**Foundation for Offshore Structures**
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**Module 1**
**Lecture 20**
**Pile Driveability Analysis 3**

You know the closed form solution using either Laplace transform or method of separation of variable is still possible but for a complex situation with multi-layer soil it is may not be of useful even if you drive. So we will directly jump on to a numerical solution wherein we are able to march forward with time and space so that every blow we can find out the stresses along the length of the pile as well the pile displacement itself.

So that we could determine when to stop driving, you know if the displacements are too small you can desire to say that pile is unable to penetrate or if the stresses are very high either the soil resistance is too high or the hammer that you have selected is too big. So that is the idea of decision making so every blow you will be able to monitor the stresses along the length of the pile as well as with respect to the time that how much dissipation is occurring. So this numerical solution is required simple.

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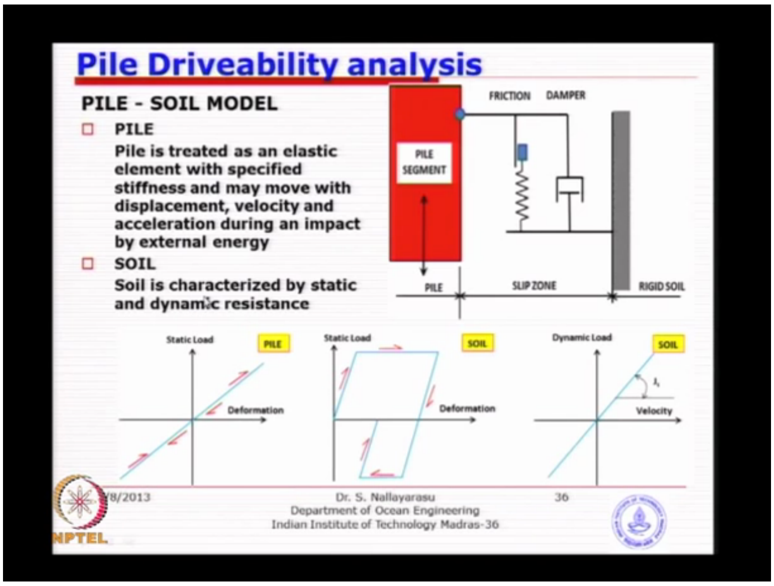


So if you idealize a pile you see in this picture take a small segment of the pile attached with a soil spring on the side of course you can also have a end spring to simulate the end bearing at the bottom and you know if you look at the overall pile length you will have several soil side springs and then one at the end with a end spring. And you can see here on the right hand side as you see normally when you drive a pile the soil in the vicinity gets disturbed and if the disturbance is so large that it actually gets the bond is broken.

But that does not happen when you go away from the pile after say 3 diameters, or 4 diameters the pile may not actually get disturbed because by the time the energy is absorbed and basically the soil remains in static condition. So that means a faraway the soil which is not getting disturbed which is considered as a boundary condition. So in between you have either a contact or no contact that is why you see a frictional spring with a limit switch.

So after it will be able to behave like a spring and if the applied load is higher than that limit load it will just disengage that means it is total failure. So elastic perfectly plastic that is the idea that proposed by Professor Smith when he was trying to develop a concept of pile driving simulation. But this is slightly different from what we have learned if you look at your TZ curve for a sandy material it is okay you have a linear like elastic distribution but it is not vertical it is just going inclined and then a perfectly plastic after I think 0.1 percent or 0.1 inch, you know.

But for clay you have a slightly nonlinear, now you strictly speaking you have to follow that but what proposed by professor Smith is in dynamic condition most of the time the soil behaves something similar like what he proposed and he has connected several test and ultimately I think for the last 30, 40 years we are using his assumptions because it is becoming very simple.

Suppose if you have taken the other assumption of nonlinear distribution of load versus displacement, the solution to the problem become quite complicated and though he assumed those days with such a simple solution even we use it now because the approximation is not too bad. So that is what we are going to see, the frictional resistance has a limit and beyond which soil will get disengaged very easy to understand.

And on the side you have a damper which is very similar to fluid damper which is going to be associated with the velocity of the movement. So the frictional resistance is basically depending on the displacement and the damper is due to the velocity or the movement of the pile along the length. So this is also needs to be taken into account because this is not anymore a dynamic, static problem is a dynamic every impact pile tries to displace, move by certain velocity and the pile component is going to have accelerative component which is going to create inertial force.

So that is why we need to have a damper which is associated with the pile velocity and basically within this slip zone this is what we were looking in fact if you go back to few classes backwards when we were looking at the pile capacity the soil disturbance due to the load applied on the pile itself is taking a shape of a bulb, you know and as the stress wave moves this bulb also will start moving down, whereas in static condition that bulb will be something very similar and when you go away from the pile the stress patterns will be the magnitude will be reducing, whereas in this particular case when you have a blow the stress waves are going to travel along the space from the pile head downwards that bulb shape will be moving downwards as much resistance created by the soil which is going to just soap in the stresses in the soil as well as in the pile.

Now how do we simulate, so that means the soil is going to offer a static resistance which is very similar to what you calculated using pile capacity calculation like you will take a clay or sandy material, alpha method or beta method which is going to offer such resistance as long as the soil is soil is not broken within the limits of the friction capacity and also the pile is going to get the resistance from the dynamic resistance generated by this damper because if the damper is good that means it is going to resist against an absorbing energy.

So we need to find out what is this component, how we are going to estimate that is the challenge actually due to this, static resistance not a big problem because you all know very well to calculate the capacity based on alpha method, beta method for soil like sand or clay. But the one that is quite though is to estimate the dynamic resistance not much literature is actually available on the soil behaviour against dynamic loading which is one of the major problem.

But as early as 70's this professor Smith proposed method some empirical method which works reasonably even today, we will be using that is why we call it this is Smith model of pile driving equation. So having derived the dynamic equation of the wave equation and use that and make assumptions made by professor Smith to adjust the values of resistance by a simple linear damper, you know those days he assumed such assumptions and even today it works several instrumented pile driving have proved that his model is very close to the reality.

So you look at this picture here on the left side is basically a simple linear model of static resistance, compression tension as you know very well when drive by impact hammer the compressive stress tries to move the pile downwards, so load is compressive and when the soil is very strong reflects the stress wave, the load induced on the soil is tensile because the stress wave is trying to move upwards.

So you can see here this part of it is trying to move the pile down and if the soil is soft pile will move down energy is work is done and final settlement will happen. But if you are driving against a hard soil for example a rock or the pile tip as much energy goes down is getting reflected that the pile will try to jump upwards by inducing tensile stress or tension force on the interface between the pile and the soil.

That what we normally happen when you are trying to drive against a very hard surface the whether it is a nail or it is a pile it will try to jump upwards that is because the stress waves are moving upwards. So you can see here it is quite obvious that the behaviour is within the elastic or within the limit it is almost very much linear and you could see how things are happening during the compression force it is for example it goes through a settlement of 10 mm, one blow and when the stress wave gets reflected it is trying to pull the pile upwards.

So the net when it comes to this place that is the 10 mm and again the reflected amount of energy brings the pile backwards, bring the net to something less than 10 mm. So every time pile goes down by 10 mm, or 20 mm, or 50 mm but then because of the reflection and it just moves up by little bit, perfectly there is no reflection that means every blow is absorbed and work is done you will see that it has to come back to this position but it depends on the type of soil and the type of hammer.

The second component so this is basically the static component what we were looking at and the second one is a dynamic component as the pile is moving down because it is associated with a certain displacement, certain velocity and an acceleration. So you can see here the dynamic component is basically associated with the velocity, so we need to link the velocity and empirical coefficient which is basically the dynamic resistance of the soil and I think if you remember having studied the dynamic foundation, foundations for moving equipments or rotating equipments you will use this.

But the constant which we call it J s is not very easy to obtain some people have done experiments. So we will use some literature on you know basically as early as 1960's Smith has collected so much of information but after that nothing much has been done in fact in this area. So we will still continue to use that value of the dynamic resistance coefficient.

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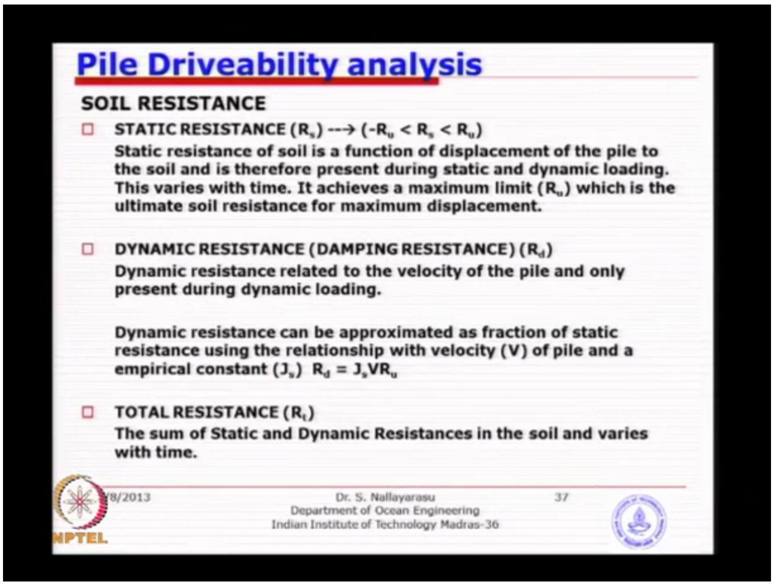


So how do you get the total resistance is the summation of static resistance plus the dynamic resistance. So static resistance can be from the ultimate resistance that we have calculated for pile capacity using API methods or other methods can vary from positive R u to negative R u that means it can be compression or tension which can be either way and this R u can be different form our capacity because the reason I explained clay can actually degrade or sand can increase the resistance during deriving because of the obvious reason that the soil gets densified.

So it does not mean that R u is a static capacity R u is the soil resistance during driving it can be lower or it can be higher than the static capacity that you have estimated depending on the type of soil and the disturbance that it is generated. So you have to be little bit careful this is R u is the resistance against driving and it is a static component.

The dynamic resistance is Smith proposed a simple idea that let us relate with respect to the pile movement which is basically the velocity multiplied by a simple coefficient to adjust so what you did actually is he was trying to measure the dynamic resistance using an experiment and the J s is a coefficient he was adjusting in terms of R u, so you take the R u which is static resistance. So certain percentage of that is going to come as a dynamic resistance and that is what he was trying to do by adjusting this coefficient which will be using in our analysis. So the total resistance is the summation of static resistance which is this plus at any instant of time you have cumulatively add.

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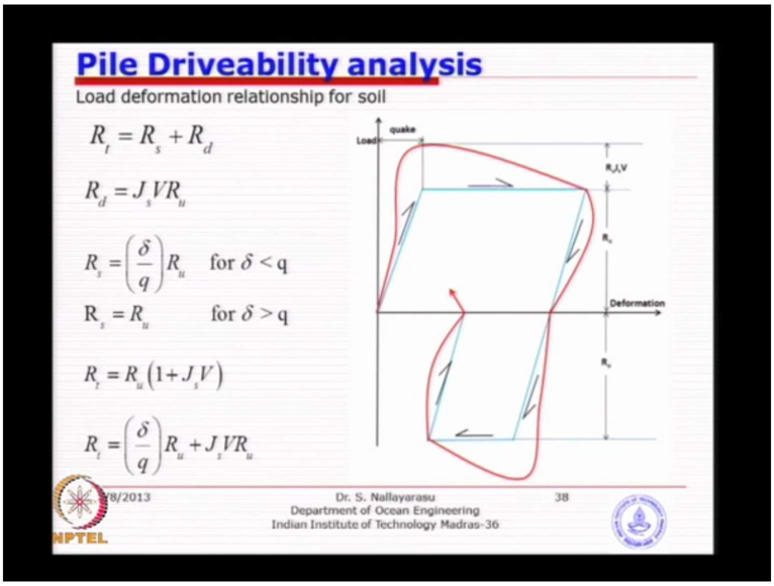


So if you draw a picture of that blue line what we were earlier looking at as static resistance is basically shown in this diagram together with a dynamic resistance, dynamic resistance is simply the multiplication of velocity times the coefficient of the dynamic resistance J s and the R u whereas R u itself is a static resistance, so when you just do a summation of this substitution of this finally you get this so is basically 1 plus J s V or you can have it separately.

But one thing you need to remember this diagram when we look at T z curve for sandy material, exactly almost similar like this it goes like that and straight line .So the value of displacement that makes the plastic deformation of the soil with respect to the pile interface is called quake or in fact in our T z curve we took it as 0.1 inch and for clay material it was something similar I think.

So basically the quake value or the value of the displacement at which the soil static resistance becomes constant, you know basically it is becoming a plastic deformation and that is that is what we need to give as a input to the methodology that we are going to use because this the larger this value is the pile is going to actually behave softer that means it is going to go very faster, the smaller the thing smaller the value of quake that means the resistance is going to be or the pile moment is going to be smaller.

So this will be one of the input that we need to determine at what value of quake the deformation becomes permanent. So you can see here the dynamic resistance is proportionated as R u times J times V and the static resistance we are trying to model this line and this line basically delta by q this and the horizontal line is this R u, so R s for delta value greater than it is quake value basically a constant, so it is a two segmented model which will be easy to program in computer programming.

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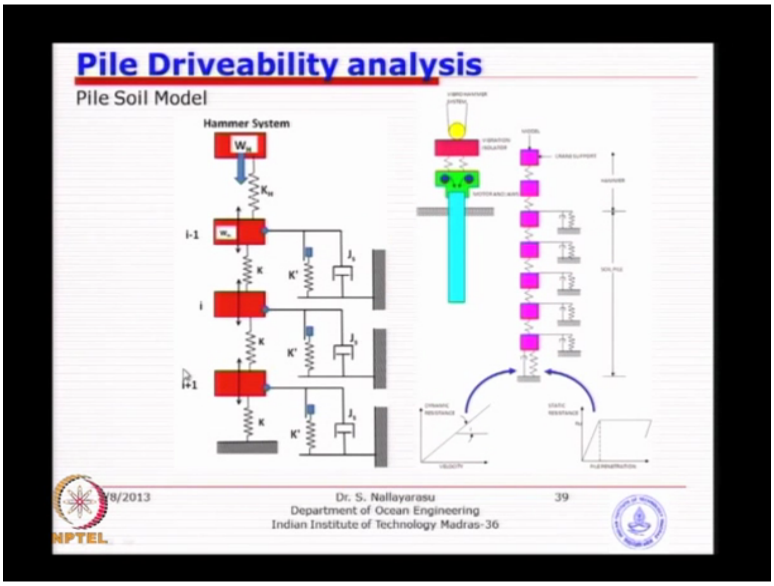


So what actually is being done in this numerical model is to divide the pile into several sub segments including the hammer component for example if you look at the top one is a hammer and denoted by a spring value which is K h and the remainder part of the pile is divided into several sub segments with associated springs. Now this K values not necessary that it will be same because if you look at the practical applications you will have different wall thicknesses of course not different diameter, different diameter means not very good.

So remember all the piles will have outer diameter same, you know why because if you have a stepped diameter. For example what will happen when you drive the pile some portion of the pile surface will have the contact, some portion of the pile will not have contact. So your pile capacity will not be very good, in vice versa when you have a smaller and bigger driving becomes problem you know basically you will have a increased resistance.

So always remember all whether it is onshore, offshore or coastal pile outer diameter will be flushed that means it will be a continuous single line surface. Suppose if you have a wall thicknesses 20 mm here, 50 mm here, 100 mm, the inner wall thicknesses will change that means the surface will not be uniform in the inside, outside will be. So you have to make the pile in such a way that the outer surface will be, because we know very well the piles are going to get plugged for offshore conditions.

So once it is plugged you are not worried about the internal friction whether you are going to really get it or not. So most of the time we design the pile in such a way that or fabricate the pile in such a way that outer surface is outer diameter is constant, inner diameter can vary depending on the wall thickness. So in such a case what will happen is the stiffness values which is basically axial stiffness in this case we are not worried about bending stiffness because it is mostly axial problem.

So how do we calculate the axial stiffness, you have a segment length of say 1 meter of something, so A e by L you can calculate what is the stiffness and input into this value. So basically this K value what I have shown here as constant not necessary that it will be constant for a realistic problem, you may have actually stiffness values varying along the length and this whole problem is written in such a way that you need information for the next element you need the information about the previous element and the current element.

So you can use a several iterative schemes whether Newton Raphson or other methods you can merge forward, so that is the idea. So any time you will be looking at three elements in consecutive location. So you can just step forward. Similarly in time you know if you know past time step you can calculate the next time step using the present time step values with an approximation and do an iteration until the present time step and the next time step the difference is within an acceptable limit.

I think most of you will be familiar with this finite different scheme once you start programing something yourself that it is a very useful scheme because what we are trying to do is we are trying to go and compute the unknown with the known values of the past with certain assumptions and then try to do adjustments in such a way that the difference between the estimated value and the value that you have in hand is smaller or within the limits of your accuracy you are looking at, if your accuracy require is larger than you keep on doing iterations until your acceptable limits come sometimes the solution will converge some of the problems and if the problem is slightly complicated you may not get convergence. So you need to look at what parameter will need to be adjusted.

So there are several classes of problems, some class of problem straight away within two interactions you will get the answer, some class of problems you may not get even convergence so you need to look at carefully. So this particular problem most of the time we get convergence but some cases when the soil is very soft we do have problem even these computer program does not converge. So you have to adjust parameters sometimes we actually artificially adjust the parameters to get convergence because this is a iterative solution.

So you see on the side the K is the pile spring K dash is the soil spring, you know just very similar to what we learned few classes back you know linear spring, I think when I was drawing a nonlinear T z or T y curve and you just straight away join a line the delta divided by the load or P divided by the delta will give you the spring value. So similarly you could calculate the soil spring with a limiting value of quake and on the sides you have a damper soil damper which the only value that you need to know is the damping coefficient for a different type of soil, different type of condition it could be skin friction damper or it could be end bearing damper and it could be for sand and it could be for clay, so there is four numbers of values are required so what you need to understand.

So each of this is modelled by which we were discussing about the associated resistances, so once you define all these variables what we require is the starting condition and then we can just merge forward and that is what the solution I am just going to discuss.

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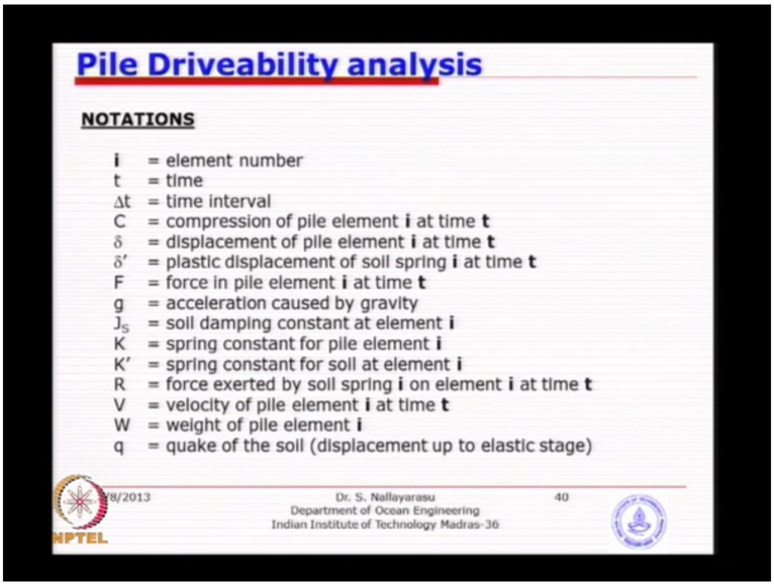

The variables that we need to remember is the element number for example the current element which is this one time and delta t for example when you blow a hammer on top of the pile how long it takes for the stress wave to travel down and then reflect back will be a very very smaller time. I think you must be knowing the transmission of stress wave into the steel material is very very fast and basically within fraction of second it will go and come back.

So we need to have a delta t computed in such a way that if your delta t is very large even before you go to the next step already the reflected wave has come. So your computational iteration will not converge because your delta t is so large, if your delta t is too small what will happen it will take a long number of iterations before you see a convergence solution. So you need to find out what will be the best estimate of delta t which will make the solution to converge quickly and that is something based on experience several suggestions have been given by the literature mass publications, so we will be using exactly what they were being doing it.

And then C is the compression pile element at time t for ith element, so the displacement of that particular element for a particular time. Similarly all other variables delta displacement of pile element this is basically the elastic compression because of force divided by area you find out the stress and then you find out the strain and you find out the elastic compression. This is displacement because the soil has given away certain amount of so this.

Then force in the particular element at the time t, gravitational acceleration, soil damping constant, spring stiffness of the pile, spring stiffness of the soil interface and then force exerted by the soil spring because of the resistance and then the velocity and the weight of the pile and the limiting quake value. So you see here a set of values some of them are known, some of them are not known but we need to do an estimate. So how do we start is a very interesting thing.

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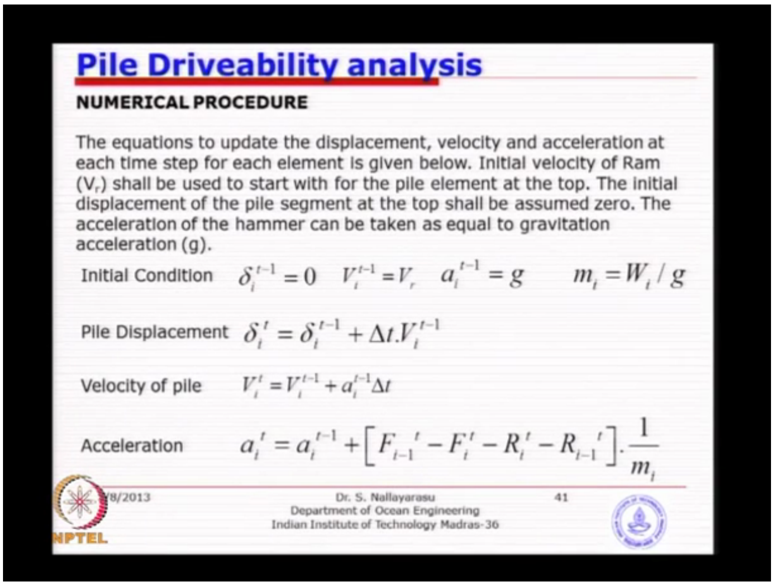


So if you look at the starting time initial conditions, initial velocity of the Ram you know basically you have a hydraulic system which lifts of the Ram, Ram is nothing but a large weight just a piece of metal it goes up and then allow to go down by gravity just freely. So it has got its own velocity which will be known by the hammer manufacturers details. So you can assign at least the velocity which is known to us because that is what the speed it at which it coming down and hitting.

Suppose if it is a gravitational effect only because you just lift it off, release it and is easy to compute you can find out from your weight of that the Ram itself or if it is a double acting hammer both sides it goes up, down by hydraulic pressure then you can calculate from the manufacturers details. So that value of the velocity is known which is called a V r, V r is a velocity of the Ram or the metal piece falling down.

And initial condition that delta basically is definitely 0 because before striking the pile head is not at all moving, is it or not. So it is just in static condition. And at that time the pile element is subjected to gravitational acceleration which is no external forces. So the pile element is only subjected to just the g value and the mass of the element is the weight of that element divided by g. I think all these four parameters are very clearly known.

Now we can start forward marching basically the displacement of the pile, the displacement of the previous time step which is basically 0 because we only start right now plus the delta t which we need to estimate what will be the best to delta t multiplied by the velocity at the previous time step which is already known because just at the time of striking we have the velocity of Ram. So this is one way of just trying to find out what could have at the time of striking what is the movement of the pile segment.

Similarly velocity of the pile can be updated if you have the velocity at the previous time step multiplied by your acceleration times the delta t this acceleration at this time is basically the gravitational acceleration which is already known and then you also update. So you can see the sequential update of each parameter from a starting value to an updated value and basically that is the idea behind the this is the procedure is exactly same where any type of problem finite different scheme is like this.

And then the acceleration also can be updated with the previous time acceleration or the previous time step and if you can somehow estimate the forces induced on that element divided by the mass, you know very well force is acceleration times the mass. So that is what we are trying to do. Mass of that element is known from the weight which you already have divided the element into several sub segments divided by g give you the mass.

So this so one of the biggest problem is how do we estimate the force induced on that element which we were trying to derive earlier on the static component. So this you can see the force induced on that previous element to the current element that means if you have a element in the middle this previous element your balance force only is going to act. So that is what we need the difference.

So this is ith element, this is i minus 1 element just the element before and similarly on the resistance generated by the soil so the differential force is going to act on it and the mass associated with it is m i. So now we need to find the way of finding out because once you find this you can actually go back and then do an iteration and set a differential value. For example that displacement computed in the present time step to the previous time step I want to have a tolerance of 1 mm. So until 1 mm is achieved I will keep on doing the iterations and basically every time step I will be updating this computed force value, computed resistance value and keep adjusting that.

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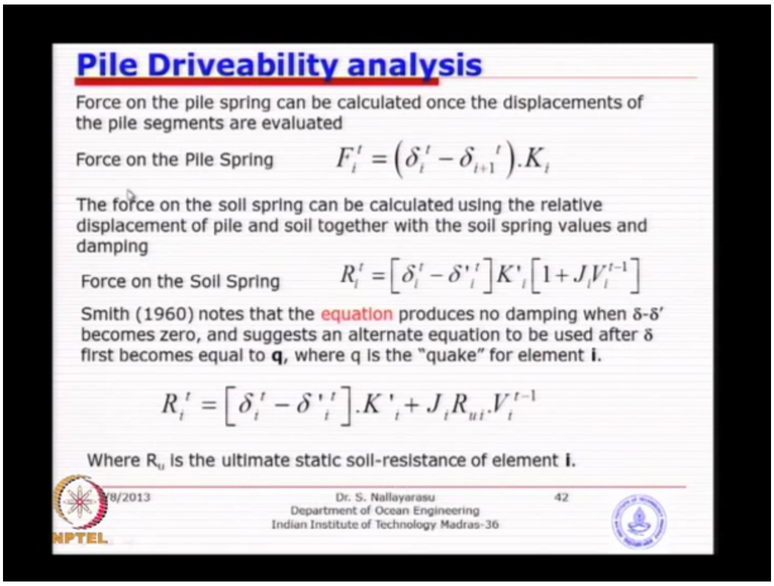


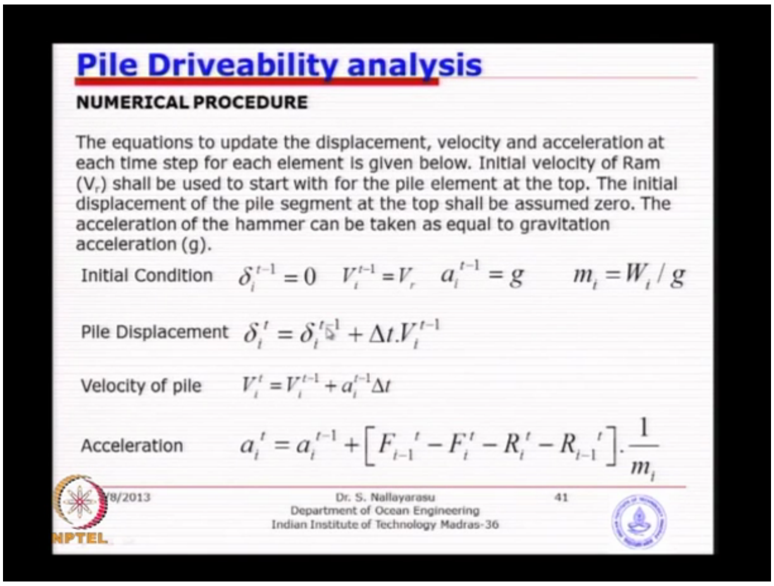


Now the methodology of computing the values of F is somewhat several methods are available, originally proposed by Smith and then quite a lot of modifications and if the software company is developed by 3 persons actually, they have published several in fact they were also consultants as well as well as teaching professionals they have published several papers on various methods of doing this estimation of this forces because some of the methods takes large number of iterations before convergence, some methods can easily converge in two or three iterative steps. The one adapted here in fact I am trying to explain is from that software manual where they use this method.

So force on the pile spring is the K i which is nothing but your spring stiffness of that particular element which is you know the cross sectional area and the modulus of elasticity and the length of the segments we can calculate that multiplied by the displacement of the next segment i plus 1 segment from the current segment.

So basically what we require at the both of them are at the same time step you know it is not that from the previous time step. So what you are going to do is from the previous time step already you have the values and you can take that value and then deduct the difference between the displacement between the two subsequent segment either you can for a forward or sometimes you can use i and i minus 1 either one you can use it what we require is the differential settlement of the pile say the segment that you have divided multiplied by the corresponding pile spring will give you the force due to that particular pile segment.

Similarly you can calculate the force due to the soil spring which is the resistance again similar idea but one of the problem is how do we estimate this. So what was proposed by Smith was you see the soil spring which is K dash which is available to us and then we have a two component one is the static component which is associated with R u and the second component is associated with the dynamic resistance which is J times velocity, velocity is of course known to us from the previous time step and one of the problem is a combined form you have displacement, you also have velocity.

So here if you actually make the displacement 0, so what happens is the total resistance offered by the soil is 0 or either way if you make the velocity 0 then it is only a reduced component that way is correct. So only when displacement becomes 0 this becomes not a good solution that means your iterations will take a longer time and what was the proposal was to separate that static component separately and the dynamic component separately so this is the form that is currently being proposed basically soil spring is associated with the displacement and the dynamic resistance associated with the velocity.

So the current time step if you know the values of all the parameters in the current time step only velocity from the previous time step because we are calculating the velocity after the calculation of displacement. So that is why we will have the previous time step. So once you calculate the force due to the soil and the pile spring you can go back here because the previous time step is already known the current time step you can calculate at this time and update the value of acceleration and then again go back and you just repeat this time step repeat this step within that particular element until the tolerance is achieved once you do that then you go to the next element.

So basically this iterative scheme you can see here as early as 1960's in fact no change has happened over the last 50 years we still use this method of course some researches happened in US but not much of improvement specially in the scheme itself because some people have tried to do finite element solution instead of finite different scheme but convergence was a major problem in finite element scheme and in fact has not been proceeded. So all over the industry we have only one program which is working on this basis of.

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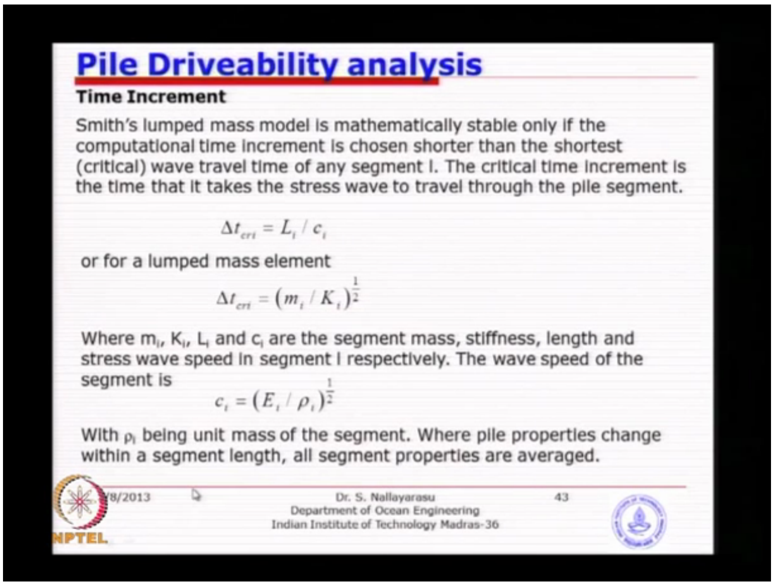


So the time step increment what was proposed by Smith was something like this the delta t critical is the length of the pile divided by the velocity the c and the velocity is estimated by length the modulus of elasticity divided by the density of the material. So you can see it is very similar to our sound propogation problem you know it is very very similar. So you can find out using either this or this whichever is actually governing which is smaller normally used in the program, in fact this particular program having an option you can go by method one or method two but by default we actually leave this method of lumped mass approach because in any case we are dividing by several sub segments, (this is not required).

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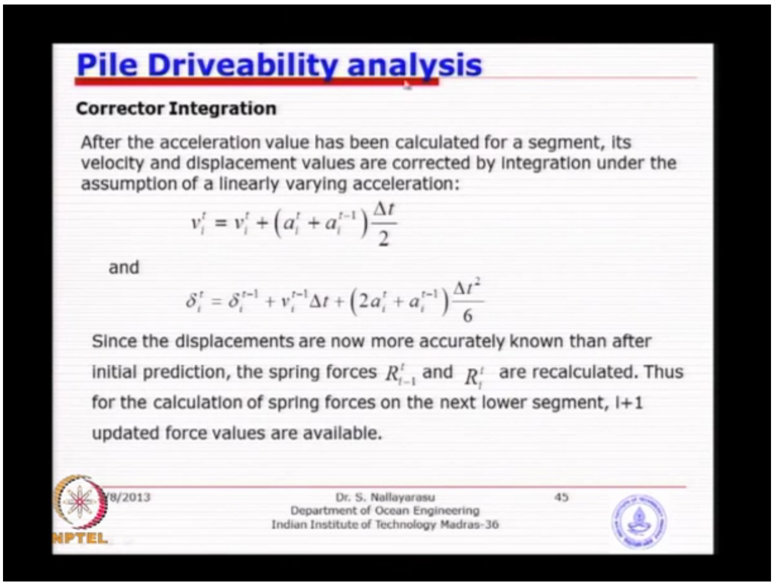


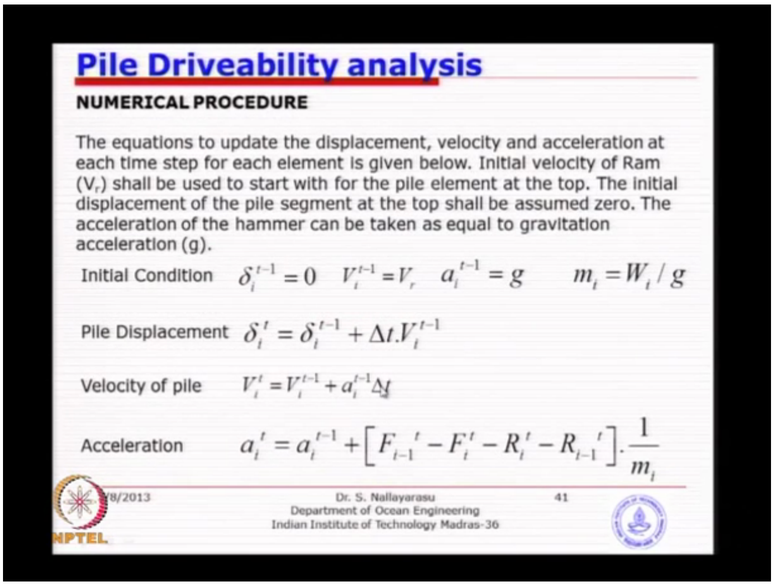


And one of the problem found by this JRL actually I forgot the name of three persons each letter stand for one person, three of them developed this company and the software, they have published some papers wherein they found that the adjustment or so called character which will make the convergence very fast instead of hundreds of iterations in within few iterations they can get the solution, only for updating the velocity and displacement.

So what they are proposing is velocity at that current instant of time is plus updated by delta t by 2, you know instead of if you look if you look at comparison of that and previous one you see here is delta t and basically the half time integration. So that is one of the proposal where they have given and also the acceleration is taken from two time step, one previous time step and the current time step and the displacement also is taken in a second order (())(33:34) so that the iterations can converge quickly. So this two also integrated into the computer program which we are using so this is one of the study work in one of the ODC paper.

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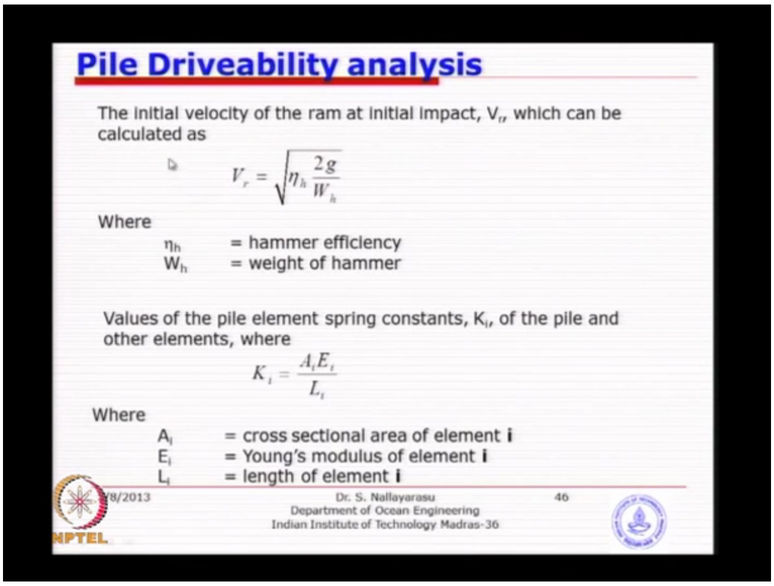


And the initial velocity as I was talking about earlier on you can find out the Ram velocity using this root 2g by W, which is very simple and the stiffness values for your pile is A E by L, stiffness value for soil we have to get it from your T Z curve which is linearized into a very single line, both for soil like sand and clay because for clay it is almost not exactly linear it may have a slight modification but still the assumption is we can use a linear.

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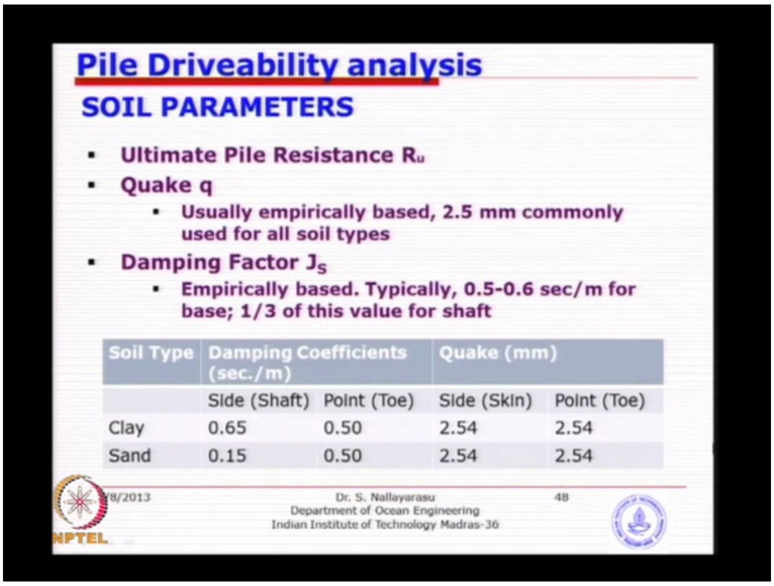

The next one is the values of the damping coefficient which is what is unknown. So you can see here there is a table as given here, damping coefficients for side and point and the displacement values. So you can see here clay is 0.65, sand is 0.15 the unit of this is second per meter and for quake values which is the definition of the displacement at which soil becomes plastic deformation is almost irrespective of type of soil, it is proposed that 2.54 mm which is very obvious that I think for sand we are taking 0.1 inch if you look at the T Z curve we take 0.1 inch, so that is exactly is reflected here unfortunately the problem is it is not 0.1 inch for clay but then that was assumption taken earlier because of the disturbed soil during driving and we still continue to use this because there is no updated information even recent times we still use these values.

But the damping values you can see here for clay and sand considerable you know difference but for end bearing not much of difference. So these are the values that you need to remember to apply when you are developing numerical scheme for the pile driving.

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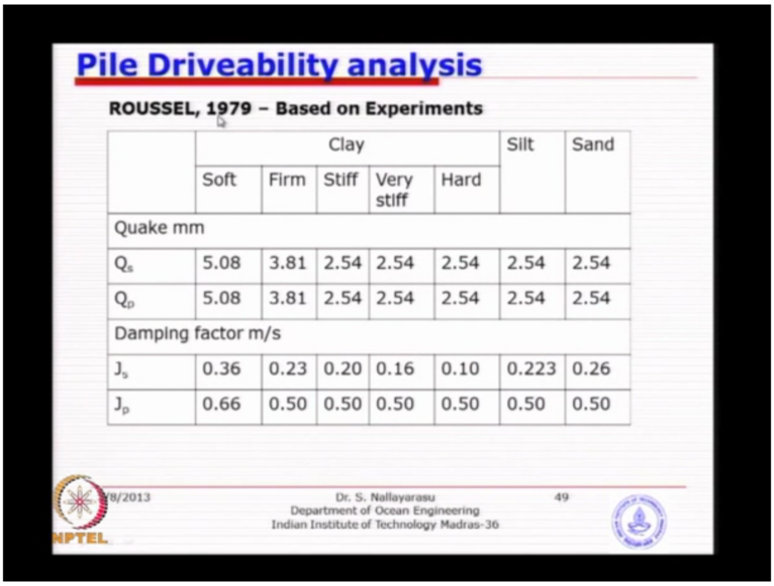
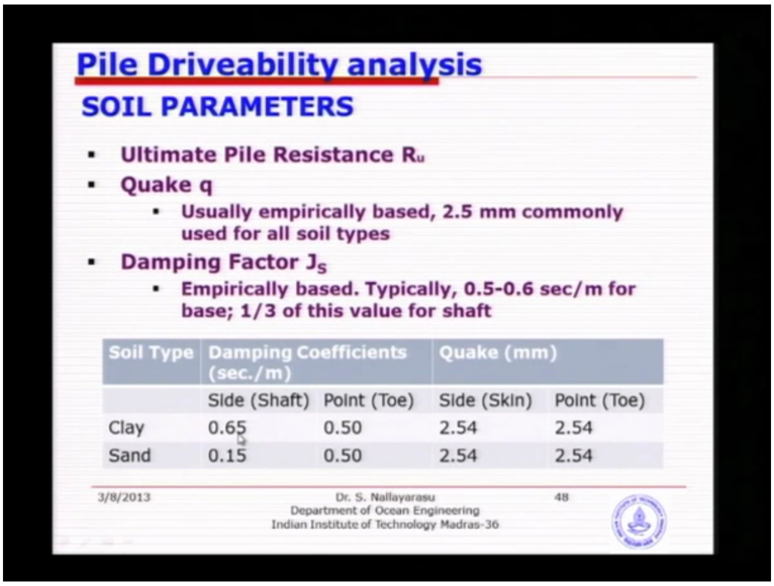



| | Clay | | | | | Silt | Sand |
|---|---|---|---|---|---|---|---|
| | Soft | Firm | Stiff | Very stiff | Hard | | |
| Quake mm | | | | | | | |
| $Q_s$ | 5.08 | 3.81 | 2.54 | 2.54 | 2.54 | 2.54 | 2.54 |
| $Q_p$ | 5.08 | 3.81 | 2.54 | 2.54 | 2.54 | 2.54 | 2.54 |
| Damping factor m/s | | | | | | | |
| $J_s$ | 0.36 | 0.23 | 0.20 | 0.16 | 0.10 | 0.223 | 0.26 |
| $J_p$ | 0.66 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |




Some studies done by Roussel is basically he did instrumented pile testing in middle eastern areas where he was trying to develop for different types of soil and the values of quake and damping that is the only paper available within last 30, 40 years. He has try to come up that for sand this 2.54 is good enough which is what we were having our T Z curve. But for soft clay the quake values are almost double, so that is the only paper available.

But it is not substantiated with large number of measurement because he has done only one experiment. So that is why several times we are reluctant to use this because if you make a mistake in this what happens is your hammer selection becomes wrong because instead of 2.54 you use 5 mm it obviously proved that the pile can be driven even with a smaller hammer and that will become a potential problem.

So that is why unless is proven in that particular area of locality you cannot use this. So this paper is recognized in that area where the soil behaviour is something similar. Similarly you can see here the damping values have a considerable differences specially on this skin we can see here for sand it is 0.26 and then the soft clay is 0.36 and the hard clay or stiff clay have a lower value comparing you can see here a constant value of 0.65 versus 0.36 all the way to 0.1, so you could see here considerable difference instead of 0.65 versus 0.1 and 0.36 whereas end bearing not big difference because most of times we use the 0.5 value and he also suggested a similar value except for very soft clay it is slightly a bigger.

But many occasion we do not use this but if it is proved in that particular locality for pile driving then it is recommended to use the values given by Roussel you have to use this otherwise we will use a standard values which is given by API, these values are also recommended by API so we should be using these values.

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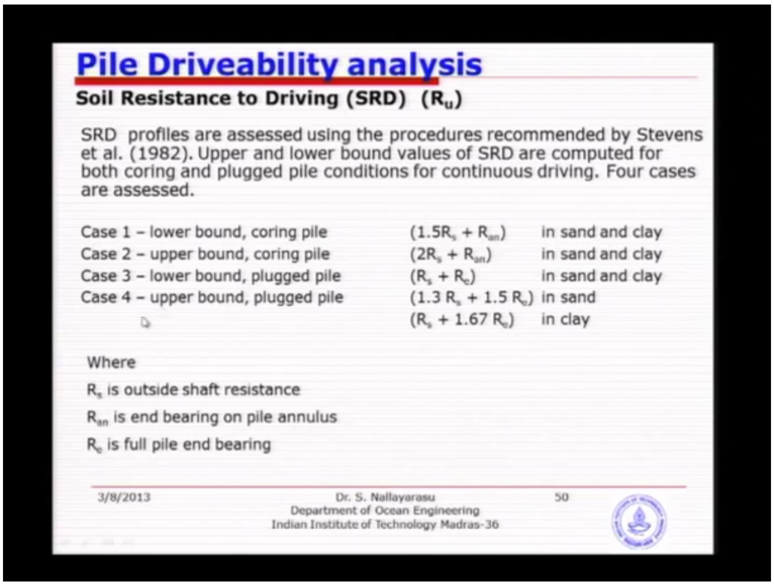


The next one what we were looking at the discussion on the pile driving resistance which we were looking at static resistance and dynamic resistance, dynamic resistance in anyway is not going to be the estimation by yourself because the values of the J has to be in available and automatically is calculated at every time step the velocity which we were doing an iterative scheme, once the velocity is known J value is known and static resistance is multiplied to get the dynamic resistance.

So what we are going to focus here is the estimation of static pile driving resistance, there are 4 cases you can see here case 1, 2, 3, 4 lower bound, upper bound, lower bound, upper bound, one is the coring pile, another one is coring is nothing but your unplugged pile you know you have a internal resistance, outer resistance and annular end bearing. Our plugged pile is basically with a external skin friction with a end bearing.

So there are 4 cases, in fact Professor Steven has conducted quite a number of tests in the Middle East again this particular location is calcareous sand. So he proposed a methodology like 1 and a half times the resistance due to basically skin friction and 100 percent of annular end bearing. So basically this for lower bound estimate, for upper bound estimate 2 times the skin friction and 1 times the annular end bearing for sand and clay.

And lower bound for the plugged case will be 100 percent skin friction and 100 percent end bearing and last one has got two options only for sand and clay for slightly, 30 percent increased for skin friction in sand and 50 percent increase in end bearing and then vice versa here skin friction is 100 percent and so these 4 cases he did study and did the pile driving monitoring time and he was proposing that these methods predict similar capacity in that area but does not mean that this method is 100 percent to be applied to all other areas unless the soil profile is like a calcareous sand.

So this particular location he was trying to do that but most of the time we do agree with the increased end bearing resistance because of the reason I was talking about when you drive a pile against a sandy material the soil gets densified as you go down the more and more compaction happens, in fact for compaction a sand we actually do a vibration so that is exactly the idea.

So the bottoms forms with the soil plugged which is densified in material so the next time when you try to derive the pile become very difficult to penetrate. So the agreement is increased end bearing resistance is correct but increased skin friction not always correct. So that is why when you develop a design requirement for your own pile driving methodology you have to look at the soil whether I should increase from static resistance or reduce from static resistance is to be decided by the geotechnical engineer for that particular location rather than simply applying the methods that somebody have developed for a particular location, most of the cases for you know west coast, or east coast we normally degrade the resistance to driving which we call it SRD which is basically soil resistance to driving will be a percentage of the static resistance. If you have 100 percent static resistance it takes 60 percent as the resistance to driving for most type of soil like clay, if it is a sand you apply slightly increased end bearing may be 70 percent or 80 percent higher.