Expansive Soil

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Lecture 12

Classification and Prediction

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Hello everyone, welcome to the course expansive soil. Today's will be the 11th lecture and it will be in module 4. Here we will learn about the swelling behaviour of the expansive soil and particularly in this class we will learn about the classification and prediction of the expansive soil.

In the earlier classes, we learned about the method to determine the expansive behaviour of the soil, like swelling potential, swelling pressure, free swelling, liquid limit. And in this class we will learn how to classify or predict the swelling behaviour of the soil from those parameters. So, we will look into all these parameters one by one or one, we will look into the different methods which are available one by one.

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The first method is Indian standard. Indian standard is one of the very few standards, which actually talks about the classification of expansive soil behaviour. This standard, Indian standard mostly classify the soils based on its liquid limit, plasticity index, shrinkage index and free swell. In this free swell means the differential free swell index, which we have already learned how to determine the free swell index of the soil.

If the liquid limit is in between 20 to 35 or plasticity index is less than 12, shrinkage index is less than 15 and free swell percentage is less than 50, then the degree of expansion of the soil will be low and the soil can be termed as non-critical. If the liquid limit is between 35 to 50 or plasticity index is between 12 to 23, shrinkage index between 15 to 30 or free swell percentage is 50 to 100, the degree of expansion can be medium and the soil will be termed as marginally severe soil.

Similarly, if the liquid limit is around 70 to 90, plasticity index is greater than 32, shrinkage index is greater than 60 and free swell is more than 200 percent, the degree of expansion of the soil will be very high and the degree of severity of this soil can be termed as severe.

So, this is about how the Indian standard classification of expansive soil. In Indian standard the soil has been classified as low, medium and high and very high based on these parameters, liquid plasticity index, shrinkage index and free swell index and depending on the degree of expansion, the soil is termed as non-critical, marginal, critical and severe.

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The other method which is most widely used in India was given by Sridharan and Prakash in 2000. This classification is based on the percentage expansion of the soil, which is determined in an oedometer test on the sample compacted at maximum dry density and OMC and under a surcharge load of 7 kPa. And also, it also takes free swell ratio of the soil into consideration.

Here I need to tell that, the free swell ratio is different from the DFS, that is differential free swell. In free swell ratio, the sediment volume of the soil was measured in a DI water and the sediment volume of the soil, the same soil was determined in the kerosene or CCL_4 solution and that ratio is known as the free swell ratio.

So, based on the expansion in oedometer test result and the free swell ratio data, the soil can be termed as non-swelling, swelling and the soil expansivity can be classified as negligible, low, moderate and high. If the swelling potential, which is measured in the oedometer test, is less than 1 percent or the free swell ratio is less than equals to 1, the soil can be termed as non-swelling soil and the expansivity of the soil will be negligible.

If the swelling potential is in between 1 percent to 5 percent, or the free swell ratio between 1.0 to 1.5, then the clay type or the type of clay present in the soil can be a mixture of swelling and non-swelling soil and the expansivity can be termed as low. If expansion in oedometer test or the swelling potential in oedometer test is more than 25, the free swell ratio is more than 4.0, the soil clay type will be a swelling type soil and the soil expansivity can be termed as very high.

So, depending on the swelling potential, which is determined from the oedometer test by compacting the specimen at MDD and OMC and applying a surcharge load of 7 kPa and then submerging in the water, if we get the swelling potential, then that can be used here. Similarly, the free swell ratio which is obtained also can be used over here to determine the swelling type of the soil and also the expansivity of the soil.

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Talking about different classification it started long back. Holtz and Gibbs classified the expansive soil based on swelling potential of an undisturbed soil sample after submerging the soil and under at one psi load, that is approximately 7 kPa of load in an oedometer test. So, based on this test result, he determined the swelling potential and based on the swelling potential, he classified the soil as low, medium, high and very high soil.

Say for example, if the swelling potential is in between 0 to 10, the degree of expansion of the soil can be expected to be low. If it is in between 20 to 35, the degree of expansion can be expected as high. If it is more than 35, it will be very high. Then again we need to remember that this test was carried out on the soil, which were undisturbed and were submerged in the water under a load of 1 psi or 7 kPa in an oedometer.

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Then the other classification is given by United States Bureau of Reclamation, this method is based on the clay content, which is less than one micrometres size, plasticity index, shrinkage limit. We know that the more clay content on the soil, the specific surface area of the soil will increase and that soil will tends to absorb more water. Similarly, more plasticity index, soil will absorb more water and the degree of expansiveness will be more.

The classification is based on the clay content, the plasticity index and the shrinkage limit. If the colloid content is less than 15 percent, or plasticity index is less than 18 percent, shrinkage limit is less than 10 percent, the degree of expansion of the soil will be low and the probable swelling potential, which we can get will be around less than 10 percent. At the same time, if the clay content is between 13 to 23, plasticity index between 15 to 28, shrinkage limit is between 10 to 20, the degree of expansion of the soil will be medium and the expected expansion of the soil will be 10 to 20 percent.

The most critical condition arises when the colloid content is greater than 28 percent, plasticity index is greater than 35 percent and shrinkage limit is greater than 30 percent. In that case, the degree of expansion of the soil will be very high and the probable expansion will be greater than 30 percent.

So, this method you just need three parameters, one is colloid content, plasticity index and shrinkage limit and based on this, the soil has been classified either as low, medium, high or very high. And depending on whether low, medium, very high, the probable expansion can be less than 10 percent, 10 to 20 percent, 20 to 30 percent or greater than 30 percent.

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The next method which is also widely used is given by seed et al. Seed et al's method classified the expansive soil is based on the swelling potential of remolded soil, which is compacted at standard proctor MDD and OMC and submerged in soil in water, under a load of 1 psi, that is 7 kPa in an oedometer.

Based on this test result, the swelling potential which we can get, can be linked with the degree of expansion. If the swelling potential is in between 0 to 1.5 percent, the soil can be termed as less or low expansive soil. If it is in between 1.5 to 5 percent, the soil can be termed as medium expansive soil, if the swelling potential is between 5 to 25 percent, it can be termed as high expansive soil. If it is greater than 25 percent, it can be termed as very high expansive soil.

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Further the Seed et al result were used to determine the swelling potential by using the activity and clay fraction. This method of classification is based on the activity of the soil as well as the percentage of clay fraction present in the soil. From the previous result, the swelling potential were determined for different types of soils and based on what is the clay fraction and activity, the soil were classified as very high, high, medium and low expansive soil based on their swelling potential here.

Here if the swelling potential is more than 25, that means in this zone, the soil can be termed as very high. If the swelling potential is between 25 to 5 percent, that soil will fall in this zone and the soil can be termed as high swelling soil.

If the swelling potential comes in between 5 to 1.5 percent, that means the soil will fall on this zone and the soil can be termed as medium swelling soil. If it is less than 1.5 percent, then the soil will be very low swelling soil. This method is based on the previous method or the result of this were used to determine the classification based on activity and clay fraction.

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The next method used were, the Ven Der Merwe Method, which was given by Ven Der Merwe in 1964. This method uses the empirical relationship between the degree of expansion, the plasticity index, the percentage clay fraction and the surcharge pressure acting on a soil. In this method, the total heave on a ground surface can be determined using this equation.

Total heave at ground surface, $\Delta H = \sum_{D=1}^{D=n} F \times PE$

So, in this method the soil has been divided into various layers, each layer is approximately 1 feet depth and then the ΔH were determined.

In this equation ΔH is equals to the total heave in inch on the ground surface, D is the depth of the soil layer in increments of 1 foot up to deepest level, F is a reduction factor of surcharge pressure, which can be determined using this equation. PE is the potential expansiveness in inch per foot of depth.

Using this equation, we can find out this graph. In this graph the soil has been classified as low swell, medium swell and high swell, very high swell by assuming different values of PE. That is PE 1, PE 1 by 2, PE 1 by 4 and PE equals to 0. So, by assuming different PE value, we can find out what will be the soil expansive type, or what can be the heave of the soil using this equation.

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Now, this method is based on the differential free swelling test result. In this differential free swelling test result we know that we need to take to 10 gram of dry soil and put it in water and also another 10 gram of soil we need to put it in kerosene, then we need to measure the volume of the soil sample in water and kerosene, and then we can determine DFS value. The measure DFS value can also indicate what will be the degree of expansiveness of the soil.

If the DFS value is less than 20 percent, the soil can be termed as low expansive soil. If it is in between 20 to 35, the soil can be termed as medium expansive soil. If it is in between 35 to 50, the soil can be termed as high expansive soil. If it is greater than 50, the soil can be termed as very high expansive soil. So, this method is based on the differential free swelling test method, which is given by Indian standard.

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Another method was proposed by Altmeyer, in 1955. This method is based on the shrinkage limit or linear shrinkage of the soil. In this method, the use of clay fraction was eliminated and instead of that, the shrinkage limit and linear shrinkage was taken into consideration for determining the expansiveness of the soil. Here we can see the linear shrinkage and shrinkage limit is being used to define the probable swell or degree of expansion of the soil.

If the linear shrinkage of a soil is less than 5 percent or the shrinkage limit is greater than 12 percent, the probable swell will be less than 0.5 percent and the soil can be termed as low or non-critical soil. If the linear shrinkage is in between 5 and 8 or shrinkage limit is in between 10 to 12, the probable swell will be 0.5 percent to 1.5 percent and the degree of expansion of the soil can be termed will be termed as marginal. If the linear shrinkage is greater than 8 percent or the shrinkage limit is less than 10 percent, the probable swell will be greater than 1.5 percent and the soil will be turned as critical.

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This method is based on the percentage finer, that is less than 75 micron particle size, liquid limit and SPT values and this was given by Chen in 1988. This methods correlate the laboratory data that is liquid limit, clay content and the field data that is SPT value to determine the probable expansion of the soil as well as the degree of expansion of the soil.

So, this method uses three parameters percentage finer, liquid limit and the standard penetration resistance, that is in blows per fit unit. If the percentage finer is greater than 95 percent, that liquid limit is greater than 60 percent, standard penetration resistance is greater than 30, the probable expansion of the soil will be greater than 10 percent and the degree of expansion of the soil can be termed as very high.

Similarly, if the percentage finer is in between 60 to 95 percent, the liquid limit is 40 to 60 percent, the standard penetration resistance between 20 to 30 and then the probable expansion will be 3 to 10 percent and the degree of expansion can be termed as high.

Similarly, if the finer content is less than 30 percent. the liquid limit less than 30 percent the standard penetration resistance less than 10 percent and the probable expansion of the expansion of the soil will be less than 1 percent and the degree of expansion can be termed as low. This method takes into account the percentage finer, liquid limit and SPT value.

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There are two other methods given by Raman and Chen, which uses the plasticity index and shrinkage index to classify the soil. As far as Raman, if the plasticity index is less than 12 percent and shrinkage index is less than 15 percent, the soil will be termed as low expansive soil. Similarly, if it is between 12 to 23 percent and shrinkage index is between 15 to 30 percent, it will be termed as medium expansive soil. If the plasticity index is greater than 32 percent, shrinkage index is greater than 40 percent, the soil can be termed as very high expansive soil.

Chen, only uses the plasticity index and based on this plasticity index, he classified the soil as low, medium, high and very high soil. If the plasticity index is between 0 to 15 percent, the swelling potential of the soil will be very low. Again, if it is between 10 to 35 percent it will be medium. If it is more than 35, it will be very high. Raman methods takes into consideration the plasticity index and shrinkage index, whereas the Chen method takes only plasticity index into consideration to define the swelling potential of the soil.

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Another method was given by Snethen in 1977. This method is based on the liquid limit, plasticity index and in-situ suction of the soil. So, these three parameters were used to determine the potential swell of the soil and then potential swell classification of the soil based on this potential swell. If the liquid limit is greater than 60, plasticity index is greater than 35, soil suction at natural moisture content is greater than 4 tsf, then the potential swell will be greater than 1.5 and the soil classification will be highly expansive soil.

If the liquid limit is in between 50 to 60 percent, plasticity index between 25 percent to 35 percent and suction at natural moisture content is between 1.5 to 4 tsf, then the potential swell will be 0.5 to 1.5 percent and the potential soil classification will be marginally expansive soil. If the liquid limit is less than 50 percent, plasticity index is less than 25 percent, suction at natural moisture content is less than 1.5 tsf, then the potential swell will be less than 0.5 percent and the soil will be classified as low swelling soil.

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This method is based on the liquid limit and plasticity index and it was proposed by Daksanamurthy and Raman in 1973. This is also a widely used method in India. This method takes into consideration, the liquid limit and the plastics limit of the soil. Based on the liquid limit and plastic limit, here we can see, few lines has been drawn based on their liquid limit. So, these lines are at 20 percent, 35 percent, 50 percent, 70 percent, 90 percent, and these are the different zones, which has been drawn here. One is a non-swelling soil, low swelling soil, medium swelling soil, high swelling soil, very high swelling soil and extra high swelling soil.

In this method, if the liquid limit is between 0 to 20 percent, the soil will be termed as non-swelling soil. If the liquid limit is in between 20 to 35 percent, then if your soil falls on this zone, then the soil will be low swelling soil. If the liquid limit is in between 35 to 50 percent and if a soil falls on this zone, the soil will be a medium swelling soil.

Similarly, 50 to 70 percent, the soil can be high swelling soil, 70 to 90 percent will be very high swelling soil and greater than 90 percent will be extra high swelling soil. This method was proposed by Daksanamurthy and Raman in 1973. And it classify the soil based on its liquid limit and plastic limit.

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Then this method classified the soil based on the mineralogical classification chart. First this method was developed by Pearring in 1963 and then it was modified by Holt in 1969. This method of classification correlates between the clay mineralogy, the clay activity and a new parameter was used to classify the soil, that parameter is the cation exchange activity.

$$\text{Cation exchange activity (CEAc)} = \frac{\text{Cation Exchange Capacity (CEC)}}{\text{Clay content}} \times 100$$

So, this is a new terminology, which was used to classify the soil in this method, that is the cation exchange activity.

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Here we can see based on the cation exchange activity and activity of the soil, the different mineral present in the soil has been determined using this technique. Here we can see these are the different zones. If you have soil falls on this part, based on their cation exchange activity and activity, then the montmorillonite content will be more. If it is here, it will be a attapulgite. If it falls on here, it will be illite, chlorite and kaolinite. If it is here, it will be like halloysite. This method tells us about what kind of mineral present in a soil based on their cation exchange activity and activity.

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The next method of classification is the classification based on COLE and activity. COLE means the coefficient of linear extensibility. This is a method of determination of shrinkage of a soil, which I will explain later on. Generally, this coefficient of linear extensibility is defined by this formula;

$$\text{Coeffficient of linear extensibility (COLE)} = \frac{\Delta L}{\Delta L_D} \times 100 = \left(\frac{\gamma_{dD}}{\gamma_{dM}}\right)^{0.33} - 1$$

Where, ΔL by ΔD is a linear strain relative to dry dimension, γ_{dD} is the dry density of oven dry sample, γ_{dM} is a dry density of sample at 33 kPa suction. So, in this method, which I will explain well I will be talking about the shrinkage behaviour of the soil.

In this method, the soil will be dried after a particular water content and then the change in length of the soil will be determined based on that, the COLE values or COLE value will be determined. And this method combines the engineering index properties of the soil with the cation exchange capacity. Here also the cation exchange activity parameters is used to classify the soil.

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This method first based on the reports of US soil conservative service, the clay mineralogy of different soils collected from different parts of the US were plotted on a chart drawn between cation exchange activity and activity. That means, soil collected from the different parts of US were taken and their cation exchange activity and activity were determined and then they plotted on a chart. Then based on that chart and by knowing their different types of mineral present, the chart boundary for mineral groups that is kaolinite, illite, montmorillonite, and vermiculite were drawn.

Then, five mineralogically similar regions were drawn in the chart and then a relationship between COLE and clay content was developed for each of the five chart region. So, once the soil has been placed in different five regions, the COLE value were determined and then based on the COLE value, clay content and this region, this zone, the soil classification was carried out which I can show you here.

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Here the soils were classified based on their mineralogical composition, then the COLE value. Here we can see Zone 4, Zone 3, zone 1, Zone 2 and Zone 5. This is based on there cation exchange activity and activity. The soils were collected, then their cation exchange activity and activity were determined, then the soils different mineralogical compositions were determined and based on this cation exchange activity and activity, the soil has been zoned into five different zones.

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Then the soils were plotted and if the soil is in zone 1, the different clay fraction of the soil will be like smectite will be greater than 50 percent, illite will be none, kaolinite will be none and there will also be no vermiculite. If the soil falls on zone 2, then the smectite content will be greater than 50 percent, some trace amount of illite will be present trace to 25 percent of the illite amount will be there, trace means less than 5 percent, kaolinite will be like some trace content to 25 percent will be there and no vermiculite will be there.

If the soil falls on zone 3, then it will be 5 to 50 percent smectite, 5 to 25 percent illite and Kaolinite will be none and vermiculite will be none. If the soil falls on zone 5, there will be traces of smectite, illite content will be from trace to is 25 percent, kaolinite will be 10 to 50 percent and vermiculite will be some trace amount will be there. Based on this classification. mineralogical content were determined like this.

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Once the mineralogical content were determined, then the coal values were determined and then the coal and the percentage of clay were plotted and then this lines were drawn. So, here we can see again zone 1, zone 1 to 2. If the soil falls on zone 1 to zone 2, the expansion potential will be high to very high. If the soil falls in between zone 3 to zone 4, the potential of expansion will be moderate.

And if the soil falls on zone 5, the potential of expansion will be very low. That means zone 5 soil means the soil will have this amount of mineralogical content. Zone 1 means, zone 1 soil will have this amount of mineralogical content. So, based on the cation exchange capacity, then the COLE value, the percentage clay value, the soil can be classified as highly expansive soil, moderate expansive soil and low expansive soil.

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Then another method was used that, which takes into consideration of cation exchange activity and activity. And here the soil can be classified as moderate, very high to high expansive soil, or low expansive soil. This method was developed from the mineralogical classification chart. But here they do not use any mineralogical composition, they only use the cation exchange activity and activity to determine whether the soil will be very high to high expansive soil, or moderate expansive soil, or low expansive soil. So, these are the different kinds of classification, or prediction of the soil based on few parameters.

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Mostly you have seen, all the classification are based on either their index properties, or some engineering properties, like swelling potential, swelling pressure, or liquid limit, plastic limit, or shrinkage limit and all these methods are unique. So, here we can see that no two methods will give the same results. Say for example, there is a comparison between the Chen method and Indian standard method which is based on the liquid limit. If the liquid limit is less than 30 percent as far as Chen method the soil can be termed as low expansive soil, but IS standards gives 20 to 35 percent liquid limit for the soil to be termed as low expansive soil.

Similarly, for very high expansive soil, Chen suggested the liquid limit should be greater than 60 percent. But Indian standards suggested, the liquid limit should be 70 to 90 percent. So, here we can see, even the two method uses the same parameter, the classification are not unique, they are different.

Similarly, if we compare with the Chen method, Holtz and Gibbs method and IS method based on the plasticity index, we can see, the Chen method suggests the plasticity index should be 0 to 15 percent for a low expansive soil, Holtz and Gibbs suggest it should be less than 20 percent, Indian standard suggests it should be less than 12 percent.

Similarly, for a very high expansive soil Chen methods suggest the plasticity index should be greater than 35, Holtz and Gibbs suggest it should be greater than 32 and IS standard suggests it should be greater than 32.

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Similarly, if we use the oedometer test result, say for example, Holtz and Gibbs and Seed et al. data, in which the swell potential were determined using an oedometer test, it is surcharge of 7 kPa, we can see that as far as Holtz method, if the swelling potential is less than 10 percent the soil can be termed as low swelling soil. But for Seed et al method, it should be between 0 to 1.5.

Similarly, for mediums expansive soil, the Holtz and Gibbs suggest the swelling potential should be between 10 to 20 percent. At the same time Seed et al. suggest it should be 1.5 to 5 percent. For very high expansive soil, Holtz and Gibbs suggest it should be greater than 30, whereas, Seed et al. suggest it should be greater than 25 percent.

So, here we can see, although they use the same parameter, the classification uses different limiting values of liquid limit, or plasticity index, or swell potential. Therefore, all these classifications are not uniform. Only thing is, all this classification provides only a qualitative rating, such as high, medium, low etc, but it do not say about how much swelling can be expected.

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Here we can see in this graph, the four different methods has been compared, the swelling potential and plasticity index were used. The first you can see this is a Holtz and Gibbs method, which uses a surcharge pressure of 1 psi. And here you can see the graph is here the curve is here.

Similarly, if we take Seed, Woodword method, which also uses a surcharge pressure of 1 psi, we can get a curve like this. If we take the Chen method, which uses 1 psi pressure, the curve goes here. Similarly, if the Chen takes a surcharge load 6.94 psi, then the curves will be here. So, even if we take same surcharge load, if we compare these three methods, we can see the there is a large variation in the swelling potential of the soil at different plasticity index.

So, this may be because of the initial condition. In Holtz and Gibbs method, the soil were allowed to swell from air dry to its saturated state, whereas, in Seed, Woodword method, this remolded soil sample were used. Whereas, in Chen method, the soil were allowed to swell from its natural moisture condition to saturation condition. So, here you can see, the probable reason for this variation are like, the different type of soils were used, different initial conditions were used, initial condition means, whether it is remoulded or undisturbed, initial moisture conditions were different, like whether it is wet, air dried, compacted or natural. So, depending on all these variations, the results and the classifications were also different.

So, therefore, when we go for any classification, we need to see what are the different things they have taken into consideration? What are the testing methodology? What is the soil type? Therefore, when we use some classification technique, we need to first see what is the different type of soil they have used for the classification? What are the testing condition? What is the initial condition? Whether it is remolded or undisturbed? What is the compaction condition? Whether it is MDD, or in-situ density, or some other density? What is the initial moisture condition from where the swelling were allowed? What is the surcharge load?

So, based on these load or all this testing conditions or all these initial conditions, we have to use some method, which is more identical to our conditions. So, based on those criteria, we need to select which method to adopt for classification of the soil. So, with this I will conclude this lecture here.

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And these are the different references, which are used in this in lecture. And thank you for your attention.