Earthquake Geotechnical Engineering

Prof. B. K. Maheshwari

Department of Earthquake Engineering

Indian Institute of Technology Roorkee

Lecture 57

Ground Improvement Techniques: Vertical Drains

I welcome you for this NPTEL online course on earthquake geotechnical engineering. Today we are at lecture number 57 of this course which is on the ground improvement technique, and we are going to talk about vertical drains. As you may be aware that we are discussing the last module of this course which is on ground improvement techniques. Already two chapters on this ground improvement techniques, one is types of ground improvement techniques, second ground improvements using geosynthetics are over. Now today we are going to talk about the third chapter which is newly introduced that is ground improvement using vertical drains. So, in this lecture 57 as well as lecture number 58 we will talk about vertical drains only.

When we talk about vertical drains like these are the drains which are used for the mitigation of the particularly for liquefaction. Here using those drains, vertical drains you drained out the water out of the soil and once you drain out the water it help in the ground improvement because many of the issues in the soil is due to the presence of the water. That is why drainage or dewatering is one of the ground improvement techniques. Here vertical drains which are very popular to for particularly for mitigation of liquefactions we are going to introduce them introduction of that those drains.

Then two types of vertical drains that is sand drains and another is called prefabricated vertical drains that is short called PVD we are going to discuss in detail. And then finally, we are going to talk the efficiency of these vertical drains. So, let us start with the introduction with the vertical drains. A large parts of the Indian coastline particularly are covered with very soft clay deposits and the shear strength of these deposits is very low and compressibility is very high. So, if you go along the coastline, so particularly these like due to two reasons, one is that because the presence of water and the second is like compressibility is very high.

So, as a result shear strength is low and they are mostly like clay soil, marine clay near the coastlines. Hence these soils exhibit very low bearing capacity and large settlements. So, even in the clay you may not have the issue of related to liquefaction, but it is still during shaking these there is a what you call the softening effect these soils lose their shear strength. So, these soils exhibit very low bearing capacity and large settlements and as a result ground improvement is necessary. Among various ground improvement options vertical drains is a common type of ground improvement technique which is adopted on this type of soils particularly in the marine clay near the coastlines.

Now, what is vertical drains? They are continuous vertical columns of pervious sand or fibers. So, normally because if you made from the sand that means it is from the natural material or it could be fibrous which could be like synthetic fiber or natural fiber. So, about synthetic fiber, geosynthetics we already discussed in detail, and they can be used for making drains. These like this pervious materials is installed inside clay or sandy soils mostly in clay. Those drains provide the pathway for the pore water pressure to escape from consolidating soil by traveling a shorter path that would be necessary without these.

If like you know that when you have to provide a vertical drains, the effect of providing vertical drains that it the water find a path to escape, and that path is shorter. If you do not provide the vertical drains, then water need to travel a long distance before it get dissipated. So, the vertical drains will provide the drainage path which is shorter in compared to what was the path before when you did not provide the vertical drains. These drains allow the flow inside the soil to take place along the either horizontal direction which is in the least resistance or in that case it will serve the purpose of collecting and discharging the expelled water faster during the process of consolidation. So, in fact, in these vertical drains or using these vertical drains the water travel in the horizontally and then it may travel vertically also.

We will discuss in detail how the path goes. Come continue with this introduction. When we talk about the installation part of the vertical drains this is in conjunction with preloading and this will bring a rapid dissipation of excess pore water pressure and thereby accelerating the primary consolidation. So, vertical drains will help. First of all, it will help you to dissipate excess pore water pressure which is generated maybe due to shaking or other reason.

As a result, it will also help to accelerate the rate of primary consolidation. So, primary consolidation will be at a faster rate. However, vertical drains have no direct effect on the rate of secondary compression. So, here the vertical drain is helping you in one factor that is there are three types of settlement when we talk about the settlements of the soils. First is called immediate settlement which is for the basically for the sandy soils.

But when we talk about clay or cohesive soils then two another primary consolidations and secondary compression which is mostly for basically organic soils are two more here. So, primary consolidation is one of the major factor for the clay or cohesive soils and these vertical drains help you to accelerate the rate of primary consolidation at a faster rate. So, these drains may not help you in the secondary compression. However, because your primary consolidation stage get over early, it will lead to early occurrence of secondary compression. As a result, it will reduce the total reduction in the time for consolidation or settlement.

So, when we start time required for total settlement will also decrease because the primary consolidation is faster, and the onset of secondary compression is early. Vertical drains help to improve the strength of soft cohesive soil by removing water voids and accelerating settlements. So, they are basically these vertical drains of course, like because they are mostly many times particularly made of the sand itself. So, their most purpose is in soft cohesive soil rather than in sandy soil. So, that is the application part.

Bearing failure may occur without vertical drains and clay soils may develop settlements over many years. Why? Many years because consolidation take longer time compared to when we do not provide the vertical drains. And as a result, there could be differential settlement also. So, preloading combined with vertical drains has become an easy and economical choice of ground improvement techniques. So, what is done preloading? Basically preloading where we say it is kind of a densification.

So, you can compare preloading with the densification of the soil and so, then the densification along with vertical drains are mostly used. Depending upon the site condition vertical drains efficiency may maximum up to 80 percent. If it is not 100 percent, at least they may go up to 80 percent. However, it should be noted that the artificial sand drains are not suitable in expensive soils like if your soil conditions are which is made like for example, black cotton soil, which may expand due to water like montmorillonite and organic soils because major part of settlement is secondary compression, which is independent of pore pressure. So, in such kind of soils, which is basically organic soils, most of the settlement comes from the third component that is secondary compression.

The secondary compression cannot be controlled by vertical sand drains which we already discussed, and the vertical sand drains are also dangerous in quick clays, quick clay conditions where the due to seepage your pore water pressure reaches to the point where you have this pressure is equal to the effective stress and then net shear stress becomes 0. So, effective stress becomes 0 in that case. This is in quick sand condition clay due to sudden increase in settlement and there is a need to consider this in order to place sand drain in these before disturbance. So, this was about introduction of the vertical drains. Now, as we discussed there are two types of vertical drains that are widely used for ground improvement techniques.

One is called sand drains, another is prefabricated vertical drains, which we will call in the short PVD. Coming to this sand drains first, which is as the name suggests, they are will be made from the sand. Sand drains is best based on principle of rapidly and centrally dewatering system. So, sand drains will act like a pipe. Sand drains is a process of radial consolidation, which increases rate of drainage in the embankment by driving casing into the embankment and making vertical boreholes.

And once vertical borehole is created, these holes are back filled with suitable grade of sand. So, you create a borehole first and inside the borehole provide the suitable grade of sand. Driven cases then withdrawn after sand has been filled. So, what is done? We create a hole, put a casing there and this casing is filled with the sand and then you pack out that casing and the whatever thickness you have due to like you know casing whatever space is there that will be taken over by the sand will cave in. So, you now you have let us say clay, two clay layers are there or I say in the vertical direction the clay I have completely clay.

So, the clay layer has been punctured with the sand drains. So, you have a and then when the water comes, water will find a path in this sand drain. The sand must be capable of allowing the efficient flow of water. So, that means, its permeability should be high, it should not be impermeable, which is a clay case. While preventing fine soil particles from being washed in, this is important.

First of all, your sand grade should be such that it allow the flow of the water number one, but it does not allow so much flow of water that with the water the soil particles or clay is also being washed out otherwise what will happen? Your this sand drain will be chocked out after some time. So, careful backfilling is also essential to avoid discontinuities which could give rise to necking and which can render a drain ineffective. So, that is also as I said. So, you know inside the drain that clay particles comes otherwise the drain will be chocked out. A sand blanket is placed over the top of sand drains to connect all sand drains.

So, what is their connectivity? You see here. So, in this case, you have a sand drains here. So, here of course, this dimension little may vary, but let us say you have a thickness of the soil layer is 3 meter, it could range very large, 3 meter to 30 meter. So, it like you know it could be quite much varying. Now, you have the clay layers, and these are one.

So, I can put the numbers here. This is 1, 2, 3 and 4 and the last one is 5. So, these are basically your sand drains. And for example, between these two clay layers, this third number let us discuss third number sand drain. In the third number sand drains, like you have this horizontally arrows are showing that water will try to come because this is the nearest path. The nearest path like water will try to find the water will always travel to the nearest path.

So, the nearest path is this one for this one, particularly if you are away from the middle towards this and if you have this side, the nearest path will be here for this is here. So, similarly in this case, so you have vertical drains. So, horizontal radial drainage path will be like this. So, what will happen from the clay, you can say it for understanding this is your clay, this is also clay and this pipe is basically your sand drain. So, from the clay layers, the water will come out and then it will go to the sand drains.

When this like you know the water comes on the top of it, then it top horizontal drainage layer has been provided, which connects your all the vertical sand drains and then ultimately water can dissipate this side or this side and it may go away. So, this is like typical like how the sand drains are installed. The sand used for filling the holes should not contain fines, if your sand itself contain fines, then its permeability will decrease and it may not allow the flow of the waters and then it should be uniformly graded rather than poorly graded. The sand should not be coarse at the same time, this should not contain fines, fines means the sand should not contain your clay and the silt. But at the same time, you may not be using very coarse sand, otherwise what will happen, so much water is passing through the sand drains and that because flow need to be controlled in the sand drains basically.

If your flow is at a very slow rate, then also its effectiveness is not there. If flow inside the sand drain is at very large rate, then it is possible that the water may take away with its clay particles and your sand drains will be choke out. So, it should not be very coarse also to over facilitate the migration of the fine particle from the soil into the drain. So, if it is coarse, then it will facilitate the migration of the clay particles inside the drain and ultimately your drain will choke out. For these reasons, particles larger than 4 mm should not be used.

So, this is the suggested side that the particles of the sand particles should be less than like 4 mm and in fact, you for fine grained soils you have up to 2 mm. So, however, before using it is necessary to test that the gravel sand mixture is compatible with the surrounding soil. Void in sand created by filling the hole should be sufficiently pervious. Again, so another thing that it should be, permeability should not be very low, it should be pervious to allow unobstructed flow of water from the soil into the drain and from lower part of the drain to the top. So, as we already see it, first it horizontally the water will flow in the sand drains and then when sand drains filled out, then it will pass from the top and it will go away from the area of interest.

Now, what is the mechanism of consolidation for vertical sand drains? The excess pore pressure that is here we call in the short EPP is increased by applied surcharge load in the embankment, drainage occurs in vertical and horizontal direction which we already see. Horizontal direction occurs quickly due to sand drains, the drains accelerate the process of dissipation of excess pore pressure created by surcharge. So, what happens one thing one side you have the horizontal dissipation and then due to the surcharge loading from the top then it could be vertical dissipation. What is the typical diameter of sand drains? Of course, it may vary, but typically it is said 180 to 450 mm that means if I put in the numbers it is 18 centimeter to 45 centimeter. So, 18 centimeter is less than a feet 45 to 1.5. Too small a diameter is not desirable because of difficulties in filling the steel pipe and danger of arching up of sand pipe. So, like it should not be very like you know small diameter of the sand like if you are very narrow then what happens over the time that like it may filled out it may be the clay may cave in and then because and it may not find much path of water to go. Then sand pipe is driven to depth where penetration resistance is greater than 15. Then spacing of drains from one drain to another drain, drains are laid either in square or triangular pattern, spacing is kept smaller than the thickness of embankment in order to reduce the length of radial drainage path.

So, like spacing is given in this case. So, you have in the two patterns for vertical to sand drains one is square pattern another is triangular pattern. So, you could see the spacing is a center to center spacing between two drains here and so in triangular pattern it is also shown. So, these two patterns that is square pattern or triangular patterns with of course, this is in plan. So, this is in plan. So, this is plan and these are most popular.

So, this was about vertical sand drains. Now, the second part of the drains which is prefabricated vertical drains or in the short it is called PVD. They are also known as weak drains or weak if the sand is patterned filter soaking, they are called as sand weak. These drains can also be flexible corrugated plastic pipe. So, it is basically when we talk about PVD, mostly these are the drains made of synthetic material which we are going to discuss, or it could be including your synthetics also. So, for example, Kjellman in 1948 was the first to suggest the use of driven cardboard drains to replace sand drains.

So, you have the cardboard, cardboard you know that which is basically made of the papers and the hardboard. And then that cardboard has been used to replace the sand drains and cardboard drains are easy to install with less soil disturbance because it is not heavy, it is not like metal or like this. And especially processed cardboard has long life, but cannot sustain large deformations. Of course, their life is limited and because they may be you know that decomposed all the time. So, they have their limitations, but installations are easy.

So, this was history where in the early first was cardboard it is started from cardboard and then it replaced by the geosynthetics. Later on these cardboard drains have been replaced by plastic drains also known as plastic bench shaped drain and has been manufactured in large scale. The well-known brand for the plastic drain is geodrain which is like basically geodrain is you can say one type of geosynthetics only because you have geotextile like drain has been used here. So, this is geosynthetics which we have discussed which consists of a 100 mm wide and 3 mm thick paper covered polythene strip which contains channels along both sides. The configuration is so chosen such that a drainage channel of more than 70 percent of the total drain area is available.

So, when we have polymetric materials such as polypropylene or high pressure polythene are normally used for manufacturing of PVD drains. The system comprises of two components one is called core, and another is called filter or sleeve. So, it is here what is core and filter. You have in the vertical drains these are the synthetic geosynthetic materials types of PVD, lay field drain and geosupply drain. So, in this case you could see this is corrugated material this one corrugated and on the top of it you have the sheet which will prevent the water to come out.

So, basically between this corrugation and the top part a piping is there the space between that there that will act that will provide a path to flow the water. Similarly, here these drains are used in our laboratory also this is corrugated and then you have the filter. So, between there filter and the corrugation you have a space and through between like you have the let us say filter on the top of video of corrugation the space of course, it is not very thick space thin space the water will go from this. So, typically PVDs are classified based on material core structure durability and stiffness. The PVDs should suffer stiffer enough to withstand higher compression and bending.

Materials which is used in the PVD and in the saturated property play a crucial role in quality management. So, what type of material you use depending on that your PVD will be like the performance will depends on its material property. Choosing of material should be done carefully for the PVD such that it minimize soil disturbance and also protect the PVDs from cuts, tears and abrasions and can be successfully installed to the required duct. So, here there is a tradeoff one side if you like select very stiff PVD then it is ok it may not get damaged with the cuts and tears and other things. But then if you use very stiff material then while installing it will be disturbing the soils.

On another side if you have very soft PVDs then you can easily install, but then it may be vulnerable to cuts and tears. So, there will be tradeoff between these two. Usually anchor plate will be provided in the bottom to hold the PVD in place during withdrawal of mandrel. Mandrel is kind of a casing. So, like when it is withdrawn what will happen when you withdrawn the mandrel then it may happen that with this withdrawal of mandrel your PVD may also come out.

To protect it some kind of anchoring is done, anchoring plate is used which hold the PVD in place. Installation of anchors also prevent the entry of surrounding soft soil into the mandrel. So, the PVDs are anchored. Steel and flexible plate anchors are used for installation. Now, two types of anchors are there one you have steel another is flexible metal plate.

The flexible metal plate introduces more disturbance but used widely in larger size mandrel. So, if the size of the mandrel is larger then it is recommended to use flexible metal plate anchor and they will provide of course, when you use a flexible metal plate anchors because it is consist of metal they produce some noise, but that need to be used for the larger size mandrel. But when you have a small size mandrel then steel anchors can be used which will create less disturbance compared to metal because it will be the smooth surface. So, depending on your size of like mandrels you can use either steel or flexible metal plate. When installing mandrel into the soil tension will be created in the PVD.

So, there will be tension in the PVD. Then intensity of loading will depend on the unit weight, length and friction between the soil and mandrel. In adverse cases the loading leads to the rupture. If you have this like you know that the case is such that where it is not effective, then it will lead to the rupture of the PVD. Coming to continue with the geodrains, which is one of the types of for like drains have been claimed to have the following advantage.

They are low cost like PVDs and also geodrains. Then fast installations ensure drain continuity, clean site, lightweight installation equipment, high permeability, negligible soil disturbance, positive drainage. So, these are all the advantage of the PVDs to use and because they are lightweight, they are economical, they have less disturbance and fast installation is possible. Common types of PVDs are in dimensions they vary from 90 to 100 mm wide that is 9 centimeter and 3 mm to 5 mm thick. So, thickness is not very large it is very small 3 to 5 mm. And usually installed by a lance which is lance is kind of a you know that equipment which is kind of a gun with a rate of about 140 mm in cross section.

Installation speed of the order of 0.3 to 0.6 meter per second and driving depth could be up to 45 meter. So, like it could be vary. PVDs are wound around reels. Reels means you know kind of like when you have this threads and like stitching threads and there is a reel. Similarly, PVDs are wound and as the mandrel is lowered like you have reels and then PVD is connected and the when the mandrel is lowered.

So, PVD also will be lowered with the mandrel. So, when the mandrel moves the PVD from the top to bottom it will go. The bends are released by unwinding then once it is done then you do unwinding and then the mandrel will be free with the PVD, and the mandrel is taken out PVD remains in the place. Thickness of the PVD plays a crucial role in the selection process. Courser filter fails to as the inclusion of clay particles whereas finer filter may be subjected to tensile and puncture mode of filler during its installation. So, it is important that what types of whether you use coarser filter or finer filter because they have different their characteristics.

So, when we do this, this result in subsequent reduction in the discharge due to the clogging effects. Hence, the apparent opening site of the filter should be selected carefully considering the site and permeability characteristics of ground to be treated in order to avoid clogging in drains. So, you create whether it is vertical ascent drains or it is PVD. We need to ensure that over the time this drain does not choke out and if the drain is choke out then it will be not effective. So, this is here that what type of opening should be there, opening size of the filter basically it is also like a acting the filter where like through which water is coming out.

So, its size or the size of aperture size of opening need to be also appropriate. PVD should be selected according to the field conditions and adjoining soil properties and selection of good quality drains will enhance the rate of consolidation with improved discharge capacity. So, one type of PVD will is not going to suitable for all the conditions. Depending on the site conditions, depending on the soil characteristics, the PVD required to be selected. The efficient discharge characteristics of permeability of drain should be at least 200 times than the soil so as to achieve free drain conditions.

So, this is important. So, how we select? Like the soil conditions are given, you know the permeability of the clay which is permeability of clay is very low. Well, permeability of sand is comparatively high. So, at least the material which you are using for like you know that there should be 200 times more permeable compared to what is your permeability of the soil for which you want to make a treatment. Then there is a one term which is given by what is called the efficiency. So, for these vertical drains, efficiency need to be checked and naturally everyone will like that they should be very efficient.

So, the efficiency which is defined by a coefficient eta of the system of vertical drains is assessed with reference to the primary consolidation attained with and without installation. So, this is deals with the primary consolidation. As we already discussed, the primary objective of these like you know that drains are to accelerate the primary consolidation. They do not help you in secondary compression, but they help in primary consolidation. So, you can say the efficiency will be the ratio of primary consolidation or rate of primary consolidation with the PVD and then in the second case without PVD.

So, here this efficiency eta is the ratio of PC and PSC, where PSC and PSC are the primary consolidation and secondary compression respectively. However, the secondary compression, like you can say that like secondary compression does not, all these vertical drains do not help, there is no change there. So, this ratio when you calculate with this ratio that will be the efficiency of drain and this efficiency of the drain could be in the range of 0.6 to 0.8 that means 60 to 80 percent effective. It is difficult to have vertical drains which is, this effectiveness is more than 80 percent, but if it is 80 percent effective then it is ok. The efficiency of the drain system depends on the drain effects such as smear disturbance and drain resistance. Installation of sand drains in the soil is disturbed in two ways. First is being compressed and sheared and second being smart due to remolding. So, like if shearing takes place, compression takes place and then compression stress then you have the shearing and then the shear smearing it tear apart.

Both action reduces the soil permeability around the drains. If the change in permeability and the thickness of the smear zone were known, smear could be accounted for. The drain should be capable to collect the water which is coming from the consolidation soil and also to conduit in the surface. For water to flow upwards in the drain there should be head difference from bottom to the top with maximum head at the bottom. See the water will go in the upward direction only when the head is more at the bottom compared to at the top otherwise it cannot move like this. Buckling or folding of sand drains or PVD does not generally affect the performance of the drain even for prolonged service period.

So, this was about efficiency. Now, coming to the clay exhibiting horizontal stratification with seams of silt may affect in the following manner. First thin lenticular strata of high permeability greatly increase the efficiency of drains since they act as a horizontal drains attached to the main arteries. So, they will be acting like you have the linear material, a strata of high permeability going in the horizontal direction then the water will find a path in the horizontal direction and will drain out. Then continuous thick seams of high permeability material in is at sufficiently close spacing often render vertical drains unnecessary or greatly reduce their real effectiveness. So, suppose here issue is this one, suppose if you have very high permeability materials and there is continuous thick seams of high permeability materials, thick seams means kind of a layers basically a thick layer which is highly permeable and then in that case water may go out from that permeable layers in that case you do not require to provide the vertical drains.

In order to accurately assess the efficiency of a drain system it is necessary that an adequate geotechnical investigation has to be planned. We should include continuous core sampling of the strata, institute permeability, measurements at low hydraulic heads and laboratory consolidation test on large diameter specimens. So, this is for calculating the efficiency. Some of the figures and the materials has been taken from this book referred by which is from the book by Raj Purushothama titled Ground Improvement Techniques published by Lakshmi publications. So, it is some of the material is from this not all particularly it is related to vertical sand drains but PVDs are not from this reference. Thank you very much for your kind attention.