Foundation Engineering
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Lecture - 36
Pile Foundation – X

So, last class I have discussed about the pile load test and previous classes I have discussed how to determine the load carrying capacity of pile under compressive load by using static formula.

So, today I will discuss first about the dynamic formula by which we can also determine the pile load carrying capacity of driven piles. Because piles are driven piles or applied hammer blows by which it is driven into the soil and that based on that hammer weight, height of fall and the amount of penetration, we can also determine the loading carrying capacity of the pile.

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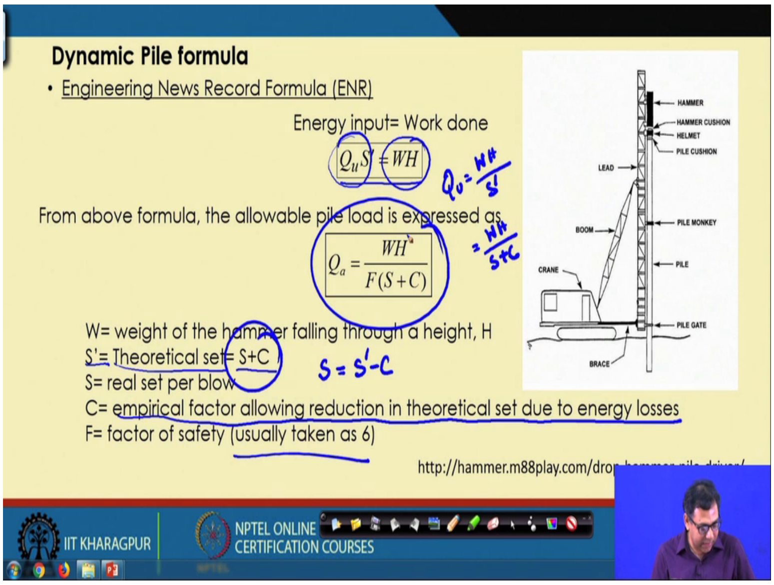

So, the first of formula that or the method that I will discuss is the engineering news record formula or ENR; so, these are called the dynamic pile formula. And so as I mentioned so this is a particular pile driven set up. So, where this is the hammer which is apply; this hammer is hammer blow is applied on the pile to drive this pile into the soil. So, this is for the driven pile and the height of the free fall and the weight of the hammer blow; hammer that is used to determine the load carrying capacity of the piles.

So, first this expression where it is assumed that the hammer efficiency is 100 percent so; that means, the energy input is equal to work done. So, there is no energy loss is assumed; so, this is S is the amount of penetration is S dash is the theoretical penetration. Now what is theoretical penetration?

Now, you can see that there is a term this S dash which is the theoretical set and then S plus C. So, when we are applying hammer blow on the pile; so theoretically that we know that this much of penetration will happen; so, that is called the theoretical penetration. But actually that much of penetration is not occurred due to some energy loss because when you are applying the hammer on a pile; so, there is a possibility that the energy that we are assuming it is this energy input is equal to the work done.

And based on that we know that much of penetration will occur, but that will not occur due to the some energy loss. So, that is why we will get the actual penetration S is equal to the theoretical penetration minus C; C is the empirical factor allowing the deduction reduction of the theoretical set due to the energy loss.

So; that means, that the amount of energy that suppose to transfer is actually not fully transfer. So, they exists some amount of losses because we are applying hammer blows on the pile; so, these may create some losses of energy. So, because of that the actual theoretical penetration will not occur; so, the real penetration that will occur in less than that. So, S is that real penetration for per blow; that means, when we are applying the blow; there will be a penetration or the amount of penetration of the pile into the soil. So, that is the real set or the penetration per blow and C is the empirical factor allowing reduction of the theoretical set due to the losses.

So, that is why the actual our equation is the amount of hammer weight into the free fall that will be equal to the load carrying capacity of the pile into the penetration because this is the energy input and this is the work done. So, work done is W into H and the weight of load carrying capacity of the pile into the penetration theoretical set is the that will equal if there is hammer efficiency is 100 percent that. So, that is why ultimately that we will get the, this is the ultimate load of the pile, but allowable load will be if I divide it with the factor of safety.

So, from here we can write that Q ultimate is W into H divided by S dash ok. So, S dash is a C S plus C; so, this will be W H divided by S plus C. So, the allowable will be you if we apply factor of safety into the ultimate. So, the factor of safety generally is taken 6; so, this is the total formula if I use this formula, we can get the allowable load carrying capacity of the pile.

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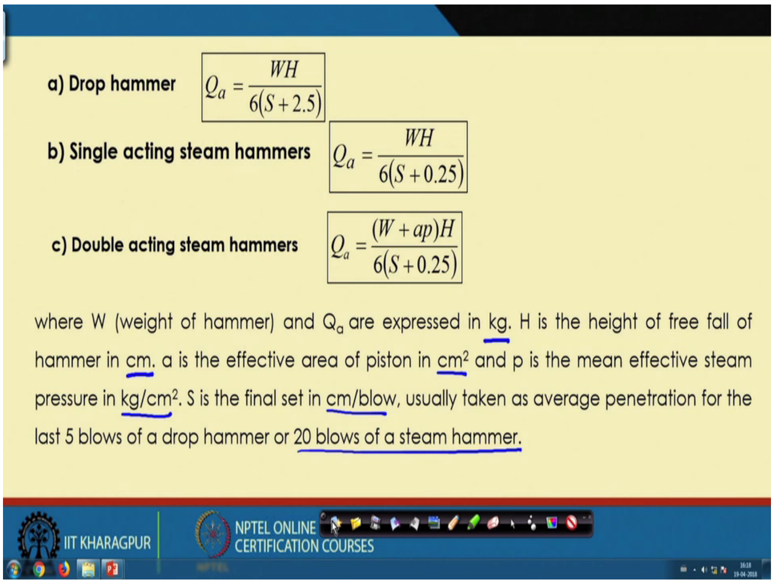

So now for different cases; so, if I use different hammer, so, then this we can use the different expression. So, for the drop hammer this is the expression where the C value is 2.5. Now as the if as I mention generally it is taken as 6.

Now, single acting steam hammer; so, this is the different hammers. So, single acting steam hammers where this is S is C is 0.25. And for the double acting hammer, so, this is one another expression is used a into p where a is the effective area of the piston in centimeter square and p is the mean effective steam pressure which is kg per centimeter square. So, these are the because we are opting the steam; so, that is the effective mean steam pressure.

Now, one thing you should remember that these are the empirical these are expression where the actual unit you have to use. So, remember that W is kg and free fall of hammer is centimeter, area is centimeter square, pressure is kg per centimeter square and set is centimeter per blow centimeter per blow. Generally the average penetration of last 5 blows for the drop hammer and 20 blows of steam hammer are considered as the S value.

So, the S value is the we take the total penetration of last 5 blows and then take the average of those 5 blows penetration or the set to calculate the S for drop hammer and for the single or the for the steam hammers; we consider the last 20 blows penetration average as the S value.

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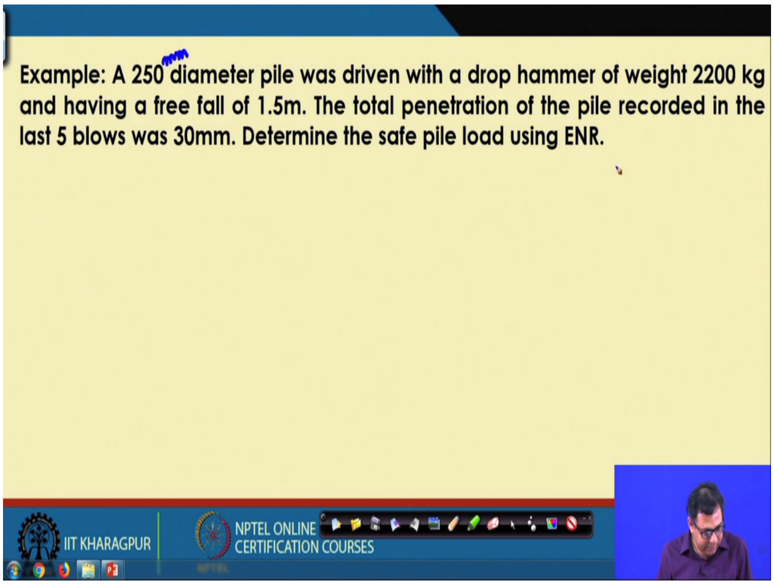

So, now I will solve one example problem which is that a 250 millimeter diameter pile; so, this is 250 millimeter diameter pile was driven with a drop hammer of weight 2200 kg and having a free fall of 1.5 meter. The total penetration of the pile recorded in the last 5 blows where 30 millimeter; determine the safe pile load using ENR ok; so, that method that I have discussed.

So, remember that here the; if you go back to that equation that we will use the drop hammer. So, we will use this expression WH divided by 6 S plus 2.5 and W is in kg, H is in centimeter and S is in centimeter per blow.

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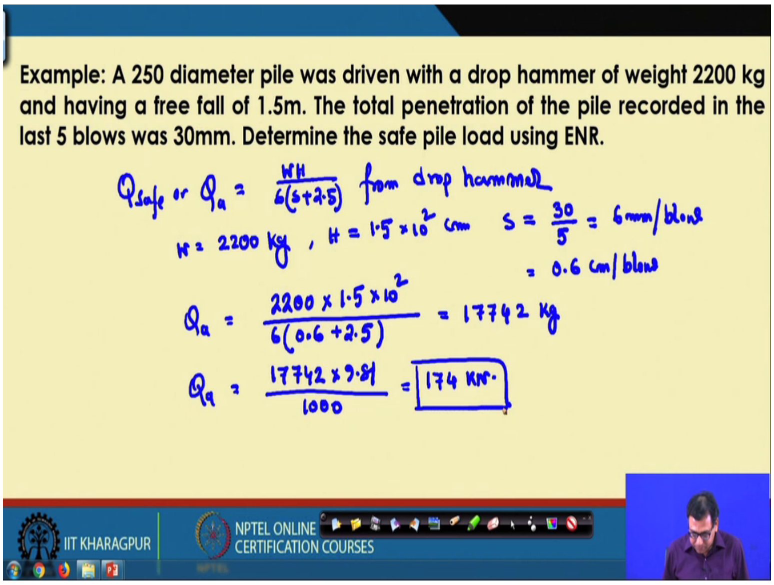

So, if I for the drop hammer if I use this expression, then we can write that Q safe or Q allowable that is equal to this value is equal to W H divided by 6 S plus 2.5; this is for drop hammer. So, W is here it is in kg; so 2200 kg H is in centimeter as I mentioned, but here it is given meter.

So, in centimeter it will be 10 to the power 2 centimeter, then S value is the average of last 5 blows. So, here the total penetration is 30 millimeter; so average of last 5 blows will be 30 millimeter divided by 5 that is equal to 6 millimeter, but this is also in centimeter. So, S will be 0.6 centimeter per blow ok.

So, if I put this value, then it will be W is 2200, H is 1.5 into 10 to the power 2 divided by 6; S is 0.6 ok, then 2.5. So, remember that you have to very careful about the units. So, though the way it is been expressed you have to use the same unit when you are putting the values in the equation.

So, that is coming out to be your 17742 kg ok. So, that is the load carrying capacity of the pile; allowable load carrying capacity of the pile. Now if you convert it to kilo Newton; then this kg you multiply it 9.81.

So, that will give you the in Newton and if you divided it by 1000; then this will give you in kilo Newton. So, if you kg multiply it with g 9.81; the unit is Newton, then divided with the 1000; it will give you kilo Newton. So, the ultimately load carrying capacity of the pile is 74 kilo Newton. So, at this is the allowable load carrying capacity of the pile 174 kilo Newton ok.

Similarly, for others hammer also you can determine the load carrying capacity of the pile.

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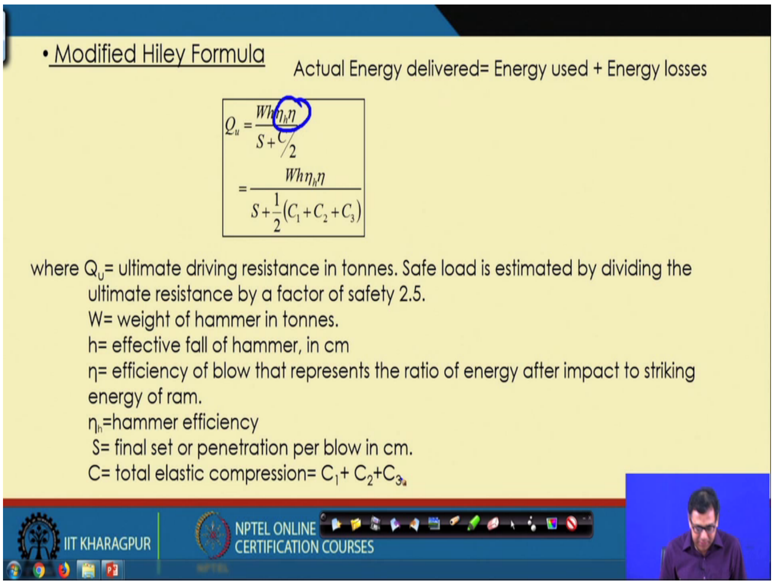

Now, next formula is the modified Hiley formula. So, where the actual energy delivered is not equal to the energy used; the actual energy delivered is the energy used plus the energy loss. So, here some energy loss is also incorporated the; so, expression which is provided is W into h. So, this small h is again the way free fall height and there is 2 efficacy factor ok; so, there are 2 efficiency factors.

So, one efficiency factor is the efficiency of the blow that represents the ratio of energy after impact to striking energy of ram. So; that means, the efficiency this efficiency will calculate based on that when you are applying the hammer blow on a pile; there is a possibility this is the pile can damage; so, those efficiency or those factors are incorporated in this efficiency factor.

And another one the efficiency h which is the hammer efficiency because we are assuming he previous one we assume that there is a 100 percent transfer of the efficiency for the hammer. But here in this case we will assume that there will not be 100 percent transfer; there will be some amount of energy loss ok. So, that is why here hammer efficiency will consider and set is the; the penetration per blow in centimeter and C is the total elastic compression. So, C has 3 parts C 1 C 2 and C 3.

So, let me explain one by one the every term and how we will determine the every term here. So, weight of hammer and the free fall are we can determine that we know that if we should know these 2 things.

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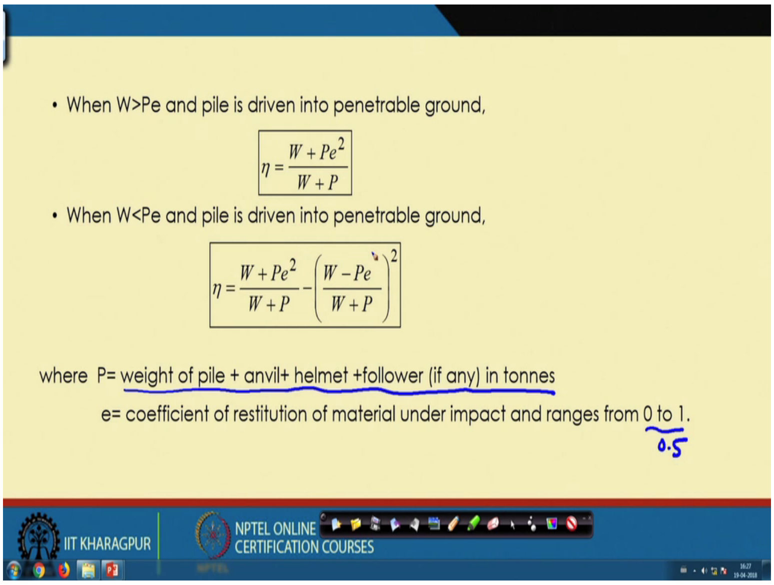

Then the efficiency for the first efficiency that will determine by using this expression ok; so, this is the eta and eta h ok.

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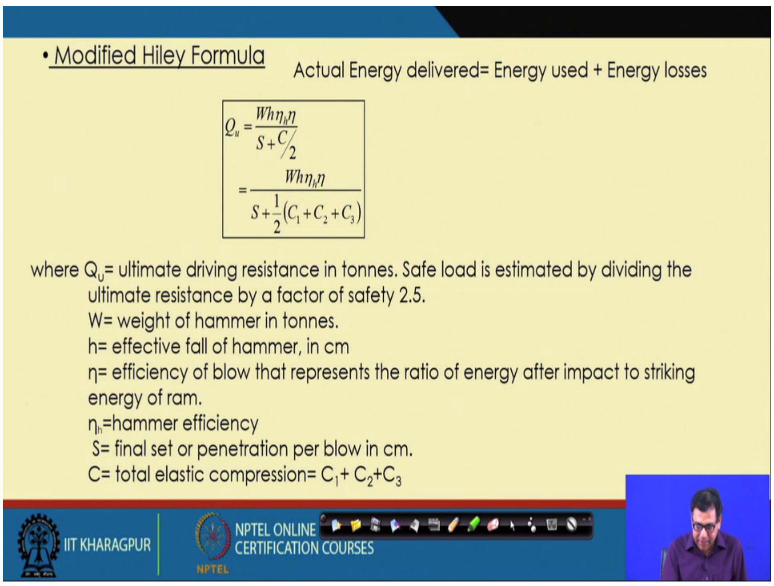

So, eta h the hammer efficiency and eta is the efficiency of blow that represents the ratio of energy after impacting to striking energy of ram.

So, how we will calculate this? If my weight of hammer is greater than P into e; what is e? e is the coefficient of restitution of material under impact and ranging from 0 to 1 or you can take for average value is ; that means, 0.5. So, what is that? So; that means, the coefficient of restitution of the material under impact means that you are applying impact on a pile.

So, that pile have some cushion or helmet; so, you are applying impact on a pile. So, there is a possibility this pile can damage; so, that is the effect this is the coefficient of the restitution. So, for the material under impact. So, it ranges from 0 to 1; so, depending upon the hammer, so average value is 0.5. So, depending upon the hammer which hammer we are using; we can take this value ok.

So, now if my weight is greater than P into e then the eta value will get from this equation. Now if the weight of hammer is less than the P is the weight of the pile with helmet or any other things that was used; I will explain what is helmet and other things. So, but this is the total weight of the pile including these accessories ok; that means, if your weight of the hammer is greater than P into e; then we will use these expression. If weight of hammer is less than P into e, we will use this expression ok.

So now, how I will calculate that next efficiency or this C 1?

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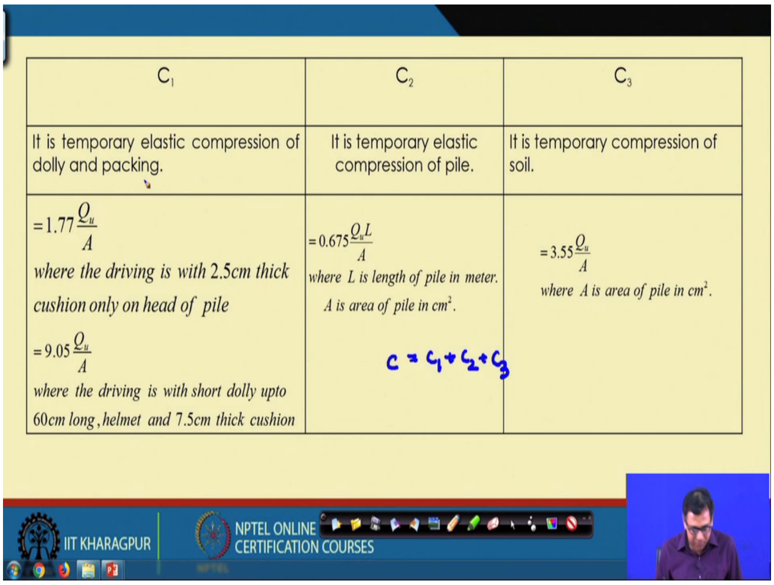

So, as I mentioned that my C; C value is the summation of C 1 plus C 2 plus C 3. C are this C 1 C 2 C 3 are the 3 elastic compression; so, first C 1 what is that? It is the temporary elastic compression of a dolly or the packing what is that? I will explain.

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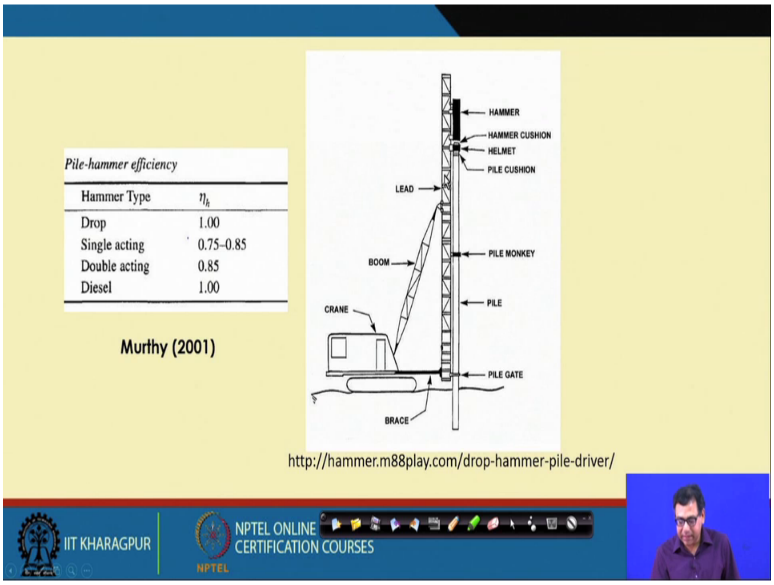

Now, you can see that when there is a pile; this is the pile hammer system. So, if you see this portion; so, on the pile there is a pile cushion; above that there is helmet, then above that there is hammer cushion ok.

So, if all these things are used then you have to use this second expression. The first expression is that; so C 1 calculation where driving is with 2.5 centimeter thick cushion only; on pile head. So; that means, here if only the pile cushion is used and the amount is 2.5 meter, then you use this first equation.

But if that pile cushion along with helmet and that hammer cushion all are used; that is the there is the drolly this dolly is that here this cushion above the helmet. So, this dolly is used then dolly is up to 60 centimeter is used and the pile cushion is 7.5 centimeter thick; then we will use these expression second one.

Because these cushions are applied to protect these as I mentioned that we have to I mean depending upon we are applying a hammer blow on a pile material; so, there is a possibility of damage. So, we can protect those damage, but still we have consider those damage in the equation. And then the C 2 is the temporary elastic compression of the pile ok. So, this is the elastic compassion we apply the hammer blow, your pile material will compressed; so that is the C 2 and C 3 is the temporary elastic compression of the soil.

So, you only apply the hammer blow the soil will also compress. So, that is 3 first one is the temporary elastic compression of the packing or the dolly that means the cushion is there; so, all these things will compress. So, that compression is C 1 and C 2 is the pile material compression and C 3 is the soil compression below the tip of the pile.

So, these way we can calculate the C 1 C 2 and C 3 and the finally, the C. And then the eta H hammer efficiency for different hammer drop hammer it is 1; single acting hammer it is 0.7 to 85, double acting steam hammer it is 0.85 and diesel hammer it is 1.

So; that means, all the expressions we will get we will get C 1 C 2 C 3; I have discussed, S is the penetration per blow that that will be measure, W is the weight of the pile, h is the free fall of the weight of the W is the weight of the hammer, h is the free fall of the hammer, eta is the pile efficiency hammer efficiency that I will get from this table hammer efficiency.

And the eta another efficiency will get from these 2 expressions depending upon which condition is actually existing during the pile driving ok.

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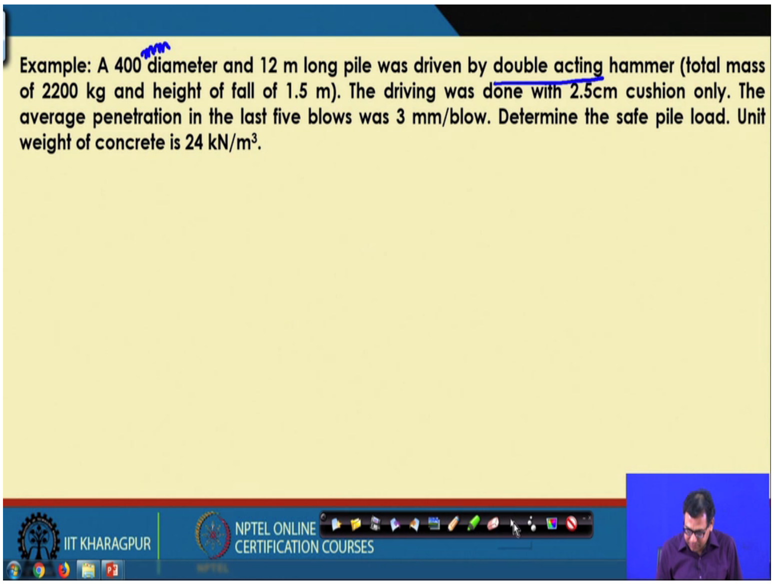

So, now I will solve one problem they a 400 millimeter diameter pile and 12 millimeter long was driven by double acting hammer a double acting hammer. And total mass is 2200 kg, height of fall again as 1.5 meter. The driving was done with 2.5 centimeter cushion only so; that means, only the pile cushion 2.5 centimeter is applied.

The average penetration of last 5 blows was 3 millimeter per blow. In the previous problem; it was total penetration of last 5 blow, but here it is the average penetration of the last 5 blows was 3 millimeter per blow. And or you can say this is the average penetration of the last blows or that is 3 millimeter per blow. And determine the same pile load you need weight of concrete is taken 24 kilo Newton.

So, now; so you have to use these expression and first of all the as it is only 2.5 centimeter thick cushion is used; so, for the C 1 you use the first expression and C 2 and C 3 only one expression. So, we will use these expression this one and this one and the; this is the double acting hammer. So, the eta H value is 0.85.

And the now we will check which equation we will use with the weight of hammer is greater than P into e and for this double acting hammer e value is will be taken as 0.5 ok. So, finally, if I solve this problem; that I am solving this problem ok.

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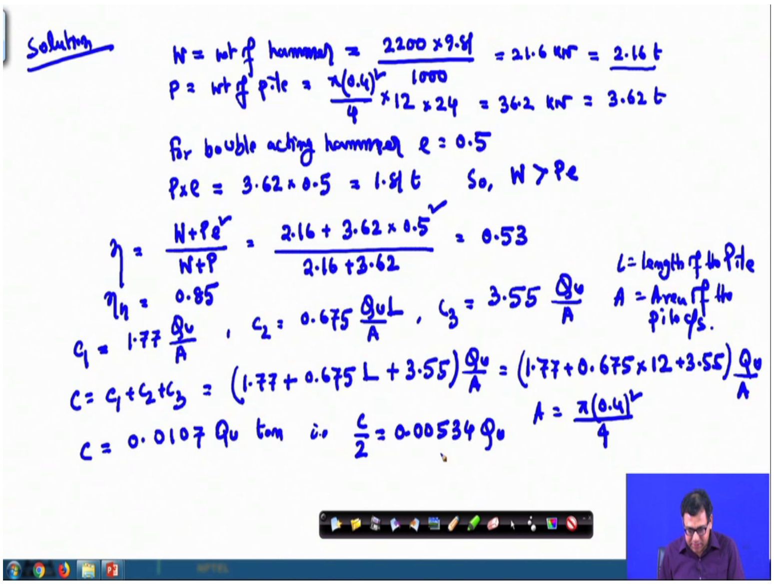

So, first one the solution of this problem the weight of hammer is 2200 into 9.81 divided by 1000. So, it is 2200 kg, then if I multiply it will be Newton then divided by 1000. So, it will be kilo Newton this is 21.6 kilo Newton.

And one thing that I want to mention that if you look at this units that is important here ; the here weight of hammer is in torn then h value is in centimeter, S is in centimeter and then; so, we have to convert them in that way ok. So, o weight of hammer is 2; so, this is in ton. So, ultimately 21.6 kilo Newton means 2.16 torn.

So, 2.16 torn is the weight of the hammer; then the pile weight P is the weight of pile. So, that is pi d square 0.4 divided by 4 into the length, length is 12 meter into the unit weight which is 24 ok. So, wallen in unit weight; so, weight of the pile is 36.2 kilo Newton; so, that is equal to 3.62 torn ok.

So, now my for double acting hammer; e value is 0.5. So, the P into e that is equal to 3.62 in 2.5; that is 1.81 torn. So, we can write; so W is greater than P into e because W is 2.16 and P into e is 1.81; so, W is greater than P into e.

So, we will use for the eta we will use for this expression this efficiency W plus P e square divided by W plus e. So, this expression I will use because that is the first expression when? Of W is greater than P into e. So, the W is 2.16, P is 3.62 and e is 0.5

square divided by 2.16 plus 3.62; that is equal to 0.53. And from the table we got that hammer efficiency for double acting hammer is 0.85 from the table; so, that is 0.85.

Now, we will use the C 1; C 1 as only 2.5 centimeter cushion is used. So, we will use the first expression. So, C 1 is 1.77 into Q u divided by A. I mean C 2 is equal to 0.675 into Q u divided by A and C 3 is equal to 3.55 into Q u divided by A ok; so, where A is the area of the pile cross section ok; if it is uniform pile. So, I can write that my C, C is equal to C 1 plus C 2 plus C 3. So, that is equal to 1.77 plus; this is Q u into L; this is Q u into L. So, this will be 0.675 into L plus 3.55 into Q u divided by A. So, we are taking Q u divided by outside; so, this is the expression.

So, finally, I can write that 1.77 plus 0.675; L is the length of the pile which is 12 meter. So, L is the length of the pile into 12 plus 3.55 Q u divided by A. Now A is equal to pi d square by 4.

So, now if I put these things finally, that C value is you put the A value is here finally, C value is coming out to be 0.0107 Q u it is in ton; it is in tom. So, now I can write C by 2 is equal to 0.00534 Q u. So, the; so C I got this expression; eta h I know.

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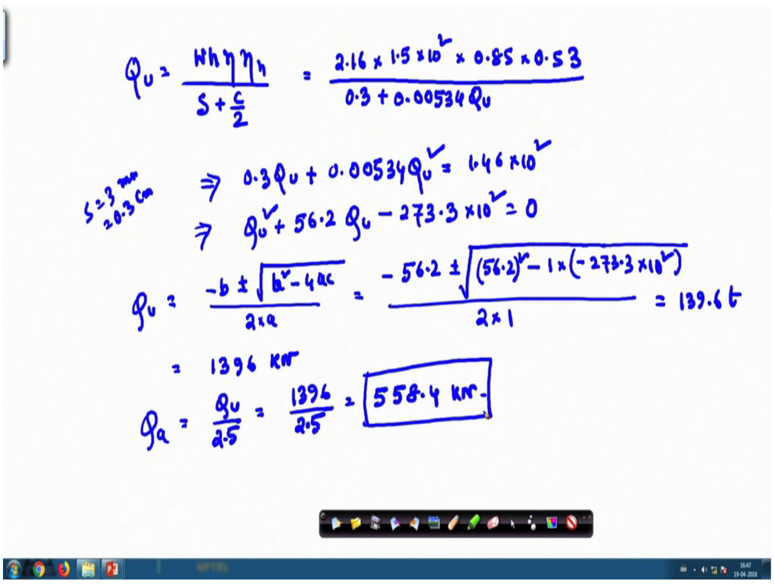

So, next one is that the final Q u is W into h eta eta H divided by S by plus C by 2 ok. So, W weight of hammer is 2.16 this is in torn then free fall is 1.5 meter, but we have to express; it in centimeter.

So, it will be 1.5 into 10 to the power 2 in centimeter then this is 0.85 and one is 0.53 because this is 0.85 and this is 0.53. And then the S; S is the average penetration is given 3 millimeter, but it is in centimeter we have to express. So, S value is 0.3 centimeter because your S is 3 millimeter. So, this is 0.3 centimeter and then plus this 0.00534 Q u ok.

So, in the previous expression; so this Q is in torn if this total expression is not. So, that is correct this is Q is in torn we are expressing, but that you should mention that this is the total this Q is in torn remember that.

This now I can write this is the Q expression. So, if I simplify this expression, then we will get that 0.3 Q u plus 0.00534 Q u square equal to 1.46 into 10 to the power 2. If I further simplify, it will be Q u square plus 56.2 Q u minus 273.3 into 10 to the power 2; that is equal to 0.

So, now this equation you solve then finally, you will get. So, we can solve by this expression that is minus b plus minus root over a square minus 4 root over 4 S 4 b square root over 4 a c divided by twice a.

So, minus b plus minus b square because this is a b c minus 4 ac divided by twice a. So, we can write this one minus b means b is this coefficient. So, 56.2 then plus minus root over b square means 56.2 whole square minus ac that mean a value is 1 and c value is minus 273.3 into 10 to the power 2 divided by twice a; a is 1 ok.

So, if I take this value the positive values. So, it will come out 3; 1396. So, it will be one we are taking only the positive value negative values we are not considering because that will not exist. So, that is that will give you a sorry it first this value is 139.6 torn. So, this if you solve this one this Q u is 139.6 torn and that is 1396 kilo Newton.

So, this is ultimate; so, allowable will be in the previous formula already the factor of safety 6 was applied. So, directly we are getting allowable, but here if I get the allowable we have to multiple we have to divided by the factor of safety 2.5. So, the Q allowable is Q u by 2.5; so, this is equal to 1396 divided by 2.5. So, that is 558.4 kilo Newton; so, the final expression is 558.4 is the allowable bearing capacity or the load carrying capacity of the pile.

So, in this class I have discussed 2 formula by which we can 2 dynamic formula by which we can determine the load carrying capacity of the pile. But still the static formulas are more reliable or static equations are more reliable compared to this dynamic equation. So, but still if you have this hammer blows penetration all these information available for the driven pile you can use this expression to determine the load carrying capacity of the pile in absence of the soil data ok, but if you have the soil data.

So, I will recommend; so, you use the static equation that I have explained or in the first method ok. So, the static equations are more reliable compared to the dynamic equation. So, in the next class I will discuss the fourth and the last method that to determine the pile load carrying capacity by using the penetration data or the field test data like SPT or SCPT.

Thank you.