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Subsurface Exploration: Importance And Techniques Involved

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Lecture 8
Geotechnical Investigations

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Welcome all to lecture 8 of subsurface exploration, introduction and technique involves. So as we are discussing in last couple of class about different geotechnical investigation methods, today also we will be talking about one more geotechnical investigation method.

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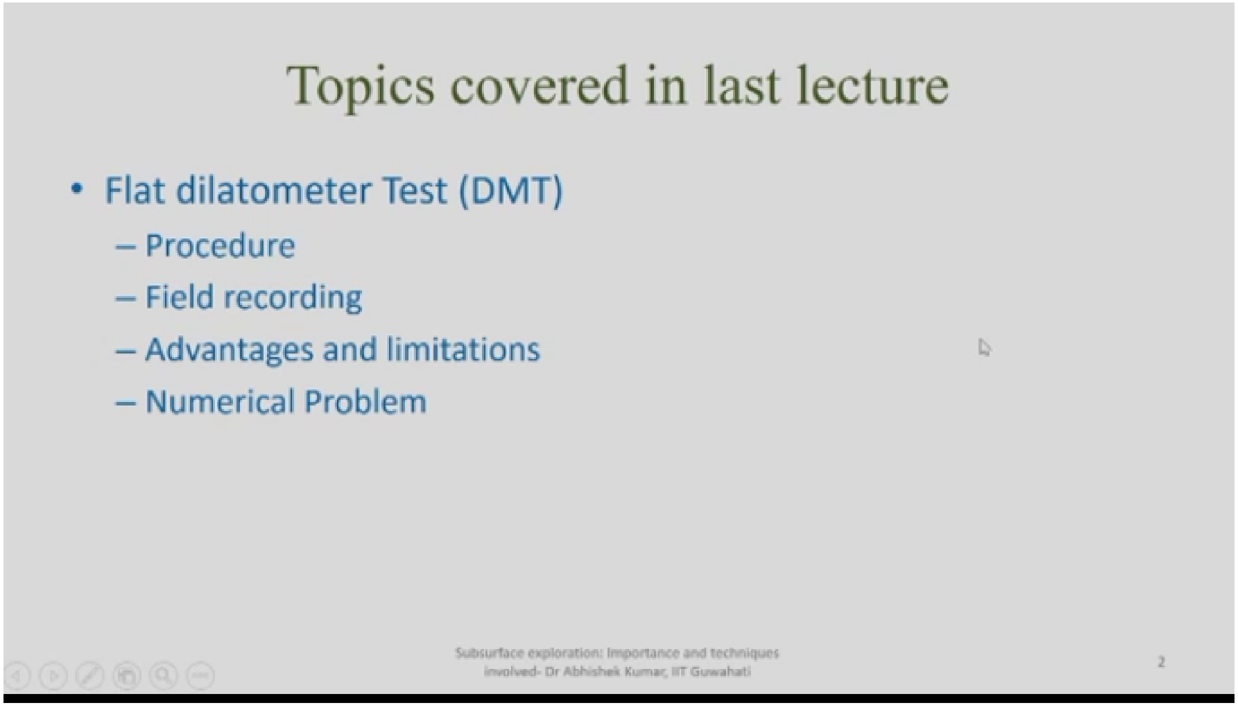

So before going to today's class material, we'll discuss about whatever we had discussed in last class, so last class we actually discussed about dilatometer test, how you do the flood dilatometer test, what is the procedure, what kind of typical field records you get once you lower your dilatometer at different, different depths you start bringing the membrane in contact with the blade, if you remember, recall, measure the pleasure which is called P naught, then pushing the centre of the membrane with 1.1mm towards the soil or overall like pushing the soil by giving a deformation of 1.1mm, that is P1 then there will be certain correction which has to be applied in order to take into account the stiffness of the membrane into account as well as the effect of water table.

And then after applying those correction your corrected P naught and P1 value you will come to know, based on those value you can determine different properties as we had estimated in last class, so what are the limitations, what are the advantages we had discussed and even numerical problem we had actually discussed.

So far we had if you go to geotechnical investigation which are called as semi-direct method as precisely mentioned in the last class,
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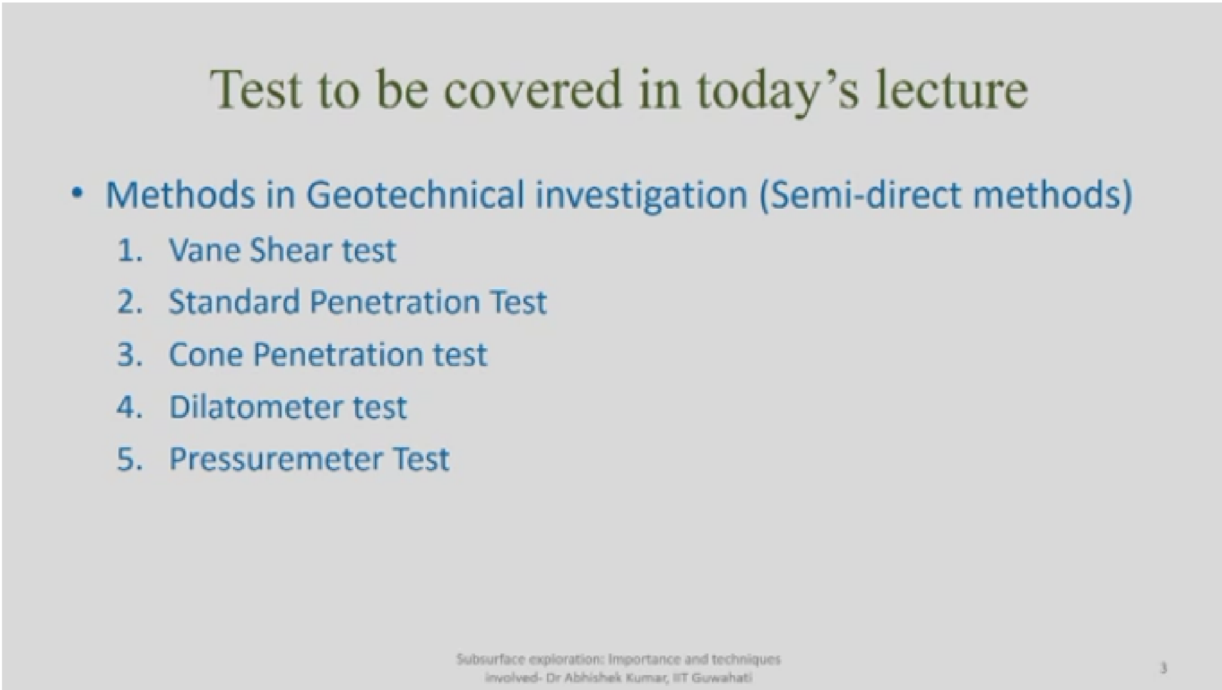

so these are the list of geotechnical investigation methods which we primarily target to focus on like vane shear test, standard penetration test, cone penetration test until the last class, even the dilatometer test was complete.

So in today's class we will be discussing about what is pressuremeter test, other test we have already covered, so pressuremeter test very less, in many of the courses very less about pressuremeter test is discussed,
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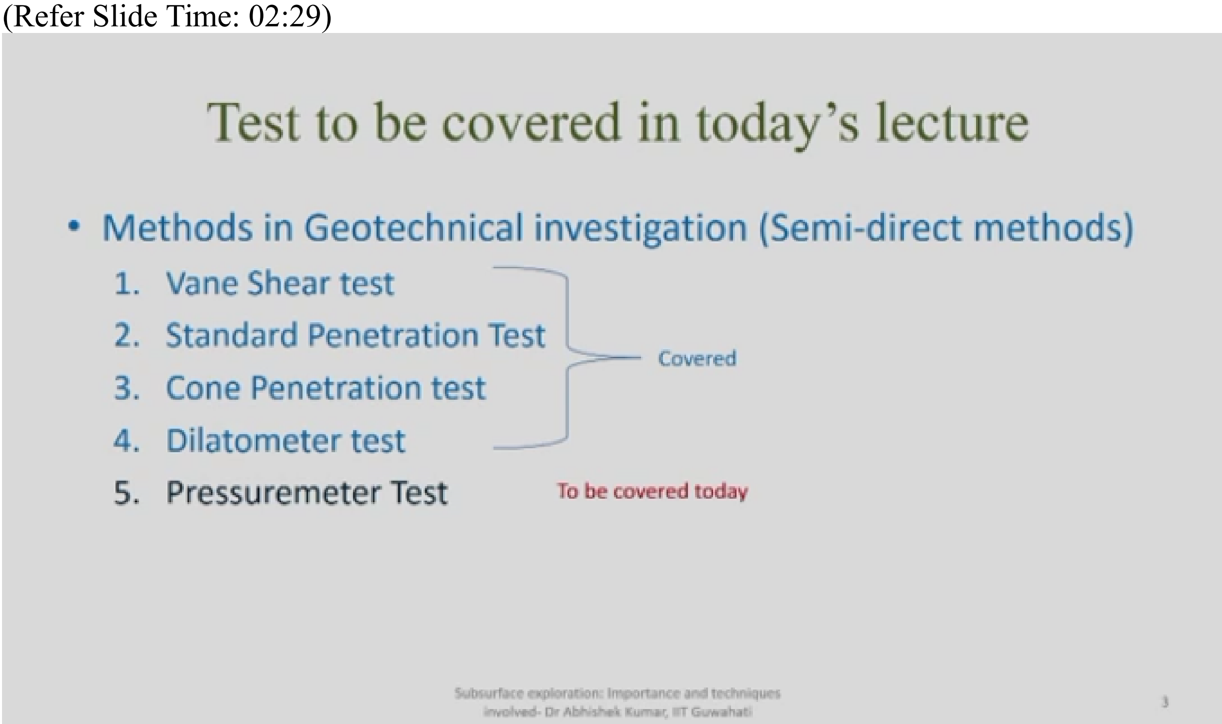

so maybe it will be more useful to the people who are really interested in exploring field data, designers, even exploration program managers, so let's hear what is pressuremeter test?
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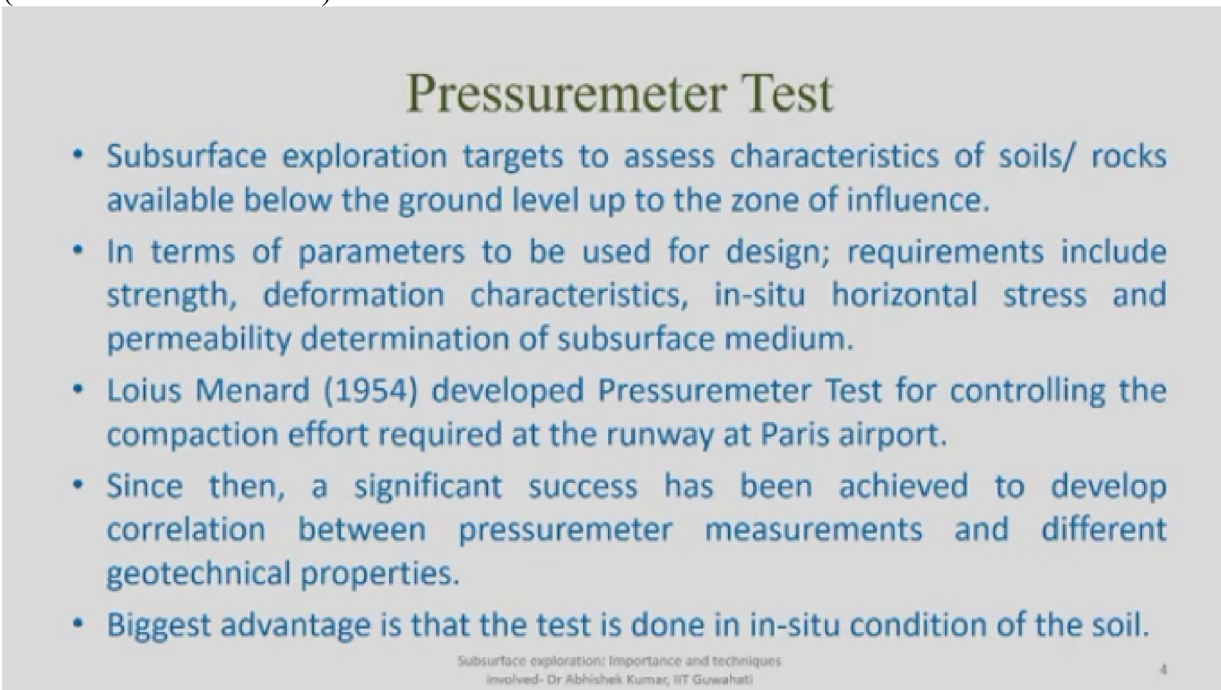

So pressuremeter test before going into detail subsurface exploration targets to assess characteristics of the soil or rock available below the ground surface up to the zone of influence, we all know like depending upon the kind of foundation, depending upon the load, depending upon subsurface material, the zone of influence may change particularly depending upon the choice of the foundation and overcoming load, so depending upon and then depending upon what is the zone of influence we will be interested to find out the characteristics of the soil, if soil is available or characteristics of the rock, if soil is not available or outcrop is there or shallow depth rock is available, so that will help you in understanding what kind of soil or rock deposits are there, strength characteristics and other parameter.

In terms of parameters to be used for design purpose our requirements mainly target for strength, what is the strength of different material weathered rocks, soil, what is the deformation characteristics against external loading, so maybe you can call it as load versus deformation characteristics or maybe pressure versus deformation characteristics, so for a known amount of pressure how much is the deformation taking place in the soil, then in-situ horizontal stresses in case of retaining structures also it may be of interest, and again for many other purpose it may had been interested, and then permeability particularly for when we are targeting for design of barriers or maybe filters or maybe particularly for any kind of assessment below the ground water table.

So even permeability determination is also important, so these are the kind of parameters which we are interested to determine when we are going for in-situ geotechnical investigation of subsurface medium.

So Louis Menard in 1954 developed pressuremeter test which can actually, for controlling the compaction effort, so under known value of compactive efforts, how to control the compaction behavior required particularly at the runway on Paris airport, so in order to control the compaction, in order to control the effort applied for compaction or in order to control the quality of compaction at Paris airport Louis Menard in 1954 actually developed this pressuremeter test, since then significant success has been achieved to develop correlations, so correlations are very important because not every time you may get soil sample, not every time you are actually able to determine the in-situ strength, you are not able to determine whatever parameter we had listed out like deformation characteristics, in-situ strength, or in-situ horizontal stress permeability, but by means of correlation which have been developed particularly for soil type, particularly for the method you use for investigation type, particularly again based on over-consolidation ratio based on relative density, even such correlations maybe region specific or country specific as well, so such correlation when over the period of time since 1954 people realized like different parameters of the soil can be very easily correlated by means of the typical field measurements, whatever you are doing in pressuremeter test.

Biggest advantage here is because you need not bring in, you are not bringing the soil sample on to the surface or to the laboratory for determining the shear strength parameter, you are actually testing the soil in its in-situ condition, so this is the biggest advantage even in the dilatometer test you are having this kind of advantage, you need not bring the soil sample that was particularly useful for in-situ investigation, this is also useful for in-situ investigation of the soil.

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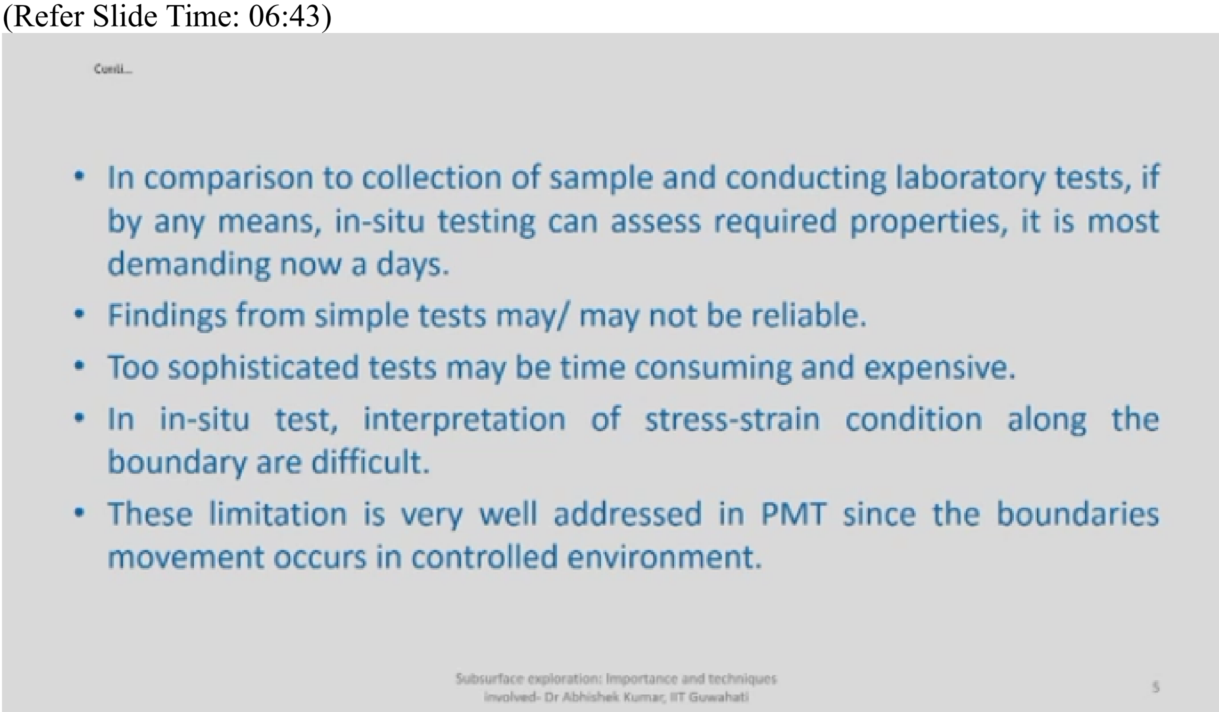

So in comparison to collection of sample and conducting laboratory test you bring out the sample because you are interested to find out what is the soil type, what is the strength characteristics in-situ, what is permeability characteristics and depending upon the overburden pressure some time one test maybe suitable, some time that test may not be suitable so you have to go for other test, but when we are going for pressuremeter test you can actually deal with larger amount of pressures here in comparison to previous discuss method, so you need not bring the sample, you can actually do in-situ investigation, and those kinds of test are nowadays more and more required because you are not bringing the sample, you can actually determine it's in-situ strength in its original for, very much similar to whatever we were discussing about trial pits, test pits, but only thing in those cases we can actually bring the soil sample, we can actually access the soil sample or maybe by visual inspection or by simple test which are designed to give a qualitative information about the strength you can use it for test pits, but here you are actually determining actually what is the shear strength properties, the quantitative assessment is there, it has been observed that once you go for simple test most of the time the findings of the outcomes of the results may or may not be reliable.

On the other hand if you go for two sophisticated test it requires time, I mean these are time consuming for field recording as well as interpretation some time it will lead to some serious errors also, and most important those stress star expensive ones, so when we go for simple test you have some limitation and you go for too sophisticated test you have other limitations.

In-situ test on the other hand interpretation of stress condition, this is another difficulty if you are going for in-situ test, interpretation of stress strain condition because whatever nature of stresses you are actually inducing in the soil are those stresses in develop and control environment, if those are in control environment of the soil is undergoing very specific or well-defined change in characteristics then it will be easy for the interpretation, but if you are inducing some kind of stresses but you are not, you are not able to control the behavior of the soil corresponding to depth stress definitely, the interpretation will be a bit challenge, so that's what it is telling like in case of in-situ test you go interpretation of stress-strain condition, you are inducing some kind of loading, pressure, but you are not able to control the behavior of the soil, like soil if you are interested to find out shear strength you are not able to control whether the soil is undergoing only shear failure or some compressive tensile other failures are also there, so these is the biggest limitation or challenge when we select for in-situ investigation, these limitations particularly in pressuremeter test are very well addressed, since the boundaries are moved in control environment, so you are actually inducing some kind of loading which is causing deformation in the soil, but you've designed the method such that the deformation in the soil can happen only in particular direction maybe along particular, I mean particular only specific nature whatever you are interested that kind of deformation is only possible in the soil, you are making sure it so that whatever quantitative assessment you do you will be more confident about interpreting the field results,
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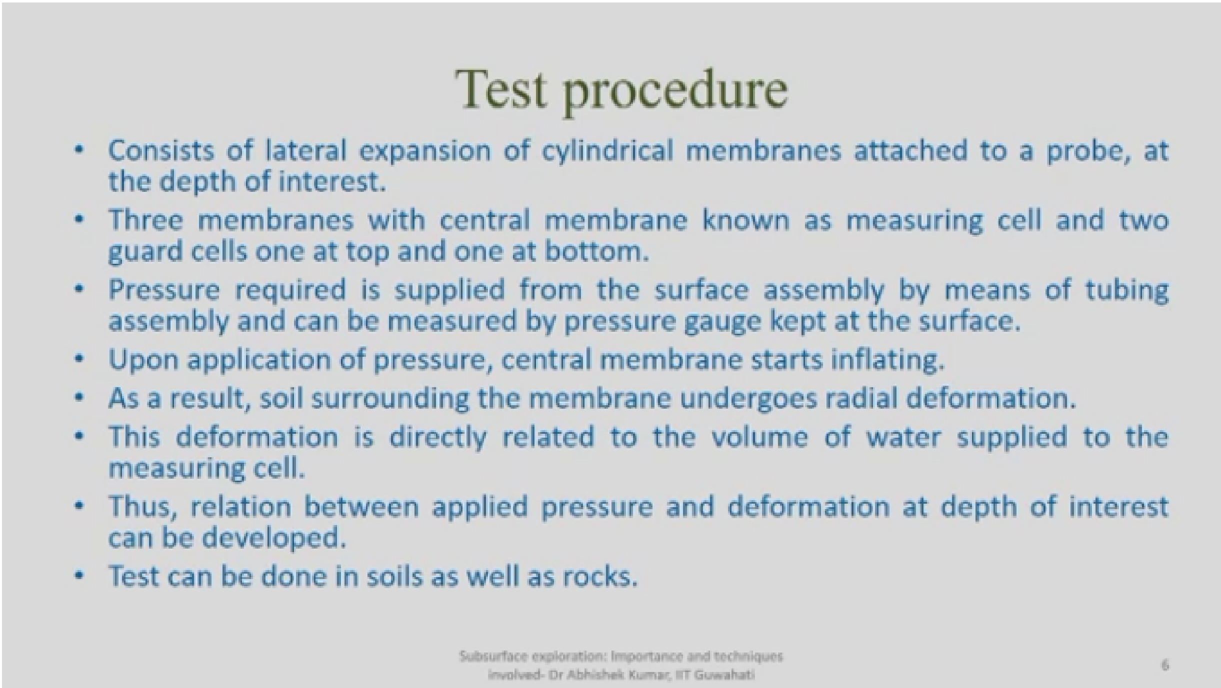

so the test procedure it consists of a lateral expansion of cylindrical membrane, so you will be having a probe which depending upon the depth of your interest you actually going to lower the probe, in the probe itself you will be having a cylindrical membrane depending upon the depth you lower the membrane and then this membrane will not be one, but it will consist of three cells, so this membrane is capable of expanding and deflating.

Once you reach a particular depth you are going to apply some pressures because of which the membrane is going to expand, so generally we have three membranes, so the membrane which is coming in the central part is called as measuring cell, the membrane which is so above the measuring cell there will be one membrane and below it there will be one membrane, each of these are called as guide cells, so each of, with reference to the central membrane or measuring cell you will be having one guide cell on the top, one guide cell at the bottom, so pressure required is supplied, so you have the probe which is having the membrane arrangement on the periphery of it, you lowered it at the depth of interest then you apply pressure on the surface, as a result of which different membrane will start inflating, so the pressure required will be supplied from the surface by another assembly which is capable of providing the pressure, so just like when we were discussing about dilatometer test we knew like depending upon the depth, depending upon the soil type which probably you can expect at the site of interest you will be prepared for the selection of the reaction frame.

Here also depending upon the depth you have to apply more and more pressure, but now because here the pressure is getting generated by means of air or water, those kind of reaction frame whatever we had discussed in earlier cases particularly for DPT, DMT and CPT may not be applicable here, here you are applying the pressure by means of surface assembly, by means of tubing arrangement so there will be a tube attached to the surface assembly, and whatever pressure you are measure, you are applying from the surface assembly it will be measured, so whatever pressure you have applied at the depth just like your dilatometer test you are actually quantifying that pressure by means of pressure gauge readings.

Upon application of pressure what will happen, the central membrane will start inflating, so if this is the central membrane you start applying some pressure, and this is depending upon what kind of pressuremeter you are using, you can actually do the test in already existing borehole, you can actually go for a test which is drilling and driving both I mean, driving into the soil on its own and then loading and unloading of the soil also same type, and the combination of these two also.

So what we do? Upon the loading it we apply some pressure as a result of which the central membrane or the measuring cell will start inflating, as a result of inflation what will happen? It will apply pressure on the walls of the membrane and once the walls comes in contact with the soil it will start actually pushing the soil back to its original position or further around that, that we will be discussing in coming slides, so upon reaching the, upon application of pressure the central membrane starts inflating or bulging out, as a result the soil surrounding the membrane undergoes radial deformation, so if soil is here because of the membrane which is there in the central part it will again start undergoing some kind of deformation, so you are actually applying some pressure and corresponding to depth pressure, how the soil is responding you are going to observe it in terms of deformation, so you are actually doing two things, what is the pressure, what is the deformation pressure, deformation and so on an so forth at each depth of interest, so that's how you will be able to understand how much is the deformation, what is the deformation characteristics of the soil.

This deformation is directly related, how you quantify the deformation because you are actually applying some kind of pressure so this deformation is directly related to the volume of water, whatever you are supplying through the pressure tube you are actually supplying the water into the central membrane in order to increase the pressure this water is again pressurize under gas oil pressure, as a result of which there will be increase in the pressure and this increase in pressure will tend to expand the central membrane, and this as a result will induce more and more deformation in the soil which is, we are going to measure, so pressure you are going to measure from the surface assembly, pressure gauge is and deformation you are going to measure by means, once you know how much is the amount of water you have actually pumped into the central membrane or measuring cell.

Same thing you keep on doing at different, different stages of loading and try to observe how much is the deformation, thus the relation so collectively you can call it the relation between applied pressure, how much is the pressure you applied and what is the corresponding deformation in the soil, of course at the depth of the interest can be developed, so though you are not bringing the soil sample on to the surface for laboratory investigation but actually in-situ condition itself you are actually going to investigate how the soil will behave under different loading conditions, so the test this is suitable for soils as well as in rocks you can do the test both in soil as well as in the rock depending upon what kind of, I mean whether you are expecting soil to be encountered during the investigation, you will be ready for that particular pressure if you are encountering or chance out there you can encounter rock also that idea you can get if you explore some preliminary investigation of the investigation already done near your site of interest, so that will give you an idea or an average what will be the range of the pressure you will be dealing with, so as I mention this pressuremeter test generally consist of three types, one is called as Menard type pressuremeter test that is MPM, so this kind of probe is generally lowered into an existing borehole.

So you have a borehole in which you are interested to find out how much is the in-situ strength property of the soil, because this is not the tradition of borehole where you are actually, which you are conductive for your boring or for sampling purpose, this will be regulatively smaller in diameter as we will come to know in coming slides, so you are actually going to drill a very small diameter of hole, and so that you can actually lower the probe and after you lower the probe there will be some pressure assembly, there will be some volume assembly which is actually going to measure you how much is the pressure you've applied once the probe is lowered in order to cause deformation in the soil.

So this is when you are, when your pressuremeter of the probe is lowered into an existing borehole, this is called as Menard type pressuremeter so MPM.
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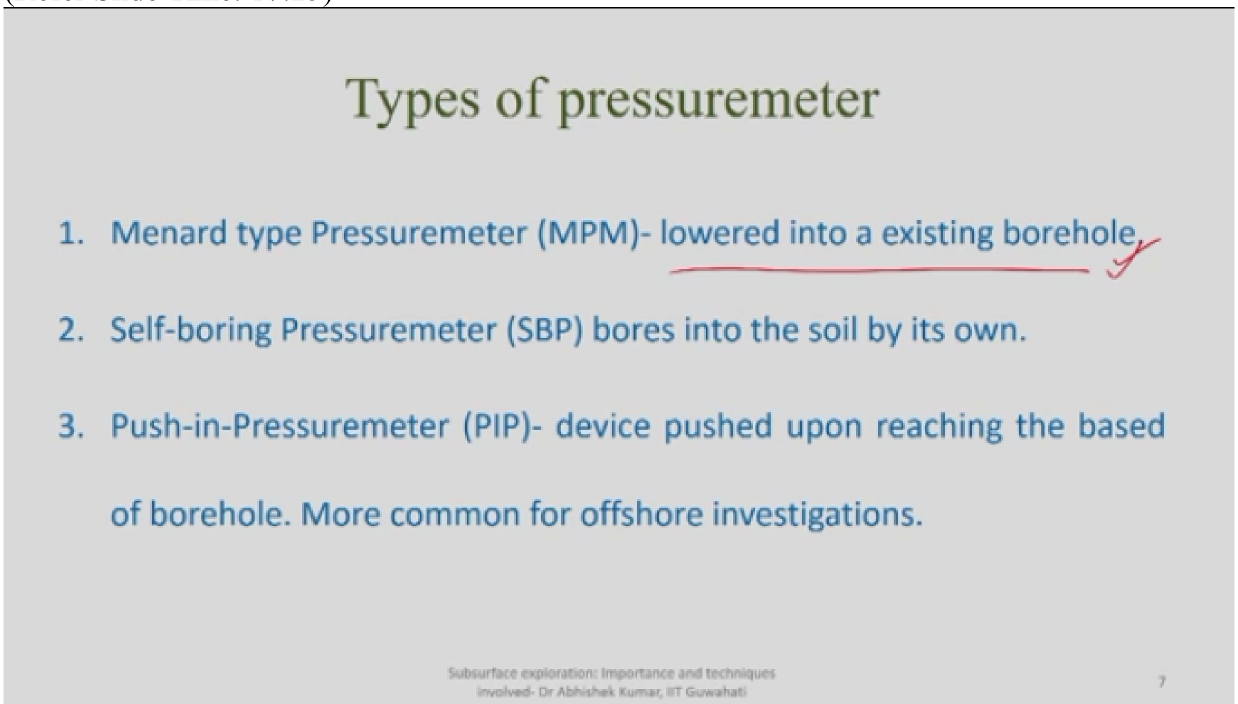

Self-boring pressuremeter where the boring itself is done by the probe itself, so that you call as self-boring pressuremeter or SBP.

The third one is push-in pressuremeter in which the soil is, the device is actually pushed upon reaching the base of the borehole, so up till the base of the borehole you are actually going to lower after that it will become like self-boring kind of thing, so it is more common once you go for offshore investigation, so you go up till the bed or maybe some more if on the bed surface you found some lot of foreign materials or lot of the material which were not supposed to be here, so you actually go for small boring and after that you install your push-in pressuremeter test.

As I mentioned previously also over the period of time people have realized like whatever pressure of field measurements you are doing from this test you are actually going to correlate with lot of properties of the soil and rock and that's why it has gained this test has given lot of popularity in the previous years, so most common for offshore investigation,

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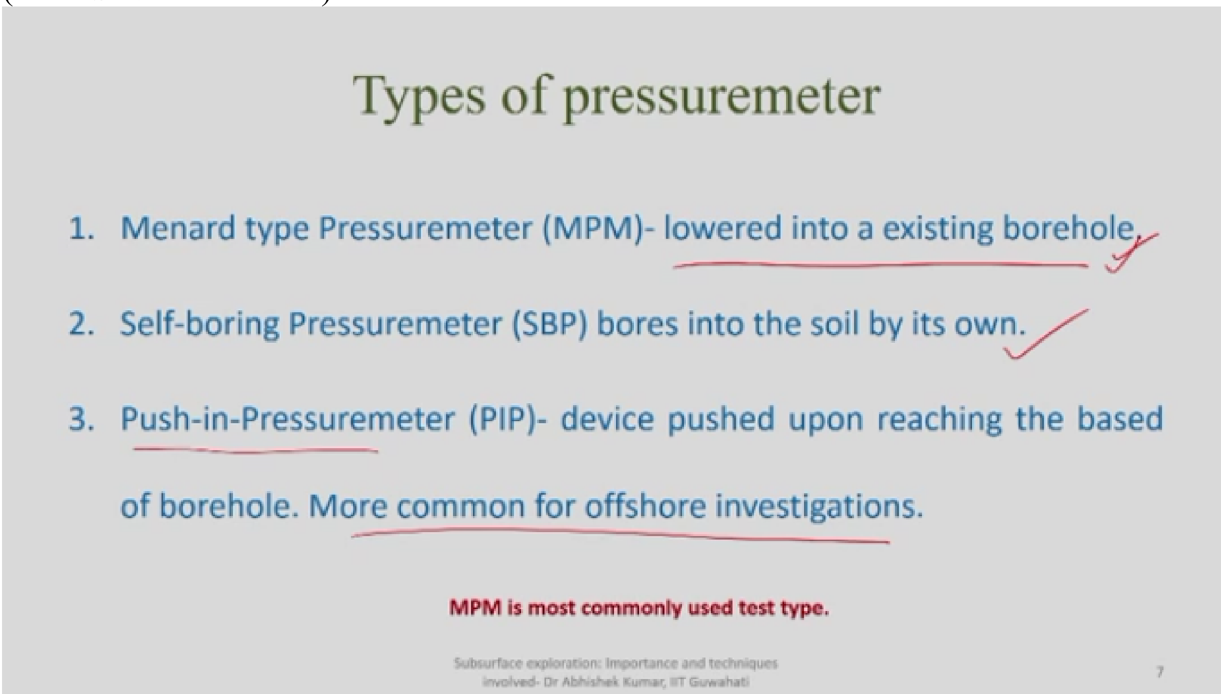

it has to be highlighted here that Menard type pressuremeter test is most common once you go for in-situ investigation particularly on ground surface, you are having a, so you actually drill a borehole, small diameter maybe 65, 75mm is the diameter then you lower the probe, again depending upon what is the diameter of the borehole you can actually select the probe, there are terminologies given for different probe sizes, so the type of field record, so whatever we are discussing here it's like you are having some assembly here and we are actually lower the probe.

So this is your probe I can call it, this is like probe, this is your depth of interest, so there is tubing arrangement is here from which you are actually going to apply water under pressure and how much is the volume? So there will be, this will be like pressure gauge and similarly there will be another gauge which will be controlling how much is the volume injected, volume of water injected to inflate, inflate the measuring cell,

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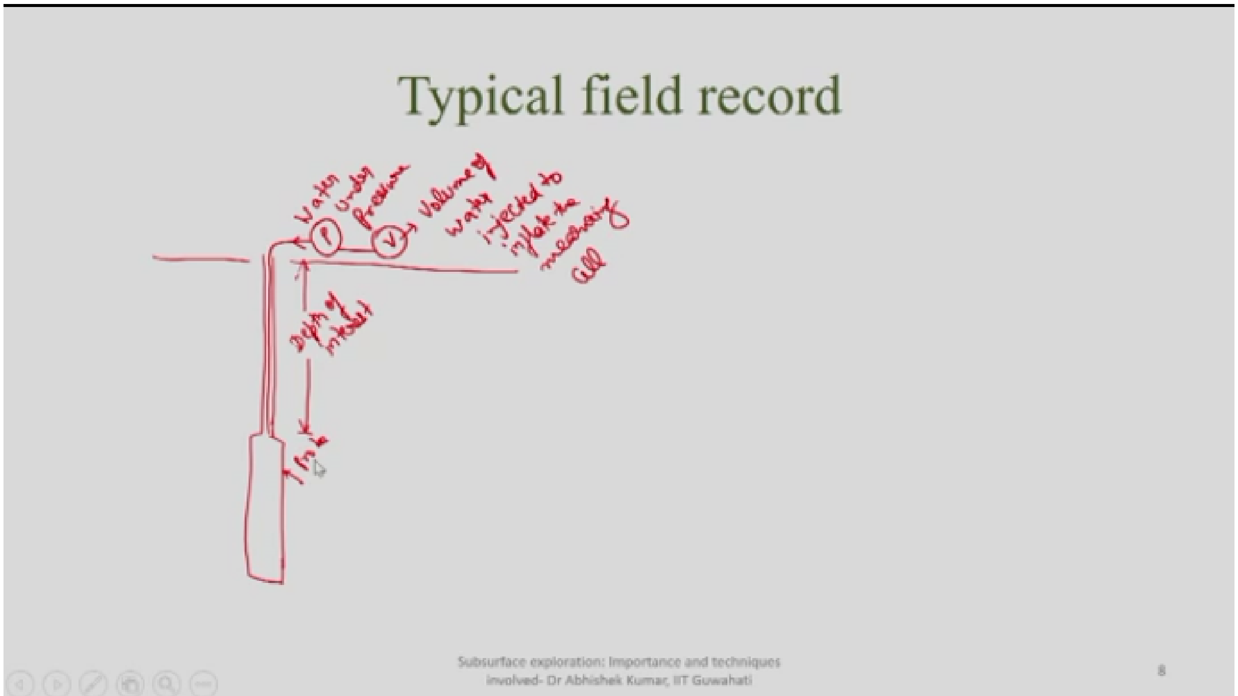

okay, this is the probe, now along this probe there will be, you can call it like throughout there will be like this membrane you call it as and same way there will be another membrane here, so this is like on the periphery attached on all the sides, that's why I'm giving you like this, so this is called as, this will be called as top guard cell, this will be called as bottom guard cell.

And then in between there will be another cell, I'm going to give different region for this, this is called as measuring cell, why? Because whatever pressure you are applying in order to understand the behavior of the soil in terms of deformation that will be measured by means of this cell. The other two cells are measured because if you don't put suppose this is your measuring cell if you do not put, and this is your probe and this is suppose your borehole, this is your borehole, same thing because your borehole should be slightly bigger than the probe or your expanded membrane, okay.

So if this membrane, this is called as measuring cell, if it does not have any guard cell on top and bottom what will happen? Once you start inflating it what will happen, it will start bulging on this side also and this side also, but in addition to this there will be end effect, which will be like this and like this and like this,
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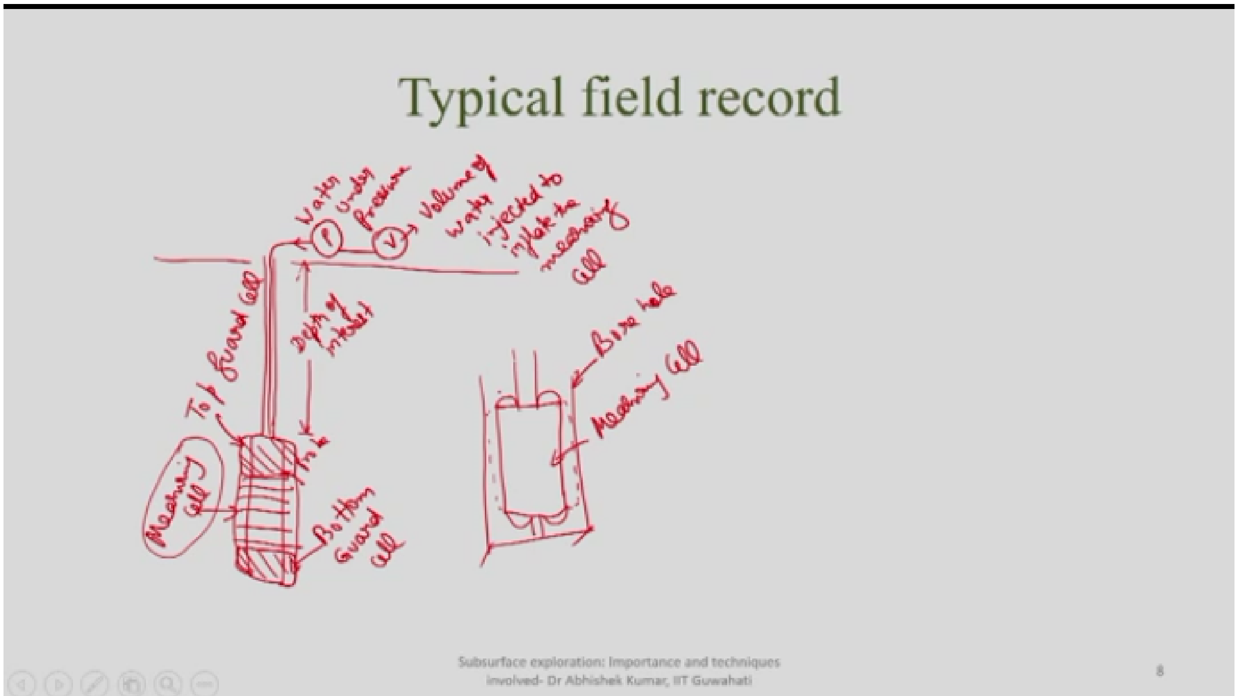

so there will be in addition to like we'll ensure like because you are interested to find out the deformation directly by correlating with the volume, so you ensure that the height in which the inflation is happening it's not changing, only inflation is happening in radial direction, so you only assume like inflation in radial direction, so whatever like the measuring cell which was before the start of the test was in cylindrical position, radial direction.

Even during loading also it will become a radial direction, so expansion should always be in radial direction, so in order to nullify this end effects it will be therefore both top and bottom, so you provide actually here the guard cells, these guard cells will also be loaded with equal amount of pressure which will ensure equal pressure as measuring cell, now the pressure is same,

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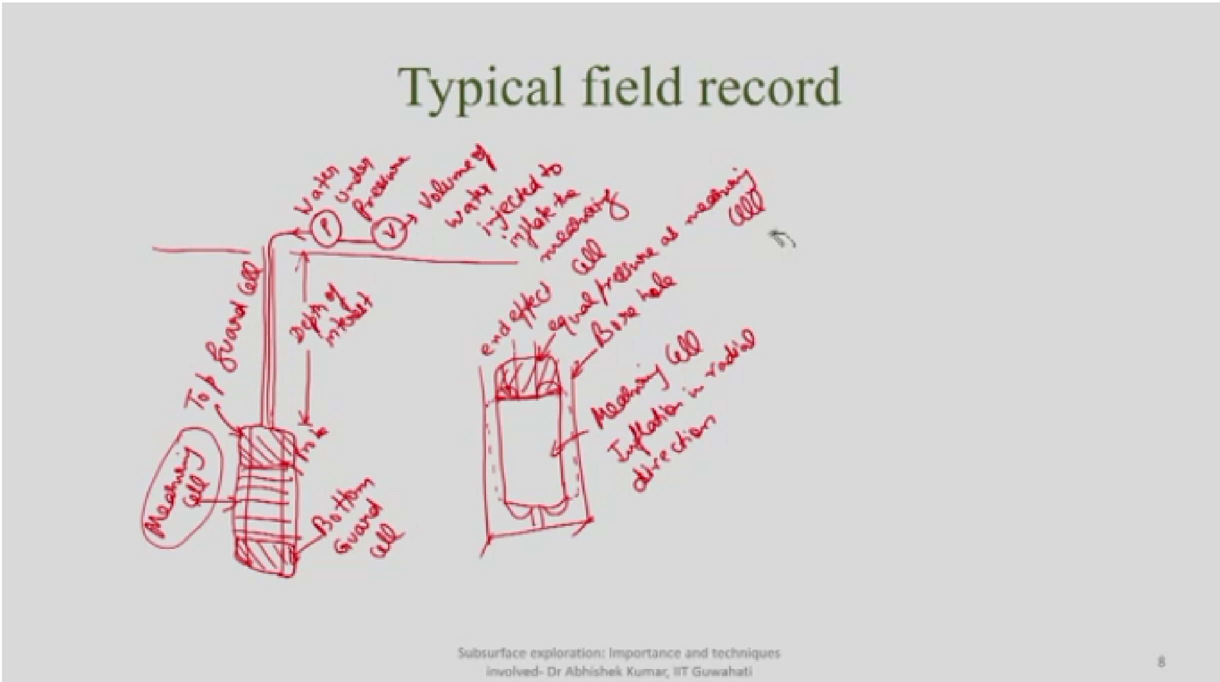

since the pressure is same in guarding cell, guard cell as well as in the measuring cell there will not be any end effect so whatever movement will be there that will be possible only in radial direction.

Similarly there will be another guard cell here which will ensure no movement in this direction, no end effect,

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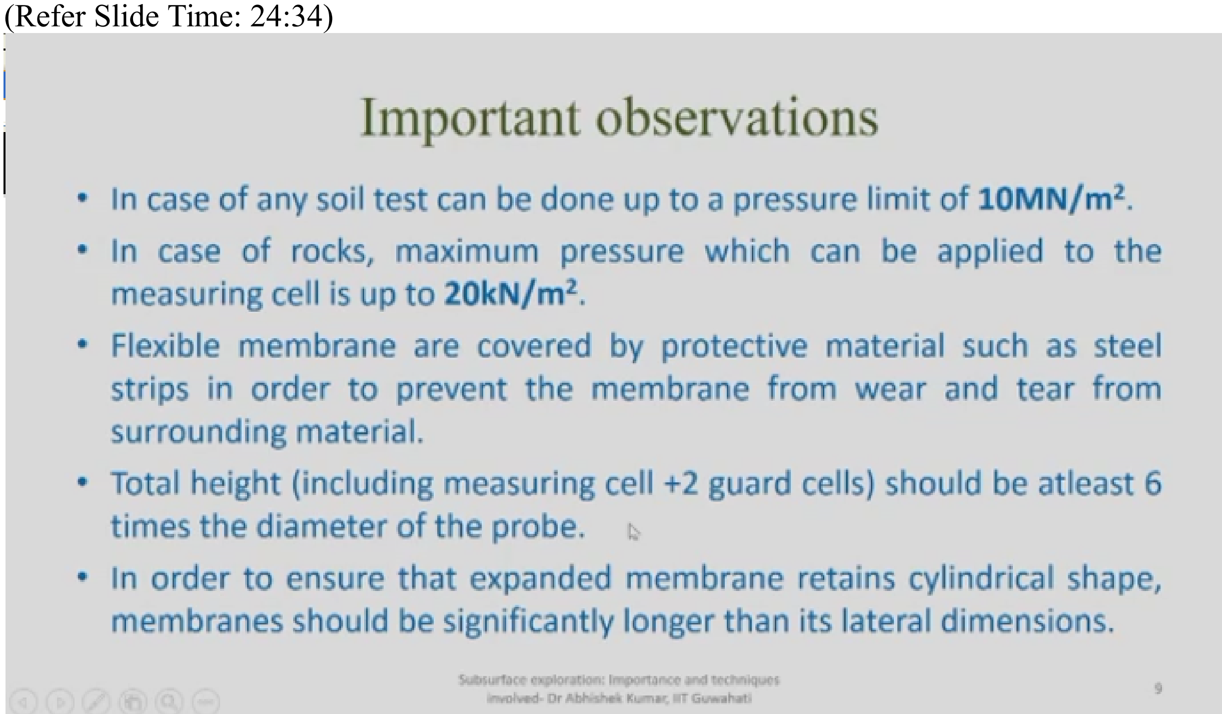

no end effect this is called as end effect the kind of bulging is happening at the top end bottom most part of this measuring cell that is called as end cell, end effect, okay, so no end effect due to guard cell.

Now another thing and so this is like I told something what is kind of measurements and why you are providing guard cell, now what is happening here if you consider only the measuring cell, supposed this is your borehole and this is your measuring cell which will start of course you can call it initial position of measuring cell.

Two things will happen, one is like once you drill a borehole, the material which was in its initial position or intact position there will be some kind of release in the material, like there will be some kind of release or just meant in the material position or this material will come on to the surface like these, so the material is no more in its initial position.

Now you started applying pressure water reserve, what will happen as a result of it there will be increase in the radius of the measuring cell, it will start deflating, inflating, so slowly first of all it will come in contact with the material which actually bulge and come on to the near to the measuring cell periphery, so first of all the measuring cell periphery will come in contact, first of all there will be a gap so some pressure will be required in order to expand it in this gap and then the measuring cell will come in contact with the soil which is slightly release one from its original position, then it will push the soil to its back position or original position, since this soil is not in its intact position though the pressure required to bring the soil in its normal position or original position will be significantly lesser than the in-situ strength of the soil, so one is like pushing the soil back, pushing the soil back to its initial position,
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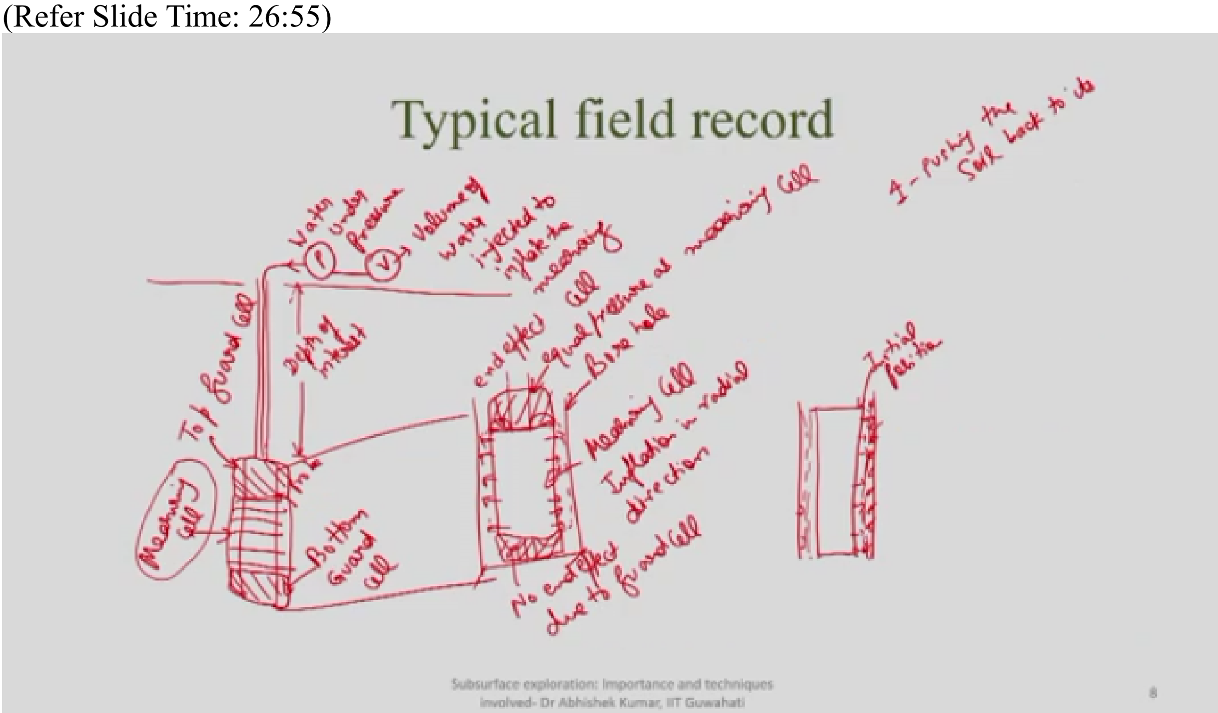

if you see the same thing what will happen here there will be volume, you can call it maybe in CC there will be pressure, because you are actually measuring two things, what will happen?

Because initially, so some volume will be contained because of the cavity, some volume will be contained because of,

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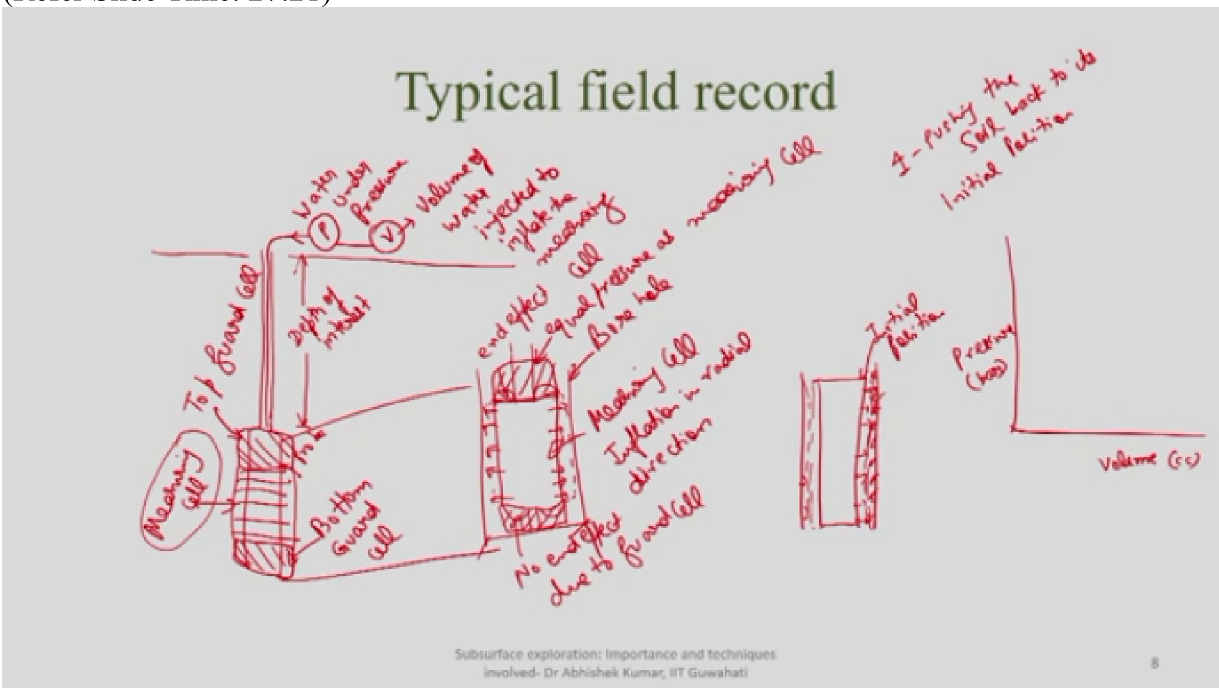

because you are actually pushing the soil which might have marginally loosen because it is no more in its original position, so as a result of which there will be like this which you can call it like pushing the soil, you can call it as zone 1.

Now once the soil reaches I mean to its original position it will kind of regain its original strength, so now then onward if you actually apply any kind of loading or pressure it will behave first of all in its, it will behave like this, so this is called as zone 1, after that it will behave just like any soil behavior in initial part of loading it will behave like linear, so this is called as, this is called as this was zone 1, this will be called as zone 2, so 2 will be called as elastic behavior, you can see here, so it's almost like straight line here.

Then after that if you again continue the loading what will happen? There will be plastic behavior, so zone 3 will be called as plastic behavior, you can understand the same thing considering like soil is there which is actually loosen because of some kind of excavation of disturbance,

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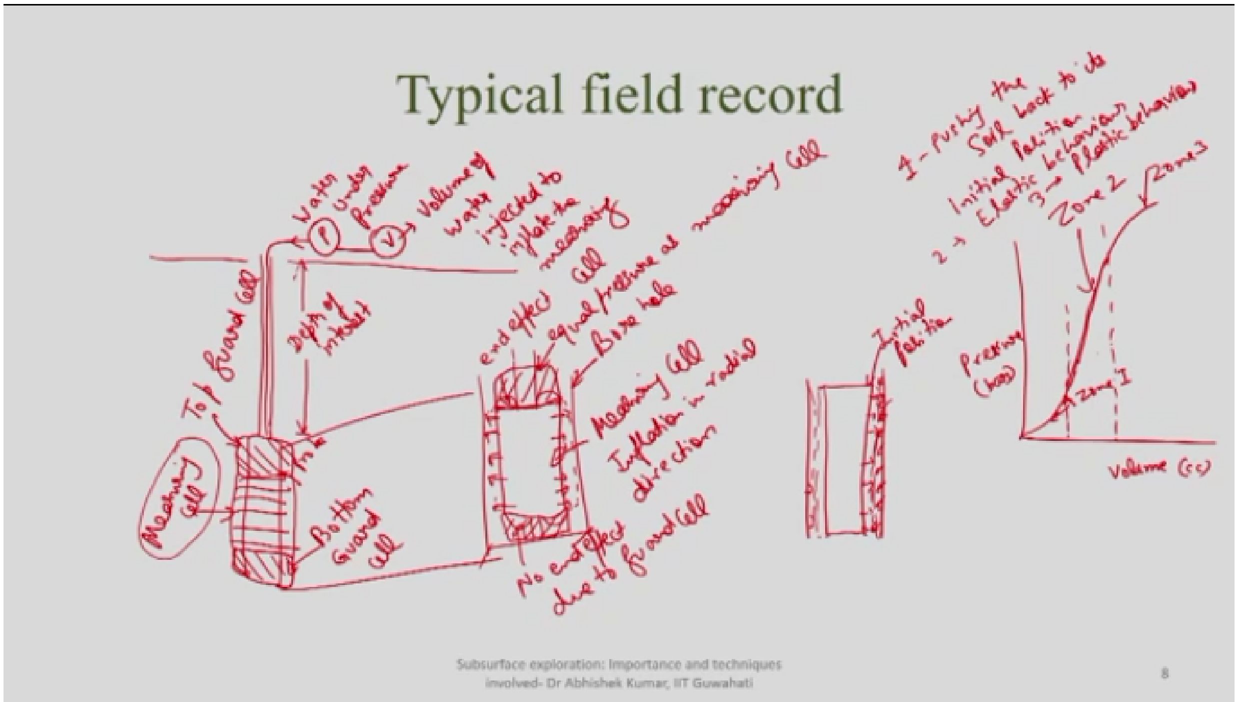

now you started pushing the soil, so by that time soil goes to its original position there will be too much change in the volume, but even for small pressures what you can see here after it reaches to its original position there will be actually loading of virgin soil kind of thing, so there will be linear pressure deformation characteristics which can be directly related to the volume also, because that deformation is happening in radial direction alone.

And then once it reaches it elastic element, so this is called as point A, initiation of elastic limit this is called as point B, end of elastic limit and then once it reaches in plastic limit you soon you will realize like after reaching certain volume there will be continuous increase in the volume even without increase in the pressure, so this is called as limit pressure, this is defined as PL and the volume corresponding to this will be called as VL, so you keep on loading unless, until the volume at failure will becomes, and the volume of the cavity that is the initial volume required by the membrane itself plus V naught times 2, so till the volume expenditure reaches twice the volume when the soil was push back to its original position you consider it as VF or the volume at the failure,

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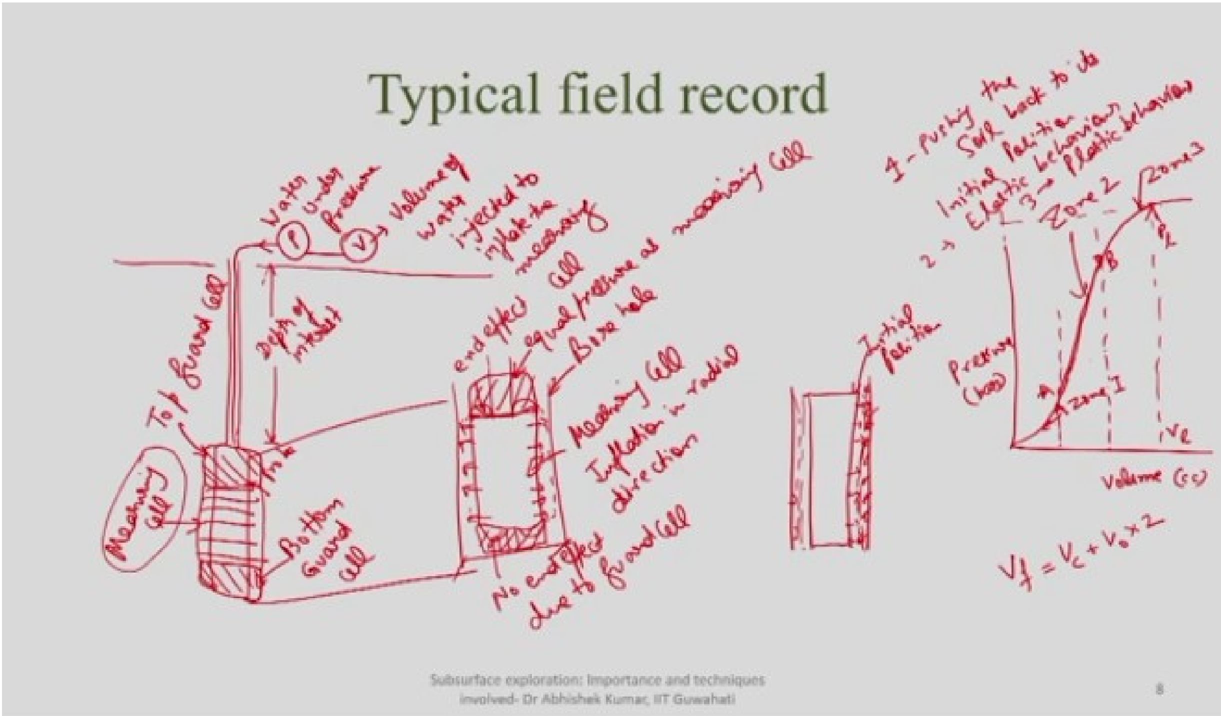

that's how you define the VF.

And then corresponding to VF what will be the pressure? You call it as PF, so once you what you target, you lower the probe and then start loading the central membrane or the measuring cell and corresponding to that equal amount of pressure you will applied to your guard cells, so that there will not be any end effect, and then start measuring at different, different pressure what is the volume? Till the volume change it becomes constant, you report that volume here for each pressure increment, then you measure these volumes, so this is called as V naught, this is called as VF that will be like, that will be called as VF + V naught, that will be called as PF + P naught, that will be called as PL and VL.

And suppose this is like VC that was the initial volume contained in the cavity, so now more on this is like after VC value, how much is the value change? So you will be interested to, from field record you are interested to find out how much is the value of V naught after which the linear relation started, then VF + 2 times V naught that is, at the failure and then VC value that you can determine based on what kind of probe diameter? Diameter of probe, so charts are there based on which if you know what is the diameter of the borehole you can actually determine how much is the diameter of the probe and corresponding to that you can actually determine this is the volume of cavity.

And then same way you are actually determining, how much is the value of P naught? How much is the value of PF? How much is the value of PL? So we are at typical field recording based on which you can actually interpret the soil properties here,
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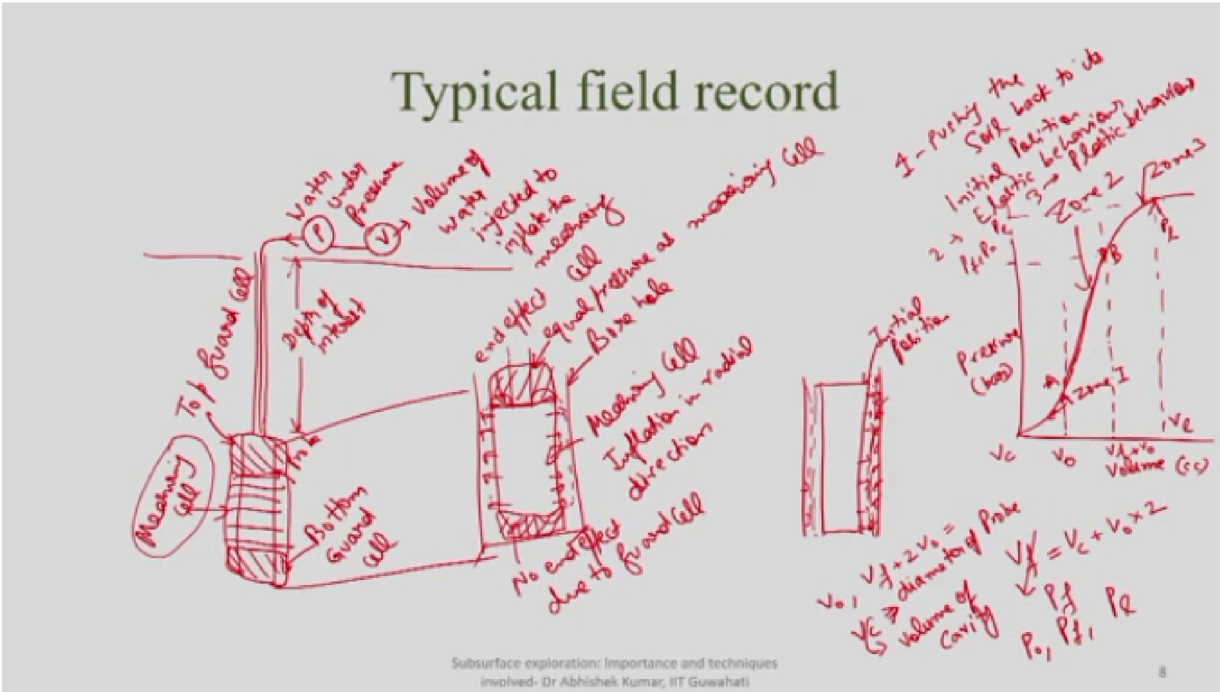

so this is how typical field record at any depth of the interest.

Important observations here there are certain important observation in case you are conducting the pressuremeter test in the soil you should be reading so that you can apply a pressure limit, this PL whatever you have mentioned it is called as pressure limit and the volume corresponding to that is called limit volume or volume limit, so if you are doing the test in soil there might be a chance you have to go for maximum pressure of 10 mega newton per meter square.

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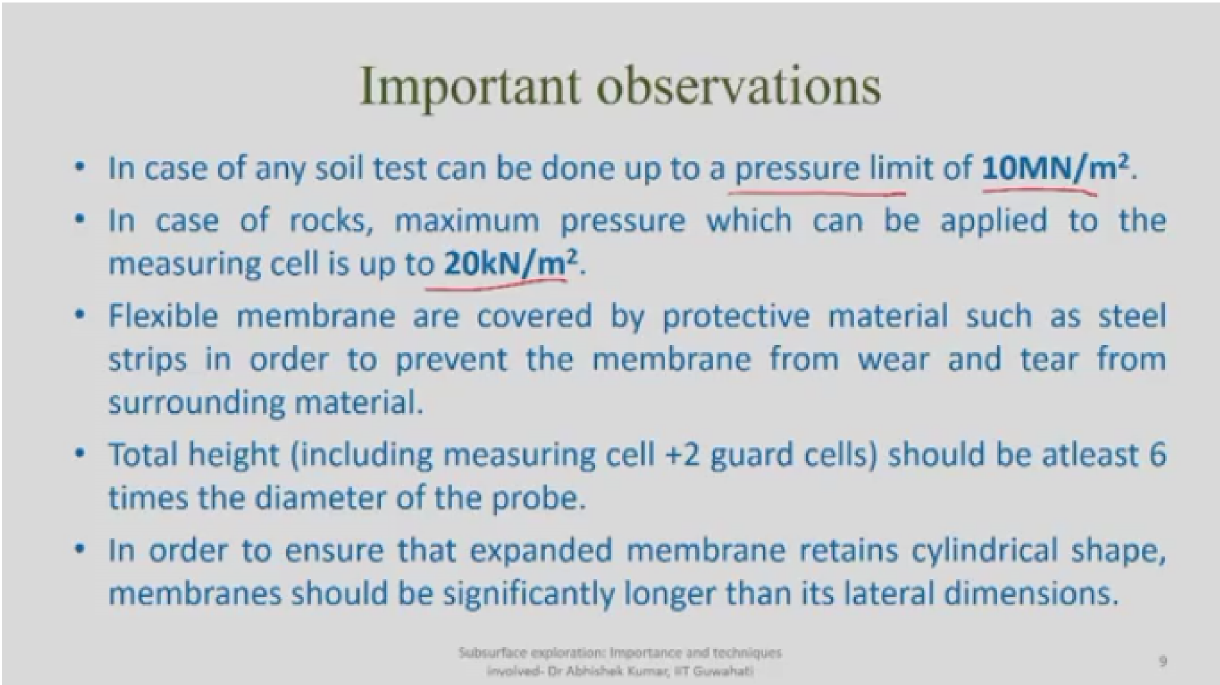

Same way if you are doing the test in rocks you can actually go for maximum pressure of 20 mega newton. Flexible membrane as I told you these membranes are flexible so that you can, they can actually push the soil back to its initial position and then there will be loading and deformation will be there, so there might be a chance like the membrane material may get some kind of wear and tear because of the surrounding material which may be the soil, which may be the rock, so in order to prevent it in the flexible membranes are covered with protective material at times also called as Chinese lantern generally made up of steel strips, so these strips will cover the membrane, so as a result of which when the membrane expand these strips will not directly come in contact with the soil, and there will not be any wear and tear or it will be minimal, and that's how you can go for different kinds of, I mean testing in different environment.

At times membrane are used these flexible membranes are used in soils, but most common when you are going for harder material or maybe rock kind of medium, so one important observation here is total height, that means the height of the central membrane plus the height of the two guard cells, measuring cell and one top and bottom guard cell, it should be at least 6 times the diameter of the probe.

In addition to this, in order to ensure that the expanded membrane retains only cylindrical shape, there should not be any end effect like the curvature I should you above and bottom of the measuring cell, in order to have that possibility as minimum as possible you try to provide the measuring cylinder, significantly longer in comparison to its lateral dimension that will ensure that the bulging or the end effect will be as minimal as possible and what kind of movement, what kind of deformation is happening it is only happening in radial direction, okay.

So we mentioned here like depending upon, so you know the diameter, you can observe here like traditional diameter when we go for SPT test particularly it is 150mm, but here you can see the diameter is range is from 46 to 72mm,

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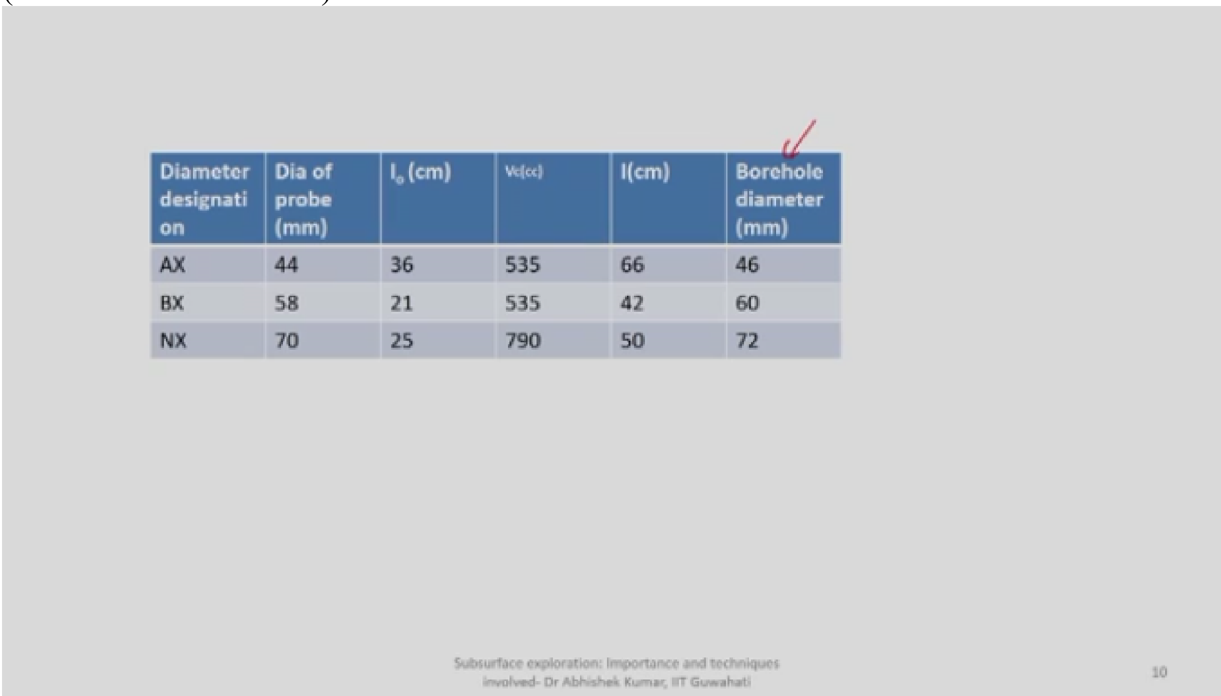

Diameter designation	Dia of probe (mm)	l_0 (cm)	Vc(cc)	l(cm)	Borehole diameter (mm)
AX	44	36	535	66	46
BX	58	21	535	42	60
NX	70	25	790	50	72

these are most standard values we use it and then depending upon this, so this is length of measuring cell, measuring cell + 2 guard cells, like the total length in which actually expansion is happening, and then this is length of measuring cell, and corresponding to the diameter of the borehole you have actually drilled you can actually driven.

What will be the designation of the probe? You can call it as AX, if you are going for 46mm is the diameter of the borehole, so corresponding to that 44mm will be the diameter of the probe, if you are going, so you can understand when 44mm probe you use there will be again cavity for 2mm, and corresponding to that cavity you can actually determine how much will be the value of VC.

Same way if you are going for 60mm as a borehole diameter you can go for VX kind of probe having diameter of 58, so again there will be 2mm cavity.

Same way if you are going for NX probe that is 70mm diameter, the diameter of the borehole will be 72mm, so the diameter of the probe will always be lesser than the diameter of the probe, in these cases by margin of 2mm.

And then this is the volume of the cavity, that is like minimum volume which is required before actually the membrane comes in contact with the, even there is no soil, so sometime what happen because of drilling of borehole there will be some kind of readjustment of the soil material along the periphery or longer finish surface, it will come like this rather than purely vertical, so whatever the volume required to push the membrane into its original position that will be called as V naught, if it is too intact may be at times you may find V naught as minimal as, I mean very minimal value it may be 0 also, it may be slightly more, but depending upon the kind of probe you can understand because of there is some kind of cavity between the borehole

as well as the probe, so there will be always some value of VC available, you can get to know depending upon what kind of probe you are using and so this is like, so you can, once you know the diameter of the probe, once you know the diameter of the borehole you can actually determine how much will be the volume of the cavity, that difference between that we do, so VC value is generally supplied by the, supplier maybe manufacturer also provide depending upon the probe diameter.
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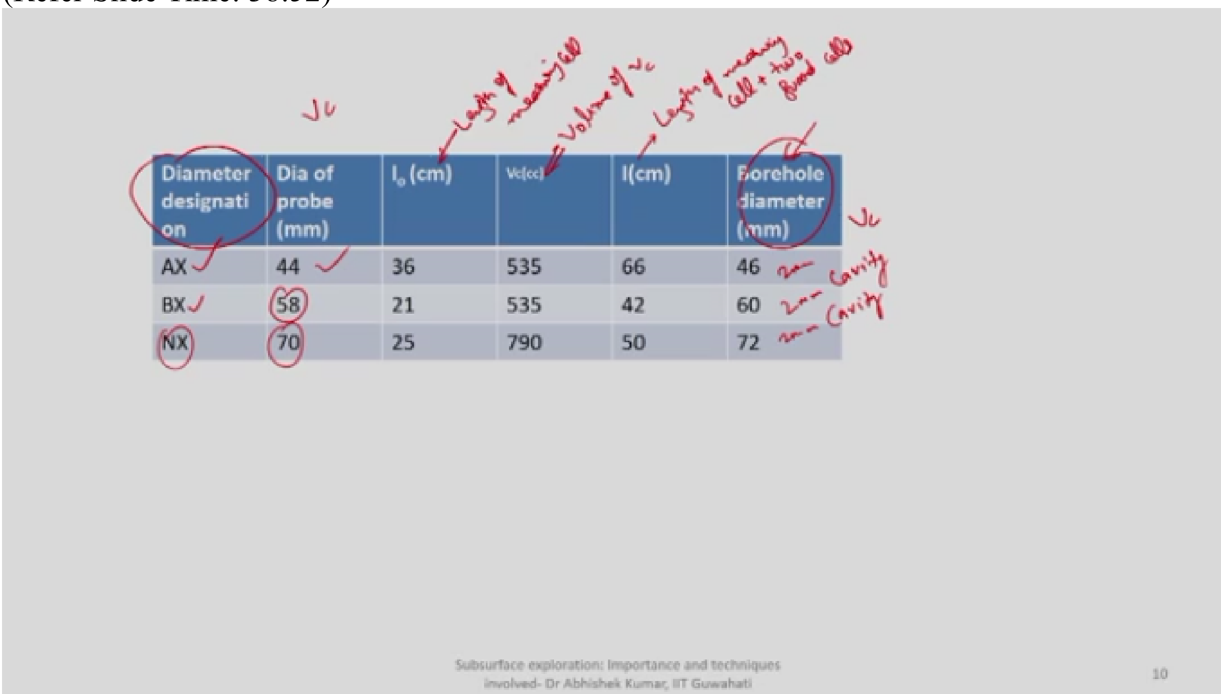

Diameter designation	Dia of probe (mm)	l_o (cm)	Vc(cc)	l(cm)	Borehole diameter (mm)
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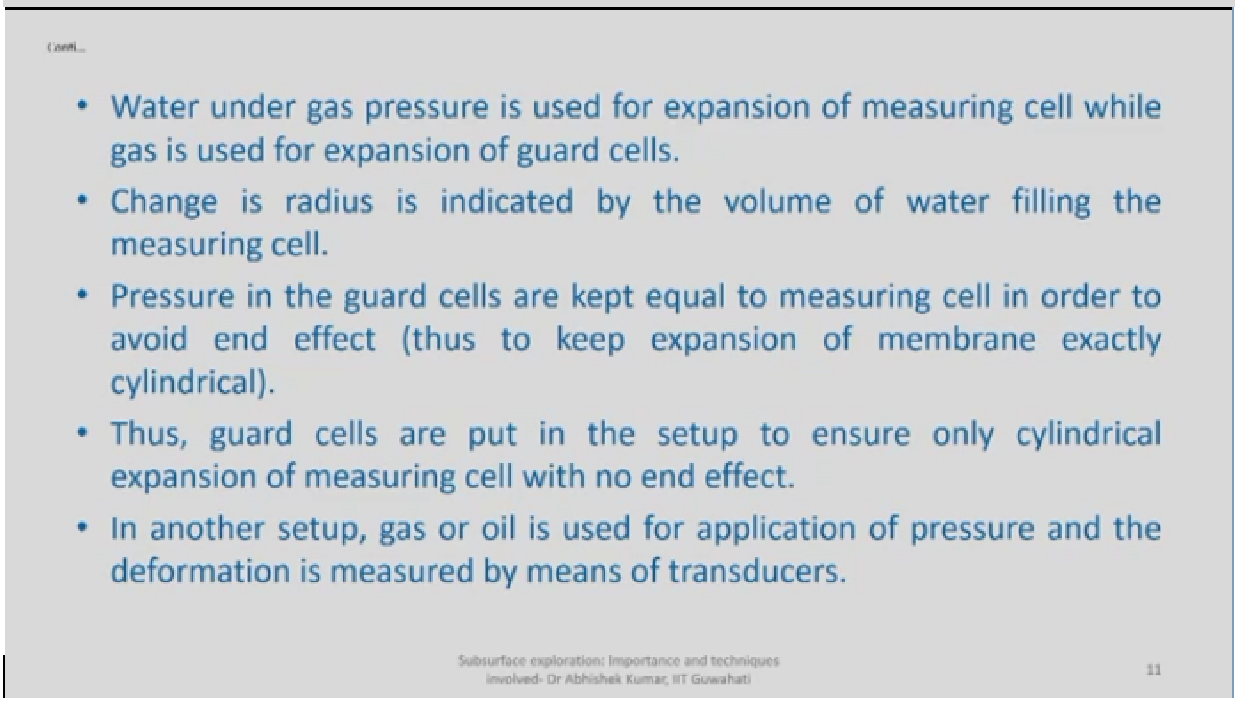

So typical observations, once you go for field testing the water because you are targeting for significantly higher pressure, so only air pressure will not be sufficient you have to go for water pressure, so water is there but it will be injected into the membrane under gas pressure, so water under gas pressure is used for expansion of central membrane or the measuring cell, while the guard cells are usually expanded to the same amount by means of air pressure, so the change in radius is indicated by the volume of water, you are actually use for filling of the expanded membrane.

The pressure in the guard cell are kept equal to the measuring cell, the pressure in the guard cell is kept equal to the measuring cell till the time it comes, till the time the measuring cell comes in contact with the diameter, the size of the borehole, the wall of the borehole because after that whatever expansion will happen it will happen in radial direction alone, so initially the pressure in the guard cell are kept equal to the measuring cell in order to avoid end effect, there will not be because the both measuring cell as well as the guard cell on the top or as well as the bottom are having equal pressure, so the interface will be perfectly horizontal, exactly cylindrical, so whatever expansion is happening in the membrane it will become perfectly cylindrical in shape, thus the guard cells are put in the set up to ensure only cylindrical expansion that we have been discussing again and again in order to minimize end effect, in order to ensure that the expansion of the central membrane or measuring cell happens only in radial direction, guard cells are mandatory.

In another setup rather than using water you can even go for gas or oil pressures, but it depends upon what is the range of pressure you are actually dealing with once you go for these kinds of in-situ investigation, and the deformation is measured by means of transducers rather than some measurements of or measurements of the volume, some way of measuring the volume.

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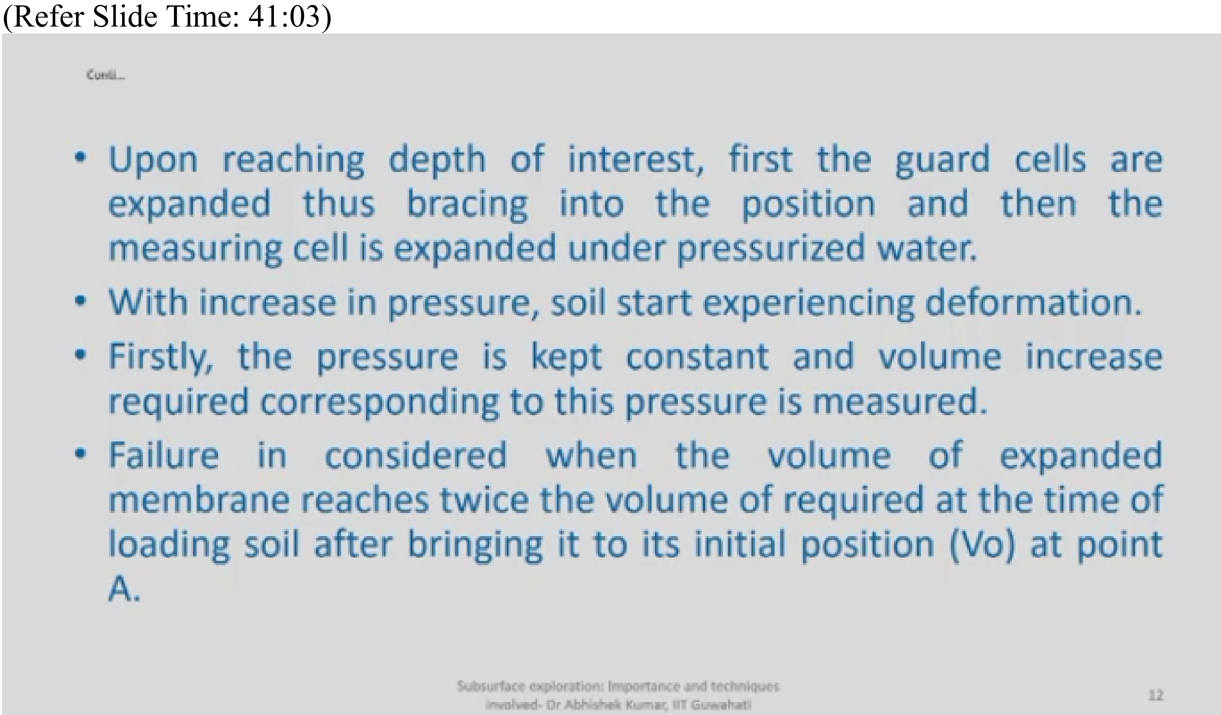

Upon reaching the depth of interest first the guard cells are expanded that will ensure bracing in to the position because if you lower the central membrane then definitely there will be end effect and later on if you apply gas pressure that will rather cause deformation in the soil rather than what is the minimum pressure required for only the cylindrical expansion of the membrane, so in order to avoid that situation you apply first pressure in the guard cells, so after that the central membrane must start expanding it will only expand in radial direction and up and bottom it will only expand till it nullifies the pressure of the guard cell.

So first guard cells are expanded and then measuring cells are expanded with pressurize water, with increase in pressure the soil start experiencing deformation, firstly the pressure is kept constant, so you apply some pressure and then leave it till the time value increase becomes constant, you measure how much is the volume increase required for this particular pressure whatever you have applied till is considered, you generally consider the failure when the volume of expanded membrane, the membrane once you start pushing it into the soil so the volume required reaches twice the volume required at that time of loading the soil, so initially what you did, you actually pushed the soil back to its original position, so how much is that volume required to push the soil back to its original position twice that volume, you call it as the volume, I mean addition to V naught + VF, how much is the volume required to cause the failure, we use generally defined that as the failure when the volume of expanded membrane reaches twice the volume required to push the membrane into its original position, so that will be generally like VC + twice VF, because VC will always be there before actually the soil comes in contact with the membrane, some minimum pressure will be required for expansion of the membrane itself so that is VC.

And after that if the soil is getting pushed by the membrane to its original position that will be V naught, additional same equal amount of pressure that will be called as VF, that is VC + two times V naught, that will define like failure, so after that okay, so as we know like with increasing depths confinement will be more, same way because the expansion of membrane is coming into picture, third thing system might be having some kind of corrections required.

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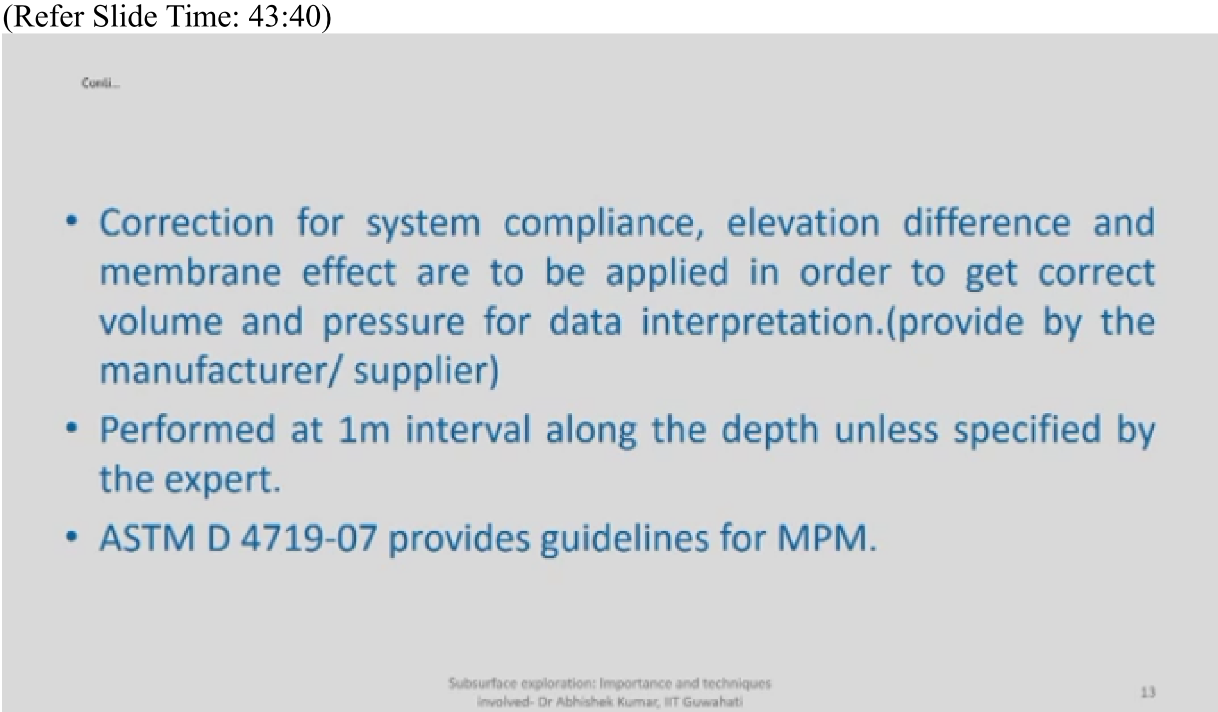

Fourth, if flexible membrane you are using, you have to apply some correction for that, so before you use the field record for data interpretation or for quantifying the subsoil property you have to apply certain correction to fill recording, these are called as system, compliance, these corrections are required for system compliance, whatever correction required by may be measuring cylinder, by may be gauge or so maybe for guard cells also, then elevation difference as you go deeper and deeper more confinement will be there so you have to apply pressure for the correction for that.

Then membrane effect, certain minimum pressure will be required for deformation of the membrane itself just like in dilatometer you had some correction required for the stiffness of the membrane, here also there will be some correction, so these correction will be required in order to get corrected volume as well as corrected pressures, once you know these parameter you will be able to understand how this data can be used further for interpretation.

So generally these kinds of correction can be provided by the manufacture, even suppliers can provide charts for this corrections, and the guideline says you can do at least you can do pressuremeter test at one meter interval with respect to depth, if you have to go for shorter interval you can follow the guideline given by the expert, it maybe the designer or maybe field engineer or maybe the person who is expert for pressuremeter test, because depending upon the soil if there is change in lithology is too high maybe these guideline kind of thing can change.

ASTM D 4719-07 provides guideline for the MPM's, Menard kind of pressuremeter test, so this ASTM code provides guideline, what are the typical field record, corrections, at what interval you have to do, what is the range of pressure you can expect at different, different soil type and so on and so forth.

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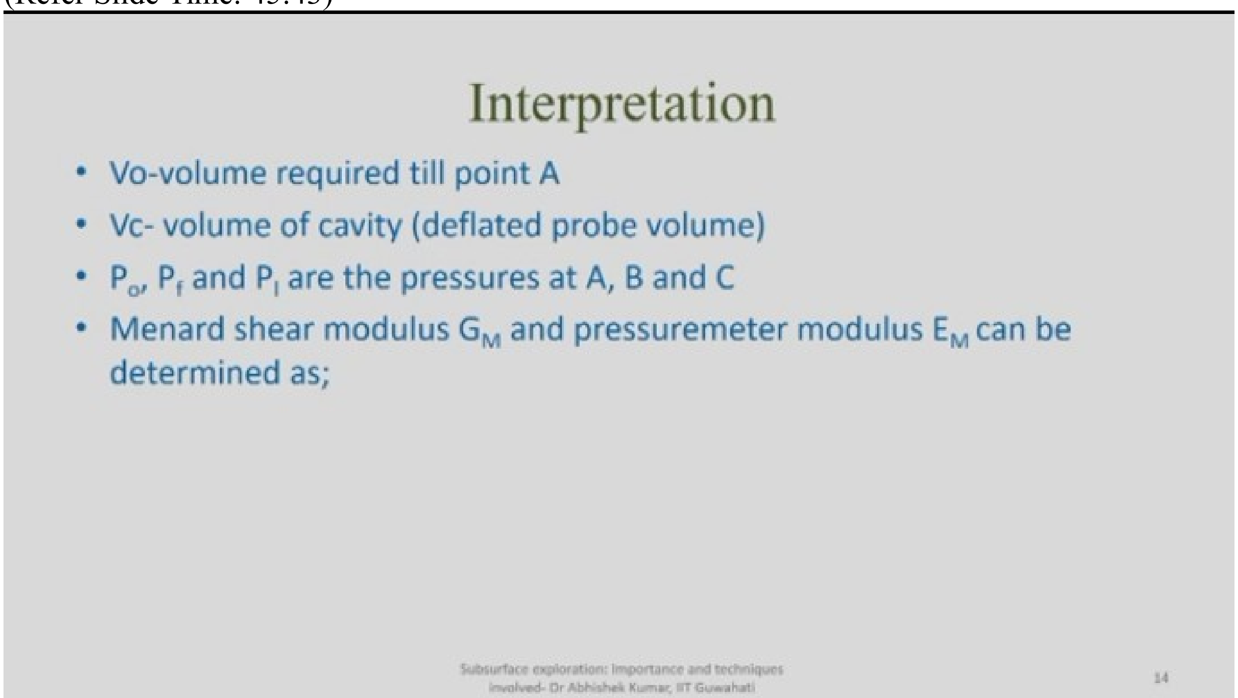

Interpretation, as I mentioned here so you will be actually based on your pressure volume method you will be actually measuring how much is the volume required if you remember here, we developed these initial when it comes in contact with the soil then like this, so this will be called as elastic behavior, this will be called as zone 1, so this is called as point A, point B and then this is called as limit pressure, pressure limit or PL, this is called as VL, this is called as V naught + VF, this is called as V naught, this is called as V naught + VC, this is called as VC, and so there will be again some VC here, so that's how you can determine how much is the pressure required at point A, point B, so V naught is the volume required till point A, directly you can get from the field record, VC is volume of cavity like the minimum required for deflated probe.

Then P naught this will be corresponding to this, there will be P naught, this will be called as the PF, and then PL will be there limit pressure, you can call this as point C, so all this measurements can be determine using this, once you know this kind of thing, then you go for interpretation,
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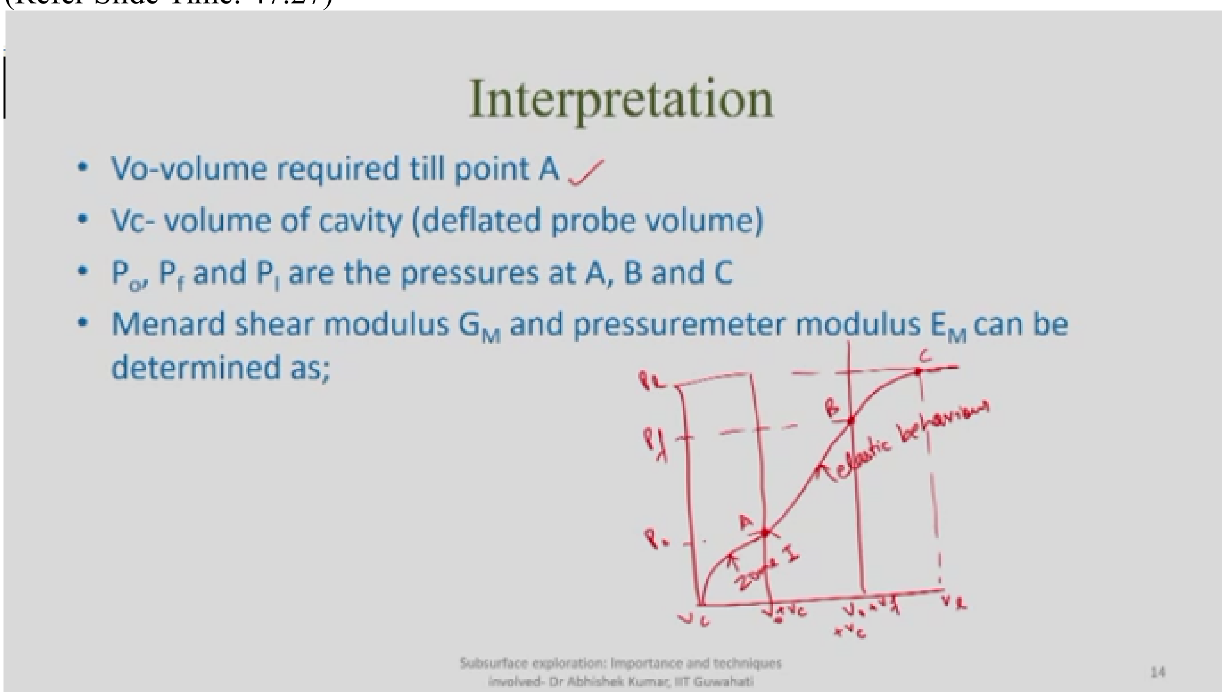

so as I mentioned you can actually determine the modulus here, so modulus you generally defined as like Menard pressuremeter modulus that is EM defined as 2.66 VC + V naught + VF divided by 2 times PF – P naught over VF – V naught, so you know all the value, this is how you can determine the value of EM that is pressuremeter modulus, then same way you can determine the elastic modulus that will be called as EM divided by alpha,
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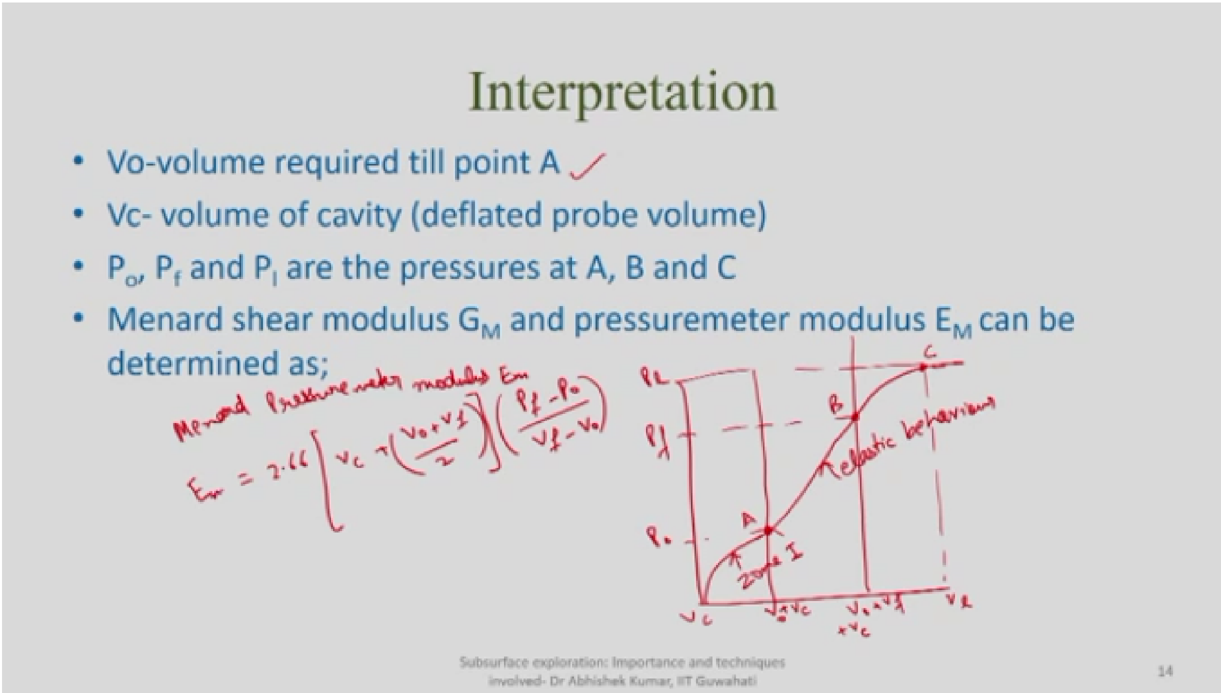

this alpha depends upon the soil type, charts are there based on which you can actually determine how much is the value of alpha. And then same way you can determine the value of un-drained shear strength that will be called as CU, that will be PL divided by 9 only for clays.

Stippled by measurement of different pressures, you are able to determine how much will be the young's modulus, how much will be the shear strength properties, further you can determine in-situ horizontal stresses and so on and so forth.

So depending upon as I mentioned here the value of alpha, so soil type if you know you can actually determine how much will be the value of alpha, so for normally consolidated clays alpha value will be 0.67.

Similarly for over-consolidated clays the value of alpha will be 1.00, for normally consolidated silts the value of alpha will be 0.50, for over-consolidated silts the value of alpha will be 0.67, and then for sand the value of alpha will be 0.33, so that’s how you can actually determine how much will be the value of alpha once you put the value of alpha you will be able to determine how much will be the value of CU un-drained strength that is PL, limit pressure divided by the value of alpha, and PL you are actually determining from your field records, okay.
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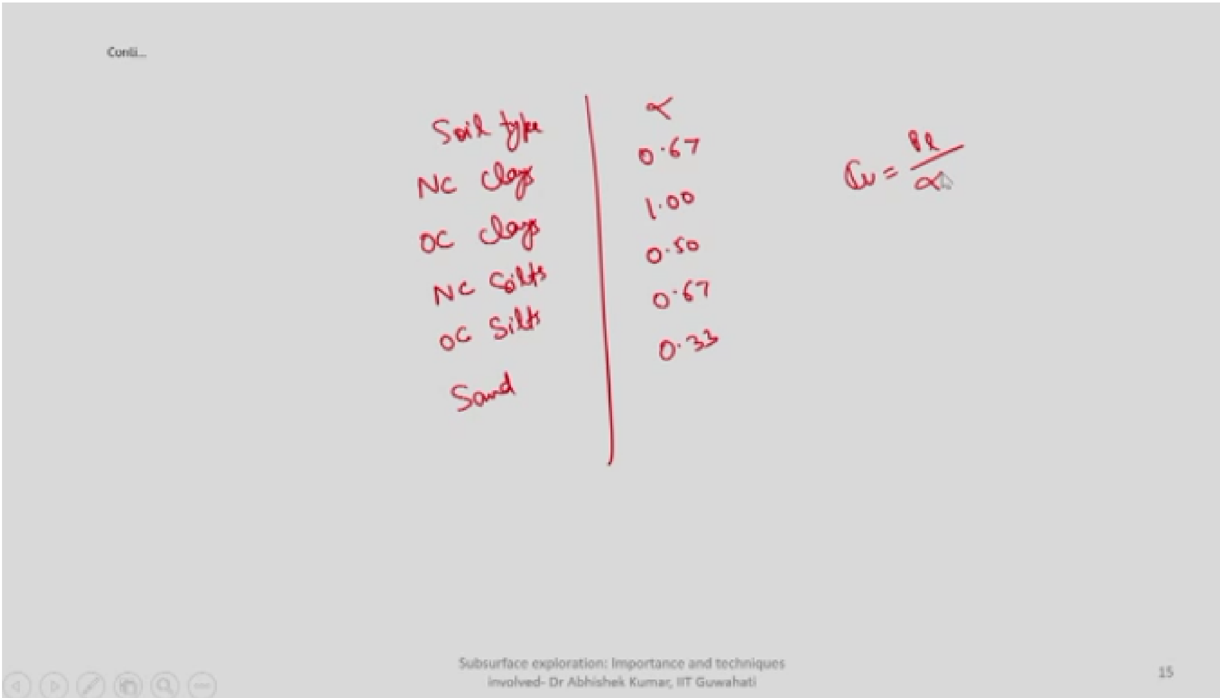

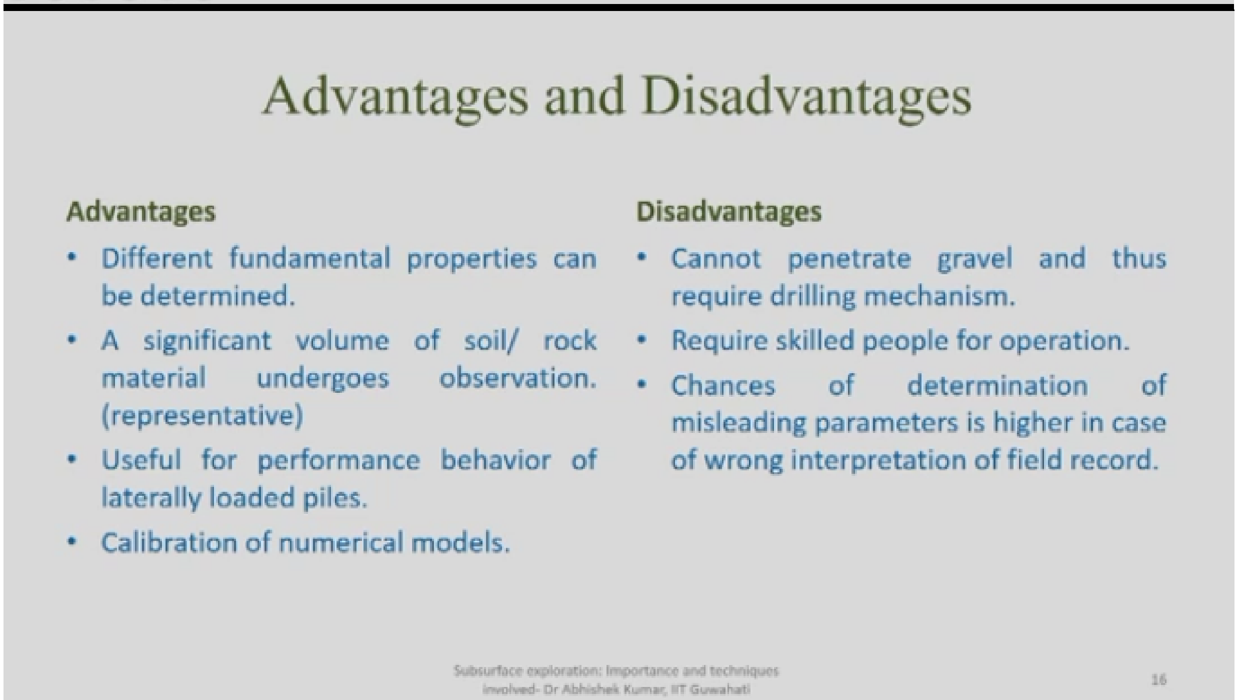

So there are certain advantage and disadvantage just like many, many methods, one is like you are, advantage is like you can determine different fundamental properties based on simple measurements, second one is because once you start loading the soil sample it's not very small area, larger area of, larger volume of the soil is getting loaded under different, different rates of pressures, so you are actually able to give the representative soil properties useful for, so whatever interpretation you are actually gaining at the site it is very useful for understanding the performance behavior of laterally loaded pile.

Then for even for numerical modeling you can get more and more data for calibration purpose. Disadvantage here, it cannot penetrate the gravel, so if gravel is encounter you actually required drilling arrangement so that actually it can push it into the gravel, later on you can actually do the test radial expansion in kind of different rocks.

Required skilled labour because you have to be very careful for what kind of pressures and volume you are measuring, then chances of determination because if you measure the volume of pressures, volume of pressure, volume of water supplied at different level of pressures if that goes wrong then you will end up in misinterpretation of the results.

So let's discuss, I mean we have discussed about different measurements of pressures and volumes and so on,
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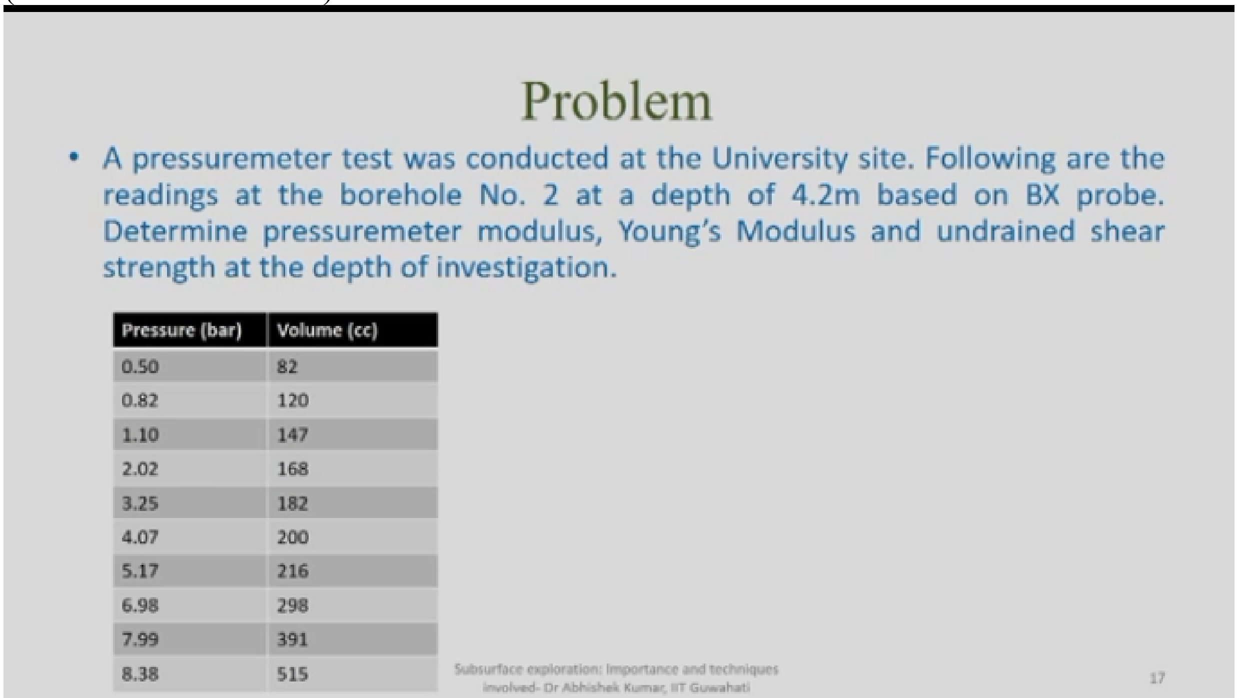

Pressure (bar)	Volume (cc)
0.50	82
0.82	120
1.10	147
2.02	168
3.25	182
4.07	200
5.17	216
6.98	298
7.99	391
8.38	515

let's discuss one numerical problem, so it says like a pressuremeter test was conducted at the university side following, at the university side and following are the readings, so you apply different pressure and corresponding to that pressure how much is the volume change is happening, so this is like at different, different instances the test was conducted at 4.2 meter borehole number 2, generally at the site if you are having more number of boreholes you actually nomenclature those boreholes, so that later stage you can actually refer those boreholes using BX kind of probe.

Determine the pressure modulus, young's modulus and dense shear strength of the depth of the investigation, so we are interested to find out how much will be the value of EM, how much will be the value of E, how much will be the value of CU, now you remember you have been given the value of BX, so keep this thing you will be plot, pressure versus volume plot that will give you how much will be the value of V naught, so V naught actually from this you can actually get the value of V naught as equals to 181CC, the value of VC corresponding to BX probe that will be corresponding to 535CC and then so volume of failure, value equals to VC + 2 times V naught that is 535 + 2 x 181 that will be like 895CC,

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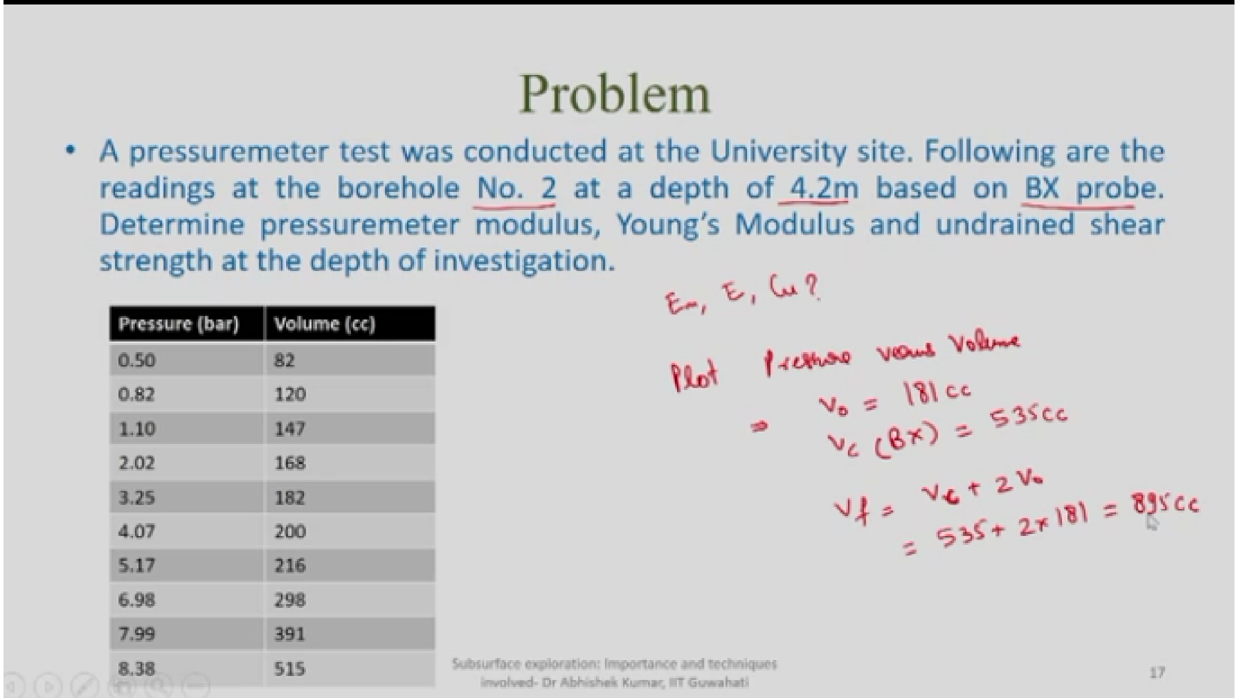

but your volume versus pressure is not going up to, since the field data does not reach VF of 895CC you are actually using, use calibration chart to determine PF that will be corresponding to 11.3 bar, okay, so you have the value of this, and again from volume pressure plot the value of PL is found out as, this will be like PL value, so PF value you can determine it as 5.05 bar based on the pressure required corresponding to point B, okay.

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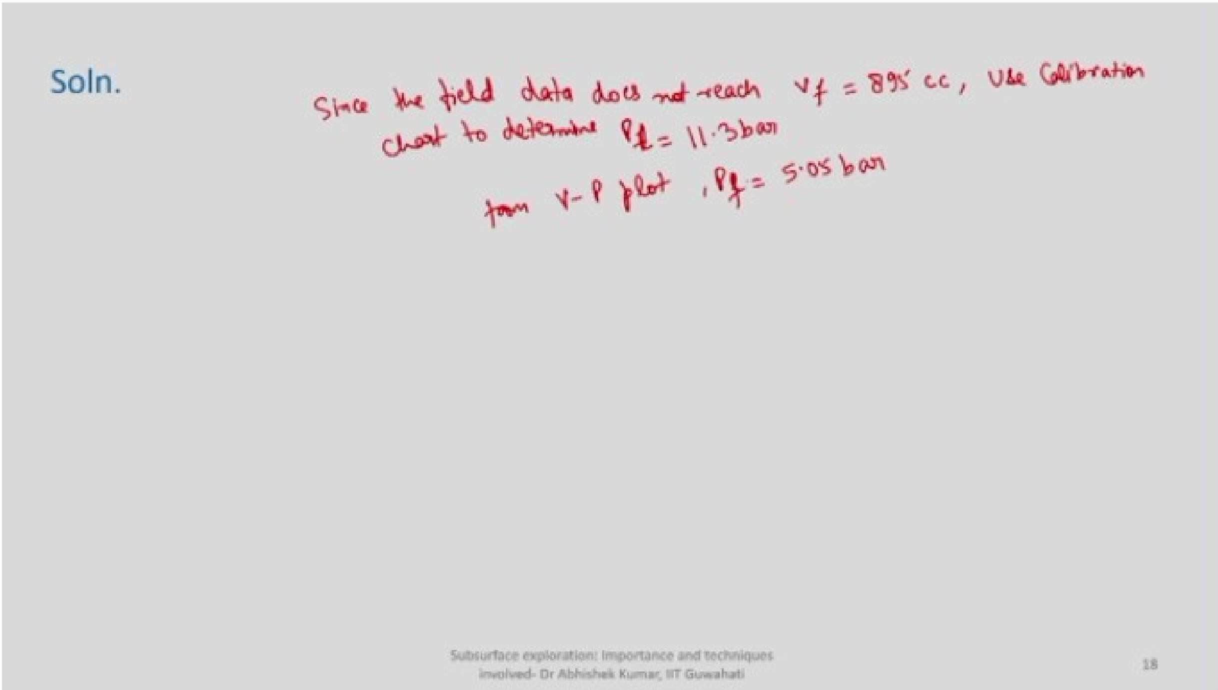

So EM you are interested to find out EM will be equals to 2.66 times VC + V naught + VF divided by 2, PF – P naught over VF – V naught, so you have estimated the values here of the different parameters VC is equals to how much? 535 provided by the supplier + VF is equals to 212 that is corresponding to point B, then divided by 2, PF is equals to 5.05 – P naught value was 2.02 again this is corresponding to point A, this is corresponding to point B and then BF is equals to how much? 212 – V naught is 181, so that's how you can get an idea how much will be the value of, so that comes out to be 182.29 bar, then young's modulus of the soil will be equals to 182.29 divided by alpha, alpha M considering normally consolidated clays, it is generally known if it is not known you can actually collect data from nearby sources and nearby borehole location and get an idea about how much will be the value of,

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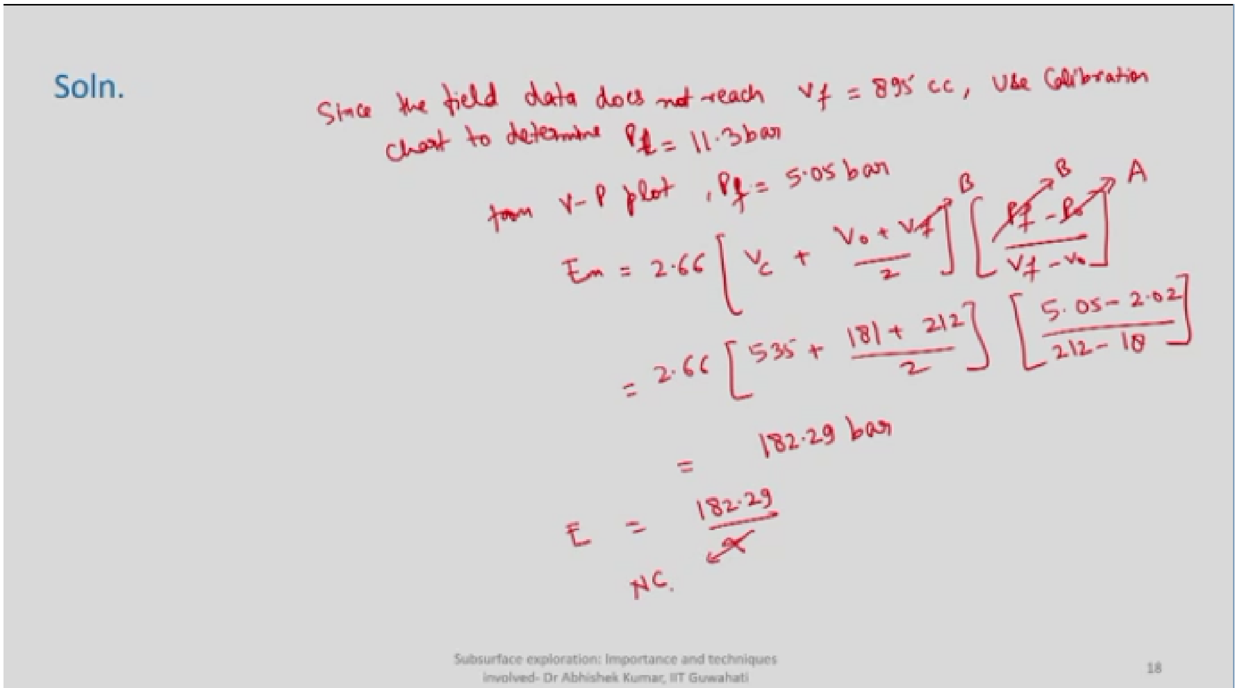

what kind of soil is there, and corresponding to NC it will be like 0.67, so you put the value here 182.29 divided by 0.67 that will give you the value like 272.07 bar.

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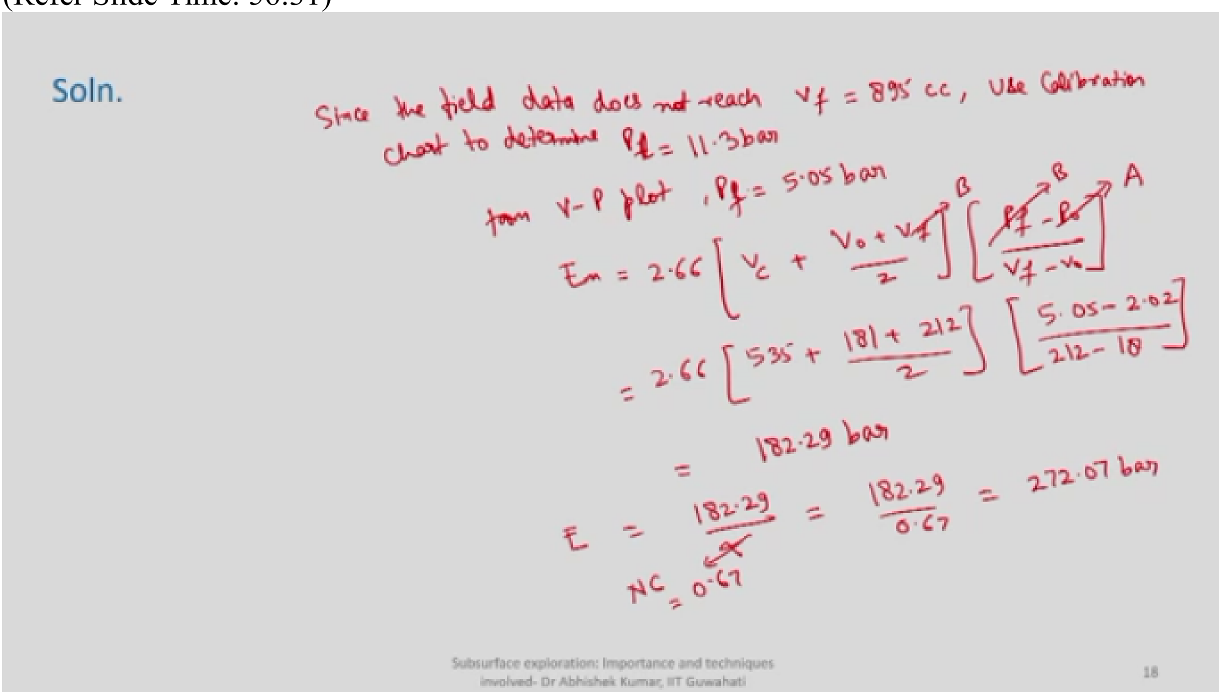

Now the last one is the value of CU which will be equals to limit pressure divided by 9, so limit pressure was found out as 11.3 bar divided by 9 that will come, that comes to be 1.25 bar, so you got all the parameters EM as equals to 182.29 bar, E equals to 272.07 bar, and CU equals to 1.25 bar,

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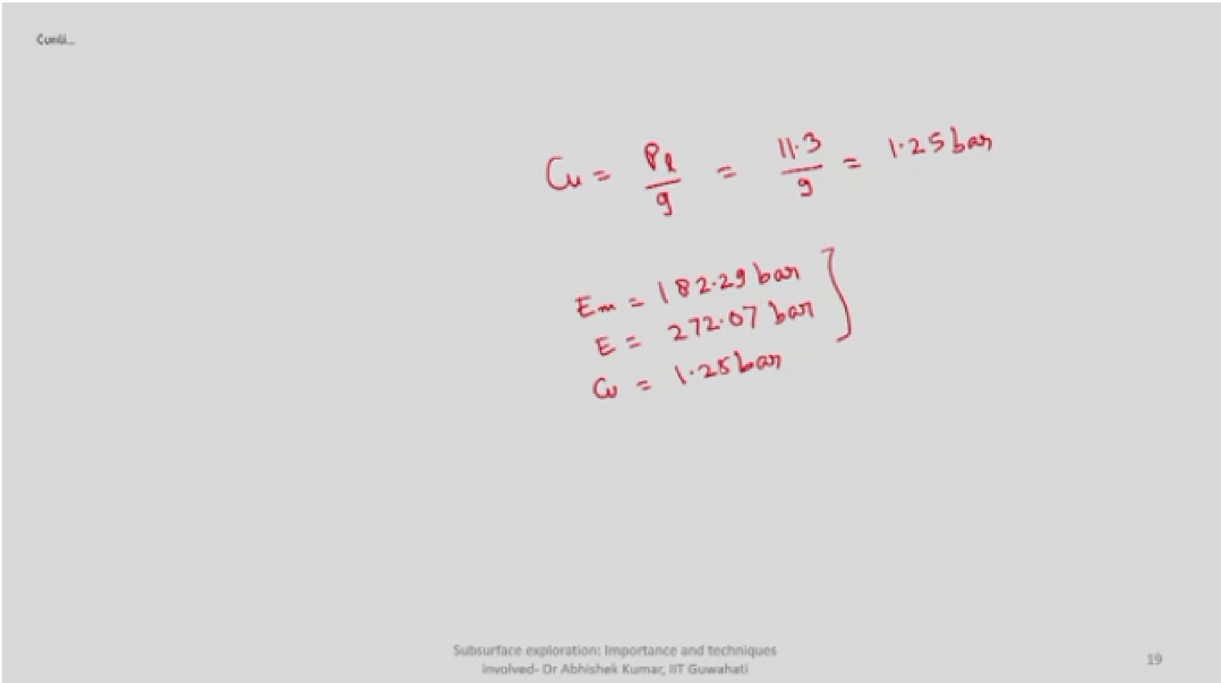

so these are the typical outcome which based on which you can actually determine how much is the in-situ strength, un-drained shear strength, young's modulus and so on and so forth, so this is about pressuremeter test, I'll stop it here, just by measuring field, typical values of volumes and pressures required at different, different level if you are able to interpret you will be able to get based on these two values how much is the in-situ strength, and remember this is more suitable, more suitable because you are actually loading the soil and corresponding to each increment of load, how much is the deformation you are actually doing at the site of interest.

So with this we actually come to an end of different geotechnical investigation, there might be other methods also but as far as the lectures for this course is concerned we will be discussing about, we have discussed about 4, 5 methods, so in coming classes we will be starting with the geophysical methods which we calls as indirect methods, so we'll go into more details in the next class. Thank you.

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