NPTEL

**NATIONAL PROGRAMME ON
TECHNOLOGY ENHANCED LEARNING**

**CDEEP
IIT BOMBAY**

**ADVANCED GEOTECHNICAL
ENGINEERING**

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Lecture No. 50

**Module-7
Lecture – 1 on Geotechnical
Physical Modelling**

Welcome to lecture series in advanced geotechnical engineering course, so in this lecture we are commencing with module 7.

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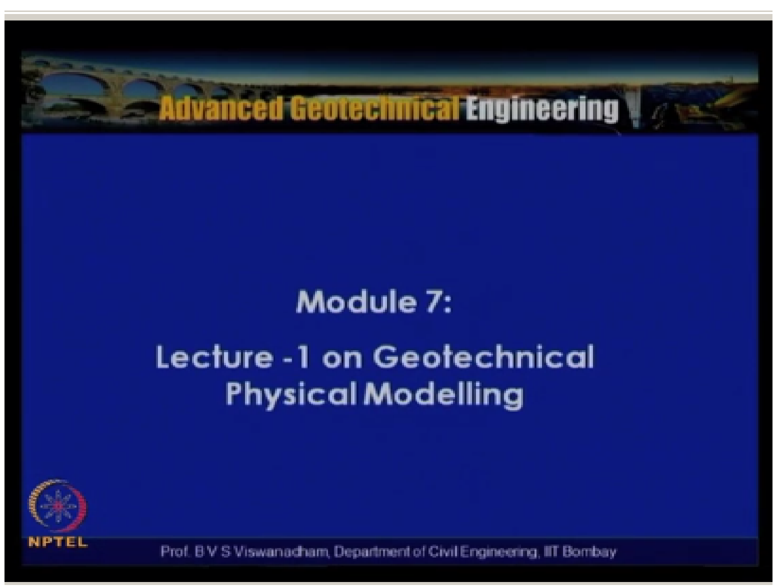

Lecture 1 on geotechnical physical modeling now-a-days within increase in the infrastructure development there is a dia need for understanding about behavior of the geotechnical structures before collapse are before failure and at failure, this will enhanced to understand the responses of these structures before failure and at failure this module is divided with the following contents.

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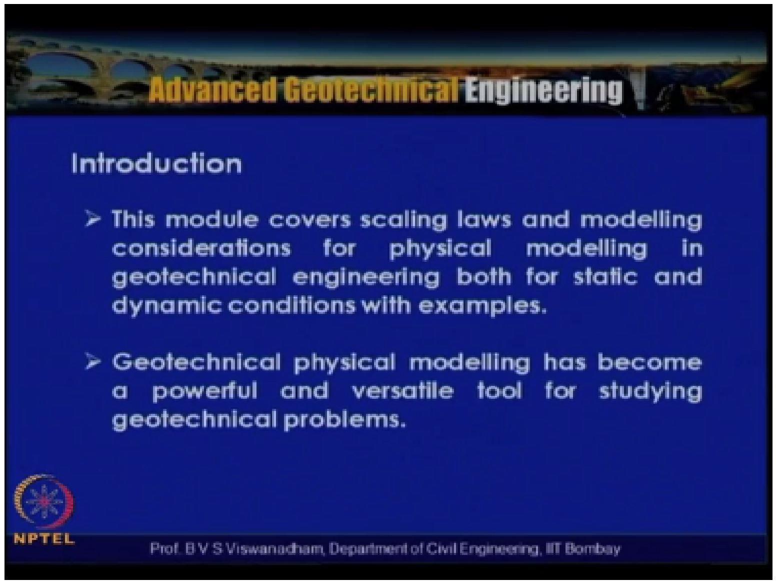

Physical modeling methods and especially a technique which we are going to expose ourselves is called centrifuge base physical modeling and it is relevance to geotechnical engineering with number of examples and we will try to see application of the text this technique for static and dynamic problems with numerous examples, so in this module we are going to discuss about what are different modeling techniques and lying down to physical modeling methods and application of this centrifuge.

Modeling and it is relevance to geotechnical engineering we try to bring out that and then with number of examples and its applications will actually try to see this introducing modeling how geotechnical structures the basic intension of this module to cover the scaring laws or what we called as scale in relationships and modeling considerations for physical modeling in geotechnical engineering both for static and dynamic conditions with examples as mentioned earlier geotechnical physical modeling.

As become a powerful and versatile tool for studying geotechnical problems a wide number of applications can be studied by suing this techniques this helps to gain inside into the behavior of geotechnical structures, so coming to the word which is there in geotechnical interviews modeling or geotechnical physical modeling.

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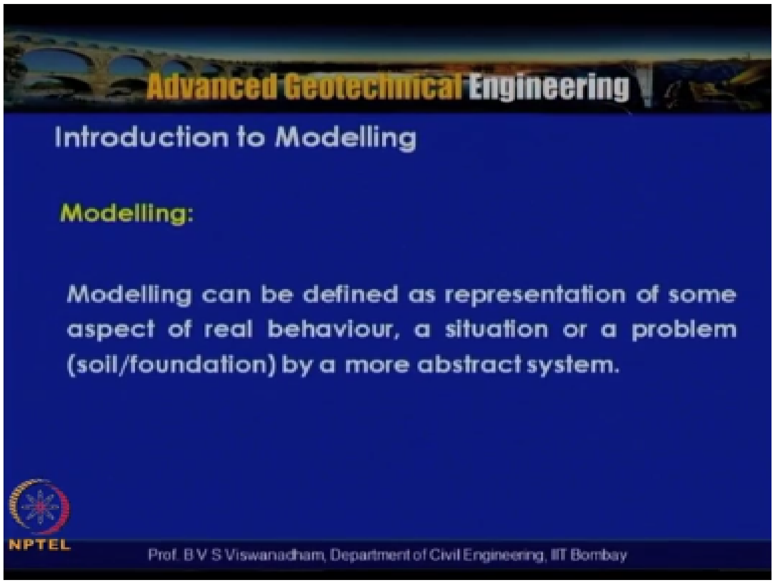

What we said is that modeling the modeling if you look into the definition it can be defined as a representation of some aspect of real behavior so it can be a real structure and a situation or a problem that is soil or foundation by a more abstract system if you are able to do that for example you consider an embankment rusting in a soil then the all aspects of the embankment need to be model and then represented similarly a foundation like a shallow foundation subjected to vertical load.

Horizontal load now-a-days people are understanding about the subjected to portion loads to the shallow foundations and similarly let us consider a file foundation subjected to vertical load horizontal load and a dark load this things can you know represented in a abstract system, so modeling can be defined as representation of some aspect of real behavior a situation or a problem by a more abstract system so in modeling it is essential to reorganize 3 fundamentals one is that oh we need to see.

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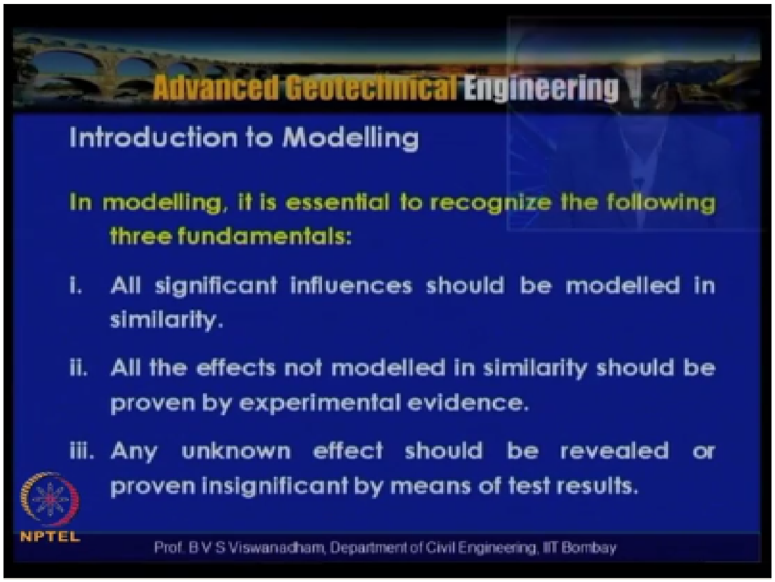

All significant influences should be model in similarity but being first a fall we say that material to be modeled and configuration let us say an embankment a slop you know of an embankment and height of the embankment and its bedding conditions need to be you know simulated similarly all the effects not model in similarity should be proven by experimental evidence, so any you know parameter which is not model in similarity should be you know proven by experimental evidence.

And any unknown effect should be revealed are proven in significant by means of test results that means that experimental verification will help us to ensure that any unknown effect you know should be revealed or proven significant by means of test results suppose if we are not able to achieve a similarity between because of in virtue of certain parameters and we hve to see that you know this is proven significant by means of experimental you know test results further a model can approximate.

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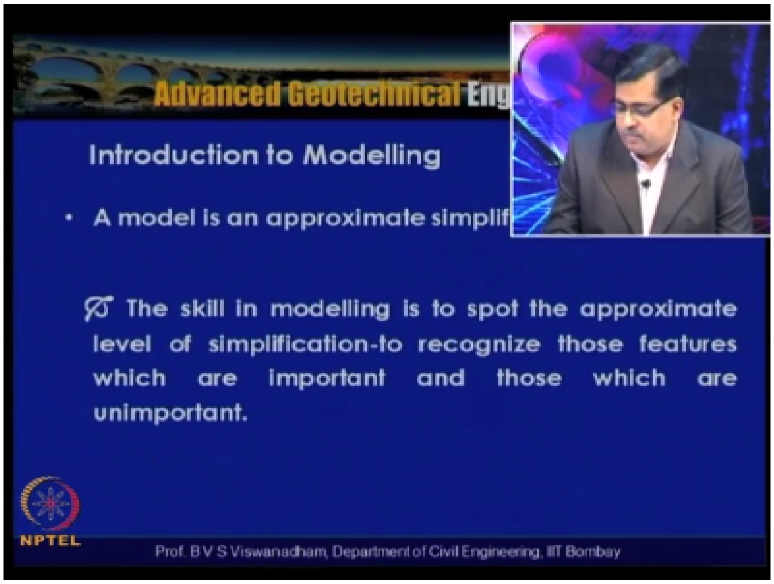

Simplification of reality so the skill in modeling is to spot the approximate level of simplification to recognize those features which are important and those features which are unimportant, so what we need to know in modeling is that the skill in modeling is to spot the approximate level of simplification and to recognize the parameter those features which are important and not important and you know this can lead to you know more understanding of the behavior of a structure being modeled.

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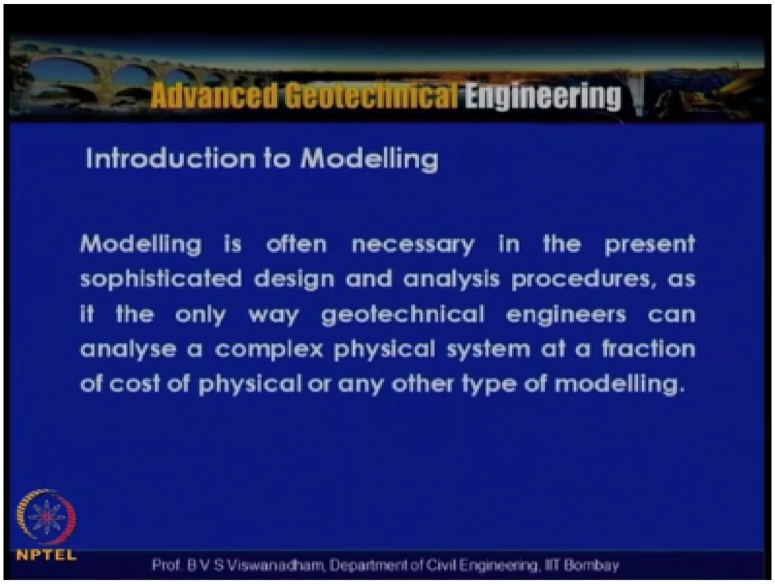

So it is often necessary basically for the you know sophisticated design and analysis procedures as in the way of the only way for the geotechnical engineers can analyze a complex physical system at a fraction of cost of physical or any other type of modeling so modeling is often necessary in the presents sophisticated you know design because of the complexity which is involved you know by modeling involved with you know number of parameters and this can be done at a fraction of cost of physical or any other type of modeling so what are the steps involved in modeling first a fall.

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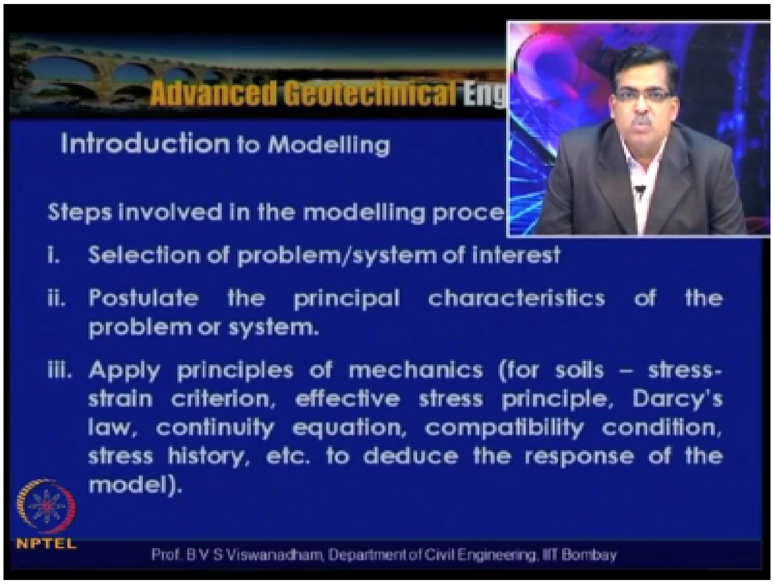

Selection of problem or system of interest and postulate the principle characteristics of the problem are system in the second step in the third step apply principles of mechanics like for a soils stress strain criterion effective stress principle Darcy's law continuity equation compatibility condition stress history etc. To reduce the response of the model so in the third step we apply the principle of mechanics for the you know for soils stress strain relationship and are stress strain criterion.

And effective stress principle Darcy's law continuity equation compatibility condition stress history etc. Basically this is done to reduce the response of the model.

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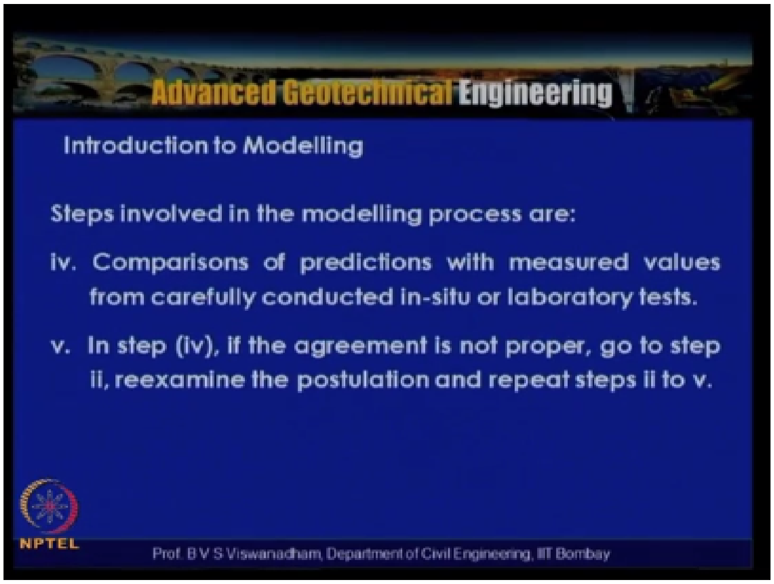

Further comparisons of the predictions with measured values from the curve carefully conducted in-situ or laboratory test, so comparisons of the predictions with measures values from carefully conducted in-situ or laboratory results, so in stuff 4 if the agreement is not proper go to step 2 to reexamine the postulation and repeat the steps from 2 to 5 that means in step 5 if the agreement is not proper whatever is predicted is not proper whatever is predicted is not in comparison with you know observed results.

Then go to step 2 reexamine the postulation and repeat steps from 2 to 5 so having discussed th and defined modeling in modeling and in geotechnical engineering modeling word is not give modeling techniques in geotechnical engineering is a conventional approach where you know which is adopted traditionally, so we have different you know categories of modeling we can say that empirical modeling.

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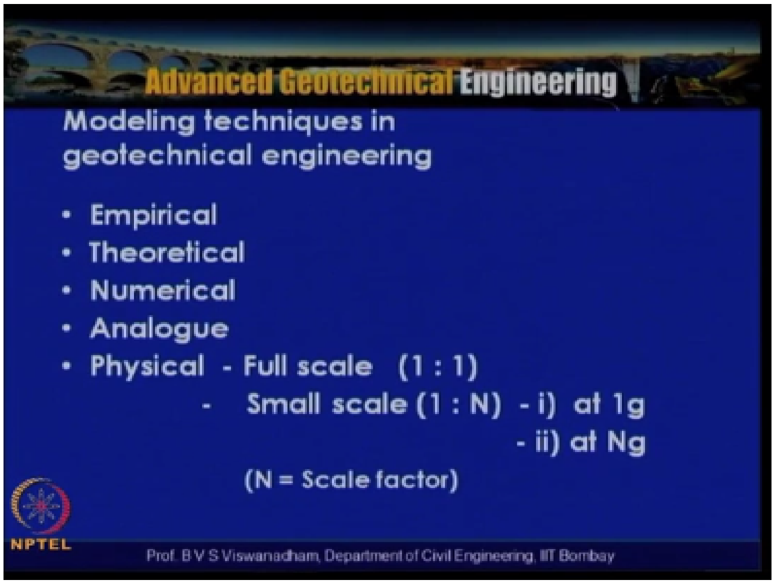

Even today because of the complex based of the soil in many cases we adopt empirical models and theoretical models these are today even today they are famous and we are using and numerical models with advent of you know computers the numerical modeling is you know gaining popularity and is also getting you know tuned with advanced techniques in you know modeling techniques which we are going to discuss in this module and traditionally we have analog models.

Which are you know very popular to stay state an example the spring analogy model adopted by Terzaghi for explain the effective stress equation stands as an example and lastly a physical model which is you know nothing but plasmid as 3 heads basically one is full scale this is admonish to one and that they construction of a full scale structure and in many situations are many places are many sides if the feasibility is a question and controlled you know experimentation of a full scale model is.

In next to impossible in such situation you know then you know small scale model is one of the vibal option and these most scale model in the sense and model reduced by n types that means that all the you know the dimensions of a full scale model are reduced by n times and this can be done at normal gravity that is at one gravity or at present please take it as at Ng that is called a certified based physical model which we are going to introduced in this modules, so the physical model is subclass weight as full scale and small scale at normal gravity as small scale at centrifuge model or it high gravities.

So why we do we need this small scale models at high gravities in what cases you know these you know techniques are applicable you know that we will be illustrating in this you know a part of lectures all in this module, so empirical models along the study of empirical model in.

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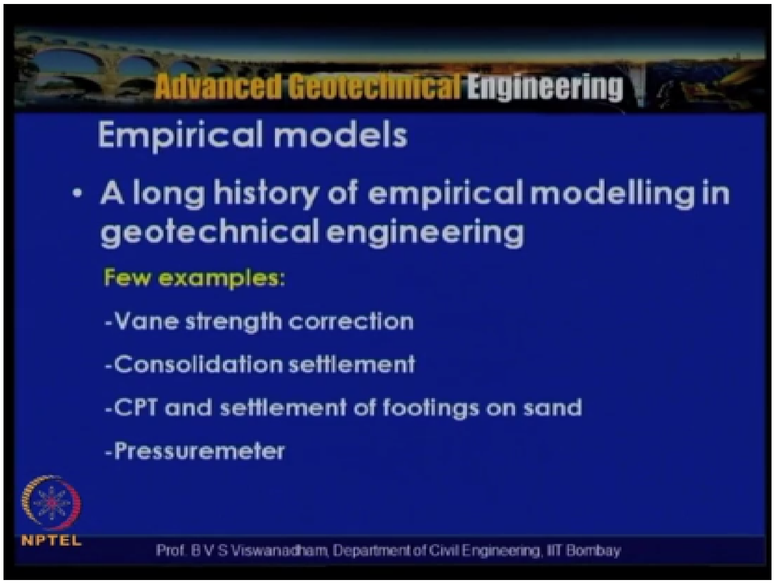

Geotechnical engineering is there and we have vane strength criterion and the vane strength criterion in the vane strength criterion considering you know number of cases of embankment failures Gerome in 1973 recommended a correction factor λ for a vane strength measures in the field with that it has been found that within increase in psaltery index of the soil the correction factorial λ is going to depressed drastically, so that means that you know by applied wthis correction factor.

To the measured value then you know we can actually get the strength value each can be adopted in the design based on that this can be you know matched close to the field observations so in empirical model was developed basically by considering the observations which are actually done in during the vane strength test particularly when th vane blade is rotating the surrounding soil is subjected to some sort of disturbance and that leads to you know to give the higher value of you know.

The vane strength or strength value so in view of that and this is actually predominant when within increase in the plastid index, so you know a correction factor has been recommended for this you know vane strength correction factor or even today it is known as zeromes correction factor for vane strength measured in the field, similarly we have concern for you know estimating consolidation settlement and we have examples like CPT and settlement of footings on sand.

And for interpreting pressure meter test result pressure meter is a device where in we can actually measure the in-situ modulus of the soil you know in the during in a by placing an inflated rubber membrane in the balloon, so deepening upon the you know the intactness and softness or hardness of the you know balls of the bore whole the response of the test can be achieved so here there is also some imprison and empirical models exist they do exist and we use in the practice of geotechnical engineering.

Theoretical model even today like for example a classical example for theoretical model is for studying study state see page conditions for Laplace equations it is one possible theortical model so once a theoretical model has been.

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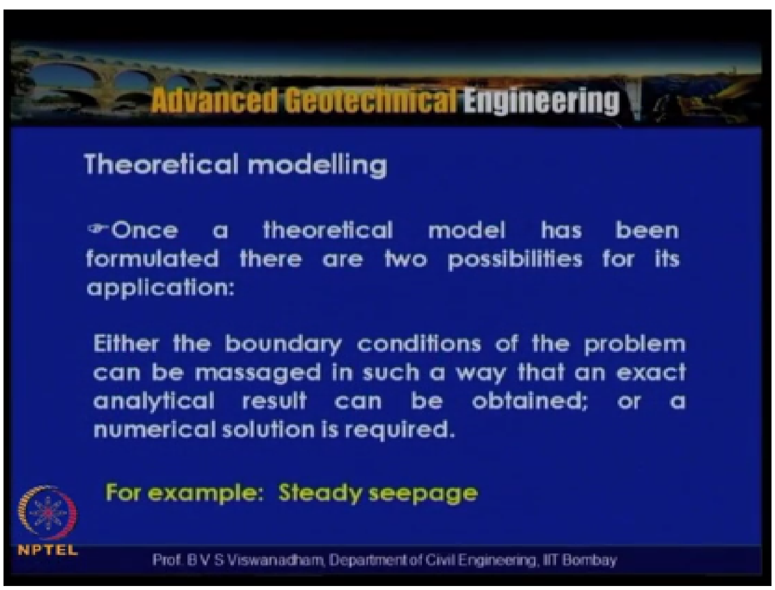

Formulated there are two possibilities for its application either the boundary conditions of the problem can be messaged in such a way that exact analytical result can be obtained or a numerical solution is required, so one of the you know examples which we can state is where study states replace conditions and this can be defined by a Laplace equation the study flow of an incompressible.

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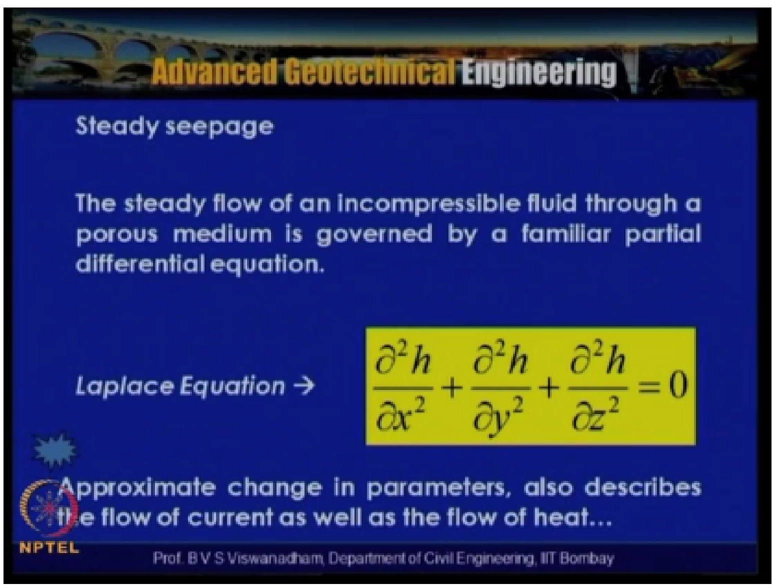

Fluid through a porous medium is governed by a familiar partial differential equation called $\partial^2 h / \partial^2 + \partial^2 h / \partial z^2 = 0$ so where in you know these head is the h is the header of and this if this is a three dimensional direction and this is reduced based in based on the continuity equation and if you have say you know only two dimensional condition then the third term which is $\partial^2 h / \partial z^2 = 0$ so in that case $\partial^2 h / \partial z^2 = 0$ that is for 2D CPS condition if we are having let us say only dimensional flow.

Like in the constant head perimeter for example wherein we can actually have $\partial^2 h / \partial z^2 = 0$ for so one dimensional flow wherein we have you know $\partial^2 h/\partial z^2 = 0$ but two dimensional flow of an embankment flow of an water through an embankment or earth and dam which is $\partial^2 h / \partial z^2 + \partial 2h / \partial z^2 = 0$ and for the 3 dimensional flow the example is you know flow of water into the well which is the 3 dimensional flow and this approximate change in parameter also describes the flow of current as well as the flow of heat so the if you look into the analysis you know representation of these theories.

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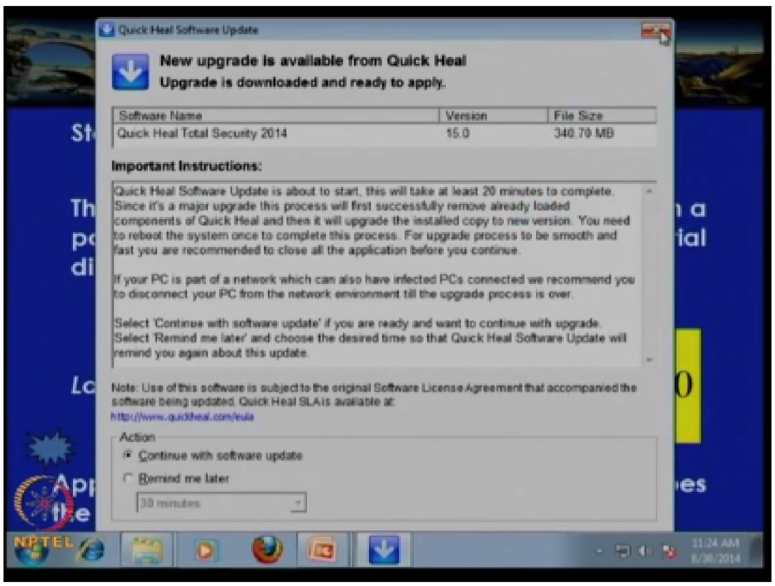

We can say that this is used in you know in study in flow of current as well as the flow of the heat that is the heat electrical analogy as well as in the heat transfer.

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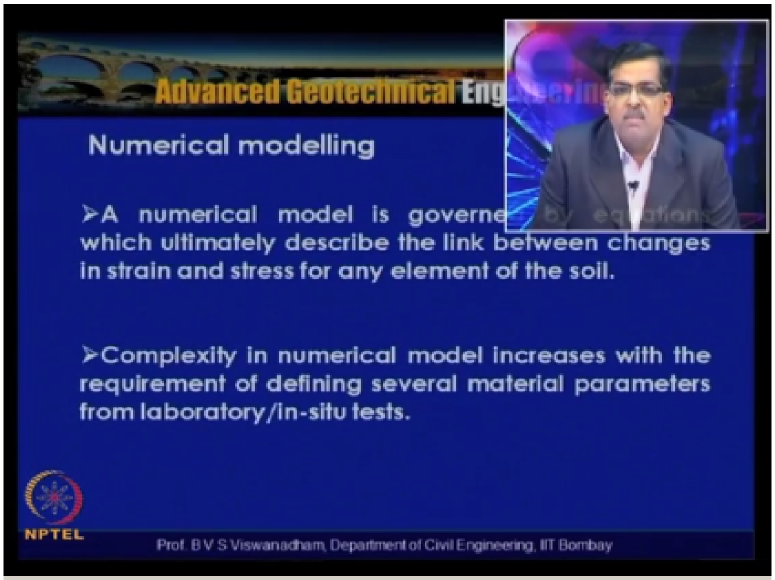

Coming to the next you know set of modeling which we have said is numerically modeling and numerical are constitutive modeling basically and numerical or a constitutive model is governed by the equations which ultimately describes the link between the changes in strain that is $\Delta\varepsilon$ and $\Delta\sigma$ changes in the strain in changes in stress for any element of the soil because of you know the loading their subjected the complexity numerical modeling increases with the requirement of defining several material parameters.

From laboratory and in-situ tests so what will happen is that the complexity and the you know the efficiency of the numerical modeling incases efficacy of the model becomes difficult with the requirement of defining several material properties from laboratory and in-situ tests whatever in a numerical model if we are actually having several materials with interacting with eact other where it difficult to you know define the stress strain relationship between those materials which are actually you know taking part in the behavior.

So this particular technique even though lot of progress actually have been made many times actually this requires verification of the developed numerical solution if this is done by using an appropriate technique if this variation is done yes numerically modeling can b considered as one of the vibal option for you know studying number of geotechnical problems, so numerical modeling is the subject of many.

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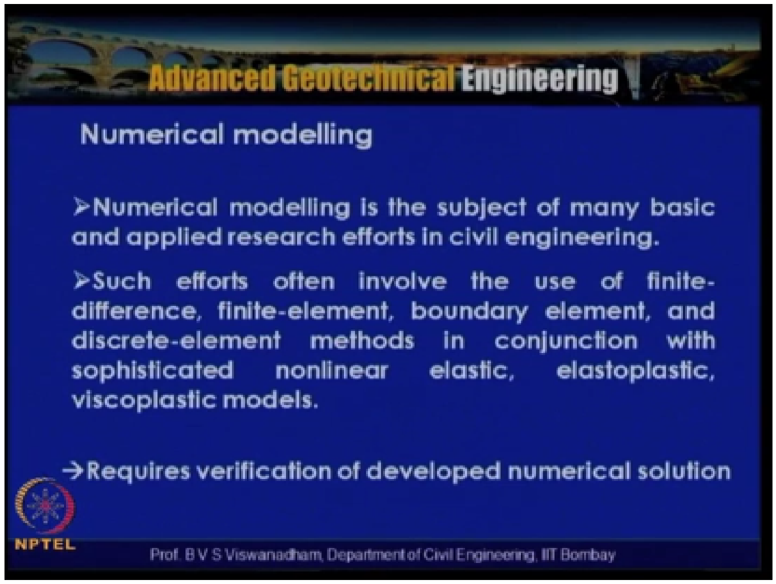

Basic and apply the research efforts in civil engineering and basically such efforts involve the use of finite difference or finite element and boundary element and or discrete elements in conjunction with sophisticated non linear elastic elastoplastic or viscoplastic models so what we are discussing is that this requires verifications of the developed numerical stimulation. Once the numerical model is verified then the contents in using this model increases.

So these effects basically doing this numerical modeling involved use of you know methods like finite difference method, finite element method boundary element method and discrete elements in conjunction with sophicated you know models like non linear elastic elstoplastic and viscoplastic models.

We have said that traditional in geotechnical engineering this analog models are famous the analog models basically the analog model carries a resemble in which a law which model follows is analogous to the law with real situation problem follows. See let us consider electrical analogy flow water.

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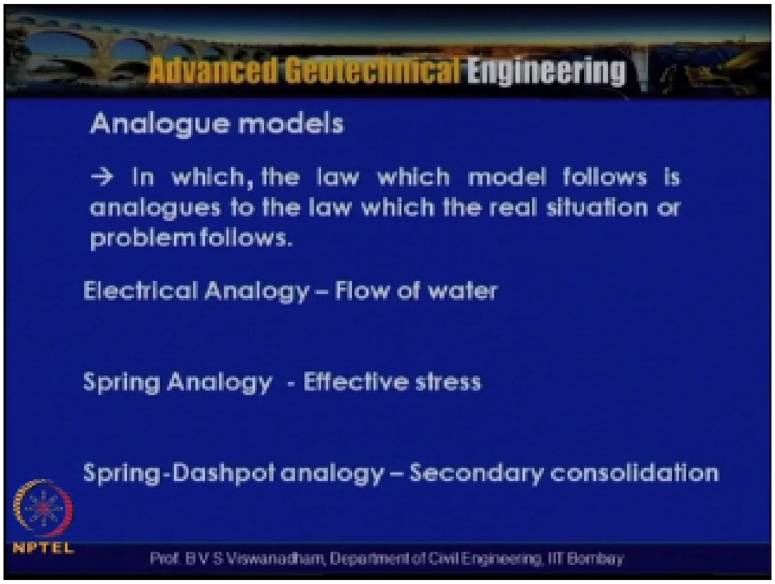

So this you know can be given with defined with tool hours one is you know in case of real situation let us say that is dashes law where in we can actually define q that is discharge is equal to k if that is the coefficient of permeability and i that is hydraulic variant and a area of cross section. So area of cross section through which the flow is actually happening where i is nothing but h/l.

Similarly in case of electrical analogy when the flow of current when we are actually considering we have Phones law where he defines you know between we using the resistivity and a potential drop over a certain length and you know the cross sectional area of the conductor through these electricity passing.

So there is you know this analog model resembles with a law which model follows is analogist to the law which real situation are the problem follows. So this particular concept was you know extended to you know for explaining the trajectories principal of effect to stress that is these spring analogy model.

In the spring analogy model what has been considered is that the, we have in the real situation we have soil particles and occupied the voids in between soil particles occupied by water, and when it is subjected to loading then what we have is that you have a situation that you know the skeleton the soil skeleton as well as the water surrounding the voids as well as the surrounding the particles is subjected to loading.

So this was actually represented by a spring analogy problem so where in what has been considered is that a cylinder of certain diameter was considered and it is actually having a piston arrangement at the top and let us assume that it actually has got a wall which is actually possible to close or open then the piston which can move up and downwards and let us assume that the bottom of the piston is attached with the spring having a certain stiffness k.

And let us see that the spring actually represents the soil skeleton and pore water is actually represented by water in the analogy model, spring analogy model also and let us assume that the you know the piston is placed in position and the valve is actually close and the load is placed a load of p is applied on the piston. So then the valve is closed initially what will happen is that the entire load is actually born by the spring.

So that means that under undrained conditions also similar situation happens, similar phenomenon happens in real situation where in entire you know load is actually born by the pore water. Then moment the valve is open then there is a possibility for the spring to undergo compression, so in a way what will happen now is that the load is a portion by you know the spring which is nothing but a soil skeleton in real situation and pore water.

So based on this after certain amount of time what will happen is that the hydrostatic conditions will prevail and in the process what will happen is that we can say that the total stress is equal to effective stress plus pore water pressure. So to explain this effective stress equation $\sigma=\sigma'+uw$ the spring analogy was used, and further the concept was actually extended for explaining the secondary consolidation that means under a constant effective stress when there is actually change in you know the void ratio which actually happens over a period of time because of the certain nature of soils like paint or from the marshal lands or we have you know the manmade material like municipal all the ways.

It undergoes you know huge amount of secondary consolidation so this spring and dashpot analogy was actually used to represent you know these you know particular phenomenon of secondary consolidation or a creep of a soil. Before explaining that let us try to look into extension of the spring analogy model.

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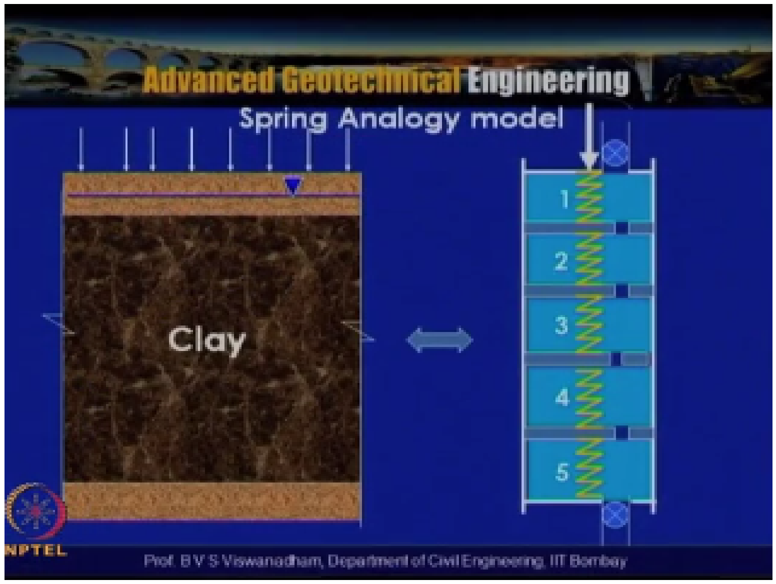

You know previously we have said that for explaining the total stress is equal to effective stress plus pore water pressure we actually have used a single spring but in order to explain the consolidation behavior of a soil layer having you know two open or two sand layers at top and bottom where they are actually having high permeability at the top and let us assume that this is the water table at which you know the saturation below the soil is come to the saturated and it is subjected to say certain increase in the load say $\Delta\sigma$.

So this situation is actually you know can be modeled analogous in a analogous way by using spring analogy model, so here what you have done is that we have taken a long cylinder and if the cylinder is assumed to be filled with water and has got top and bottom to walls and the diameter of the walls represents the you know permeability of the soil if it is you know large permeability the diameter is high.

And if it is small permeability the diameter is small and this is a piston which is movable and each at each compartment is divided into here is shown has 5 compartments 1,2,3,4,5 and between compartments there is spring of stiffness scale is attached and another spring of k is attached here and fourth spring and fifth spring and all these compartments are interconnected so that means that water can flow you know in it is freely.

Now what will happen is that initially when we actually apply $\Delta\sigma$ so we have a situation that if $\Delta\sigma$ is applied then the pore water pressure which is within the soil is nothing but Δu which is you know they have what we can say is the first isochrome which actually decades developed and what a period of time let us say a time t=0 and when time t=0 when the load is applied then we can say that you know the first isochrone is something but Δu it shifts by equivalent to $\Delta\sigma$.

Then just let us say that when time t1 where t1 is actually greater than t then what will happen is that it because of the previous nature of you know these two layers open layers here the sand and top and bottom but what is happen is that you know thus the water transfer the stress directly to the soil and the pore water pressure drops to 0. That means that at this particular point the next level the isochrone it comes towards the you know origin the center from where the pore water pressure increase to Δu or $\Delta=\Delta\sigma$.

So at both top and bottom it actually gets you know to reduce to 0 then correspondingly what will happen still at the midpoint there will be high amount of pressure, pore water pressure have to be dissipated or transferred to the soil skeleton. So here what happens is that over a period of time what will happen the tendency of you know the isochone to flow towards the, you know the initial condition tends to prevent.

That is you know initial condition is nothing but the original hydrostatic condition before the application of the load. So here the similar situation can be stimulated with the, if we are able to say open this walls simultaneously both upper valve and bottom valve then in line with you know what actually happen with two open layers which we considered in the left hand side of this figure.

We have the spring 1 and 5 will get composed first, then spring 2 and 4 will get compressed first and finally the third spring will start compressing slowly. So this process continues till you know the hydrostatic conditions prevail in the situation. So here with this, what we can actually explain is that, the consolidation phenomenon of a soil having thickness H clay layer having thickness H can be represented by a spring analogy model with multiple springs attached in the fashion which is actually shown in the figure.

And as we have said that this analogy model was actually applied to you know to secondary consolidation or a creep of a soil also and two models which are can be discussed or that Gibbson and Lo 1961 and Barden 1965.

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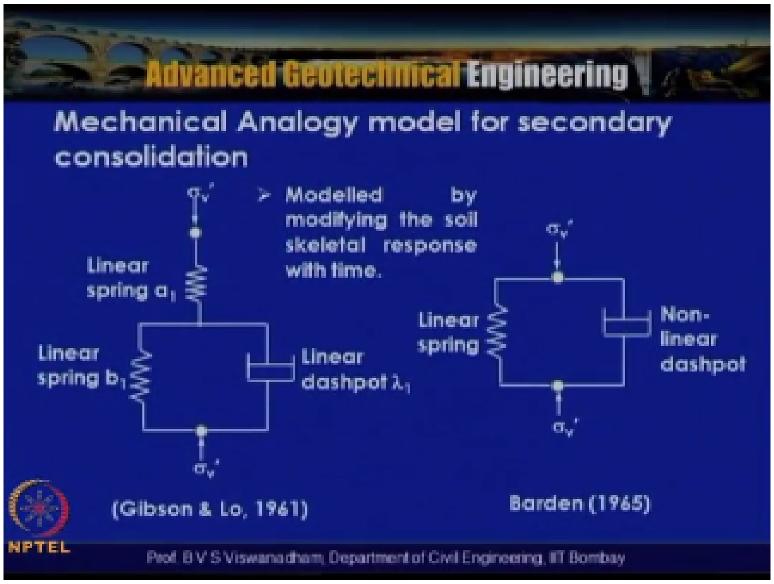

So here this model by modifying the soil skeletal response with the time, so the soil skeleton particularly what will happen is that I will do application of a constant effective stress because of the breakage of the soil particles or bending and breakage of the soil particles this phenomenon actually happens. So here this is represented by Gibbson and Lo in 1961 by a linear spring between linear spring a1 here.

And the linear spring b1 and linear dashpot λ1 and so this is actually represented and further this was actually modified by Barden in 1965 by replacing this linear spring and by putting a linear spring here and here what actually has been modified is that instant of linear dashpot a non linear dashpot has been used to go close to the you know the clay part secondary consolidation phenomenon in the real situation.

So in this way the analog models were traditionally applied and particularly to understand about the electrical analog and the spring analog they are famous in as far as you know geotechnical engineering is concerned.

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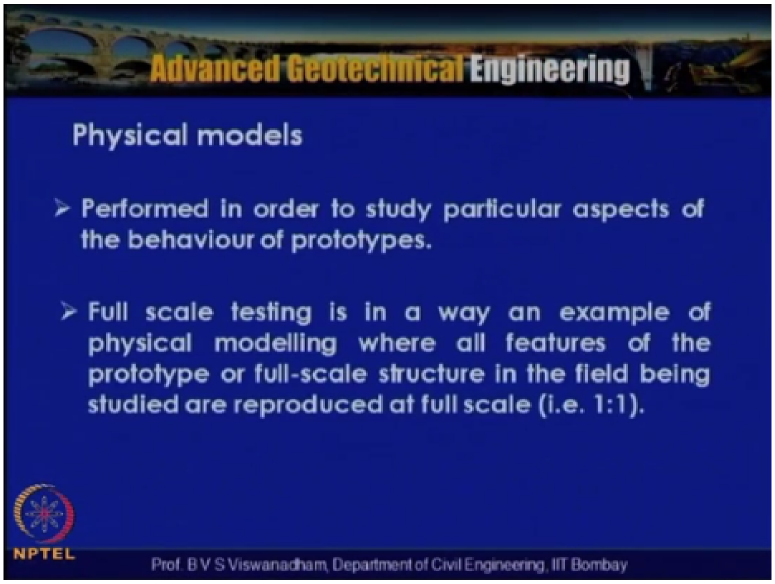

Coming to the fourth you know type of the last type of modeling which we have discuss is nothing but physical models, this physical models are basically performed in order to study the particular aspects of the behavior of prototypes and these physical models help to you know postulate or you know portrait the failure mechanisms and to understand about the behavior of a prototype before failure and at failure.

And full scale testing is in a way example of physical modeling where all features of the prototype or full scale structure in field being you know study and are reproduced at physical at full scale 1:1, that means that all aspects are actually you know represented and that means that you have real soil real ground condition and real ground motion and real loading and when we have this situation then full scales testing is in a way of example of physical modeling where all features of the prototype or full scale structure in field being studied or produced it full scale.

This full scale testing is also quick common in geotechnical engineering practice, like example like a plate load test which is actually conduced to you know estimate the barring capacity that means that from through a field plate load test we can actually carry out in the plate load test can be carried out in the at the side to get the barring capacity. Similarly in order to get the, you know axial load capacity or lateral load capacity.

There is a mandatory requirement of testing of piles which are actually you would being used in a project for you know we actually do the two categories of pile load testing one is to test up to the failure the other is to you know test only up to certain amount, certain times of design load so that you know these piles can be used in the structure. So the one which is actually applied beyond the design load is you know generally done initially as you know test where you know the piles can be abundant.

So these full scale testing is in a way example of physical modeling where all features of prototype or full scale structure in the field being studied or reproduced at a you know at a full scale.

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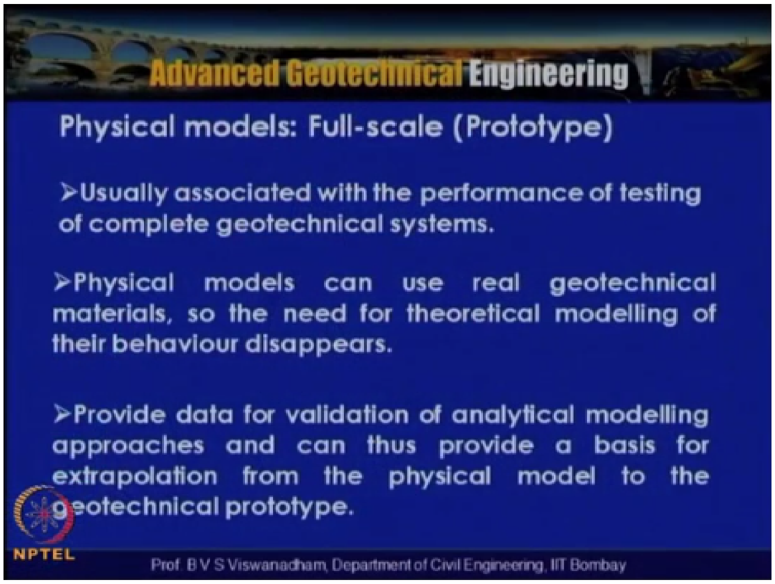

Usually the full scale models or full scale or full prototype which is you know at 1:1 scale, usually associated with performance of testing of complete geotechnical systems and can be used for, use real geotechnical materials so the need of theoretical model of their behavior disappears and because as we are using the real geotechnical materials the need of theoretical modeling of this materials disappears and provide data for validation of analytical modeling approaches and can thus provide a basis for extrapolation of physical model to the geotechnical prototype.

So with that you know there is possibility that providing a data for validation of analytical numerical modeling and approaches which we have discussed earlier and can this provide a basis for extrapolation of the physical model to the geotechnical prototype.

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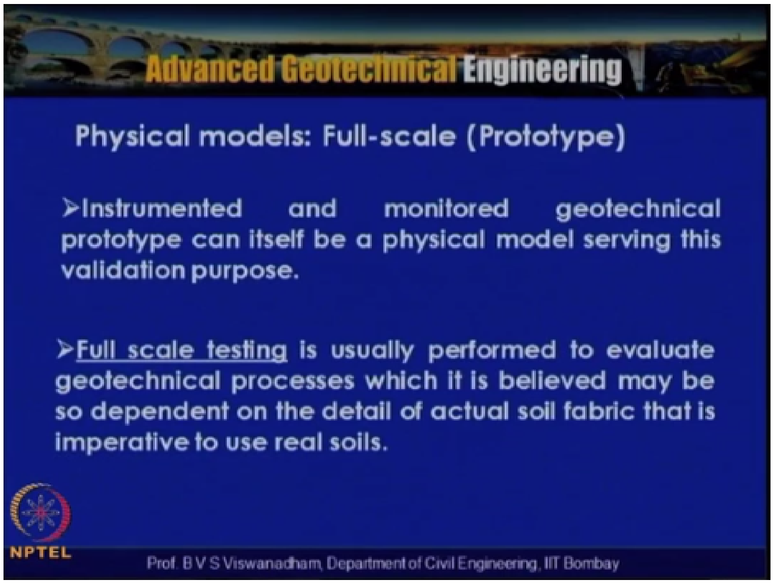

And another added advantage is that instrumentation and monitoring geotechnical prototype can itself is a physical model serving this validation purpose. So by instrumenting the, you know the physical model and monitoring the geotechnical prototype itself be a physical model serving this validation purpose. So full scale testing is usually performed to evaluate the geotechnical process which it is believed may be so dependent on the details of actual soil fabric that is imperative to use real soils.

So for example, in some type of problems like embankment construction on soft soil where in order to monitor the you know the degree of ground improvement for example for preloading of a soil and to do that you actually need to do the you know construct embankment in let us say if suppose if the embankment is of 7.5m height about the soft side and it has to be done in three stages let us say and then between each stage there should be in a weight period of certain period let us say two months or three months.

And with that in order to you know as a time the you know time for you know increasing next stage and going for next stage and all only to do the instrumentation where in measure the settlements you measure the water pressure or pore water pressure changes in the soil based on that above you can actually decide about you know about this things. So here the full scale testing is imperative with real soil fabric conditions.

And similarly when we are actually try to accelerate, we try to use the you know the drains like prefabricated vertical drains or sand drains so in a way what will happen is that you wanted to know the influence of spacing of the drains and you know the installation effects on the performance and all, one need to you know monitor and you know these full scale testing, so full scale testing is usually preformed earlier the geotechnical processes.

Which it is believed may be so dependent on the detail of actual soil fabric that is imperative to use at, use real soils. So we can put the, you know advantages of a full scale modeling or working with real ground conditions and real soils and real loads and real stress levels and real stress histories.

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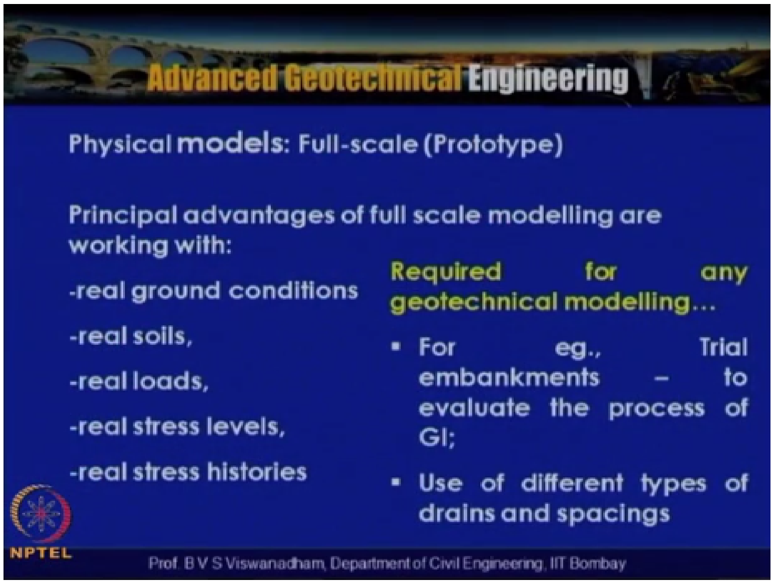

This is very important particularly for when we are referring to soft clay history whether it is normally consolidated soft or over consolidated soil and so this you know this conditions you know are you know very, very relevant and that is the benefit of you know they doing a full scale model test. But you know we have you know number of types of structures as well as all these types of structures are subjected to different types of loadings.

So many times you know simulation of the structures to climatic forces like say rainfall or earthquake and all those things are very, very difficult so these you know stimulation of you know construction of a structure and waiting for you know a certain destructive force to come is you know difficult and next to possible. So these are the you know in the right hand side here it has been show whatever we have discussed in the previous slide as actually shown here that is the trail embankments.

Where in the evaluate the process of ground improvement we tend to do the full scale testing or a full scale prototype behavior and use of different types of grains and spacing whether they are adequate or not, whether they are functionalities okay or not can be, have to be checked by monitoring only. And disadvantages is in the scene that small scale model leads to much more rapid results purely because of the smaller size, smaller the size the length required or small physical dimensions are small. The amount of the requirement material will be small so you know the small scale model leads to much more rapid results.

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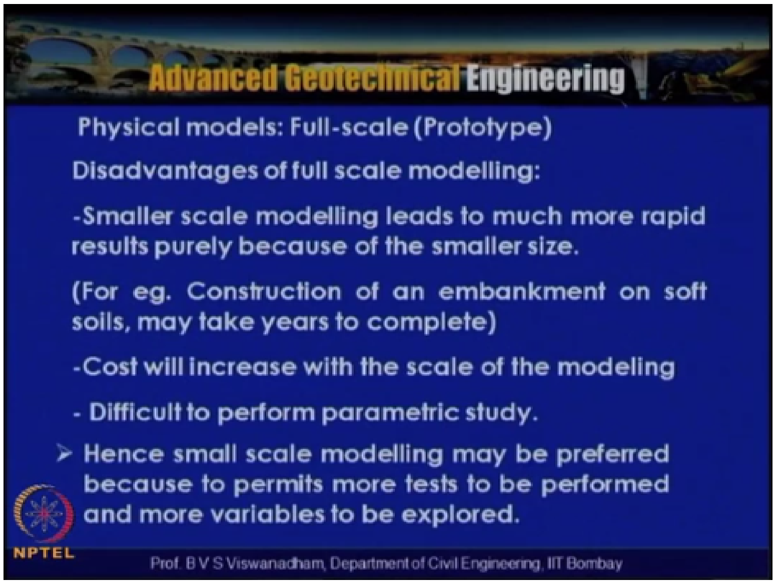

Purely because smaller size, construction of an embankment and soft soils and you know the stage construction for example if you look into may take years to complete. So that situation you know is not advantages as far as you know full scale or physical model testing in geotechnical engineering and cost will increase with the scale of the modeling that means that if you are having you know let us say you know 1:1 scale it will be you know almost equivalent to the scale which is actually the you know the cost will be equivalent to that of in the field.

And difficult to perform parametric study and difficult to perform you know control you know full scale testing and many times you know even with lot of precautions the instrumentation in modeling you also difficult. But if we are able to achieve in appropriate instrumentation and modeling and if we are able to you know do it with you know in a control way then full scale model testing, physical model testing is the you know number one option to you know validate the number of you know different new concepts as far as which can be lead to study in the geotechnical engineering.

Or to understand about the behavior of geotechnical structures, but you know considering the difficulty of the you know performing you know parametric study and also involving the construction of the cost aspects as well as the feasibility aspects you know the small scale modeling turns out to be at preferable option. The small scale option in the scene that the model which is not you know tested at 1:1 which is nothing but a reduced by a dimension n that is n is nothing but in scale factor by which the model is reduced.

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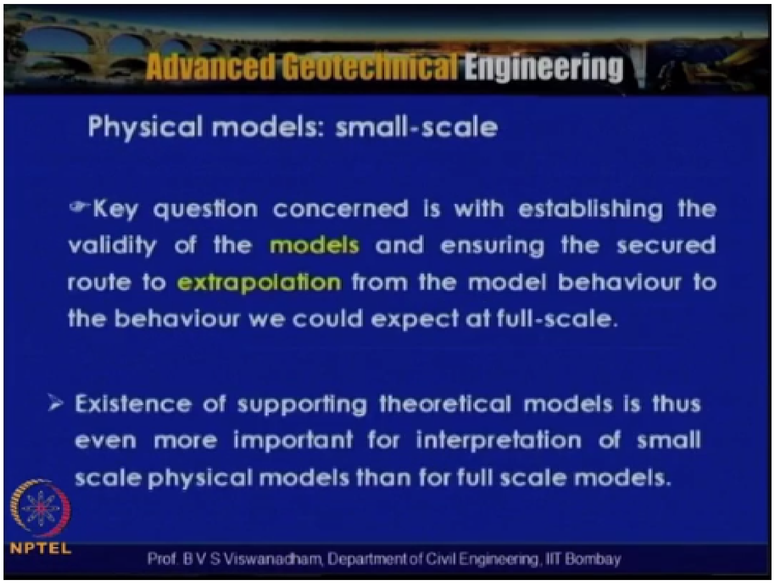

So if you look into the physical models at small scale the key question concern is you know with establishing the validity of the models whatever we have scaled on and ensuring the secured route to the extrapolation from the model behavior to the behavior we could expect at full scale. So the question which is required to be established is the you know validity of the models and ensuring the secured route to extrapolation from the model behavior to the behavior you know could actually expected at full scale.

So you know when we actually test the model at full scale you know we do not have this question because we are actually doing at 1:1 with real soils, real ground conditions and real stress histories and real loads and all. But when we do this at you know scale which is different from a full scale which is smaller than you know by a smaller by a factor n. The extrapolation from the model behavior is very important aspect to be considered.

So existence of the supporting theoretical model is thus even more important for interpolation small scale physical model than for the full scale models. So existence of supporting theoretical models is thus more important for interpolation small scale physical models then for full scale models.

So physical models at small scale you know if you look into the at merits we can say the greater advantage of small scale laboratory model is that we have full control over the all details of the model that means that all aspects of models under control in the scene that homogeneity you know or some requirement of the small quantity of soil and drainage parts if at all water is actually flowing or short so the test durations will be may be short.

Possibility exist in performing many test and performing with parametric variation is possible that means that parametric study is possible and effect of varying key parameters can be considered and another important aspect is that the smaller the scale the cost will be low. So liberty in choosing the boundary and loading conditions are the model this is another important aspect where in we can actually have you know we get the liberty in choosing the boundary and loading conditions.

And smaller quantities of soil and drainage parts will be short so the test durations will be small and but we can look into this the size of the model is you know as advantages as well as the disadvantage. It is not that you know we reduced by you know by greater factor n and say that we have done a small scale models. Always it is important for us to see that the whatever the small scale model is done is relevant as far as the particular phenomenon is being tested and see that this results represent the full scale response of a respect to full scale structure.

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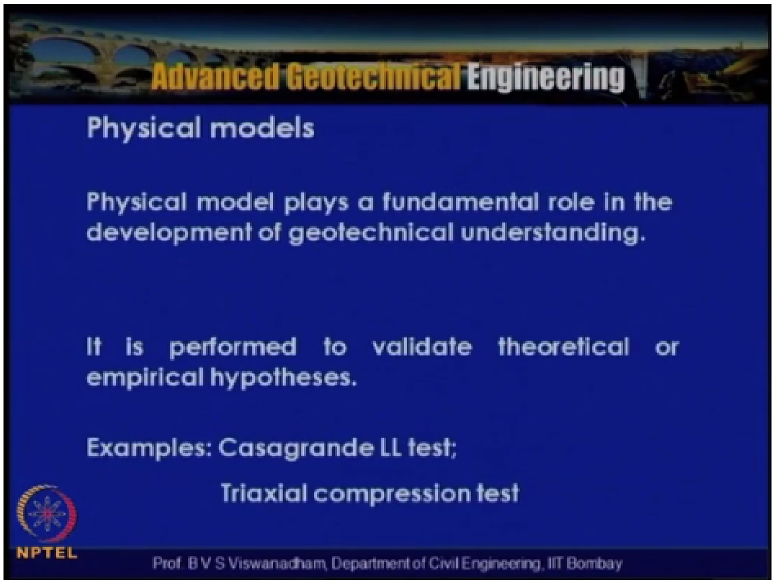

So the physical model place a fundamental role in the development of geotechnical understanding and it is you know performed basically to validate theoretical and empirical hypotheses and also is done to validate you know see new phenomenon or you know to perform under the behavior with prototypes this is you know, this is the fundamental load in developing the we place a fundamental load in develop of which geotechnical understanding.

And this physical model testing as far as in the laboratory is concerned this is we actually have two standard examples, one is casagrande liquid limit test and other is triaxial compression test. So let us look into the casagrandes cup test in which what we do is that we put you know make a soil pad in the cup which is actually having certain curvature and it is placed on a you know a standard you know base.

And it is subjected to once that pad is actually form by using the casgrandes tool what we do is that, we separate and make you know two equal slopes at formed at a you know this pad which was actually formed at a defined water content and then the tool is you know casagrandes tool separates the two slopes at the toe by a distance 2mm and the height of this slope is about 8mm and what we actually do is that you give, by giving a tamping energy to you know this particular tool separated portions. We see that the water content at you know the blows, the number of blows at which you this two you know separated slopes you know get close by about you know over a length of 13mm and we say that you know there then we can say that you know that is that critical number of blows for that water content.

So here what we are doing is that the slope height is 8mm and the slope inclination is about 60.6° also at both the sides and this is subjected to certain short of tamping energy and the you know indication of this slopes moving close that means that internally there is a failure which actually happens, we can say that critical in surface failure which actually mobilizes makes the slope to move closer at the toe and you know then we can say that, that is the point at which we take the number of blows required to you know see that this portion closed by about 13mm.

So you know this, in this what we are doing is that literally this is a type of a physical model test which we are doing knowing or knowingly in order to arrive at the liquid limit of a given soil by a casagrande cup test. And similar example is that triaxial compression test what we do is that here if you are having.

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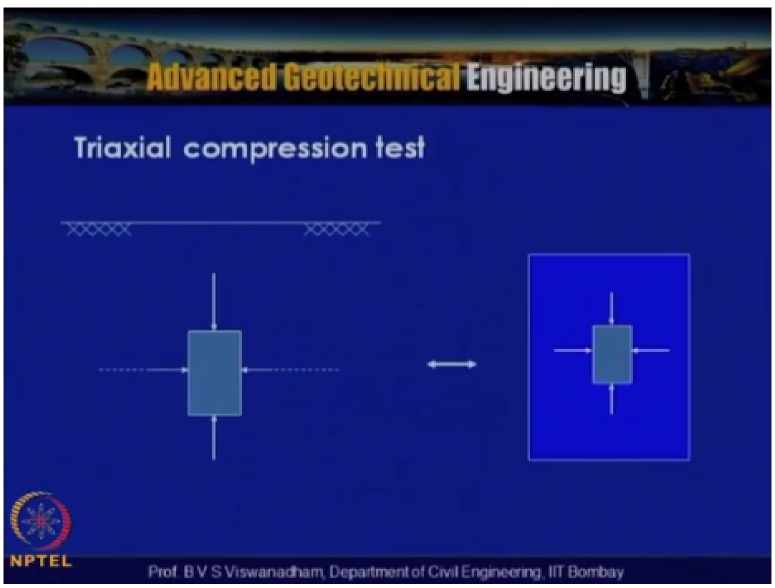

Let us say a sample which is collected at a certain depth and the sample before it is collection is subjected to vertical stress and horizontal stress at elastic equilibrium the relationship between vertical stress and horizontal stress is say $\sigma=k\sigma_v$ basically for normally consolidated soils you know where k which is the coefficient of triaxial compression test will be equal to 0.5 so in that case $\sigma_v=$ you know $\sigma_h=0.5x\sigma_v$ and moreover up on this when it is subjected to loading that is the increasing loading what you know the sample at particular level is subjected.

So this is stimulated in the triaxial compression test in order to understand the strength parameters of soil what we do is that here the sample is subjected to a shear by applying the increase in load that is nothing but what we call, so this is stimulated here what we can see is that this confining stresses are stimulated by using the water surrounding water place in the triaxial cell and the deviated load which is actually applied that is nothing but the additional load $\sigma 1=\sigma 3+p/a$.

So $\sigma 1-\sigma 3$ is nothing but the deviated load is p/a which is applied basically to see arrive at the deviator stress at the failure. So with that what we are getting is that the stress strain behavior of a soil and so that we can actually get the stress strain response of a soil to the given loading. So this what we can say is the first in a physical model test which done in the laboratory to stimulate the field or real situation condition.

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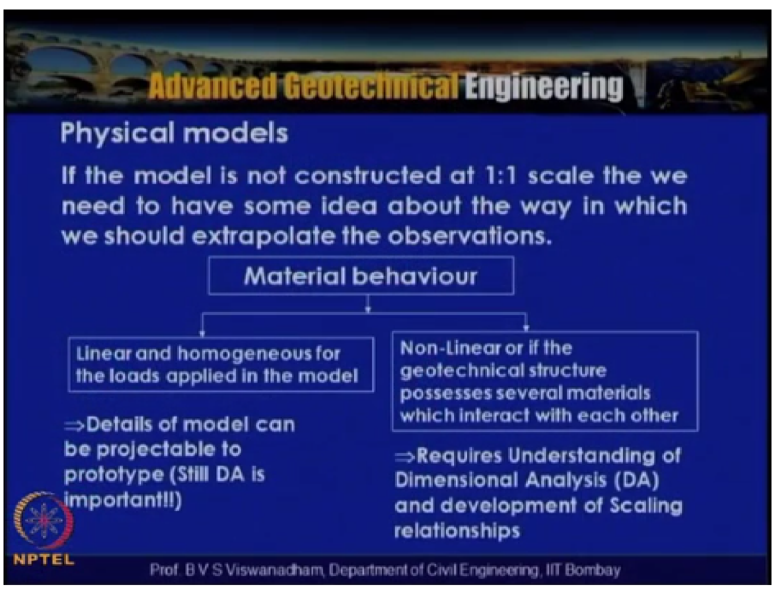

So coming to if the physical models what we have discussed is that the physical model can be done at 1:1 or 1:n, if the model is not constructed at 1:1 scale that means that we need to have some idea about the way in which we should extrapolate the observations that means that if the model is not constructed at 1:1 we need to understand about how these the model which is not tested at 1:1 but it is tested 1:n let us say reduced by n times.

How this model actually corresponds to a model which is you know which is should be at 1:1, so the material behavior particularly if you look into this we have two categories one is linear and homogeneous for the load supplied in the model. The other one is the non linear if the geotechnical structure possesses several materials which interact with each other. So in the second category what we see here non linear and if the geotechnical structure possesses several materials which be interact with each other.

So in this case by you know for example for this is that let us that we have got a cable is placed between you know two supports and let us say you know the cable is loaded at the center with let us say by load w, so here what we can say is that the span of the cable is say length l between two supports and where by loading the cable undergoes a deflection by h, so in this situation what will happen is that the cable you know deflects or extracts by h in the center.

So here if you wanted to get the relationship between you know p which is the tension and weight of the cable and then relationship between h the central deflection and you know the span can be obtained. So here details of model can be projectable to prototype stays you know but you know here in this case basically p/w which is nothing but the tension and weight of the cable to the h/l, h/l is nothing but h is the you know deflection and l is the span.

For example, if I wanted to project the results to something like you know p/w is a function of h/l now where we can actually get p/w1 and h/l1, p2/w2 and h1/l2 so h2/l2. So in the ways what we will learn is that we will be able to do and postulate from one model to other model easily without much you know moderation about the scale factors or scale issues. But if you having a situation of non linear or if the geotechnical structure possess several material which interact with each.

Then you know what we need to know is that we require an understanding about the dimension analysis and development of the scale in relationship. Because particularly we have number of phenomenon in geotechnical engineering, let us say that we have got at a self rate forces these are nothing but these body forces, so we actually have two types of forces one is called body forces and other one is you know the surface forces or contact forces was basically body forces or you know examples for body forces are nothing but weight forces.

Due to self rate of the soil or you know seepage when the water flows to the soil the forces existed by the flowing water on to the grains is nothing but a seepage forces in the process of dissipation of energy if this happens. So the seepage forces and you know self rate forces or data regarded as you know body forces and when material interacting with another material then the contact forces are actually developed.

So but when the body is subjected to forces then it is subjected to stresses and if the body is you know deformable body then body is undergoes you know a change in lengths then it is subjected to strains and because of this change in lengths can also undergo or the strains can also be undergone by collapse of the particles or by you know breaking of the particles or crushing of the particles.

So this you know this particular you know emphasis what actually required is that in understanding of the dimension analysis so dimension analysis is a technique which is actually used traditional in civil engineering and which can be applied to geotechnical engineering to understand about the you know the several relationship between parameters which are actually describing a particular phenomenon.

That means that we will be having a certain main important variable and then it is actually influenced by several variables which are called as independent variables. So relationship between dependent variable and independent variables can be obtained by dimensional analysis and from there the stimulate shoot or similarity theories can be applied to deduce this scatting relationships.

This is one of the ways of deducing then we also have by using the concept of you know the differential equations are equations governing the phenomenon we can also reduce the scaling relationships.

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