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Subsurface Exploration : Importance And Techniques Involved

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Introduction

- All Civil engineering structures transmit load of superstructure, dead load, live load and other categories of load to subsoil either directly or indirectly.
- Transfer of load between
  - Earth and Earth (pavements, earthen dams)
  - Masonry/ concrete wall to earth (Retaining structures)

Welcome all. Myself Dr. Abhishek. Today is the lecture one for our course sub-surface exploration; introduction and technique involves. So as we know different kind of civil engineering structure whether it's a bridge, whether it's a dam, tunnels, turbines, off-shore structures, buildings, and what not even retaining walls what kind of structure whenever we

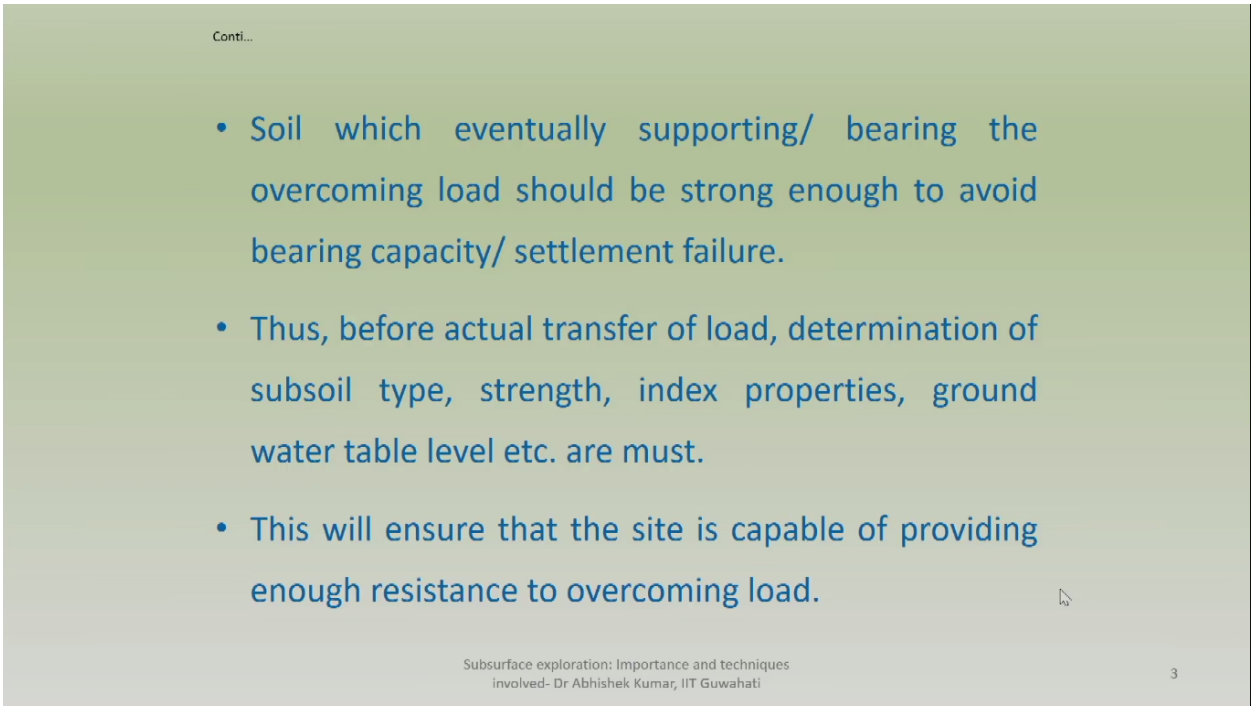
design we generally consider the dead load of the structure, the live load which can be possibly act upon structure, civil engineering structure and any kind of other load it can – whether it can be because of seismic activity, whether it can be because of winds, it can be because of floods, it can be because of frosting like ice, it can be because of some other factors. So finally though we are designing building to withstand each of these kinds of load but finally the load which the building is able to sustain the load getting transfer to the base. That is the soil beneath the ground level. Depending upon the depth of foundation, we have to make sure what kind of soil is available beneath the foundation, it should be strong enough, it should be the stand should be sufficient enough to withstand overcoming load. There should not be any kind of even differential settlement or total settlement . There should not be any kind of bearing capacity failure. So in order to ensure those kind of activities in order to ensure those kind of criteria we have to go for sub-surface exploration.

So in today's class we will be discussing what are the requirement, why should we go for sub-surface exploration and when we go for sub-surface exploration what are the tentative objectives of it. When you go for sub-surface exploration what kind of parameter, what kind of need we are generally looking whether it's a field engineer, whether it's a designer what are our requirement, whatever our desire form sub-surface exploration planning and objectives.

So I already discussed every civil engineering structure directly or indirectly transfer the load by means of different frameworks whether in case of a building we have beams, we have columns, and finally it will be – it will transfer into the medium below the ground level that is soil. It can be because of rock also, depending upon what kind of geology, what kind of soil deposit, what kind of the depth of rock is available at your site of interest.

Similarly there can be transfer of load from earth to earth as we see in case of earthen dams, as we see in case of payment. So we have sub-grade which is finally transferring the load to the layer beneath it that is the natural ground level. Similarly in case of earthen dams whatever load is coming whether it's because of water column depth finally it is getting transferred to the soil beneath it.

Similarly in case of retaining structures whether it's machinery structure, whether it is concrete structure finally the load is getting transferred by means of maybe different mechanism it is getting transfer to the foundation beneath it. So in order to ensure the safety of overall structure though we are designing the structure as a structure engineer we also have to ensure whether the soil which is actually finally overtaking the load of the super structure it should be sufficient enough to withstand that particular load and the structure which are developing due to that particular load whether it's due to seasmic consideration, whether it's due to [00:03:41] consideration static condition, whether it's due to flood situation, whether it's due to dry season lot of fluctuation in water table also that also can sometime compromise the safety of the structure.



So as we know soil which eventually supports or provide bearing or resistance to overcoming load, as a general requirement of civil engineering structure or in order to ensure the safety of the structure, the soil beneath should be sufficient enough, strong – I mean it should be sufficiently strong enough so that they should be able to provide sufficient resistance against the overcoming load. Nowadays we are seeing a lot of mega structures are coming into picture which were not there maybe a decade ago or maybe two decades ago. So the requirement from the soil beneath is not only the safety settlement criteria following. But some more criteria are also there. So to start with basic understanding the soil should be strong enough so that it should not fail any kind of bearing capacity, settlement failure. It can be total settlement, it can be differential settlement. Again depending upon what kind of foundation you are providing at the site of interest.

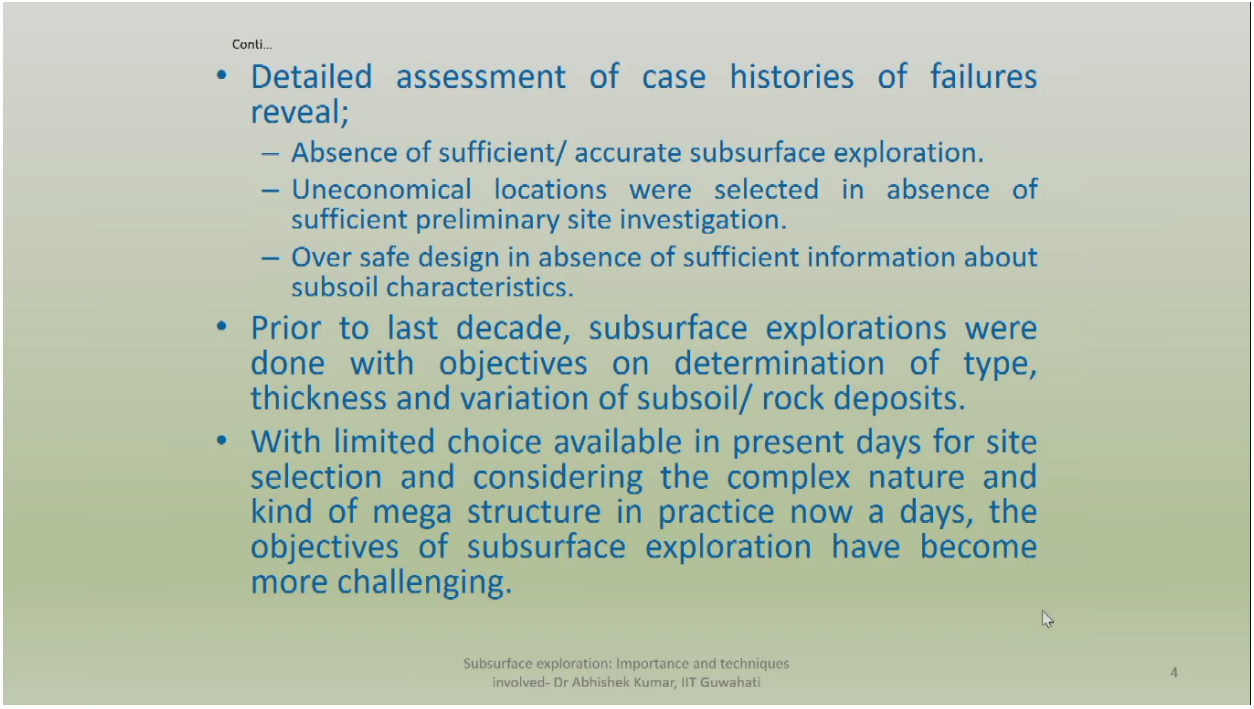
Therefore before transfer of actual load it's as a part of designer as a part of execution engineer, as a part of geo-technical engineer or civil engineer it is our duty in order to ensure the structure should be safe.

How will we do that? We will do sub-surface exploration which will help you understanding like before actual execution of the structure we have to determine what kind of soil deposits are available. [00:05:11] the depth of rock medium, straight or hard medium, whether you are going to transfer the load by means of [00:05:18] whether you are going by means of end bearing, whether you are going by combination of these two, whether the soil shallow depth is sufficient enough to withstand all the coming loads we go for shallow foundation and so on depending upon what kind of structure you are targeting with different kind of structure will be in different kinds of foundation. There are literature which suggest what is the minimum depth of foundation for different kind of structure whether it's [00:05:41] for the bridge, whether it is for offshore turbines, whether it is for ports harbors, whether it is for dams. So different guidelines are given.

Then again index properties what are the strength properties it can be measured in terms of direct measurement as we do in case of SPD test. You can do [00:05:58] test in the laboratory

determine [00:06:00] properties. Then there are index properties which will help you to identify what are the [00:06:05] distribution and then you have one important consideration when we go for any sub-surface exploration is that the depth of ground water table because based on the fluatction in ground water table at time the soil which is available at certain depth below the ground level suppose there is a lot of fluctuation in ground water table during dry season and wet season of the year then accordingly whether the soil is moist, whether the soil is dry, whether the soil is partially saturated its bearer against external loading will be different. So we have to also ensure what is the existing ground water table and also to ensure what will be the possible fluctuation depending on the kind of soil the possible fluctuation you can attain steady state within maybe couple of hours. So it can go for maybe couple of days also.

Then that will ensure that the site is capable. Once you know all these property like I know what is the kind of soil available at the site what is the strength property, what are the index property, what is possible fluctuation in ground water table I will design the foundation that will ensure that my foundation or my soil is strong enough that it can provide sufficient resistance considering what kind of dead load, what kind of live load, what kind of other activities are happening because of the construction of super structure on that particular soil.



Similarly detailed assessment as has been understood from case histories of past failure it has been found like majority of the location where sufficient information was not done we found like absence of sufficient or accurate sub-surface exploration program had led to those kind of failures like suppose the depth of foundation which was supposed to be provided it was not provided because we have not done sufficient sub-surface exploration. Like doing the sub-surface exploration at one point of location at one point of observation may not give you how the variation in soil level or how the variation in rock level is going to take place around the site. But if you go for more number of test you will be able to also understand how other little variation in the different soil layer is taking place. That will also ensure not only the safety of the foundation

at the point of test but at other locations also. That's why we go for sufficient number of test so that even if you are constructing foundation between two test location you should have enough data so that you should be able to interpolate or extrapolate data reliably. So in most of the cases we have found absence of sufficient data.

In addition, accurate sub-surface exploration whenever you go for sub-surface exploration you generally go for more than one test as I discussed earlier also so that we can validate the findings you are getting from one test by doing some other test and also certain test are having certain limitations, certain test work better in certain environment conditions, certain test will be better in other environment condition. Maybe it's because of the type of soil, maybe because of ground water table. It's maybe because of moisture content and it maybe because of the characteristics. Sometime test will work in sandish oil better, some in clay soil better. Some test you are going to do in gravely soil at all. So you have to go for what kind of test you have to do accurate information. Then at time it was also observed like because you have not done preliminary investigation properly like [00:09:17] study of map and then particularly the study of nearby areas what kind of foundation was there, what was that. What kind of challenges people have encountered while constructing foundation of surrounding areas people have often opted for uneconomical locations like they could have gone for better suitable location rather than going for those location that is part of self sub-surface exploration particularly done for site selection.

Then if you are not doing it properly you will end up under-estimating the soil strength property. Suppose you have done the test which is – a test lesser than the suppose test to be done actually at the site of interest what will happen you will end up in under-estimating the strength of the properties. Once you are under-estimating you will go for same design but in actual condition it will called as over-safe design. So when you go for over-safe design again it will be economically very costly.

So at times when you are proposing over-saved design which is comparatively costlier than other alternatives then your entire exploration program and sometime your design consideration will go waste. So you have to also understand accurate assessment of the site, accurate assessment of sub-soil properties. So prior to and as we discussed as we can see nowadays a lot of people are going for high-rise building you can see the kind of bridges people are targeting now, the span of the bridge. People are going for two stories flyovers also. People are going for road railways under the water. So the kind of challenges because of change in this these kind of structures are not the normal law routine structure which people who are practicing last year last decade or prior to that.

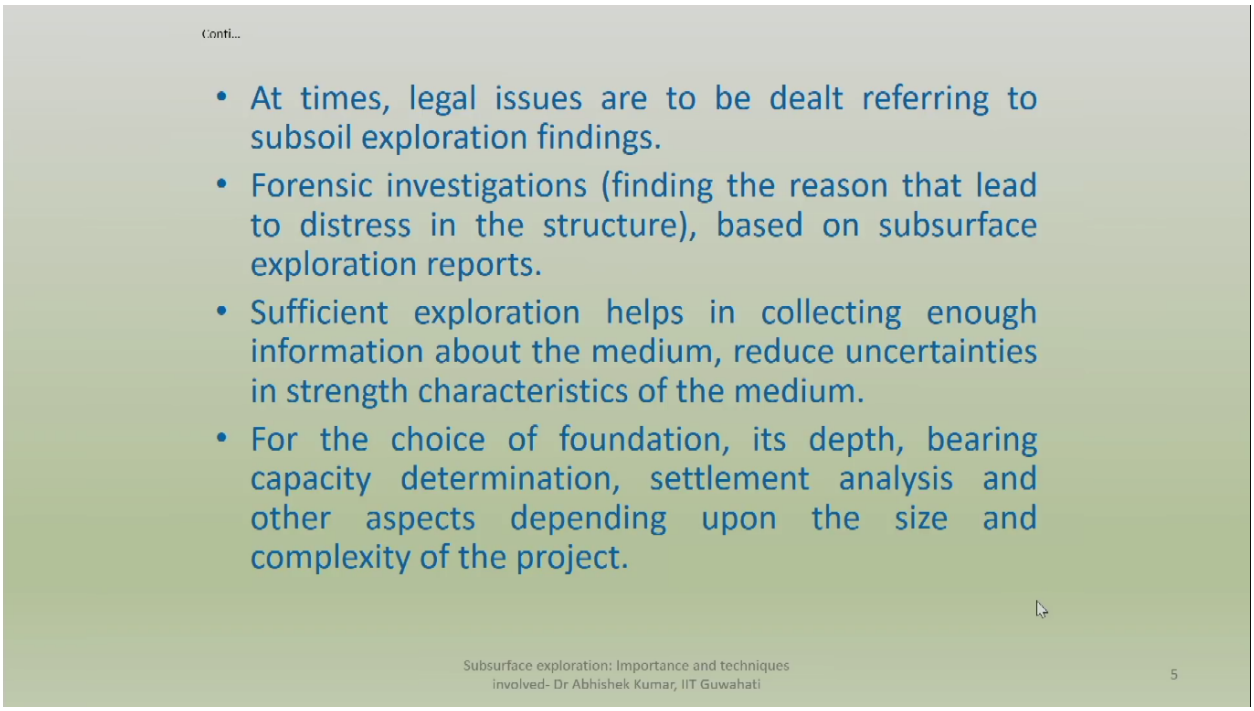
So we have nowadays more and more structures are coming up with more and more complexity whether it's because of architectural requirement, whether it's because of load requirement, whether it's because of elevation requirements, whether because of vibration requirement lot of structures and they are having – they are specially designed for different kind of vibration maybe the machine is getting operated for even several months even a year, even for years also.

So what kind of design requirements are required? Nowadays you can see the kind of structures, the requirement from the structure are becoming more and more complex and as it is becoming more and more complex and similarly you will be having other structures adjacent to your site of interest which are also equally complicated or maybe more complicated. So you will have not only a problem because of your site of interest but you can have also problem with the surrounding areas or you have to ensure what kind of guideline you have to follow for any area

which is located somewhere in built-up region so which was not there earlier and and as we know as you go for more and more site selection we often see like the choice with the owner, with the designer, with the site selection agency the choices are very limited. Most of that time you will find the site which is for example which will be containing field of soil, contaminated soil, maybe waste area, maybe swampy area, waterlogged area or sometime you may find the kind of geological deposit does not allow you to go for particular kind of foundation or particular kind of structures then you have seismic consideration also. Nowadays we are seeing the scenario of floods across the country. So those consideration will also be given due importance while going for site selection.

So unless you do proper site selection later say you will end up in getting more and more troubles at the site of interest whether it's during construction of the foundation, whether it is laying of the foundation even before laying of the foundation if you are going for deep excavation, if you are not able to understand the geology, you are not able to understand what kind of soil deposit is there up till the depth of excavation or what is the level of groundwater table there will be a lot of trouble even you plan it, your design is very fine but once you start executing at the site you will find a lot of challenges. So that is another objective when you go for sub-surface exploration you have in addition to understand what kind of soil is available you should be also able to forecast what kind of challenges which may which right now you are not able to see at the site but it may appear when you go for actual execution or when you go for laying of the foundation. So what kind of challenges can come and what are your alternate option if such a challenge is appear at the site during execution, during the layer foundation because you cannot stop your work. It's your your laborer is going to be paid and your project completion is going to delay so you cannot compromise with those things. So you have to be ready with two-three different alternatives what if this kind of challenging situation arise during the laying of the foundation.

As I discussed earlier also with limited choices available is present for site selection and considering the complex nature also like radiation also you know what kind of what is the thickness of wall we generally go for and then for the objectives also keep on changing with more and complexity more and more mega-structure and another thing which nowadays has become more and more of region of concern is legal issues. Suppose you are going for any kind of structure consideration in the surrounding area you are having similar structure maybe structure which are of more importance may be high-rise buildings are there very much adjacent to your site of interest you know the land is quite costly nowadays you cannot leave certain portion of land in order to ensure the safety of surrounding structures. So whatever land is there with you have to fully utilize that land but in order to that you have to also ensure when some kind of excavation work is going on, when some kind of pile driving is going on the vibration or due to excavation the stresses in the foundation of nearby building should not be such that it will lead to some kind of differential settlement or any kind of tilting, any kind of cracks in the buildings otherwise there are lot of legal issues which we also have to be ready in case. So when you do proper site investigation that data which you are getting from site investigation will also be helpful in dealing with those kinds of legal issues so that you can tell okay we have done based on the findings we found this kind of soil available at different depth and based on that we decided this kind of foundation and based upon the foundation this was our choice of machinery, this was the choice of execution program. So that's how we had taken all these things into account. So those ways legal issues can be handled that is another part of subsurface exploration program. If you do it properly.



Next one is forensic investigation. Forensic investigation it's now a very established term. So in forensic investigation we generally try to find out if suppose some kind of failure has happened whether it's in embankment, whether it's in a retaining structure, whether in case of routine buildings, whether in case of bridges, in tunnels. So forensic investigation means we'll go to the site, you try to collect the information you gathered earlier as well as you will try to gather more and more information about the site so you will be able to understand do u have done proper site investigation earlier, what was missing whether you had overestimated some parameter, whether you have over assumed certain -- you have neglected some assumption or you have over calculated some assumption which had led to these kinds of failure which was not supposed to happen. So forensic investigation just like other the term is very frequently used in criminal investigation.

Similarly, very identical to those we go for forensic investigations so that we can narrow down to reasons which had finally led to failure whether you are do follow codal provision for construction, codal provision for design, codal provision for exploration but why it led to failure. So forensic investigation will give you the answer to those kinds of questions. Those are also you can done. You can do once you have subsurface exploration reports or you can go for more subsurface exploration programs.

Then these exploration program will also help you in understanding or minimizing the parameter which you are using for design consideration so that finally your bearing capacity finally your settlement criteria whatever you are calculating before execution of the foundation you can minimize the uncertain individual with the values you are predicting whether in terms of settlement, whether in terms of bearing capacity and what not. So you can actually reduce once you have more and more information about the site based on sufficient number of filters you can actually reduce the uncertainty; uncertainty with respect to the final findings, uncertainty with

respect to the behavior of the foundation referring to the overcoming loads. So those also you can reduce once you are going for proper site investigation or subsurface investigation.

Again this will also help like depending upon the geology, depending upon what kind of geo-technical features available and depending upon what kind of soil is available at the site if you are having very stiff medium at shallow depth you can go for again depending upon what kind of structure you are targeting so weather stiff soil you are getting at that particular shallow depth you can go for shallow foundation. You can go for deep foundation. Nowadays we are seeing lot of flood situations. So as we know based on the flood situation the scar depth will also change. If you know the scar depth will change that will have direct impact on the depth of foundation for the pier. So if you know that depth of foundation is going to change will be the effect of a flood situation your depth of exploration for that kind of pier foundation to be executed will also change.

So the choice of foundation; what kind of foundation you can provide at the site again considering what kind of structure you are targeting for. Then what will be tentative depth. We know for different kind of foundation depending upon the zone of influence the depth of foundation or depth of excavation may vary. Again depending upon what kind of medium is actually available at the site of interest if the exploration depth whatever you are targeting if it does not meet your bearing capacity criteria definitely you have to go either for different kind of foundation or you have to go for deeper foundation depth. Then bearing capacity determination as we know so that will ensure like there is no bearing capacity failure. Settlement analysis so it's like before even executing or laying of the foundation once you have exploration program you can actually calculate that for this kind of load from the superstructure this kind of load from the vibration transfer to the machinery and many more load what will be the tentative settlement which you can expect from the foundation. So whether settlement are within the permissible limit as given by the codal provision or permissible limit what has been given for this kind of foundation with, this kind of structure maybe by the designer, maybe by the owner, maybe by the standard agencies like nuclear power plant, standard agencies are there. So what kind of bearing capacity and settlement criteria those agencies give you that is widely followed across the globe like International Atomic Energy Agency is there and same in India also. We have different agencies which work with the Bureau of Indian Standard. So they have given guidelines for different kind of foundation; what is differential settlement, total settlement and other aspects also depending upon the size and complexity of the problem. So if you are having a very mega structure so definitely that depth, definitely the extent of the foundation that choice of the foundation will not be the one you are following for routine kind of structure. So you have to go for those things.

So that was requirement like when you go for subsurface exploration why there is a need to go for subsurface exploration. Now once you go for subsurface exploration there are certain objective which your subsurface exploration program should meet. So one among is once you go for exploration you have to – your target should be determination of the nature of subsurface medium; what kind of medium is there; in terms of geology, in terms of geo-technical properties what kind of medium is there whether it is alluvial medium, whether it is [00:21:37] medium or weather it's clay deposit, whether it is limestone deposit, whether it is sandy deposit, whether it's filled up soil, yes a lot of place you can find filled up soil also dumped areas where people have been filling up or dumping different kind of waste whether it's construction waste, whether it is different kind of waste from household also people are dumping and then later on if people are using that kind of site which are like filled up area so you have to -- you should understand how that particular filled up area is going to behave because that kind of soil is not the one you are – you can easily classify it or you can categorize that site. So you do not know how that particular soil is going to behave and once you are going to put the superstructure over that. So determination of the nature of the subsurface medium is very important.

Then second is thickness of various subsurface strata. So there can be as we know if you go from the surface even at the ground level for your site of interest at times you may find even at the ground surface you may find variation in the subsurface layers. At certain times you may find clay soil. You go walk maybe for 10-15 meters away from your bore hole location you may find different kind of soil. Same way if you go from surface to certain depth below maybe 5 meter, 10 meter, 2 meter depth depending upon your depth of exploration you will find at certain depth you are having sandy soils, and clay soils certain you will have gravelly soil also and then very loose and stiff soil. So these are alternate bands of different kind of soil which are actually available and which will contribute to the strength of your foundation. So you should be able to understand what kind of different soils are available, what is the thickness of each kind of soil deposits and what is the lateral extent. Then depth of groundwater table as we know like during dry season,

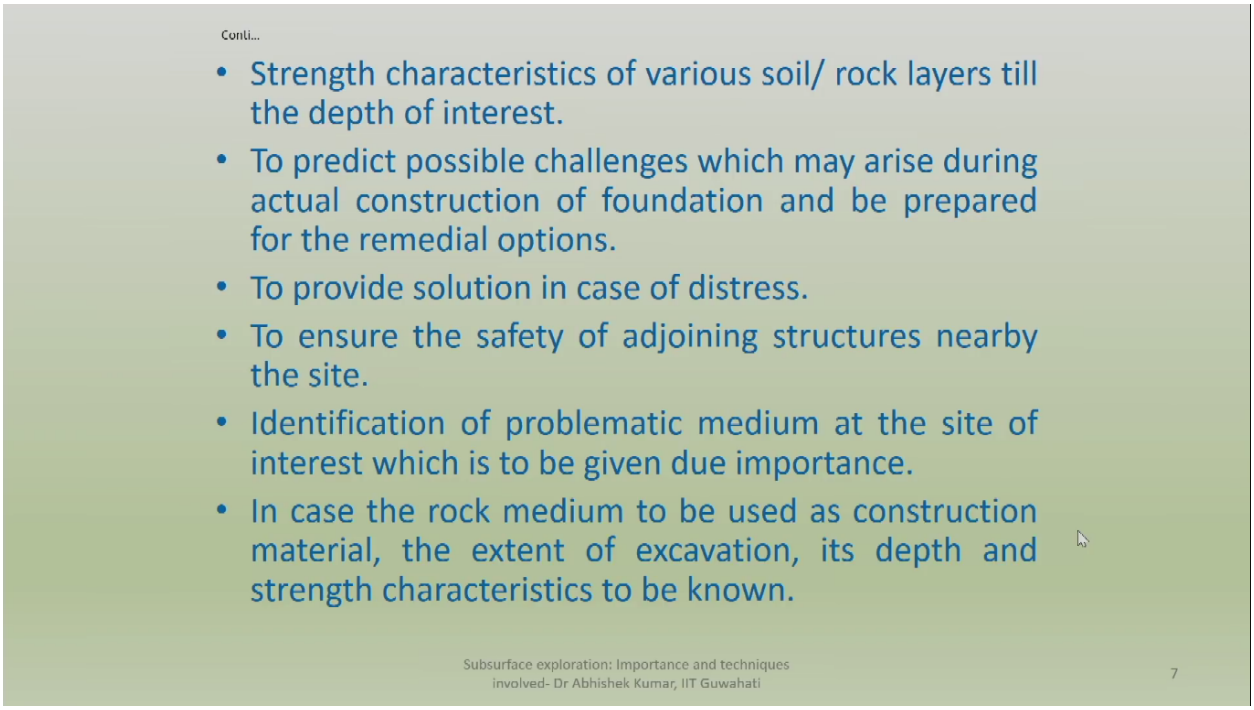
during rainy season ground water table fluctuates quite a lot. So when you are going for boring of course you also observe what is the ground water table depth. Again ground water table depending upon what kind of soil you are encountering in this bore hold you can observe the possible fluctuation or you can see like if it is corrosion-less soil you can see the water table you becoming steady maybe in a couple of hours if you are again on the contrary if you are going or you if you are finding that cohesive soil is there then for cohesive soil it will take times, couple of days also for water table to get steady because you have to measure what is the possible water table depth at your site of interest. So if that itself you do not report it properly then it will have effect on your bearing capacity settlement.

So you have to ensure the depth of water table as well as you have to also ensure what is it's possible fluctuation. Then there are agency like central ground water board you can get an idea about what kind of deposits are available, what is the possible water depth in particular location and certain more agencies are there which you can also refer what is the overall fluctuation in ground water table over the period of time at your site of interest and you can validate with your own finding at the site of interest. So this was one part.

Then nowadays as we know as we are going for multiple story above the ground level people particularly for parking spaces and for many other activities people are going for a number of stories below the ground level. So like two-story, three-story, four stories below the ground level. So when you go for that particular depth and then there are always a possibility that that particular depth of your base of your excavation will be lower than your groundwater table. So there are always chances you may encounter seepage once you go for exploration or once you go for laying of the foundation. So if you don't forecast those kinds of challenges in actual site later on it will cause problem because suppose you are laying concrete at the site of interest, you are laying your machine is operating and then one side you are seeing some seepage of groundwater at your site. So slowly it will I mean it will fill up your site and you will find it hardly -- you will find it hard to lay foundation, even the laborers will not be able to work here and then another thing so -- so that is another thing which and moreover once the seepage starts it can also cause discomfort to the adjacent structure.

So at this stage if that drainage or seepage that continues for a longer time you can find some kind of distress in the surrounding buildings or even the cracks in the vertical phase of your excavation also. So that is in addition to going for legal issues sometime it can also lead to endanger the safety of the people who are working in the excavation.

Then you have erosion problems also depending upon what kind of soil is available beneath the ground surface because of the seepage of water which is coming out from the excavation phase sometimes soil will also come out and leaving a completely void space beneath the foundation of existing structure. So again that will cause too much of differential settlement. So this is I mean in recent years it has been found like unless you are able to forecast these kinds of situation which may arise during execution or even not an execution once you have constructed everything is over during the service life of the structure also these kinds of problems like seepage, erosion can lead to permanent failure or permanent you can end up in legal activities or failure of the overall structure. So that also an objective like you should be able to forecast and you have to come with remedy election.



Then composition of groundwater table. It's not like everywhere groundwater is independent of composition of contaminants. So because of that contaminants what will be effect of those contaminant whether on foundation material as well as on the soil which is available whether it's going to disintegrate the foundation materials so that later on it can let to the failure of the foundation we have to study those things. Then strength characteristics of various soils and rocks whatever you are getting a different-different level whether in terms of end bearing whether in terms of surficial layer or whether in terms of layers which are available at intermediate depth. What are their strengths characteristics, what are their [00:28:16] characteristics depending upon what kind of load you are expecting or what kind of bearing capacity you are targeting for and their depth of interest of course. So depending upon your depth of interest whatever you are targeting for different soil and rock available you should be able to determine the strength. That is another objective of your subsurface exploration program.

Then to predict this is another important thing. To predict possible challenges which may arise one critical example I had given was for seepage which may arise when you are done with your preliminary investigation design part considering okay there will not be any seepage you go – you went for excavation and then you found okay there is seepage continuously from the sides and which can lead to additional problems. So you should be able to forecast what kind of possible challenges which can arise even during the construction. So not only during the exploration program but you have to be ready to find out alternate solutions if some problem or some challenges by the foundation soil arrive which can compromise the safety of your execution or the safety of surrounding structure and you have to be always available with some remedial option which you can directly adopt without delaying the progress of the project.

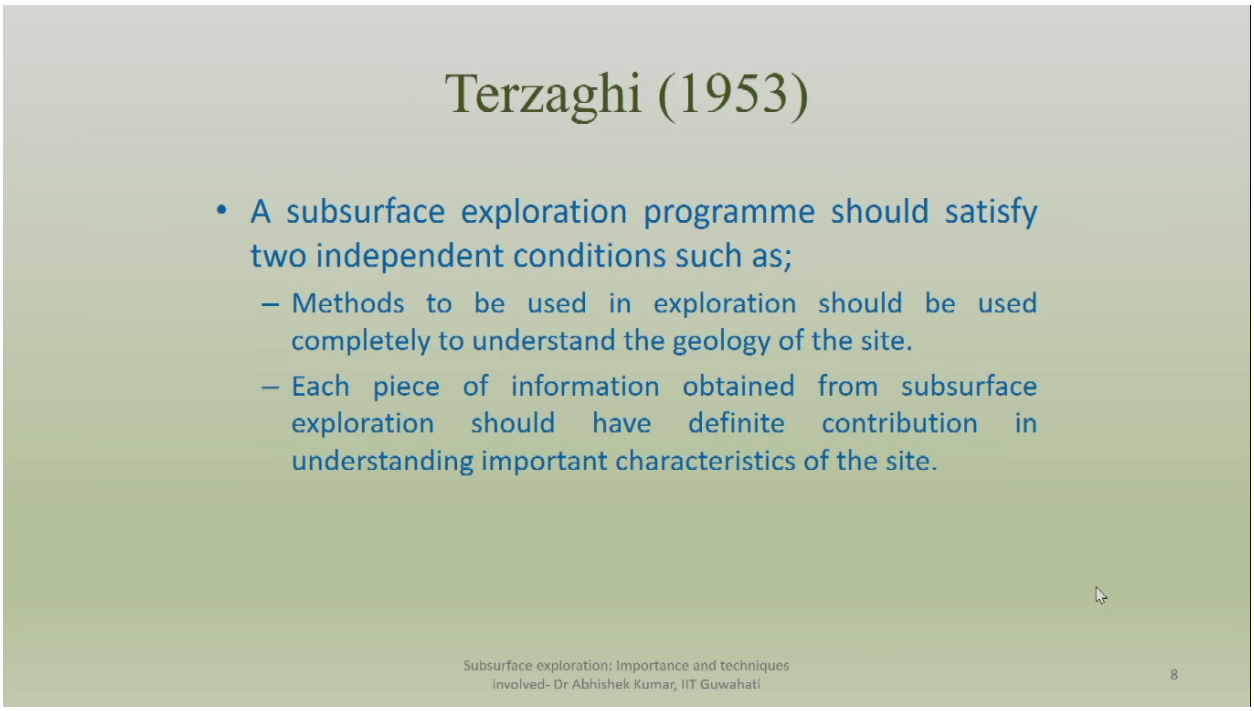
In case you are finding some kind of distress so it can be used even for as I mentioned about forensic investigation. So you have to – if you find some kind of failure is happening, some kind of differential settlement is happening it's really I mean lot of places even case of dams in case of

archaeological structure it is observed like those kind of structures are going some kind of cracks on the superstructure maybe in plinth level or some other level because the structure is going under the differential settlement. So what can be the alternate solution which will arise those kind of differential settlement further and that way you can compromise this. You cannot compromise that you can ensure the safety of the structure further. So there also a subsurface exploration has a major role to play.

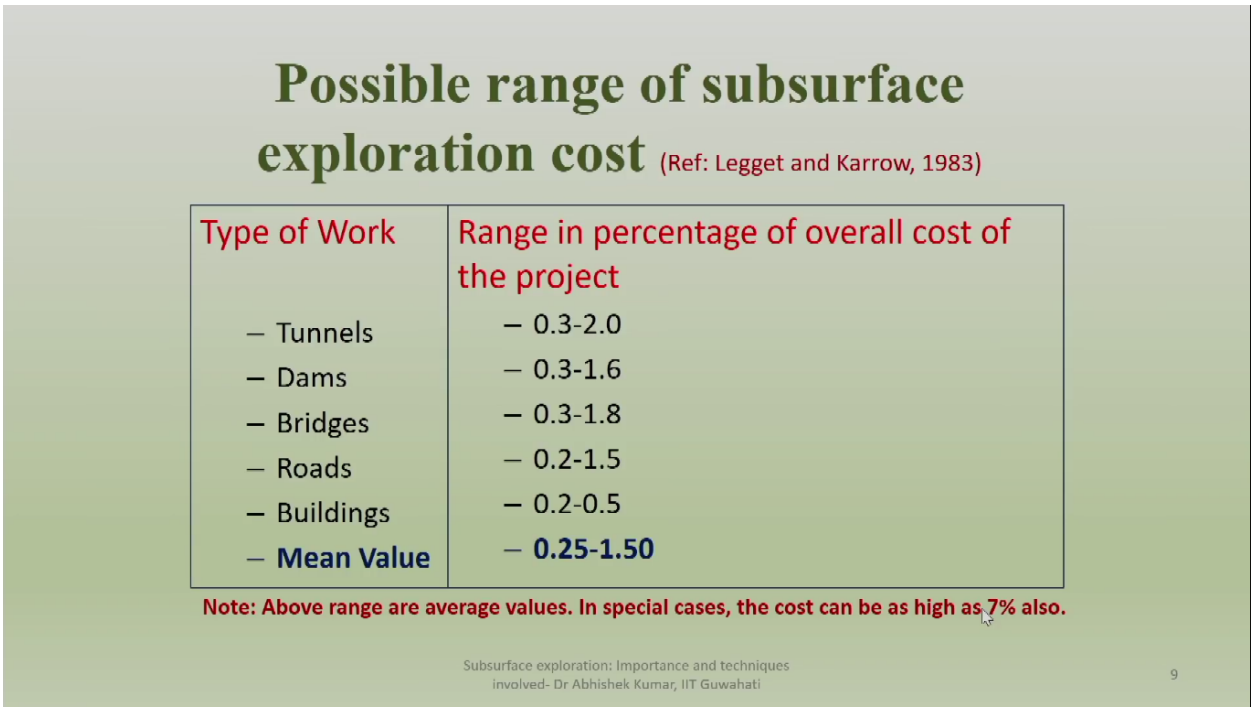
Then to ensure the safety of adjoining structures as I told you cannot consider that this X by Y dimension is my site of interest so whatever activity I have to do I can do in this where it's regeneration of axis vibration, whether it's generation of X is noise, whether it's dewatering area because that can lead directly to the discomfort or distress to the surrounding structure. So you have to also ensure when you are going for any kind of construction or exploration you have to also ensure the safety of adjoining structure.

Then while doing exploration at times you may find some soil which are like limestone, some soil which are collapsible soil, which are like expensive soil, which are like cell which can impart negative skin friction. So those we can call it as problematic soil because once those soils come in contact with water at different medium they behave completely different then what it was behaving in the absence of water. So those are called as problematic soil unless you identify those soil later on it will lead to different kind of problems maybe during construction, maybe during construction of superstructure or maybe during the service life of the structure. So identification of problematic soil is also at times given due importance while going for subsurface exploration.

Then in case the rock medium to be used as construction material. So subsurface exploration in addition to be used for finding out the suitability of the site for construction at times is also used for site selection for material to be used as construction material particularly for case of dams and in nuclear power plants where you require continuous supply of aggregate so you also search in subsurface exploration what are the nearby sources from which you can borrow these kinds of materials, what are the strengths characteristics of those material which is available in the nearby area, what is the extent of excavation you can go for, what is that depth and what is its material type. So all those things will be again the objectives of exploration program.



Then Terzaghi 1953 had proposed two independent conditions for subsurface exploration program which are like methods to be used in exploration should be used completely to understand the geology of the site. So whatever method you are using try to use that method in the most efficient way to understand the geology, to understand what kind of deposits are available at the site of interest and the second one is what kind of information like each bit, each piece of information you are getting from subsurface exploration like there are some direct method, indirect method which will give you strength property by means of two or three indirect measurement maybe in terms of – by means of friction, by means of resistance. So try to use each of those information and try to understand maximum extend, what kind of soil is there, what kind of subsurface properties are there that will help you in understanding what are the contribution you are getting from different-different parameter which you have obtained from site exploration. So overall it is like whatever data you are collecting from site exploration whether it's qualitative, quantitative each of those has some or other contribution in understanding the site characteristics that is given by Terzaghi in 1953.

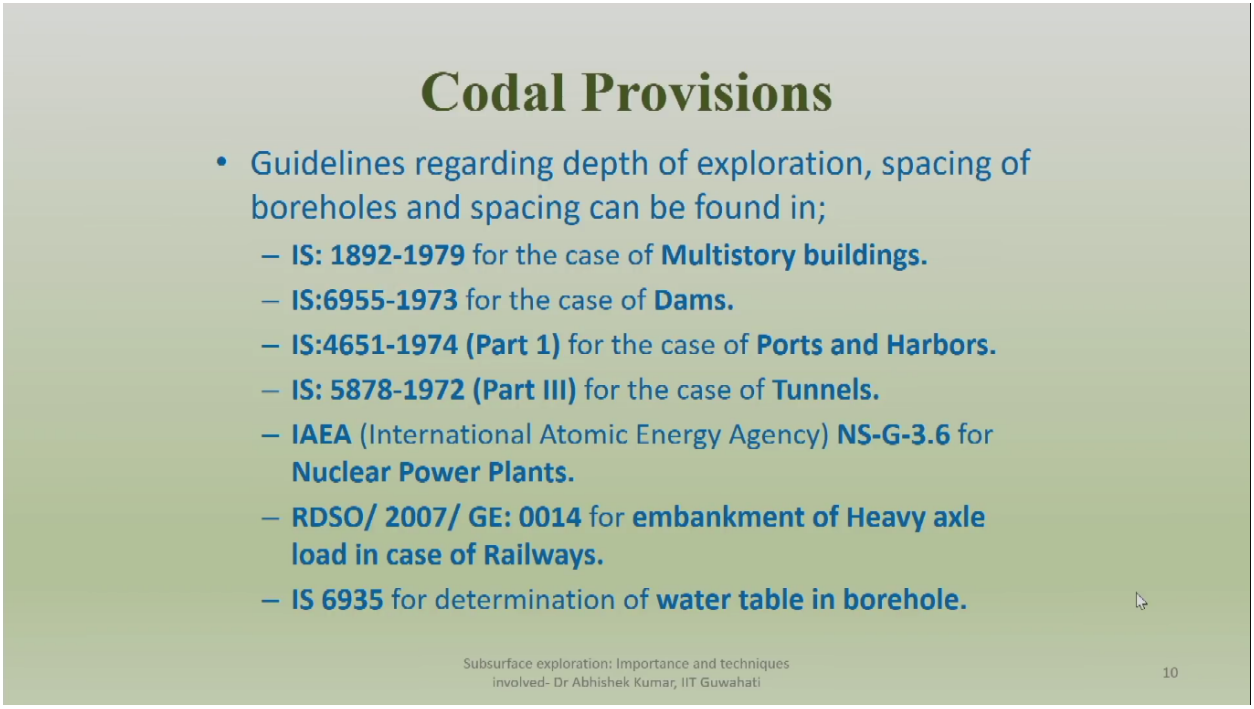


Now I am presenting here summary of different kind of structures and the possible range within this the cost of subsurface exploration can vary expressed in terms of percentage of overall cost of the project. Now this is with reference to work by Leggett and Karrow published in 1983. So you can see here when we go for tunnels, again this is like for routine kind of structure not for these findings or percentage may not be applicable for special kind of tunnels, dams like in each of this category if you are having some challenging kind of tunnels which are not in routine practice. So maybe you will find some increase in the value. So this is given particularly arranged.

So in case of tunnels the percentage cost vary from 0.3% to 2% though the 0.3 looks very small but considering the overall cost of the project that 0.3 will also be a significant amount. Then you go for dams. So it can vary from 0.3 to 1.6% . Then in case of bridges the depth of exploration can vary anywhere from 0.3 to 1.8% of the overall cost of the project. Then for roads 0.2% to 1.5% depending upon where actually you are laying the road, what is the axial load for which you are targeting for which you are designing the load, for which you are preparing your subgrade. So depending upon whether you are going for routine kind of I mean village road, whether you are going for road which will be used for military operations also. So the cost of exploration will change accordingly. So it can go from 0.2% to 1.5%. Again for routine kind of buildings like G + 2G + 3 and considering there is no problematic soil at the site of interest it can vary from 0.2 to 0.5%. Mean value on an average you can consider like your subsurface exploration program independent of whether you are going for dam, bridges it can vary anywhere from 0.25% to 1.5%. This range will at least give you an idea before you go for even quoting for subsurface exploration program like this is the tentative budget which can go even slightly higher also because it depends upon what are the labor charges, what are the complexity of the problem, what is the depth of exploration and what is the instrument you are trying to use for your exploration. Lot of indirect instruments are ready. I mean per day expenses if you see

those are seen if it can be high. So all those things will collectively will cumulatively affect your overall cost of the subsurface exploration price.

Now I have given here a note we say like the above ranges are average values for routine kind of structure as I just mentioned. However, in case of special cases like you are going for some challenging structures whether it can be bridges, whether it can be dams the cost can – you can expect the cost can go from 2% in case of tunnel to as high as 7% also but routinely it is not expected but yeah you can be because you do not know what is available beneath the ground surface and then what kind of other this designing governing criteria are there which can also lead to more and more number of bore holes, more and more number of investigation to be done, the depth of exploration, more and more understanding about the site like lot of time people go for reconnaissance survey, people go for aerial photograph, people go for a remote sensing data. So all those will add up finally to the cost of your subsurface exploration program.



Now here I have given some codal provisions which it will give you certain kind of guidelines what should be the depth of exploration, what should be the spacing of borehole, what should be the okay what should be the spacing of the borehole and what should be the minimum number of boreholes to be depending upon the size of your site of interest and depending upon what kind of structure you are targeting for. As I told you civil engineering structure does not mean every time you are dealing with the building. It can be multi-story building. It can be dams, bridges even railway embankments also another kind of structure for which subsurface exploration program is required. So again here a summary you can see like IS:1892-1979 that can give you guidelines for subsurface exploration when you are going for multi-story buildings. Similarly in case of dams the requirement will be different because the structure is different. So guidelines which have been given for exploration can be found from IS:6955-1973 and the people who are interested you can further go for these codes further to understand what are the guidelines given what kind of tests are given, what is the accuracy expected from different kind of test to be used

for exploration. Then IS:4651-1974 part 1 you can use it for ports and harbors; what kind of investigation, what kind of detail you are targeting for and then IS:5878-1972 part 3 you can use it in case you are going for tunnels. So what kind of investigations are required. Then international agency for International Atomic Energy Agency that is IAEA has given guidelines for geo-technical investigation at the site of interest that has been given as NS-G volume 3.6. So [00:39:18] followed. Then RDSO under ministry of railways has given guidelines under the volume published in 2007 as GE:0014 which talks about what kind of tests to be done, how you prepare the embankment particularly for heavy axle load particularly for railways. Similarly for other kind of structure in railways there are guidelines given in another volume.

Then IS:6935 you can use for determination of water table. As I told water table is important consideration when you go for subsurface exploration design. So again guidelines are given as per IS:6935 how you go for determination of water table in a particular borehole, how you go for possible fluctuation, how you'll take into account the kind of soil deposits available at the site and how you will also take into account the season throughout the year in which you are actually exploring this kind of soil deposits or water table.

So moreover depending upon other kind of structure for wind turbines even for like airport runways even for because the kind of load we are expecting it is different and the nature in which that kind of load is getting is acting upon the structure the mechanism of transfer of load changes and then your depth of the zone of influence of stresses will also change and that's why different agencies or different volumes of IS code they have a given guidelines which have to be followed once you go for exploration for any kind of structure. So you have to be very specific what kind of structure you are dealing with. Then accordingly you can select what kind of codal provision you have to follow. And the codal provision like [00:41:05] 2011 they came up with the guidelines which [00:41:07] particularly useful whenever you are going for seismic micro-emission studies. So what typical test you can go for, what is the spacing of the borehole, what is the depth of exploration you are targeting for and how you cross validate finding from one test you have to validate with other tests because at times there are always chances of error in doing one test or certain test are giving you indirect estimation. So those indirect estimation at least at certain site of interest not at all the test location has to be validated by some other means.

So this is for now. I hope that has given you some clear cut idea like what are the different kind of structures, what are the – actually why we go for exploration program, what is the need, why you should go for exploration rather than simply keeping the foundation level at maybe some minimal depth because there can be challenging arise due to the kind of load, the magnitude of the load, the nature of the load, surrounding areas even climatic condition, even weather conditions, even possible fluctuation in water table and seismic condition also. And then what are the objectives once you go for exploration program as suggested by Terzaghi 1953 once we plan for exploration program you should use such method which can give you more accurately what kind of deposits are available at the site and moreover once you are done with that particular test at least whatever information you are gathering all those information should contribute in your understanding enhancement toward the site, towards the soil, toward the geology of the particular site so that that will give you clear idea what kind of foundation you can go and in case you find some kind of distress you find some kind of challenge during execution, during the service life you can use it for remedial action, you can use it for forensic investigation. You can use it for any kind of recommendation. So subsurface exploration is very much required.

Thank you so much.