So, this ribs takes the structure load, whereas, this waffle zone provide or allow soil to expand within this zone. So, this is known as waffle zone, and this is generally provided at on the ground surface, or maybe just few feet below the ground surface.

(Refer Slide Time: 38:15)

The other method of controlling the swelling in an expansive soil is moisture control. As a moisture is a main culprit or main force driving the soil or main reason behind the expansiveness of the soil. If we can restrict the movement of this moisture below this foundation level, so that there will be no change in the water content. So, therefore, there will be no heaving or shrinkage of the soil.

So, this moisture control can be carried out using moisture barrier wall. This moisture barrier wall can be provided in two way. One is a vertical wall, and second one is a horizontal moisture barrier wall. This is the vertical wall, and this is a horizonal moisture barrier wall. This horizonal moisture barrier wall is mostly made of a membrane.

Maybe we can use geomembrane, which will be made of HDPE and a vertical moisture barrier can also be provided. So, maybe we can provide this one with a concrete wall. This two, the vertical barrier wall and the horizontal barrier wall will prevent the migration of the water from the outside to the soil present below the foundation level. In this case, we can see, this is a foundation level here at trench has been digged. And then this is filled with clean sand and gravel and a perforated PVC pipe is there. A geomembrane has been provided as a vertical barrier wall over here. Since the geomembrane is impermeable to water, the migration of the water cannot take place beyond this portion. So, this is also one form of the vertical barrier wall.

(Refer Slide Time: 40:07)

We can also control the moisture by providing subsurface drainage. So, here we can see, this is a foundation located very close to a stream. So, if there is ingress of the water, then again, the soil on this zone will get affected. So, to reduce the ingress of the water, we need to provide a subsurface drainage. So, water can come here and it can be extracted. So, this subdrain is provided to intercept the gravitational free water, and then it can be removed.

So, the purpose of subsurface drainage to intercept the gravity flow of water, lower the groundwater level and arrest the capillary moisture movement. This can also be provided in the form perimeter drainage wall. Like if this is a foundation, we can provide a drainage wall all around this foundation. So, this can be provided in many way, like as a cut off wall, or maybe you can provide a perimeter wall. This is all about the controlling, the swelling behaviour of the soil.

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Again, there is another factor we need to remember that the evapotranspiration of water from the soil produces the shrinkage behaviour. Say, for example, if a house is located very close to a tree, then the root of the tree can absorb moisture from the soil beneath this foundation. As the water gets absorbed, the soil will shrink. Therefore, there will be settlement. So, therefore, we need to avoid any kind of accumulation of the water or any kind of movement of the tree roots below the foundation.

And also we need to be sure that big trees should be located far distance from the structure. As a thumb rule, if the total height of a tree is H, then it should be located at least a distance H from the edge of this footing. So, that the effect of root on the evapotranspiration or the effect of the root on absorbing moisture of the soil present below this footing will be minimal. So, we need to be ensure that any big tree, if lying very close to the foundation, it should be at least at a distance of H where H is the height of the tree. So, this is to reduce the evapotranspiration below the soil present in a footing.

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So, these different references which has been used to prepare this lecture and thank you.