Geotechnical Measurements & Explorations

Prof. Nihar Ranjan Patra

Department of Civil Engineering

Indian Institute of Technology, Kanpur

Lecture No. # 30

Last class we have started this bender element and its use. As I said this bender elements is like a beam shaped bender element.

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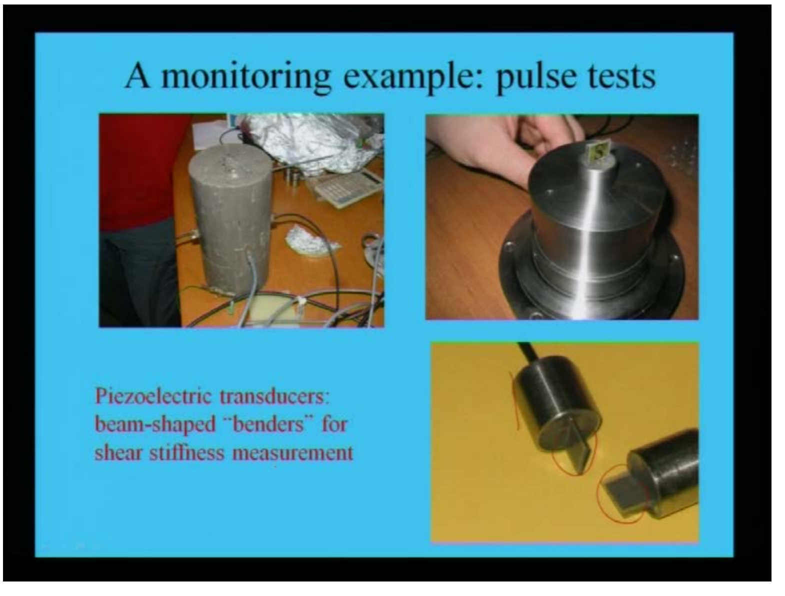

And these are all the sensors with a beam, there is a sensors has been connected. This has been put in the either base and the at the top of the soil sample. One will act as a source, other will act as a receiver. So, this bender element beam shaped benders for shear stiffness measurements.

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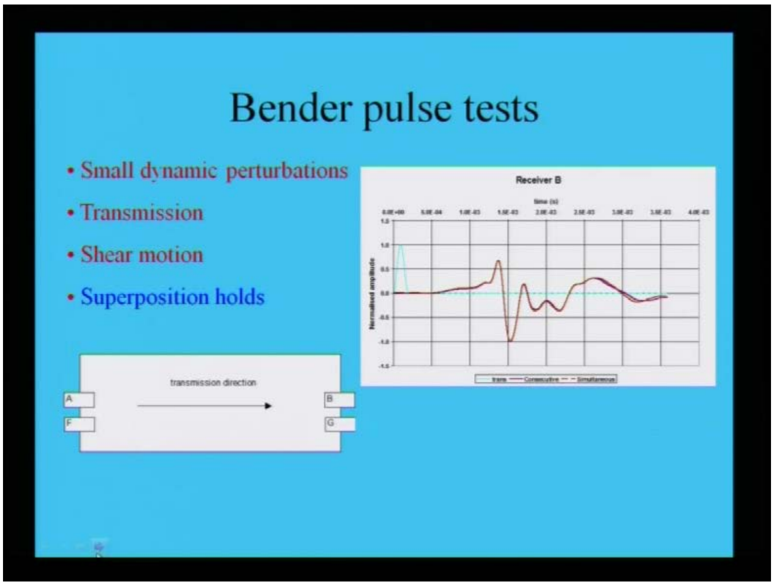

This is your bender pulse test,

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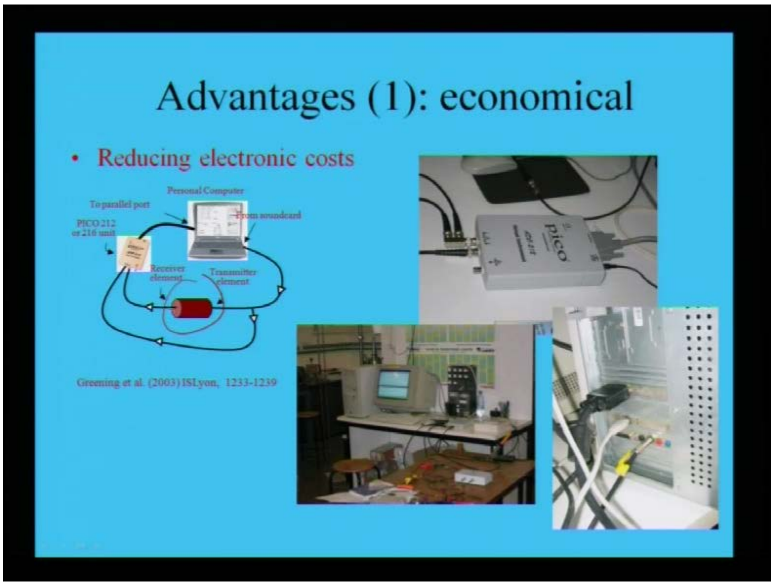

I have discussed then advantage also I discussed, this is economical because it can be easily done in the laboratory in field generally bender element test.

In field if you go for measure this shear wave velocity then you have to go for a downhole technique, seismic downhole technique or cross hole technique. In this bender element it can be easily done in the laboratory by means of triaxial cell, so that from shear wave velocity can be measured from the source to a receiver that means in the soil element one end is your source other end is your receiver. Bender element can be put in the both the ends and it reduces the cost basically in the field test the cost is very high, in laboratory test it reduces this overall cost.

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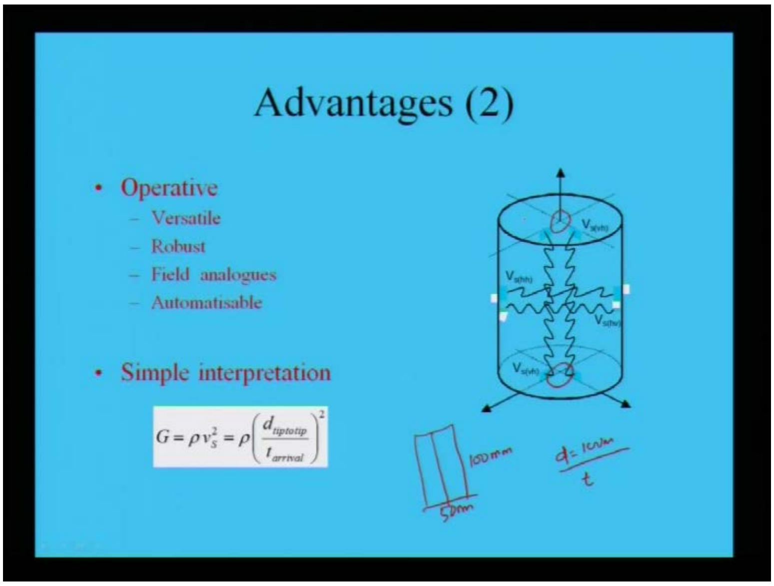

Second advantage is it is very much operative, that means it is very versatile and there is no need for a much. It is a very simple you can put it anywhere else and you can connect it top and bottom very easily and it is robust. And simple interpretation by means of knowing this density and the velocity that means distance if there is a 100 mm sample by 50 by 100 mm sample, if this is say 50 mm dia and this is 100 mm length of the sample that means the distance is fixed, that means this distance is equal to 100 mm. Only you have to measure the travel time. Travel time form bottom to top that means from here to here, travel time only you need to measure by means of source and the receivers by means of by use of bender element.

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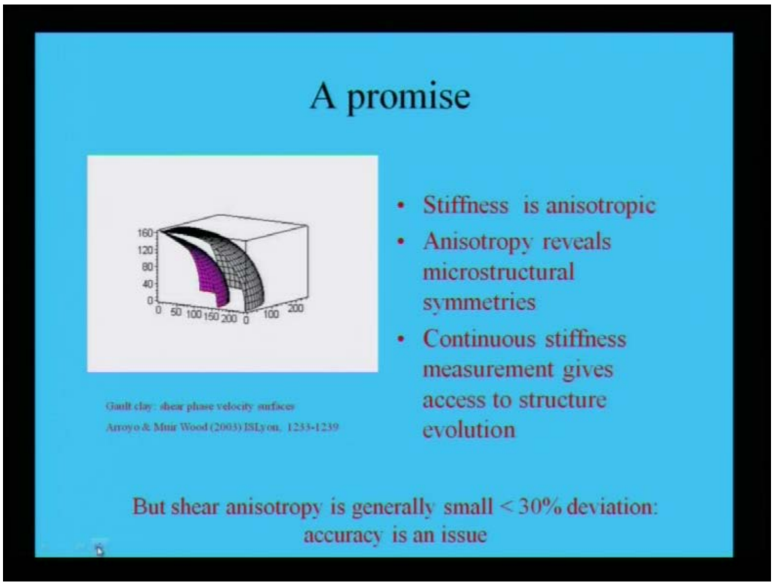

So, it is very simple interpretation then stiffness is anisotropic. So, that means anisotropy means it reveals micro structural symmetries. But, shear anisotropy is generally small it is less than 30 percent deviation, so accuracy is an issue. Basically here accuracy is an issue with proper care it has to be this test has to be performed.

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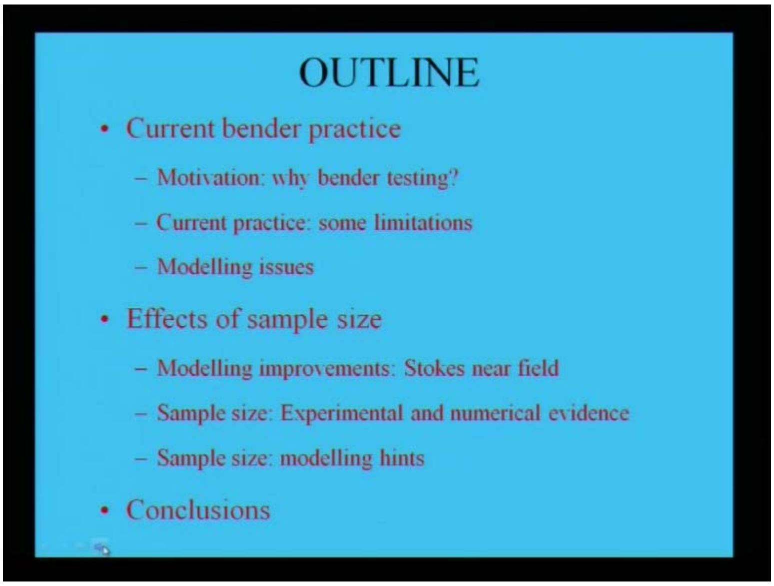

Then outline these are the things we are going to discuss current bender practice and effects of sample size and conclusion.

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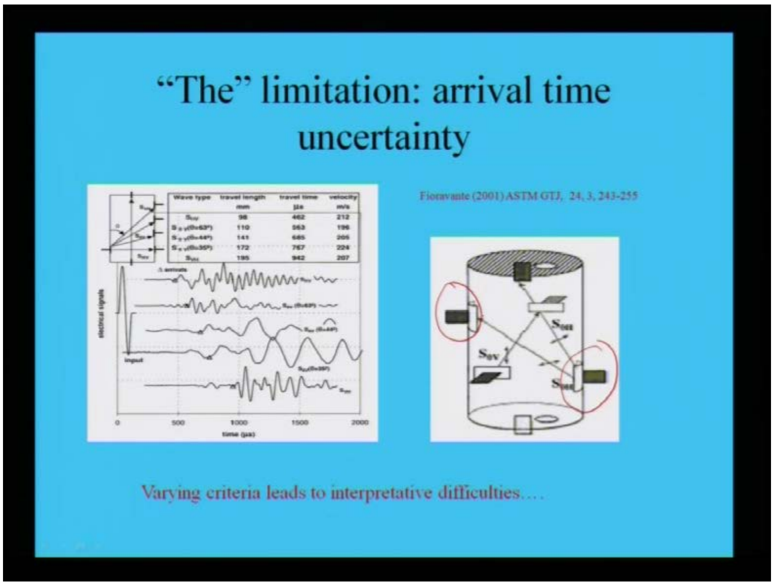

Now, current bender practice that means the limitation, arrival time uncertainty. If you look at here the arrival time uncertainty means you see the bender element you once you start a source the arrival time it can go in this way means there is a uncertainty. This arrival time it how it propagates varying the particularly criteria this interpretation is difficult. How you are providing your bender element where if you look at here one is provided here that means this is your source and this is your receiver. Instead of travelling here it may travel in this way or it will travel who knows this arrival time is fast then this arrival time will be later.

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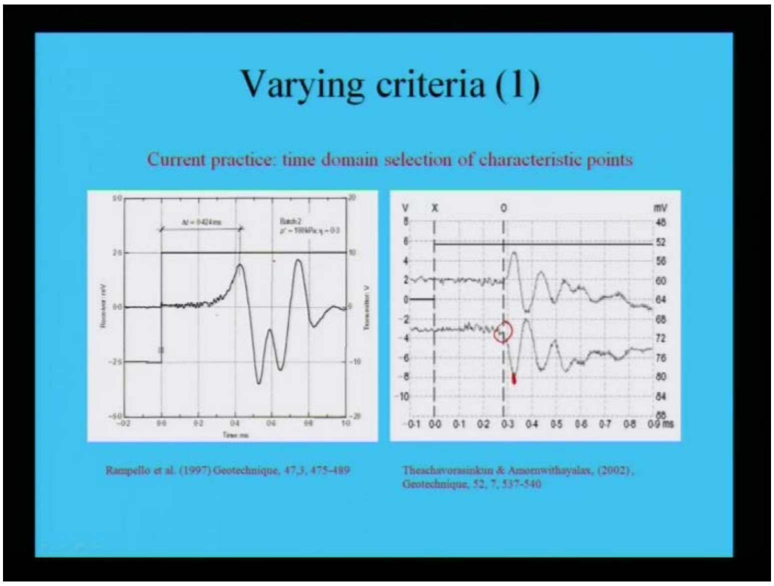

So, this is one of the limitation that means there is uncertainty in arrival time current practice time domain selection of characterization point, at what time domain how do you select your points if you look at here, it has been given by Rampello et al (1997) in Geotechnic. If you look at here this is a particular receiver and your time. How much time it takes if you look at here it starts with this 0 and from here it will go and it will peak. The peak is your, once it start it peak that means at this point it has been received. Now from which point you are going to take, there are different varying criteria. If you look at here arrival time domain selection, here it has been taken the time domain is from here to here. This is your time domain delta t is equal to 0.424 same as if you look at here, the time domain has been taken from here it is different. It has been taken from here this is negative form here to, note this point.

Now, where you will choose your arrival time. Now this is definitely a there are different varying criteria shall I choose this point as per this other author in 2002 they are chosen this point as the arrival time but, here Rampello et al (1997) they have chosen this as arrival time. Look at the difference, if instead of choosing here if I choose it here the time difference time lag will be approximately 0.15 second. Now, definitely this is a challenge means there are different varying criteria about selection of arrival time. This is criteria number 1.

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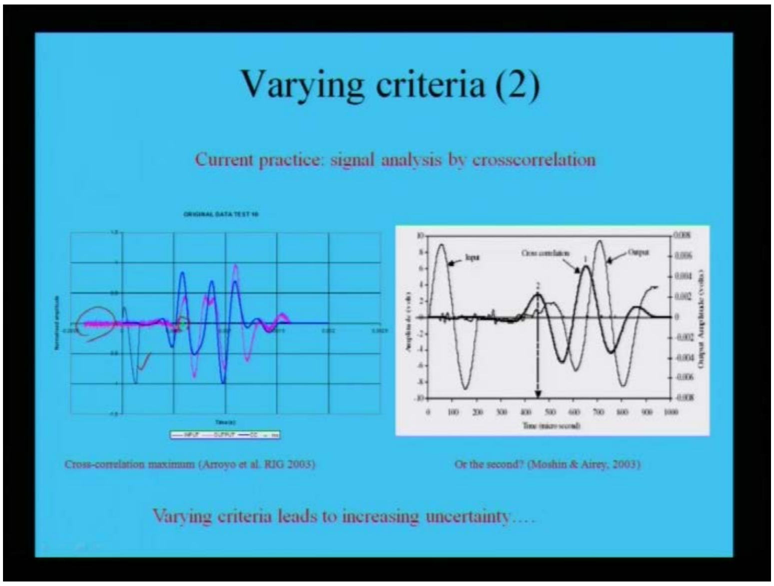

Signal analysis by cross correlation means cross correlation means original data is there.

Now, you can take it other correlations and put it super impose it. If we look at here this is my input, this is input, this is the output and if you look at this. These are your t c c that means it has been super imposed. Now, how do you analyze this signal ? This is again a challenge for us whether this signal means the moment

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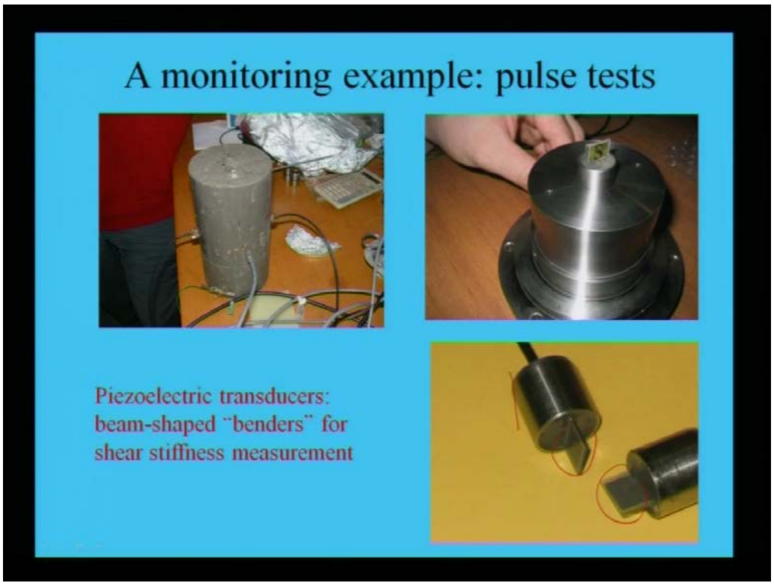

you give it. The moment you start it here then the receiving point will be here then receivers are there means how do you, now here you see there are different bender element at the side also they put it, at the bottom means how, what signal means particularly signal which signal you are going to pick,

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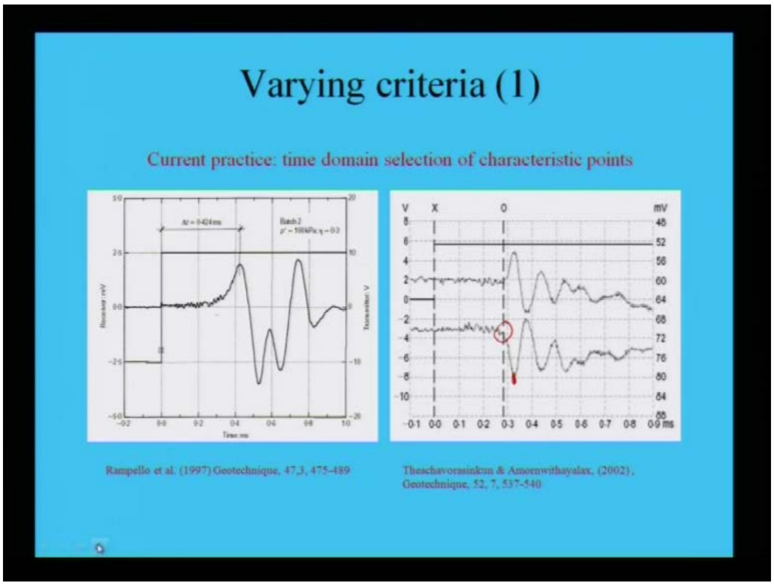

and how this is again challenging criteria number 2 about your time domain selection about your time domain is 1 criteria.

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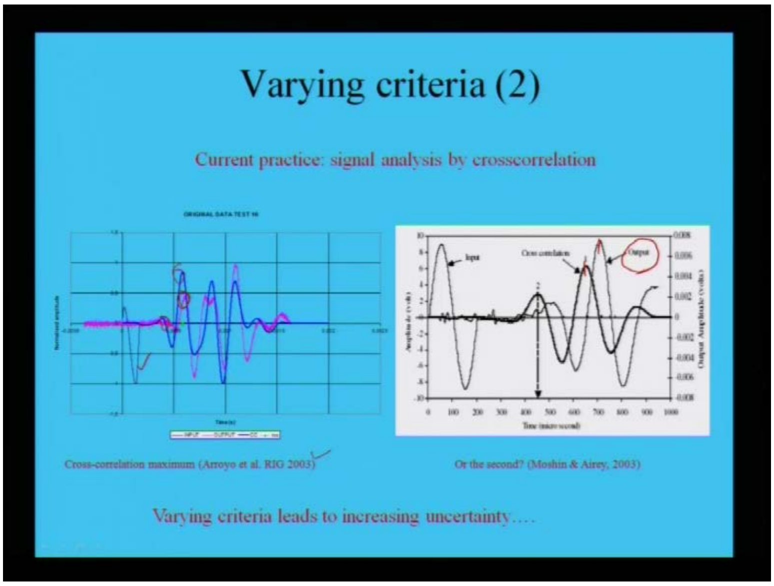

Criteria 2 is your signal analysis. If I superimpose the known signal with these original measured signal, with this measure signal or your present signal with your known signal then we will be finding out, you will be knowing there is a vast difference.

Look at here, the peak is here. Now in this case this peak is varying. So, now which point you are going to take from here to here or from here to here. So this with this now second, whether this is fine or the second Moshin and Airey 2003. If you look at here, this is the input and this is the correlation and this you are getting as an output. Now if I look at this cross correlation versus the output it is drastically, means if I take it this time look at here, if I take it is just varying. So signal analysis you can cross check the signal, arrival signal by means of your other available correlations or cross correlations. Then you find it out whether the signal whatever you are getting whether it is correct or not.

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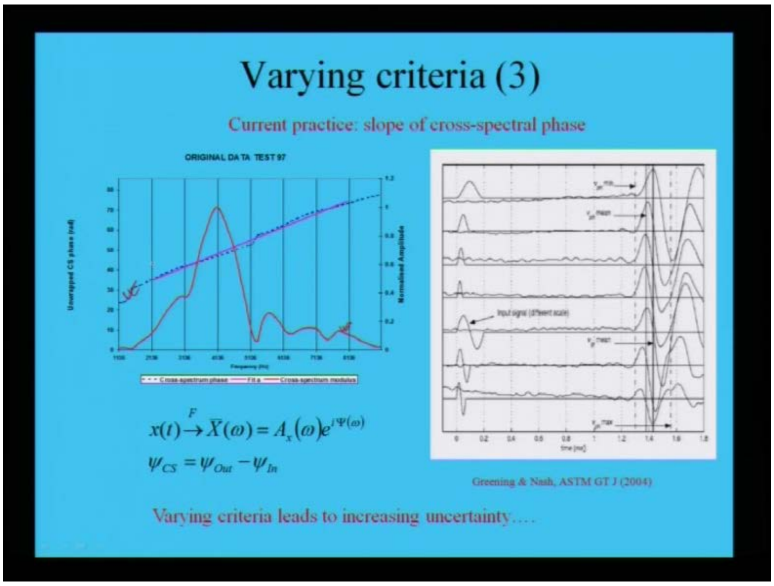

Slope of cross spectral phase, this is another slope of cross spectral phase that means whether this current practice, what slope you are taking whether it is original data, whether fit with a if we look at here this is your cross spectrum modulus. This part is your, so this is your cross phase. Now you fit a curve from there you can find it out slope of cross spectral phase.

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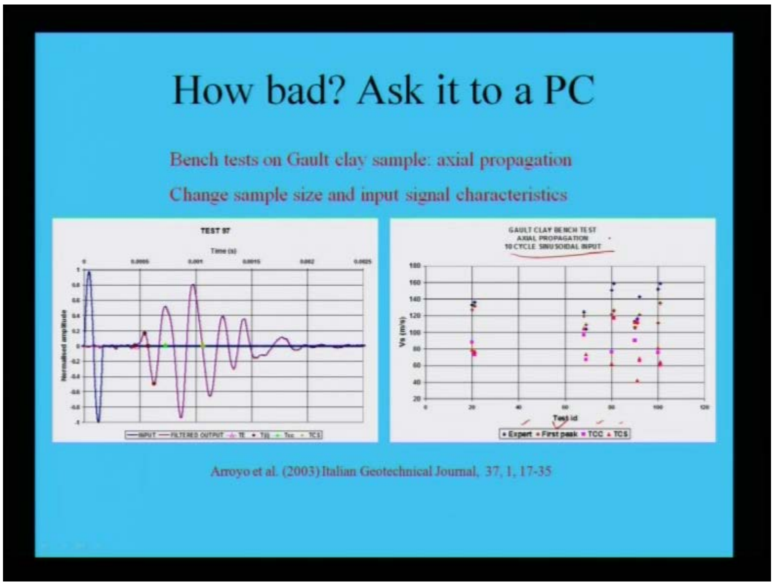

Then forth how bad ask it to a pc that means your Computer. Bench test on Gault clay sample, axial propagation change sample size and input signal characteristics. That means the moment you change the sample size, this input of the signal characteristics has been completely changed. If you look at here mean these are all your first peak expert t c c, t c s. If you look at this means particularly this 10 cycle sinusoidal input depending upon the sample size, the input signal also it varies.

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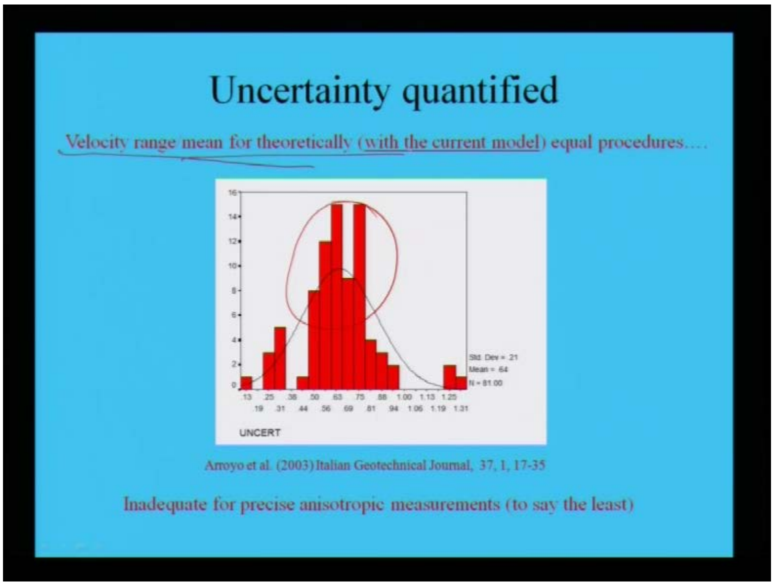

Uncertainty quantified, velocity range and mean for theoretical with the current model. If you look at here this there will be definitely uncertainty. In this qualifier means if I plot the uncertainty what is given by Arroyo et al. (2003) Italian geotechnical journal definitely there will be uncertainty, it quantified in a bigger way uncertainty how far it is certain means uncertainty will be more getting this velocity range, if you look at here your velocity range or mean for theoretically.

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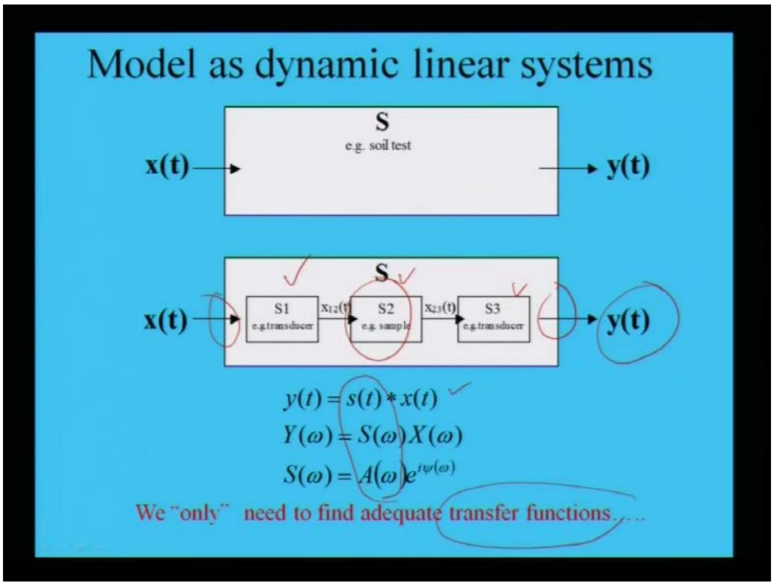

Then go to how do I model as dynamic linear system ? It has been model or model has dynamic linear system. If you look at the soil this is your x (t). x (t) is your, that means this is your source and this is your receiver.

Now, we only need to find the adequate transfer functions. For doing this model we need to find it out what is a transfer functions. If I make it to, that means transducer 1, sample transducer 3. If I put it into 3 parts, that means transducer 1 will be here, then your soil sample, then your transducer S 3. That means from source you give this wave propagation from through the transducer S 1 then it pass through the sample S 2, then through this transducer S 3, you transmit to you can receive your as receiver you can store it in the computer the travel time that means we need only transfer function. Transfer functions for model of means if you want to model as dynamic linear system, you only needed transfer function that means y (t) is equal to s (t) x (t). Y (w) is equal to S (w) X (w), these are all your transfer functions.

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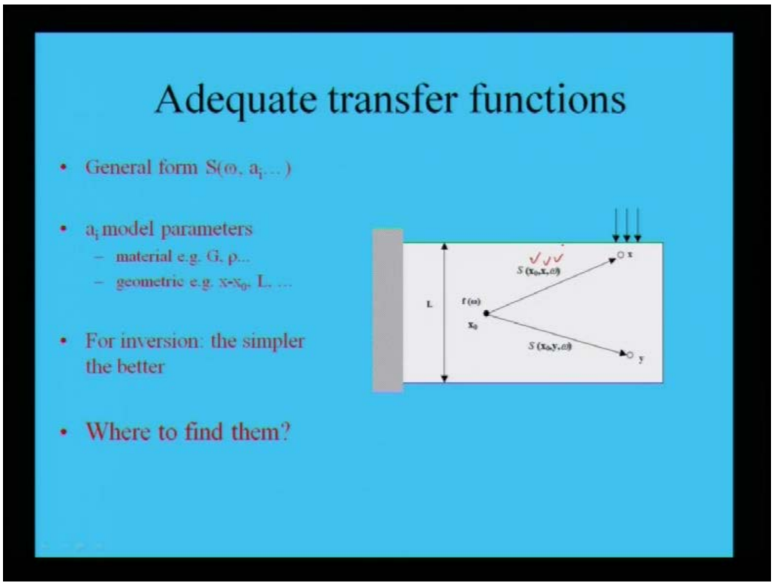

General form of transfer function S is a function of w and a one, you see this is your x 0 x and w and a model parameter that means a one is your model parameter. General form means your, as I say it is a transfer function is your, If you look at here transfer function is your nothing but, your s (w) s (t) these are all your transfer functions.

Now a i is your model parameters, what are the model parameters that means g and rho. g is your shear wave velocity and rho is your density, this is about material that means this is your model parameter then geometry is nothing but, is your length means total length or x 1 minus x 0. This is your geometry for inversion the simpler is better, more you simplified this would be better where to find them?

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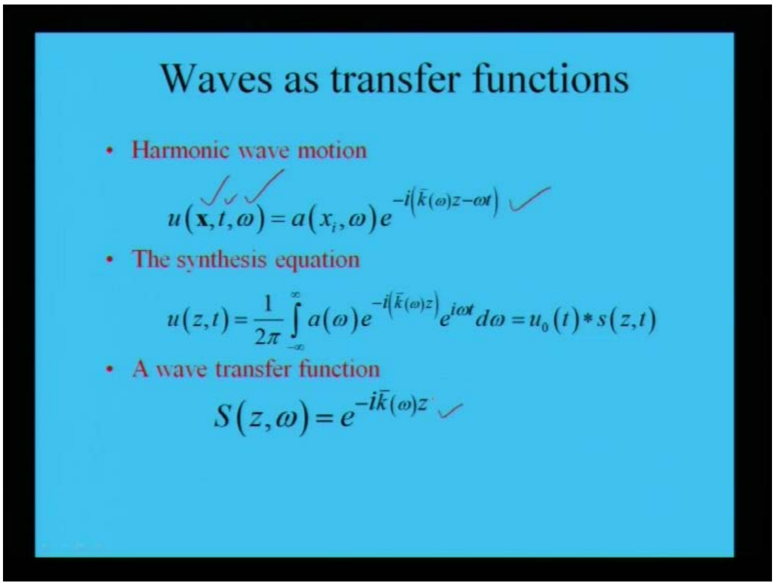

Wave has a transfer functions. How you are going to find for harmonic wave suppose a simple harmonic wave or any harmonic wave u (x t w) now look at x t w. What are the functions it depends w is your transfer function and if you look at your x is nothing but, is your it is a geometry or model parameter and t is nothing but, your time.

So, with respect to time how it propagates harmonic wave if I take into 3 wave as a transfer functions 3 as a parameter, so u means x t w is equal to a x one w e to the power in terms of e to the power harmonic wave motion can be defined. Then the synthesis equation you can do it over the integration of minus infinity to plus infinity. So a wave transfer function S (z w) it should be written e to the power function of this z. Now these are all waves as transfer functions, either harmonic wave motion or a wave transfer function.

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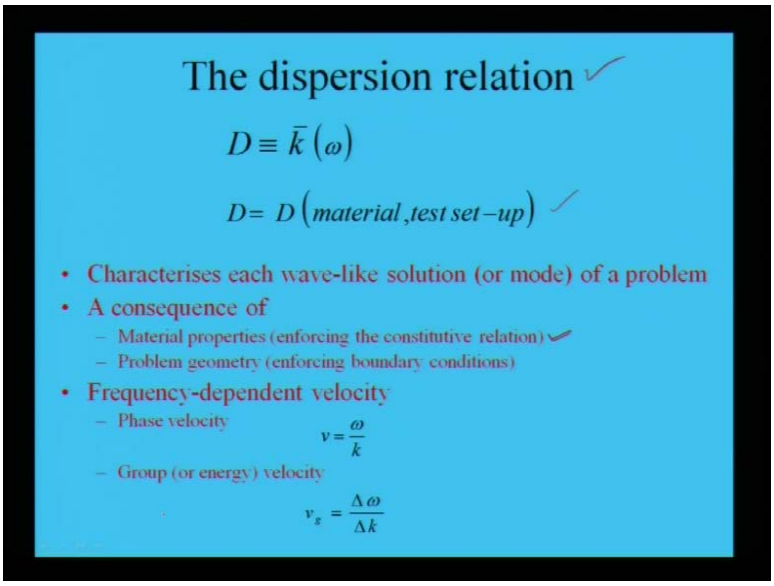

The dispersion relation D is equal to k to the power omega

So D is equal to material or test set up. D is nothing but, test set up characteristics is wave like solution or more of a problem that means a consequence of material properties, enforcing these constitutive relation that means if this material property changes that means the constitutive relationship has to be incorporated. Then problem geometry that means problem geometry means you have to enforce the boundary conditions, boundary conditions at the bottom and at the top may be at the side then frequency dependent velocity you see these are all the dispersion relations, frequency dependent velocity phase velocity if it is varying with the phase. What is the phase velocity, this phase velocity will be v is equal to omega by k or group of the velocity delta omega by delta k so this is your dispersion relation.

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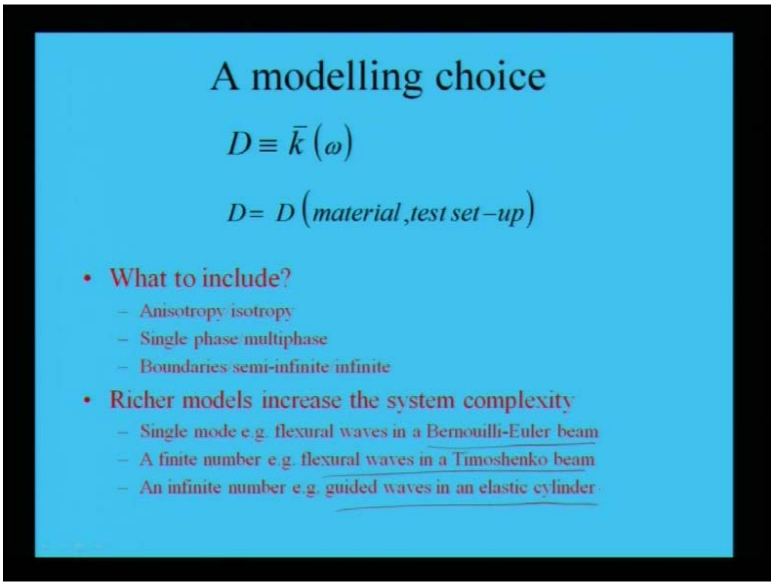

Now a modeling choice what to include in modeling, what to include whether the soil, you want anisotropy or isotropy. What you want you want anisotropy or isotropy ?

Second question you ask whether you want a single phase of wave form or multiphase of wave form. Third, what is your boundaries or semi infinity or infinity that means what is your boundary, it is a finite or semi infinite or purely infinite means these are all your modeling choice. The moment you do for modelling this is your choice what you are going to include. Richer models increase the system complexity more the model parameter you take into consideration, system will become complex. That means it will become complex, that means a single mode that is flexural waves in a this Bernouilli's Euler beam.

A finite number flexural waves in a Timoshenko beam, an infinite number guided waves in an elastic cylinder. These are the criteria means more you want to incorporate all the things the system will become complex. So how this bender element, how you are going to model, what are the parameters you put it depending upon that you can choose the bender element and depending upon that how you receive the model has to be incorporated.

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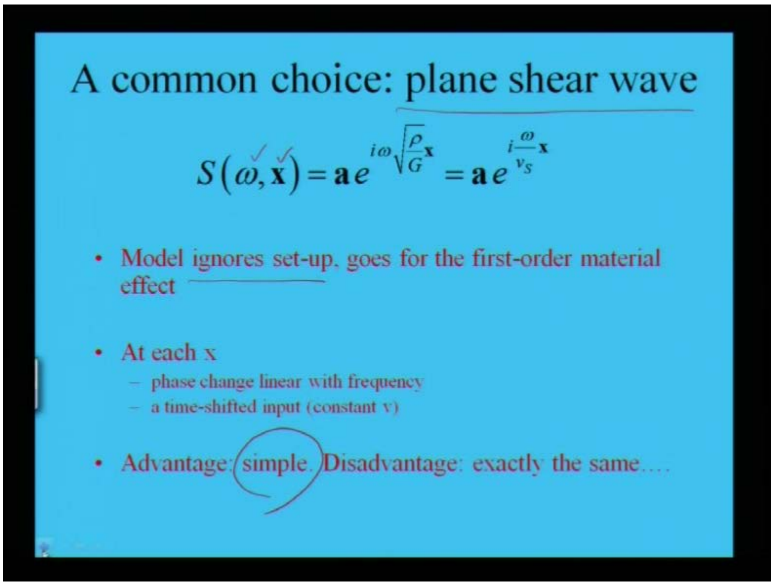

A common choice is your plane simple shear wave where let us start with a common choice simple shear wave you can incorporated in the form of w and x omega into x, this is your transfer phase transfer this is your x is your geometry parameter model ignores if this is my sample then what will happen model ignores set up, completely model ignores set up means a very simple common choice plane shear wave model ignore set up goes for the first order material effect, it goes for first order material effect at each x, what is your x ? x is nothing your geometry at each x. At each x means at each link, if I will start with this, this is my x or y or may be z at each geometry of the x, phase change linear with frequency then time shifted input that means constant v.

Advantage it is very simple, if you choose a very plane shear wave it is very simple then disadvantage exactly the same disadvantage is the means it is very simple that means it has not taken care of model inputs and only first order material effect and phase change has been taken into like linear with this frequency.

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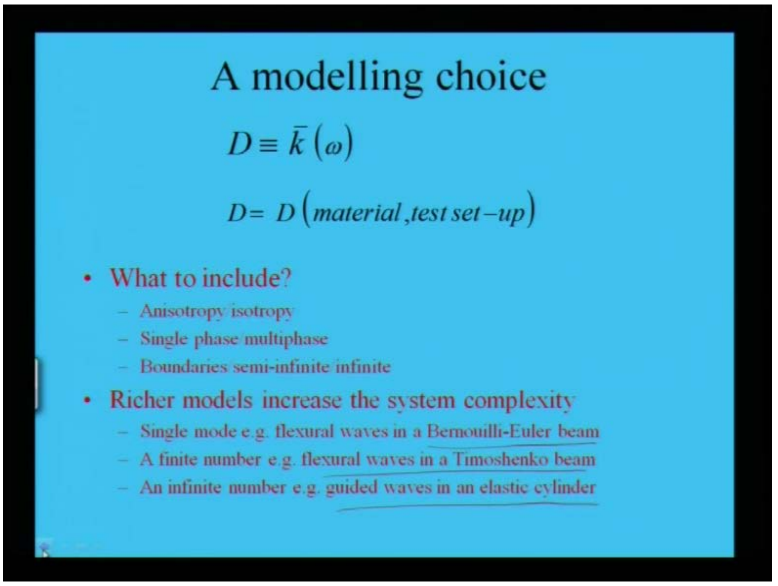

If you look at this the moment you include this anisotropy boundaries all this things it will become complex.

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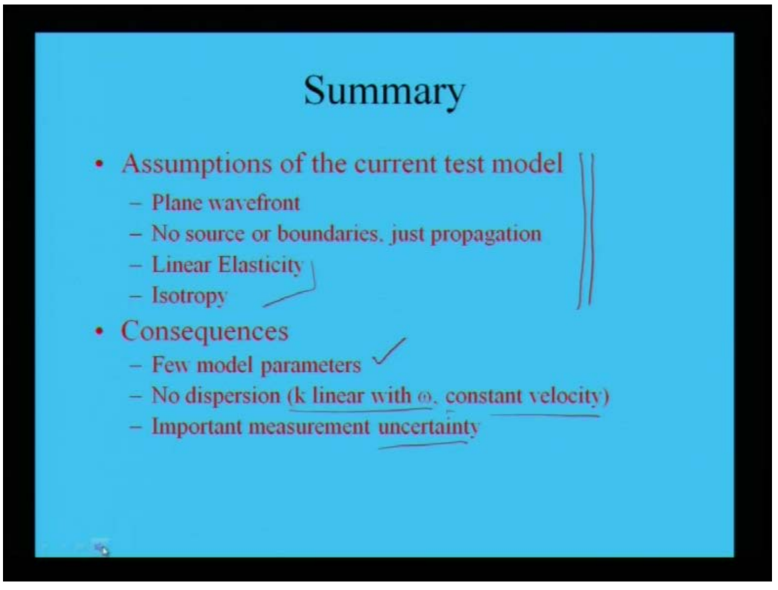

Now the summary will be assumption of the current test model that means what are the assumptions of this stress model plane wave front, no source or boundaries just propagation, its linear elasticity isotropy you see these are these isotropy means x y z direction the property will be same and linear elasticity. Then consequence few model parameters, if these are my assumptions what is the consequence? That means few model parameters, no dispersion that means k is linear with omega constant velocity. Velocity propagate with constant inside the soil and important measurement uncertainty that means while measuring, that means these variation of velocity with this assumptions there is whatever the time particularly your case, in this case you have to measure time required, the arrival of this wave important measurement that means the input signal output signal definitely there will be uncertainty.

Now the S transfer function, it is F s minus n so far field that means non dispersive near field it is dispersive.

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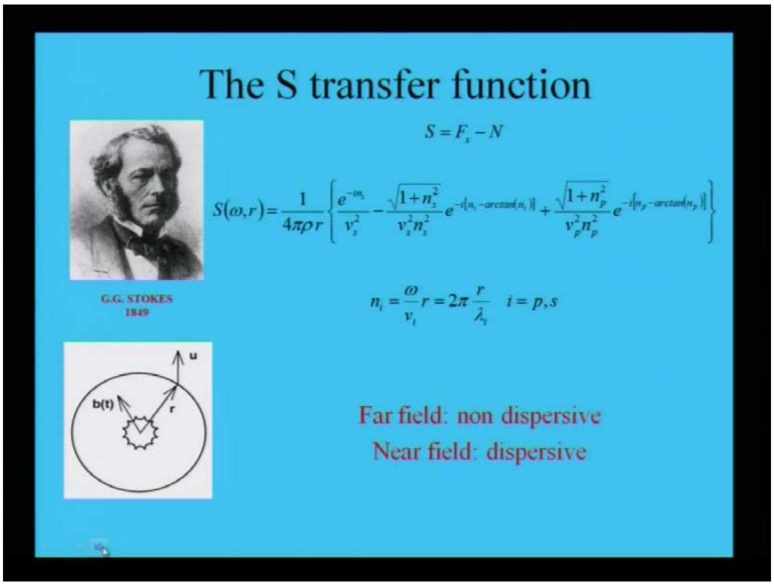

It has been given by G. G. Stokes 1849.

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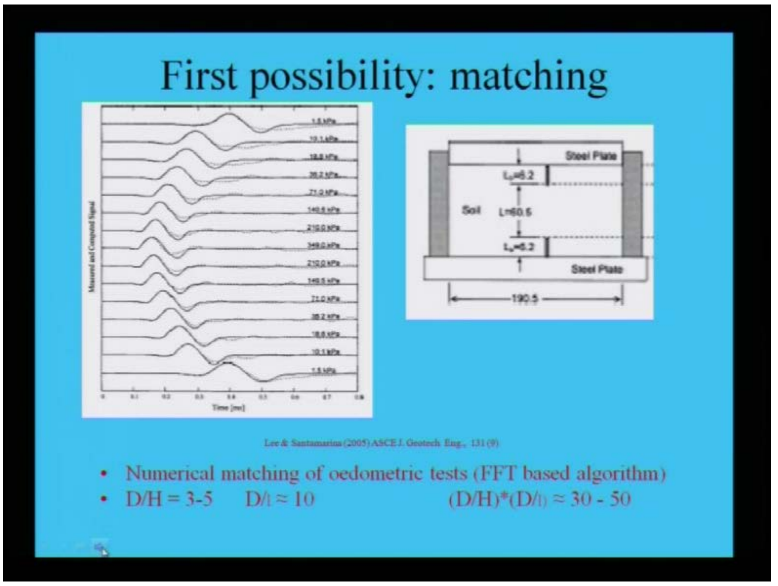

First possibility is your matching, numerical matching of oedometer test FF based algorithm.

It has been given by Lee and Santamarina 2005.

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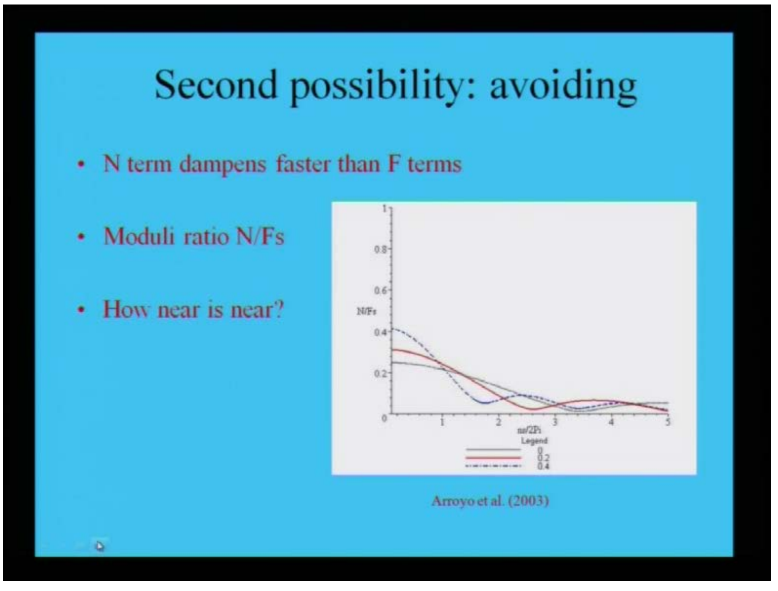

Second possibility is your avoiding that means N term dampens faster than F terms, if you look at here which is your N terms, it is N by F. N terms dampens faster than your F term Moduli ratio N by F s and how near is near that means how near it is in near. Near field number 1 how near? Near field means, how near it is. That means time domain

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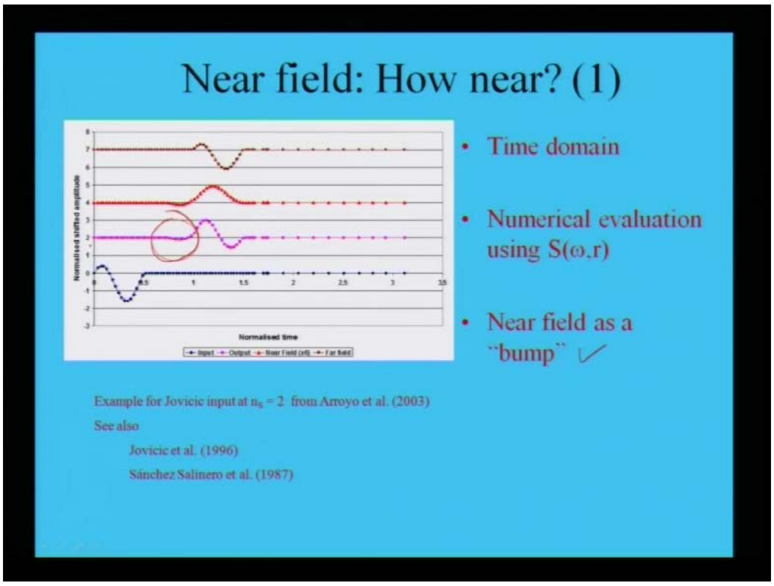

numerical evaluation and near field as a bump. You see if you look at these how near field means how near? This is shown how far, how far it is near normalize time with normalize shifted amplitude. How near it is your near field, this time domain is there.

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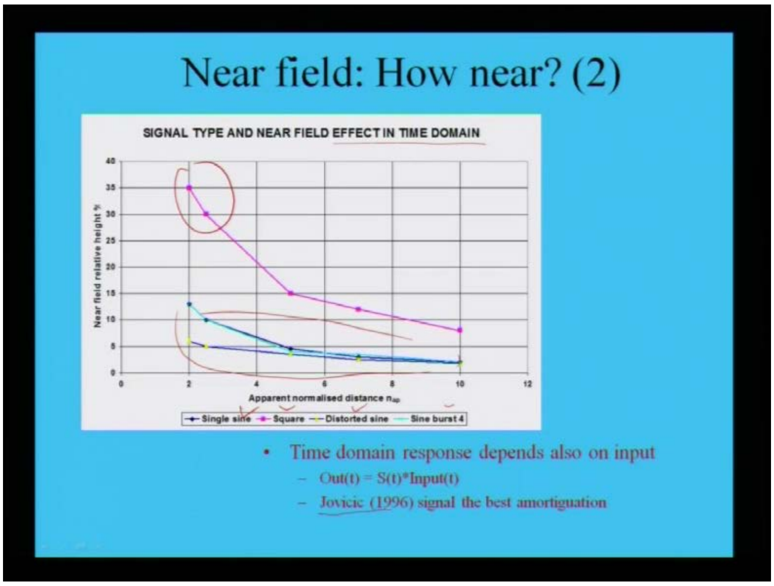

Then, how near 2 signal type and near field effect in time domain you can find it out. Signal is your sine square, distorted sine, sine burst 4 if you look at here, signal type and near field effect the time domain. Look at here signal type means your square signal time, effect your time domain that means time domain will be here it will be effecting signal, as per this signal timing and these are all overlapping, this is very means near field particularly signal time and near field it affects your time domain. The time domain response depends also on input that means output is equal to S (t) star input Jovicic 1996 signal the best particularly best one they have given this Jovicic 1996.

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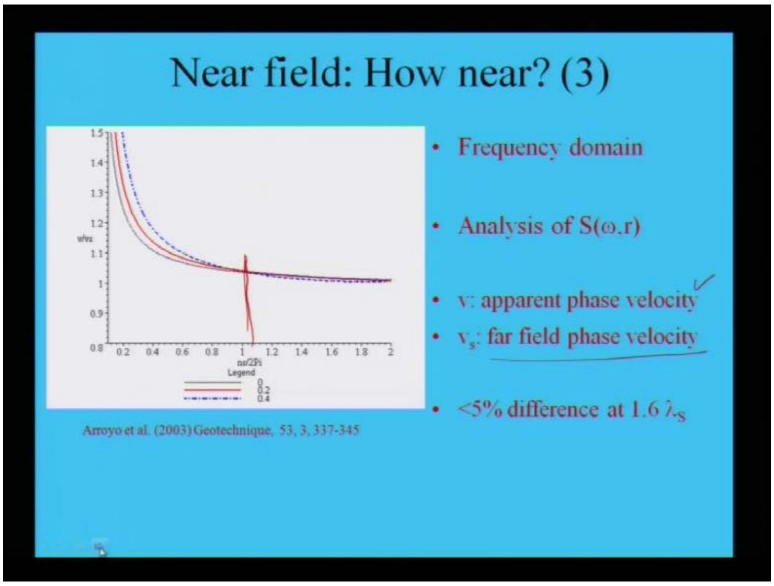

Then, near field part 3 means this is third one how near? Means I am asking this question how near ? First one is your how near it is that means it is time domain how you will get it near field as a bump.

Then second part is you’re in near field it affects how near means depending upon the signal time and near field it effect in time domain. Then third is your frequency domain if I plot the velocity without this frequency domain V is your apparent phase velocity, V s is your far field velocity now less than 5 percent difference at 1.6 lambda s, at 1.6 lambda s if I plot it 1.6 less than 5 percent difference you can find it out.

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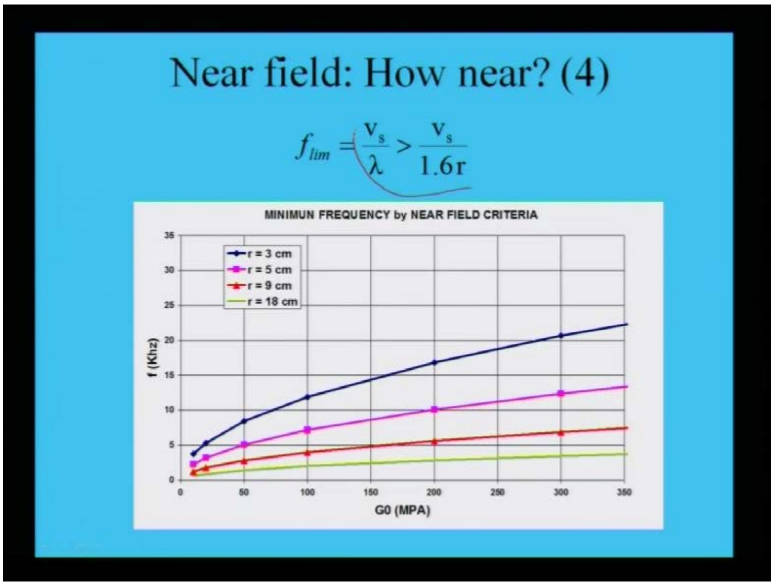

Minimum frequency by near field criteria near field, how near frequency limit is your V s by lambda, it should be greater than your V s by 1.6 r

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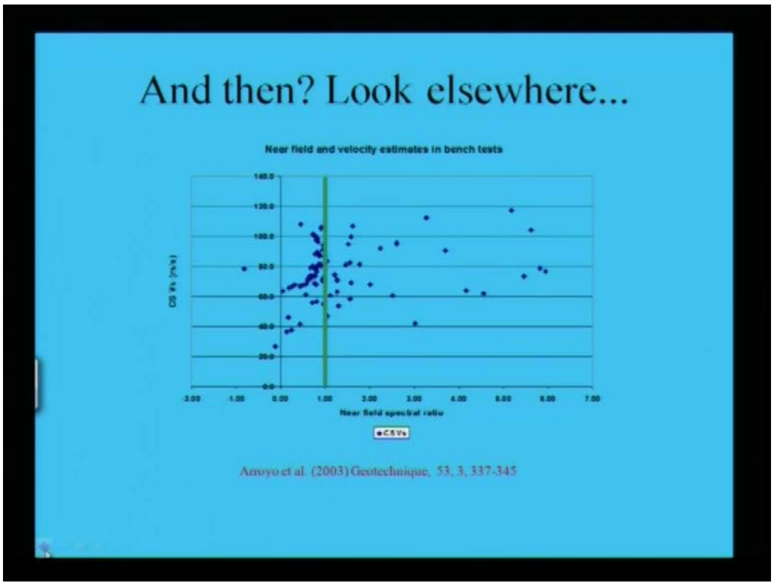

and then look elsewhere. Where elsewhere what is the then, if it is in the near field if these are the problems then looks elsewhere.

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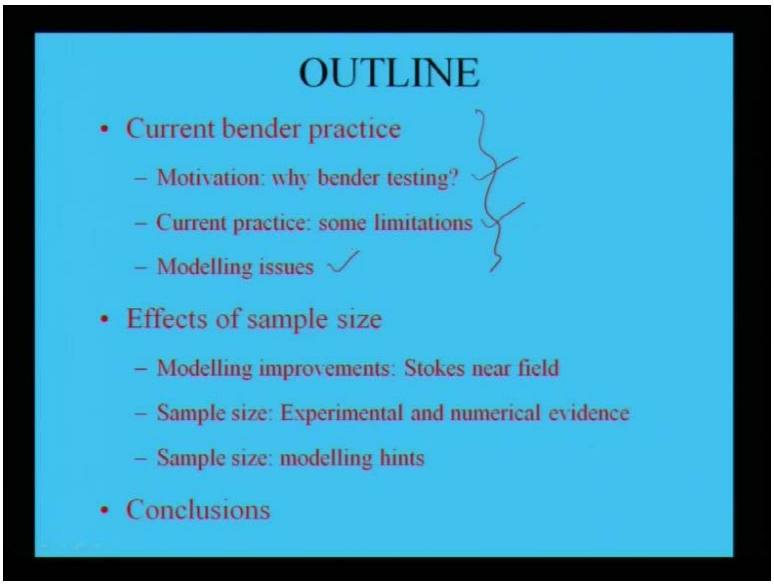

Now second part what we are talking about this that is means sampling wavelength. If you come back to this we have finished these two parts. Current bender practice means why bender testing some limitation, what are the limitations then what are the different modeling issues that we discuss in brief, then effect of sample size.

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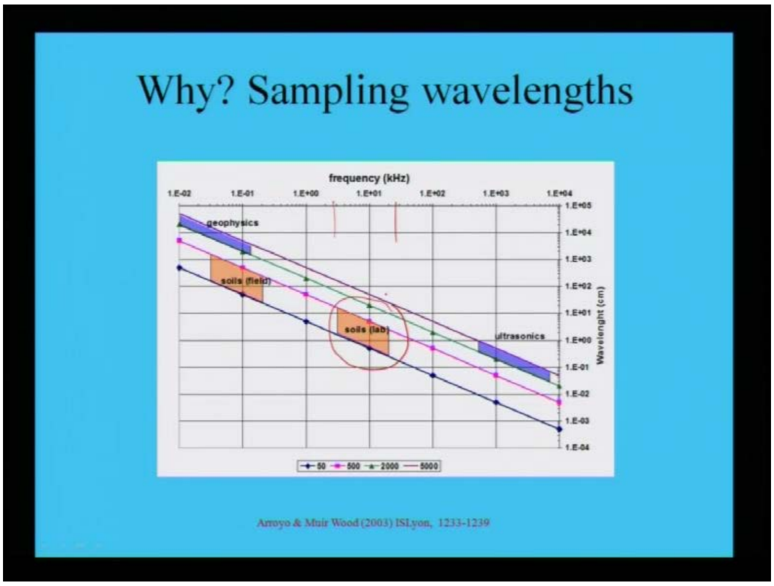

Why sampling wavelengths? If you look at the sample size look at here frequency versus wavelength my soil lab, it is lying here and soil in the field it is lying here.

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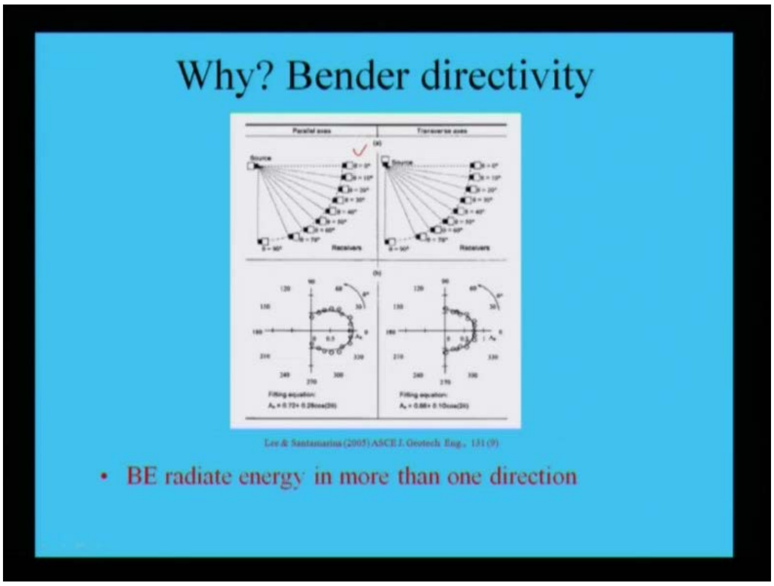

So, bender directivity why bender directivity? BE radiate energy in more than one direction, that means in the bender element in the source it radiate energy the source cannot travel like one it will radiate more than 1 direction.

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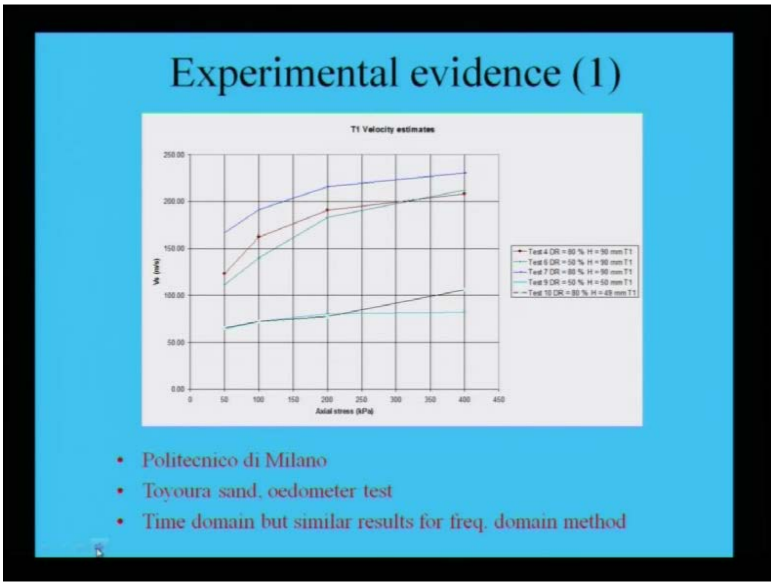

What are the experimental evidence? These are your experimental evidence of to your as and oedometer test time domain but, similar results for frequency domain method, shear wave velocity versus your axial stress.

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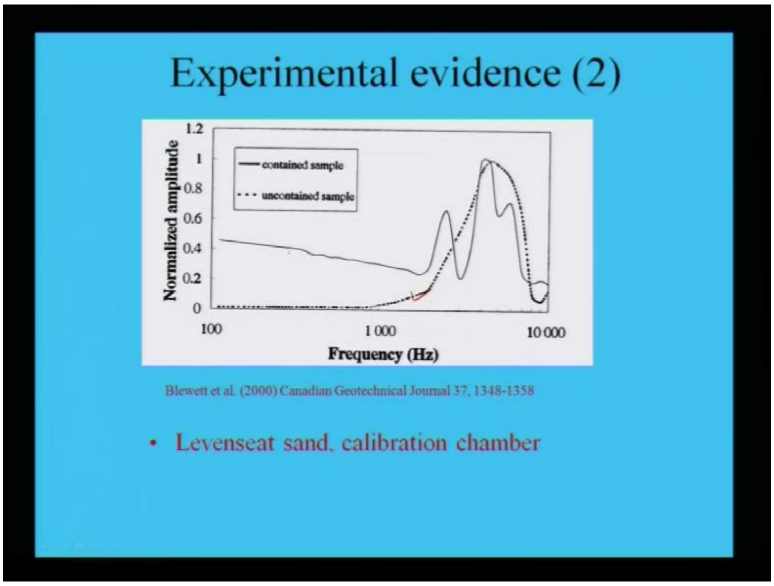

Experimental evidence 2, that means normalize amplitude versus your frequency, contained sample and uncontained sample. These are the two this is your uncontained sample, this is your contained sample.

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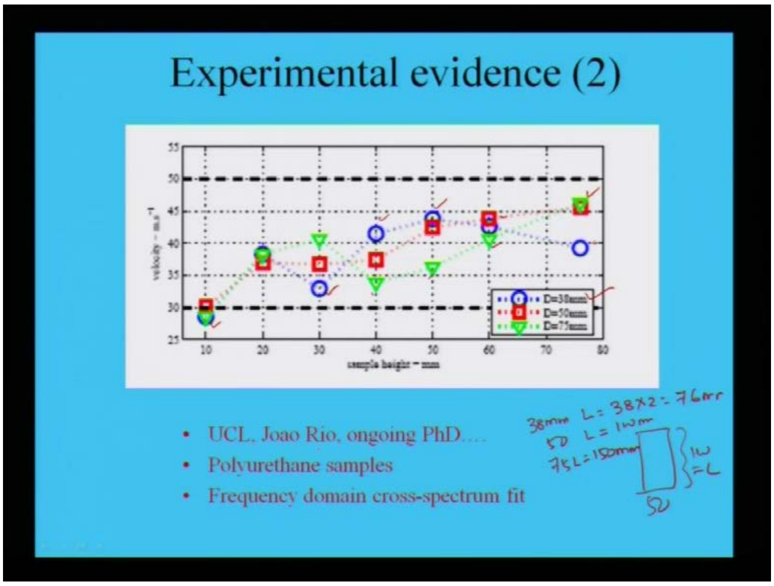

Experimental evidence 2 if you look at here velocity versus sample height as I say sample size or sample height this is your sample size.

So, this sample size if 50 by 100 this is your length so that means different diameter of a sample has been put it 38 mm diameter. 38 mm diameter means sample size length is equal to 38 into 2, so it will be 76 mm. 50 means length is equal to 100 mm, then 75 means length is equal to 150 mm. Now, sample height in mm with this velocity. This is your experimental evidence 2 if I look at here this is your sample height of 76 mm and this is your 75 mm of the sample height, how wave propagates for sample height with the time how the shear wave velocity is varying.

So, these are the if you look at here these are your effect of sample size means stokes near field then sample size experimental and numerical evidences, then modeling hints. How the modeling hints has been done particularly this part I am not discussing now I have shown these particularly why sampling wavelength. What is, why we are doing this wavelength of sampling changing the wavelength sampling particularly in laboratory. If you look at here in soil lab the frequency is varying from here to here where it is lying soil lab. Soils in the laboratory that means remolded soil sample. Soils in the field if we look at here how it is lying? Where it is lying? What is its frequency?

Now, how the bender element directivity means bender element it travel radially radiate energy more than one direction. The moment from the source inside the soil sample you allow this source to travel, it will travel more than one direction. Now these are all your experimental evidences case 1. Case two is your contained sample and evidence 3 is your with your sample size. So these are all parameters particularly if you look at here these are all your parameters means outlines we have finish what is bender element we discussed. What is the motivation? Why bender element has been used in the laboratory and what is its current practice and what are the limitations. Of course, there are certain limitations, if I will take the bender element as an input parameter in modelling what are the different modelling issues that also I discussed.

Then effect of sample size, how the effect of sample size it will affect your modeling improvements. Then sample size experimental and numerical evidence this is all about the bender element application of bender element in laboratory test to find it out shear wave velocity and once you get this shear wave velocity you can find it out shear modulus or dynamic property of soil. Now I want to show you case study.

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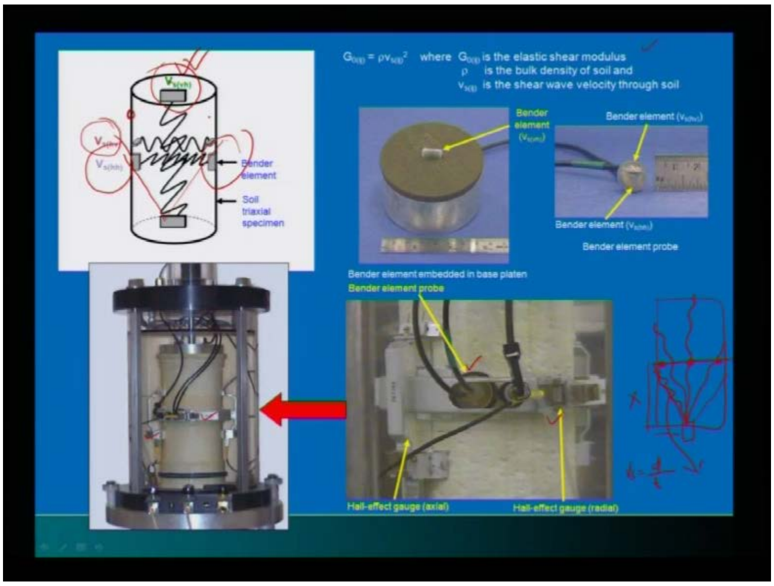

I can show you in a very clear way this is your triaxial specimen, soil triaxial specimen and these are the bender element you see, these gives your V s of horizontal and V s of means how this shear wave velocity varying. It is varying horizontally or it is varying vertically means radially you can put the bender elements across the sample radially you can put the bender elements where you can find it out V s of h h with this radial direction and V s of v h with vertical direction at the top we can put it. That means bender instead of putting bender element at 2 because it propagate this waves means once at the source you start this wave propagating, it will propagate in any direction.

So that you can measure the travel time based on the travel time receiving you can measure, place the bender element radially also vertically. Now as I said this bender element how it is placed embedded in the base platen and this is your bender element, so with this bender element you can find it out shear modulus with getting your distance ,travel distance with your time. Just a clear picture I am showing in the triaxial cell, if you look at the triaxial cell if I take this enlarged view because this is the sample this is your source bender element provided and this is your source the wave can propagate in any direction. Radiated in any direction because you have to measure this because distance shear wave velocity is nothing but, your distance travel by time that means in this case it is very straight forward means what you are getting here. Your distance is fixed and travel time you can measure particularly in this case you fix first half of the distance so that if you know this distance x if you know this distance.

So, the radially travelled the distance can be you can determine. So, that is why at the half of the section, half of the soil sample the bender element has been placed you see this is your bender element probe. If I take a bigger picture this is your bender element probe and half effect gauge, radial gauge and this is your half effect axial gauge. This is axial gauge, this is your radial gauge and exactly bender element probe is here the yellow mark is there, it has been provided. So, I can place here one bender element opposite also I can place many one here, one here, one here around the periphery I can place it so this is just to showing how the bender element has been placed. How it travel time you can measure, you can measure here shear wave velocity, you can measure here, you can measure here, you can measure here how this time receiving time means time arrival based on that and distance travel you can measure.

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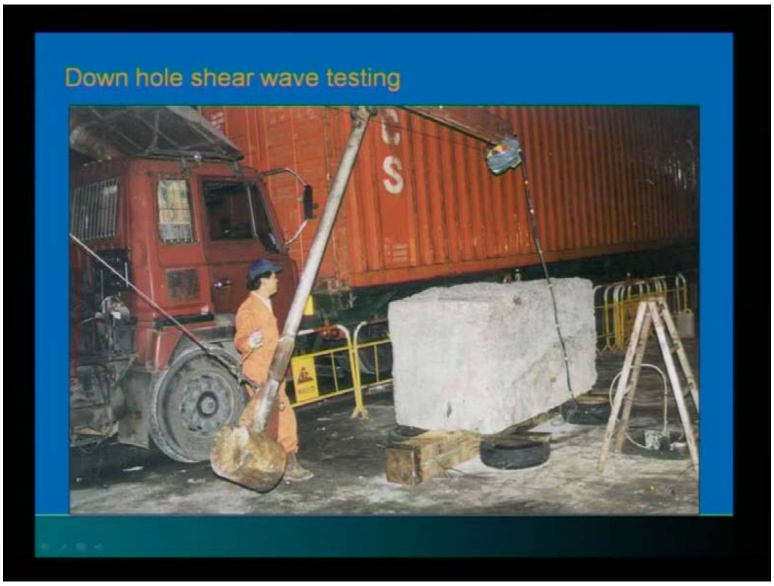

Now other thing I want to show one more slide look at this, how down hole shear wave testing has been made this is a case study in Japan. If you look at here, here is your borehole and the probe shear wave velocity probe has been inserted inside the borehole, now this is your wooden plank. If you look at here this is your wooden plank. With this wooden plank this is a hammer look at this field study what hammer, either you can hammer it by hand or you can real test you can do it. This hammer has been pulled by a trolley here arrangement has not been shown it has been pulled then this hammer will go here it will exactly hammer. Then by means of interesting case study in the Japan this is, by means of dead weight it has been placed below the truck.

You see look at the truck, one part of the truck this has been elevated this side has been elevated and this is pushed so that entire truck load will be placed in the wooden plank. So that what happen while hammering these wooden plank should not slip. No slip that means the moment I hammer it will exactly generate shear wave. If I hammer at the top it will generate the compressional wave that means p wave or sorry s wave or p wave. p is nothing but, your compressional wave. s is nothing but, is your shear wave. So, this is a typical interesting case study I want to show how the down hole shear wave testing has been done. This is a case study which has been done in Japan. That is all and tomorrow I am going to start one that is your compaction, laboratory measurement compaction curves and other part of this geotechnical lab.