Expansive Soil

Professor Doctor. Anil Kumar Mishra
Associative Professor
Department of Civil Engineering
Indian Institute of Technology, Guwahati

Lecture No. 27

Use of expansive soil for various geotechnical engineering application

Hello everyone, welcome back to the course Expansive Soil. Today we will learn about some of the applications of expansive soil particularly application of expansive soil for various geotechnical engineering application. This will be the lecture number twenty fourth and the last lecture of this course, and it will be in module 8.

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So, far we have learned that expansive soil as a problematic soil. The problem associated with any expansive soil is lies because of its swelling characteristics, shrinkage and uneven settlement or swelling. When an expansive soil absorbs moisture, the water content of the soil will increase and that will lead to the swelling of the soil.

Similarly, when the water content reduced because of the evaporation or evapotranspiration, the volume of an expansive soil will decrease and that will lead to the shrinkage of the soil. When the swelling and shrinkage takes place, there will be heaving and settlement of a structure and if this heaving or settlement of the structure becomes non-uniform or uneven, then that will lead to a damage to a structure. So, therefore, the different problems associated with an expansive soils are swelling, shrinkage, uneven settlement and swelling.

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And we know that 17 percent of Indian landmass is occupied by expansive soil and the damage caused due to that expansive soil is quite large. In an estimate that total amount of damage caused because of expansive soil is far more than the total damage caused due to earthquakes, tsunami, flood or hurricane combined together. So, therefore, we can know that how big the problem is.

Here we can see an example, in this case a structure is resting on an expansive soil. So, this is one expansive soil and there are cracks or fissures present over here. And these are known as the desiccation cracks. When there is a rainfall occurs or when this cracks comes in contact with water, the volume of this soil will increase or when the water comes in contact with this cracks, the water can migrate into the expansive soil or the water will ingress into the expansive soil which is present below the foundation.

In this case during the monsoon season or rainy season, the water will penetrate to the expansive soil and because of this penetration of the water into the expansive soil, the volume of this soil will increase. We have also learned before that the ingress of the water is not uniform below a foundation. Due to the presence of slab or other structures, there will be non-uniform ingress of water to the soil.

And as a water ingress is non-uniform, the swelling behaviour of the soil below this foundation will also be not uniform. In this case, we can see here, a large amount of water has been ingress at this portion, whereas, less amount of water has been ingress to this portion and because of less amount of water over here, the swelling will be less at this point.

However, due to large amount of water ingress at this point, the swelling will be high at this point. And because of this uneven swelling, the structure will be lifted unevenly. In this diagram, a large amount of heaving has been occurring at this point in comparison to this. So, due to this uneven heaving or uneven swelling of the soil, the structure will get damaged, crack will start to appear on the structure and that will damage the structure.

Similarly, during the drying season, the reverse thing happens; that means, the water will be removed from the soil because of the process of evaporation or evapotranspiration. Again, the removal of the water will not be uniform. And because of this non-uniform removal of water, again the shrinkage of the soil will be different. In this case, here, the amount of removal of the water is less in comparison to here. So, as the less amount of water has been removed here, the amount of shrinkage on this portion will be less in comparison to this portion.

And here in this structure, we could see an uneven shrinkage has occurred and because of that, this portion has been tilted. And due to this uneven settlement or uneven shrinkage, again cracks will start to appear on the structure. And this process takes place regularly that means, there will be cyclic swelling and shrinkage behaviour. So, in rainy season there will be expansion of the soil and during the dry season there will be shrinkage of the soil and due to this uneven swelling and shrinkage taking place regularly, the structure will get damaged or collapsed.

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So, here you can see, this is a seasonal wetting. In the seasonal wetting, the swelling of the soil will take place unevenly and that will lead to uneven heaving of the structure. Similarly, due to seasonal drying, there will be shrinkage of the structure and the shrinkage will be more at the center point in this diagram, and in this diagram, this swelling will be more at corner.

So, therefore, the swelling-shrinkage will give non-uniform settlement or non-uniform swelling to the structure and if the process is repeated for a quite long time or quite large number of times, then the structure will get damaged.

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In this pictures, we could see some of the damaged structure, the cracks has appeared on this buildings from the corner. All those pictures has been taken from the internet. And again the columns, there is a large cracks appeared in this column. Similarly, if we look into the highway here, we can find a wavy surface because of the uneven swelling and shrinkage and also large amount of cracks has appeared on the surface. So, these are the total, the different types of damage which we can expect in the field due to the expansive soil.

So, therefore, expansive soil can be treated as a problematic soil, but we have to remember that expansive soil also possess some of the good characteristics. So, these are the different properties of expansive soil which differentiate it from the other soils, one is the swelling, the second one is low hydraulic conductivity and the third one is a contaminant adsorption capacity.

Swelling means the volume of the soil will increase due to the absorption of moisture and it will give a lower value of hydraulic conductivity in comparison to all other soils. And it has a tendency to adsorb contaminant due to presence of negative charge on its surface. So, these three characteristics of an expansive soil, particularly bentonite, distinguish it from the other soil. Therefore, bentonite can also be applied for different engineering application due to these three characteristics. So, we will learn about all those applications particularly in the area of geotechnical engineering.

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The first application is application of expansive soil at landfill. This is particularly related with geoenvironmental engineering. So, going by the definition of geoenvironmental engineering, geoenvironmental engineering is an interdisciplinary subject which studies the effect of environment on the geotechnical behaviour of the soil.

Say, for example, this is our earth, we have atmosphere where we have air; we have biosphere where we have plant, animals; we have lithosphere where we have soil and we have hydrosphere we have water. So, if there is a contamination or pollution takes place to one of this sphere, then that will also contaminate the other sphere.

Say for example, in this case, if air is getting polluted, then the pollutant can come back to the earth's surface with the rainwater. And this pollutant can ingress into the soil along with the rainwater and then it can migrate into the groundwater source. When we take this groundwater for our drinking purpose or day to day life use, then it will affect our health. Similarly, the plant or other animal when they intake this water, polluted water, then they will get affected. Therefore, the effect to any of this sphere can also affect the other sphere say like affecting the atmosphere can cause a problem to biosphere, lithosphere and hydrosphere.

So, geoenvironmental engineering deals with the effect of environmental factors on particularly the lithosphere or the soil.

Because of its low value of hydraulic conductivity, high swelling characteristics and contaminant adoption capacity, expansive soil can be used for a landfill application. Before that, we would like to know what is the meaning of landfill.

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So, you might have seen these things around your city. So, these are the waste which we used to dump. So, these are the different kinds of waste, mostly this is a municipal solid waste which we generate from our home or any residential building or any restaurant. So, this waste generally are dumped into a landfill and this waste mostly contains the organic matter and with time this, this organic matter gets disintegrate and they produce leachate. Here you can see these are the leachates. So, here we can see the leachate which are produced over here.

The leachate is very harmful, toxic chemicals and it contains a large number of different types of contaminants which is not good for health. And also these leachates has high BOD, COD and also toxic chemicals. So, when these leachates migrates through the soil and joins or contaminate the groundwater resource, then if we intake those contaminated water, then that will impact our health.

So, therefore, we need to prevent the migration of this leachate through the soil and joining the water table. So, that is the purpose of a landfill.

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Generally, a landfill is provided to reduce the effect of leachates on groundwater. This is a diagram of a landfill. These are the waste which are dumped in a landfill. These are the waste material. So, this waste can be municipal solid waste, or can be industrial waste or hazardous waste. Now this waste will produce leachate and this leachate can migrate through the soil and can contaminate the groundwater resource.

Now in order to prevent this leachate to migrate into the groundwater, we provide a barrier layer in between the waste and the groundwater. This barrier layer is known as clay liner. The main objective of this clay liner is to prevent the migration of this contaminant through it and thereby not affecting the groundwater resource.

So, therefore, the clay liner should have a lower value of hydraulic conductivity and as the contaminant are present in the leachate the liner material should have a tendency to adsorb the contaminant. And as we know earlier that bentonite possesses both these characteristics, that means it has a lower value of hydraulic conductivity and also it can absorb a large amount of contaminant.

Therefore, bentonite is used as a liner material in the landfill site and bentonite is an expensive soil. Here we need to provide a layer of bentonite which will act as a liner material. So, bentonite will act as a liner material, and it will be like acting as an impermeable or barrier material between the waste and the water.

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Now, if we look into different guideline given by the different organization for a landfill liner material, we can see there are several layers of impermeable soils are there, all has a different function over here. But if we look into all these layers, then we will find a compacted layer of clay is present here. This layer acts as a liner material or a barrier material. So, main purpose of this material is to provide an impermeable layer between the waste and the water and generally this clay is bentonite and this is for a surface liner system.

Here again we need to remember that the rainwater should not migrate into this waste. Therefore, at the top also we need to provide a barrier layer. So, this is known as the capping system or cap layer and this is known as the bottom liner. On the surface liner or the caps liner here also we need to provide an impermeable layer of soil.

So, again, the purpose of this impermeable layer to provide a lower value of hydraulic conductivity to this capping system such that water will not migrate into the waste. So, this clay, here, can be replaced by an expansive soil or an expansive soil can be used as an impermeable layer for a liner system.

Similarly, if we look into the other design criteria given by other environmental agencies, we could see again somewhere it is given like layer of a clay liner in the form of a compacted clay liner and geosynthetic clay liner. We learned in the previous classes that geosynthetic clay liner consisting of layers of two geotextile and in between them a layer of expansive soil is present. So, this this is a GCL or geosynthetic clay liner.

So, here we can also replace this one with a geosynthetic clay liner and presence of bentonite will provide a lower hydraulic conductivity to the GCL. So, therefore, whether we go for a compacted clay liner or we go for a GCL, bentonite or an expansive soil occupy the most important position in this lining system. So, the first application of this expansive soil will be the liner application.

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Here we could see a geosynthetic clay liner this is a geotextile and this is bentonite which will be sandwiched between two layers of geotextile and this is the construction of an liners here you can see the compacted clay liner and also the GCL.

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If you look into the construction of a landfill liner, here we can see layers of compacted sand-bentonite. This is bentonite, is being mixed with sand. And after the compaction they are covered with a sheet so that the evaporation of the water will not take place. Now, here we need to remember another thing is generally bentonite is not used alone. Bentonite has to be used along with sand. Mostly around 10 to 20 percent of the bentonite is used with sand and bentonite is used with sand so that the hydraulic conductivity will decrease. The compaction characteristics of the bentonite we know is very less. So, by adding sand, the compaction characteristic of that sand-bentonite mixture will also increase and also by adding sand to bentonite that will also reduce its shrinkage characteristics or it will reduce the desiccation shrinkage of the bentonite.

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So, next, the use of expansive soil at nuclear waste repository. This is one of the another major use of an expensive soil particularly bentonite at a nuclear waste depository site. We know that radioactive nuclear materials are used for production of electricity, once the material is used up, then we just cannot throw that in a landfill because this radioactive material will be emitting some radiation. Therefore, it has to be buried hundreds of meters below the ground surface mostly in a rocky area.

So, this is an example of an underground nuclear waste repository site. Here we can see this is the access tunnel, and here the nuclear waste materials are buried. And this is generally located at a depth ranging from 300 to 1000 meters below the ground surface. These are the underground facility and this will mostly cover with a bedrock and these are the access tunnel. If we enlarge this portion, we can see here this is the access tunnel. This is the canister containing high level nuclear waste and this is a layer of compacted bentonite.

Now, here bentonite is provided as a buffer material and when we talk about this spent fuel, generally this spent fuel has 95 percent of uranium dioxide, 3 to 4 percent of fission product and around 1 percent of plutonium or other actinides. And these are located at a depth of 300 to 1000 meters below the ground surface. Because of the problem associated with the spent fuel it has to be buried under the ground.

Now if we look into this the cross sectional view of this underground facility, we have the access tunnel, this is the canister and there will be some space over here and these are the bentonite compacted at a high density. We need to remember that the water which are present here should not react with this canister. Generally, this canister is made of either steel or copper. So, if the water reacts with this canister, then the corrosion may occur and that may release the radioactive waste to the outside. Therefore, bentonite is provided to act as an impermeable layer between the canister and the groundwater or the rock.

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So, this is a cross section of a repository site. Bentonite can be used in the three forms; one is a fill form with containing sand-bentonite mixture in a ratio of 80:20 in this part, and a fill of compacted sand-bentonite mixture in a ratio of 90:10. Then these are the different blocks of bentonite which are compacted to a very high density mostly around 1.8 to 2.0 gram per cc to provide a very low value of hydraulic conductivity. This is the canister with spent fuel and generally a gap of 50 mm is provided between the bedrock and this layer. So, this is around 50 mm.

Then it will be filled with the powdered bentonite and there will be a gap of approximately 10 mm will be there between the canister and this block. And when there is a water ingress this can fill this void. And when you use the bentonite as a buffer material, then it should have certain characteristics like the hydraulic conductivity should be less than 10^{-12} m/sec.

And also the material which is used for the buffer should have a swelling pressure which should be very high and it should not be more than 20 MPa to avoid any excessive pressure on this canister. And also it has should have a very high thermal conductivity should be more than 1.0 watt per meter per degree Kelvin to dissipate heat from the canister.

Since this canister will be consisting of spent nuclear fuel, this radioactive material will be emitting heat and with time it will get heated. So, therefore, this buffer material should be able to release this heat without any problem and also the organic content present in this buffer materials should be less than 0.5 percent. Here we need to remember one thing that the migration of this radionuclides can take place in two ways. One is known as diffusion and another one is known as the advection.

If the hydraulic conductivity is less than 10^{-8} m/sec, then the migration will be in the form of diffusion which will be better in comparison to if it is happening through advection. Therefore, this buffer material should have a hydraulic conductivity which should be less than 10^{-8} m/sec. Therefore, here, a design value of 10^{-12} m/sec has been taken such that the migration of the radionuclides can take place only through the diffusion not through the advection.

Similarly, as we have seen earlier, this is surrounded by bedrock and the water can also ingress through the bedrock and generally this bedrock which is mostly of granite has a hydraulic conductivity ranging around 10^{-8} m/sec to 10^{-10} m/sec. Now, if the hydraulic conductivity of this buffer material is less than this value, then the water will bypass through this buffer material and it will not come in contact with the buffer or it will not try to ingress into the buffer and it will bypass through the buffer material. So, therefore, the hydraulic conductivity of buffer should be less than this value.

So, finally, a hydraulic conductivity of 10^{-12} m/sec or less has been proposed as a buffer material. Now, when we provide bentonite as a buffer material because bentonite has certain characteristics like it has a high tendency to sorb cationic radionuclides, it has a high swelling capacity, thereby, sealing any cracks or what is present here. It provides a very low hydraulic conductivity and also it provides a long term stability under high radiation.

So, because of all this properties of the bentonite, bentonite is used as a buffer material at a nuclear waste repository site. And bentonite is generally compacted at a density of around 1.8 to 2 gram per cc and at a water content of around 4 to 6 percent and generally these are compacted in the form of a block and then they are placed here.

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Bentonite or an expansive soil can also act as a containment system as a cut off wall or a barrier wall. Suppose, there is a storage tank which contains some oil or some organic contaminant and suppose, there is a leakage occurs. And due to this leakage, the contaminant will migrate through the soil and then they will join the groundwater.

Now, we know that organic contaminants are mostly two types, one is L-NAPL and another is D-NAPL. Generally, L-NAPL is very light, lighter than water. So, it will float on the water surface and D-NAPL is dense NAPL and it will be heavier than water, so, it will shrink. Now, depending on the type of organic contaminant, either it will float or sink, but when it comes in contact with the water, it will try to move from one point to another point or it will try to migrate because of the flow of water.

Now, in this case, we need to provide a slurry wall, or known as cut off wall or barrier wall such that the contaminant will not be able to migrate from one point to another point, thereby, the area of contaminant will be limited only to this portion. So, this can be achieved by providing a vertical barrier wall or a slurry wall which will be digged into the ground and because of the lower value of hydraulic conductivity of bentonite, it will be used as a slurry wall.

In this case, we could see, this slurry wall is not going into the bedrock; it is only floating above the bedrock. Because in this case, the contaminant is lighter than water, so, it will float and this slurry wall will prevent the movement of this contaminant from going this point onwards. Now, using an extraction well this contaminant can be removed. So, this barrier wall or slurry wall will be provided to prevent the further migration of this contaminant from the point of leakage to a large area.

So, going by the definition the cut off wall is a device used to reduce or prevent the seepage of water or prevent the migration of the contaminant from one point to another point, thereby, reducing the area which is exposed to this contaminant. This can be either a floating type or it can be a keyed-in type.

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In this case, we could see this slurry wall is going deep into the bedrock, because in this case, the contaminant which is present is D-NAPL. That means it will be denser than water. So, the contaminant will not come to this surface. And if it is not keyed-in, then the contaminant can migrate through the gap between the bedrock and this slurry wall. Therefore, this slurry wall has to be keyed-in into impermeable bedrock, such that this contaminant cannot move further and again this will be extracted using an extraction well.

Similarly, the vertical barrier wall can also be provided all around a waste in order to contain it from moving further. This is a waste material which is present here, this is water table. And if we do not provide this barrier wall, then water will come in contact with this waste. Therefore, we need to provide a vertical wall in this form, as well as a bottom wall like this such that the contaminant will be arrested within this zone and the water table will not come in contact with this waste. Therefore, the water will not get polluted. Bentonite can be used to prepare this slurry wall or vertical wall.

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The bentonite can also be used as a compacted clay barrier wall all around the waste such that it cannot migrate. This compacted clay barrier can be used for a shallow depth and mostly a mixture of sand-bentonite is used as a compacted clay barrier.

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The bentonite can also be used as a slurry trench barrier. And also this is known as cut off wall or slurry wall. And this is most commonly used as a vertical barrier wall for waste containment at hazardous waste site. This is an example of a slurry wall. So, in this case what happens is wall has to be provided which will be made of this slurry. So, in this case these are the different excavation sequence, first a narrow trench or a vertical trench of width 2 to 4 feet will be made and if the soil here is weak soil, then once we made this trench then the soil may cave-in.

So, in order to prevent or to stabilize this soil, we need to fill this one with a slurry. The main function of this slurry is to stabilize the wall so that it will be not caved in. When we provide a slurry, mostly a mixture of bentonite and water, then it will exert a hydrostatic pressure and due to this hydrostatic pressure, this will balance the lateral earth pressure coming from the side and therefore, it will prevent the falling or caving in of this wall. And when we provide bentonite slurry, then the bentonite slurry will also migrate into the nearby soil. Here we can see the migration of the bentonite slurry is taking place over here.

As the bentonite slurry migrate into the nearby soil it will provide a low permeable area all around it. So, this is known as a filter cake. This filter cake will be of low permeability soil and this filter cake will prevent the slurry loss that means, because of its low hydraulic conductivity, the slurry will not migrate into this area, therefore, the slurry will stay in here. So, this is the filter cake and once this is done, then it will be filled with the slurry mixture. So, this is the slurry trench barrier.

So, going by the excavation sequence, first a trench will be made which will be of 2 to 4 feet wide and then to stabilize the slurry is to stabilize the sidewall from collapsing we need to add slurry which will be a bentonite suspension and that slurry will provide a stabilisation to the soil or will resist the lateral earth pressure coming from the soil, thereby, preventing the collapsing of the sidewall. And also this slurry wall or the bentonite slurry will migrate into the nearby soil and thereby providing an impermeable layer around it.

Therefore, slurry will not further move to the soil and thus it will prevent a slurry loss to the soil. So, in this case, a bentonite suspension can be used as a slurry barrier wall.

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Now, the selection of this material, the slurry material, the bentonite-water mostly used or a mixture of bentonite, cement and water should be used. And the slurry should have a density of 1025 kg per meter cube. So, this minimum density is required so that the slurry can be flushed out from this trench and the backfilling material which will be used should be able to displace the slurry and the unit weight of the backfill should be more than 240 kg per meter cube then the slurry material such that when you pour this backfilling material over this slurry material, the slurry material can be flushed out from the trench.

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Now there is another application of bentonite that will be as a drilling fluid. During the drilling operation, particularly in the case of a weak soil, the sidewall can cave in or there will be collapse of the sidewall. Say for example, when we go for a drilling or piling operation, first we need to dig a hole and then we need to put the reinforcement over here. So, when we dig the bore hole, then if the bore hole is made of weak material, then because of the earth pressure here, the soil may cave in and that will provide a difficulty in the piling.

So, therefore, in this case, we use a bentonite slurry to prevent the collapse of the sidewall. And this collapse of the sidewall depends on the density of the soil, the cohesiveness of the soil, the pore water pressure and vibration, all these factors can control or can affect the collapsing of this soil. And when we add a bentonite slurry, the main purpose of this bentonite slurry is to prevent the sidewall from getting collapsed.

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So, therefore, a drilling fluid in the form of bentonite slurry is provided and this bentonite slurry should satisfy the following criteria, that means, it must support the excavation by exerting the hydrostatic pressure on the sidewall, it must remain in the borehole and should not flow into the soil, it must not have significant interference between the bond between the reinforcement of pile and concrete, it must be replaced easily and it should be easy to pump.

So, this should be the role of drilling fluid. That means, when we provide a bentonite slurry or drilling fluid into a borehole, then it should apply a hydrostatic pressure. So, this hydrostatic pressures should be sufficient enough to counteract the earth pressure of the soil around this wall such that the wall will not cave in. So, this is the primary function.

Similarly, the slurry material should stay within this hole, it should not move or it should not penetrate to the sidewall. Therefore, it there should not be any slurry loss during the entire process until the reinforcement has been put into the drill. Once the construction is over, then it can be replaced quite easily such that this slurry material can be reused again and also this slurry material should be easy to pump in so that it can the hole can be filled.

Here you can see this is a drill hole where the reinforcement or piling should will be carried out and before the piling will be carried out or before the inserting this reinforcement this will be filled with the slurry material. Now, when we use a drilling fluid, it should have certain requirement like the liquid limits should be more than 400 percent, the viscosity should be 30 to 60 stoke, the slurry density should be 1.03 to 1.1 g/cc the pH should be 9 to 11.5. So, this is as per as Indian standard 2911.

Now, this liquid limit is given says that the slurry should have a sufficient swelling behaviour that means, when we add water to bentonite it should have a sufficient swelling tendency so that it can exert a pressure over here. And the viscosity should be 30 to 60. And the slurry density we need to maintain between this to this a lower value of slurry density is given such that the slurry can be displaced and a higher value of density is given such that it will exert a pressure on the sidewall. We know that with increasing the density the hydrostatic pressure will increase. So, therefore, a higher value of density is preferred, but if we increase the density to a large extent then while removing this slurry or this drilling fluid, it will be difficult. Therefore, we have to have some minimum value of the density that means, it should be 1.03 so that it can be replaced or it can be flushed out quite easily and it should have higher value of density such that it will exert a hydrostatic pressure to counteract the earth pressure from the sidewall.

So, therefore, the density should be in the range between 1.03 to 1.1 g/cc. And here bentonite is used because of its thixotropic behaviour. In the thixotropic behaviour, the bentonite will gain its strength with time. So, therefore, when we put this slurry material with time the bentonite will gain its shear strength and therefore, it will give an effective counterbalance to the sidewall earth pressure and also when we agitate this bentonite slurry mixture, then again it will come back to its fluid form.

So, therefore, all this reasons, the bentonite is used along with the water for a slurry fluid and generally bentonite in the proportion of 6 to 8 percent by weight is mixed with water to prepare a drilling fluid for a piling operation.

Apart from this geotechnical application, some clayey soil like kaolinite or a illite can also be used for other applications. So, for example kaolinite can also be used as an insulator for using at transmission line and also kaolinite can also be used as a porcelain to prepare a different kind of pottery and sometimes the bentonite is used to manufacture some of the medicine.

So, these are the various engineering particularly geotechnical application of expansive soil particularly bentonite. These are the few references or bibliography which has been used for this lecture. Thank you.