Advanced Foundation Engineering
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Lecture – 60
Well Foundation - I

So, in this lecture I will start a new module that is well foundation and before I go to that well foundation part the quickly, I will give one information that is related to that uplift capacity of the pile.

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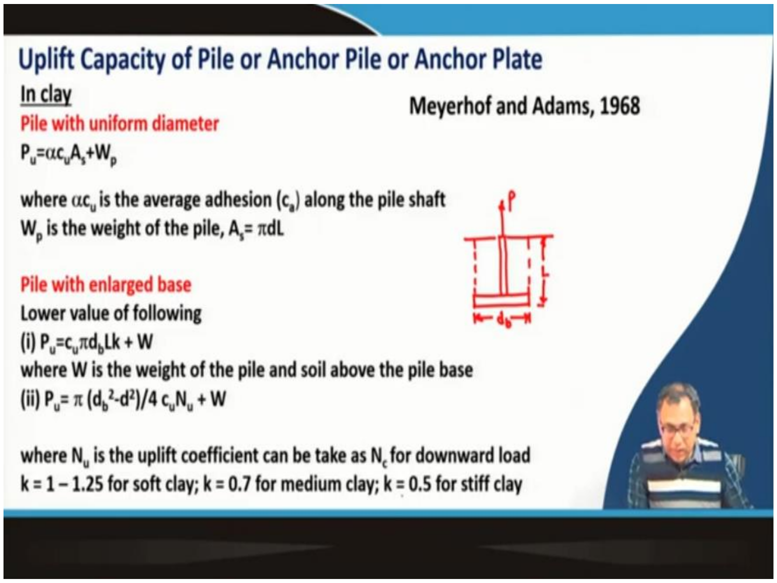

Or I can give you the anchor pile or anchor plate because uplift capacity of the pile I have discussed in the last class. And then you can determine but there is another approach also where you can determine the uplift capacity of the pile or you can say it is the anchor pile or uplift capacity of anchor plate or uplift capacity of foundation also. So, that is given by Meyerhof and Adams in 1968 which is for clay and it is same as the uplift capacity of the pile.

There will be an adhesion factor × the undrained coefficient × the area + the weight of the pile. So, that means the frictional resistance plus the weight of the pile. So, adhesion factor you can take same as the adhesion factor under compression and then this way you can determine the uplift capacity of the pile in clay or I should not say it is the pile it can be anchor plate it can be foundation also uplift capacity of the foundation and then it is for uniform diameter.

So, suppose if it is for enlarged base then that means base or that as I was talking about this kind of foundation or it is a kind of anchor plate. So, all you can say this is the enlarged base of the pile and then how we can get the uplift capacity of the pile. So, in previous case in previous lectures this is the only pile which can be treated as anchor plate can be treated as foundation, it can be treated as pile also. So, that is why I have kept it in separate lecture. So, discuss this one.

So, for the pile with enlarged base this is for the enlarged base whose base is d_b. So, we can determine by using this lower of these two values that means here this L is the length of the pile or the foundation and then we can get lower of these two values and you will get the uplift capacity where k is generally taken as 1.1 to 1.25 for soft clay, 0.7 for medium clay and 0.5 for stiff clay because there is a k term. And that is $N_u$which is same as N_c for pile under compressive load. So that also you can take this is the uplift coefficient can be taken as N_c for downward load. So, that is same as the N_c that we can take.

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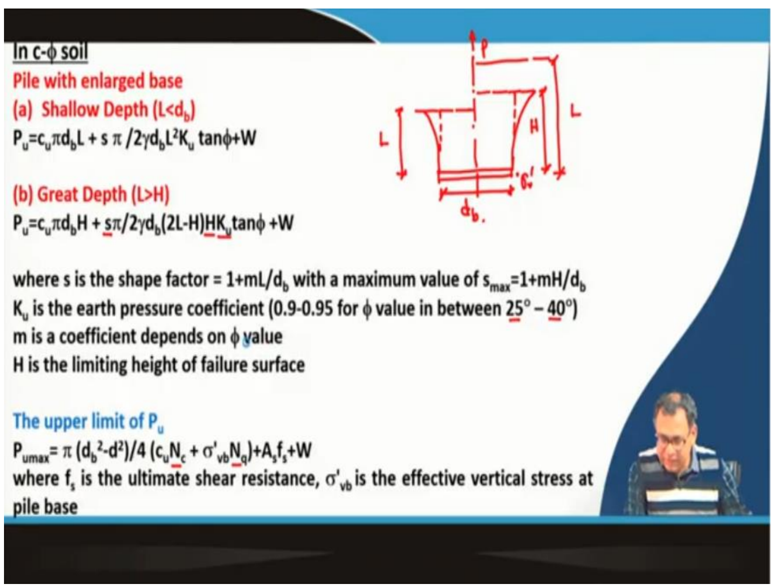

Now similarly for a $c-\phi$ soil that for shallow depth, if the foundation is in 2 cases I consider that pile has enlarged base, so I am taking two cases this is the center line. So, this is the shallow depth. So, this L is the length of the pile, if L is less than the d_b then I will use this equation for $c-\phi$ soil then there is a term s and then there is a term K_u. So, these two we have to determine.

Now for the great depth, great depth means suppose a failure line will go up to a particular length or beyond that failure line will not extend what your length of the pile is more than that, this is the H up to which failure line is being extended and this length is more than the H. So, H is the height up to which failure plane is being extended under uplift because this is under uplift. So, previously also this is also under uplift.

So, it is assumed that there will be a plug which is moving up here also this he assumed that is why in adhesion factor α is taken as 1 because then in such case the adhesion is between soil to soil. So, and then this is the value then how I will calculate that, so what are the unknowns that we have to calculate, we do not know what is the H value, we do not know what is the K_u value and we do not know what is the s value.

Other parameters c_u is known, d_b is known, unit weight is also known, L is known, but you have to know the values of K_u and H. So, for the great depth either you can use this equation or there is an upper limit also this is the upper limit. So, that means these values should not be greater than this equation where σ'_{vb} is the effective vertical stress at pile base.

That means, at this point we have to calculate σ'_{vb} and N_q and N_q is same as the N_q that we used for the foundation or you can use it for the pile under compressive loading. So, the same N_q we can use for pile under compressive load. So, now, I will give you how I can calculate the K_u, H and s. Here also N_c and N_q are same as the pile under compressive load we can use those N_q and N_c as suggested by Meyerhof that we can use here.

So, and then we have to determine the H and K_u. So, K_u is the earth pressure coefficient which is 0.9 to 0.95 for ϕ value in between 25° to 40°. So, K_u part is over, m is the coefficient that depends on the ϕ value and H is a limiting height of the failure surface, s is the shape factor which can be determined by using this expression and the maximum value of the shape factor is this value.

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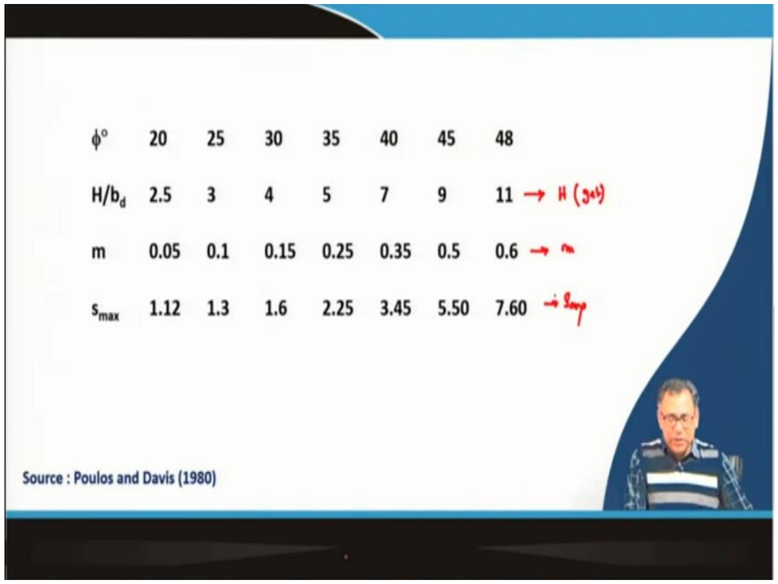

So, now, let me explain that how we can use these things. So, suppose this is for the ϕ. So, this is H for different ϕ, this is the $\frac{H}{b_d}$. So, we know the b_d we talked about the diameter of pile base, then using these table different ϕ value we will get the H. So, from here, we will get the H value, from here because we know that d_b and we will get the H value and we will get the m value also here and we will get the s_{max} also here.

So, once we get the m value and the H then I will calculate s from here also. I know the L, I know that d_b and I will get the m from this table. So, I will get the s value. So, s is known once I get the H I will check with that L is greater than H or not. So, if it is not, then I have to use the previous equation and if L is greater than H then I have to use this equation and so that when H part is gone, I know the H, K_u value is given, K_u value will get.

And s also I will get because I will get m from here and then I will determine the s by using this equation. Now in this equation I know m, I know L, I know d_b, but then I have to check the s that I am getting is within s_{max} or not if it is within s_{max}, then I will get that H that s and if it is greater than s_{max} then I will use the s_{max} value. And then other equations are straightforward that we can use remember that the N_c, N_q are the coefficients.

I can use this factor I can use the same as for piles under compressive load, α value also I can use for uniform case the same α for pile under compressive load and these other factors are already explained. The two cases one is either the failure of surface within the pile length and if the failure surface is up to the pile length or I should say one is the pile length is above the failure surface and another is pile length within the failure surface.

So, that I have to check for calculating H and the length and then I have to check which condition I have to use. So, these are the equations for enlarged weights. So, if it is shallow depth then I will use the equation A if it is great depth then I will equation B, but remember that these values either you will use equation A or equation B should not be greater than the upper limits. The upper limit will be this one and that is the upper limit.

So, d_b is the diameter of the base and d is the diameter of the shaft. So, that means, what is the difference between d_b and the d suppose, this is the diameter of the base d_b and this is the diameter of the shaft, so this is the difference between d and d_b. Other things and f_s is the frictional resistance, so that means for a $c - \phi$ soil you can calculate the f_s value and A_s value is the area of that shaft.

Then that will be your f_s, f_s is the ultimate shear resistance and A_s is the area of the outside area of the shaft. So, this you have to check and then you will get the uplift capacity of the pile. So, this is another approach. But I have discussed another method in the previous class also. So, you can use both of them, but generally I prefer to use the uplift capacity of the pile by using the approach that I have discussed in the previous class. But this is a general one you can use it for the pile, you can use it for the anchor plate and this is the uplift capacity equation for a general kind of solution.

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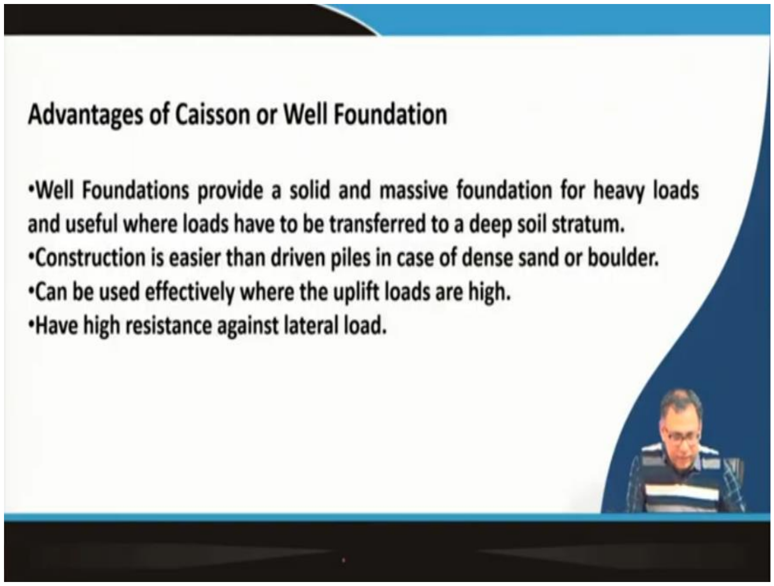

So, next one I will discuss the well foundation. So, this well foundation is sometimes called as the caisson foundation also. So, the advantage of these caisson or well foundation, this well foundation provide a solid and massive foundation for heavy loads and useful where loads have to be transferred to a deeper soil strata. The construction is easier than the driven pile in case of dense sand and the boulder.

And can be used effectively where the uplift loads are high and have higher resistance against the lateral load that means here I can replace this well foundation or I can replace the group of piles a number of piles by providing well foundation that is also one advantage.

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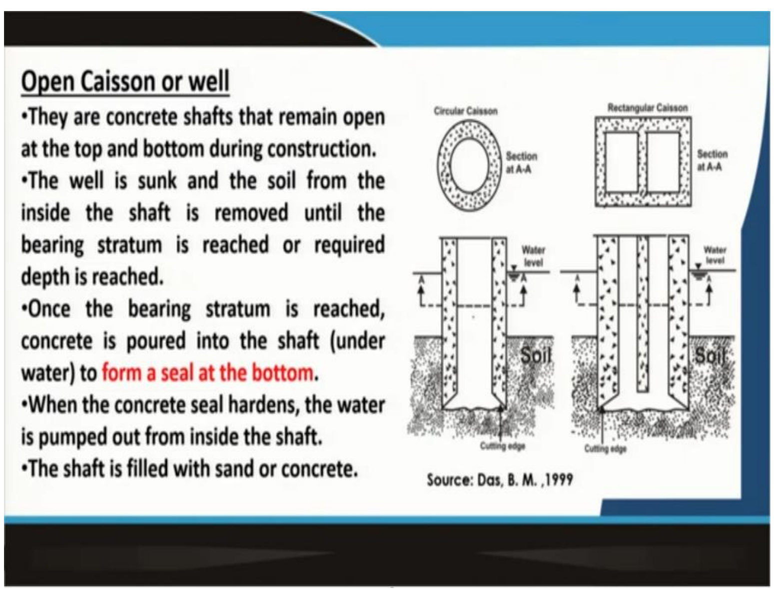

So, now this well foundation can be different types. So, first one is the open well or the open caisson. So, here you can see this is the plan and the cross section. So, this is a circular caisson and this is a rectangular caisson. And here this is a section. So, this is the soil where the foundation we have to install and definitely above that it is the water table or water, generally these type of foundation are suitable for the beach structure.

So that means and it will be most of the time constructed within the riverbed. So, that is why there will be water then the riverbed and then I will discuss how we will determine the depth of this well, we have to determine the scour depth and based on that you have to determine what would be the foundation depth or depth of the well. So, now we are discussing what are the different types of well and how they are constructed?

So, this type of open well, these are top and bottom portion. So, this is the top portion and this is the bottom portion. So, these are open during the construction. So, these are concrete shaft. So, this is a basically hollow sealing kind of thing, hollow shaft kind of thing where this is the concrete which has the thickness and then it is the hollow and open it is also in the top it is open bottom is also open. So, this is a hollow shaft which is remained open at the top end of the bottom during construction.

So, that means this hollow shaft is been constructed within that soil and within the riverbed or the soil and during the construction this bottom and the top will be open. Now this well is sunk and the soil from the inside of the shaft is removed until the bearing strata is reached or the required depth is reached, so that means as it is sunk into the water and the soil which will be within the shaft because the lower part is open, so that means soil will come within the shaft.

So, that soil we have to continuously remove during the construction process or during the installation process. So, until it reached the required depth or bearing strata. So, that means, this soil inside the shaft is removed, once it is reached the required depth or bearing strata then concrete is poured into that shaft because now, this is a hollow shaft which is installed up to the required depth, but water is still inside the shaft, water is not removed only the soil is removed within the shaft.

So, there is always water but once it reached the required depth, then the concrete is poured within the shaft and the underwater that means water is there within the shaft and the concrete is poured and to seal the bottom part of the well. So, that means top part is open bottom part is open. Now, once it is reached the bearing strata this concrete is poured through under water to form a seal at the bottom of the stack.

So, now the bottom is sealed by concreting and then once the concrete seal hardens, then the water is pumped out from the inside of the shaft. Now, once the concrete is hardened then water can be pumped out because before if you pumped out the water, the water surrounding that portion will enter into the shaft. So, that is why the bottom portion of the shaft is sealed. Now the water is pumped out once the seal or the concrete seal hardens. Now water is pumped out from the shaft and then now within the shaft there is no water even there is no soil also concrete is at the bottom of the shaft. Now inside that portion is filled with sand generally or concrete.

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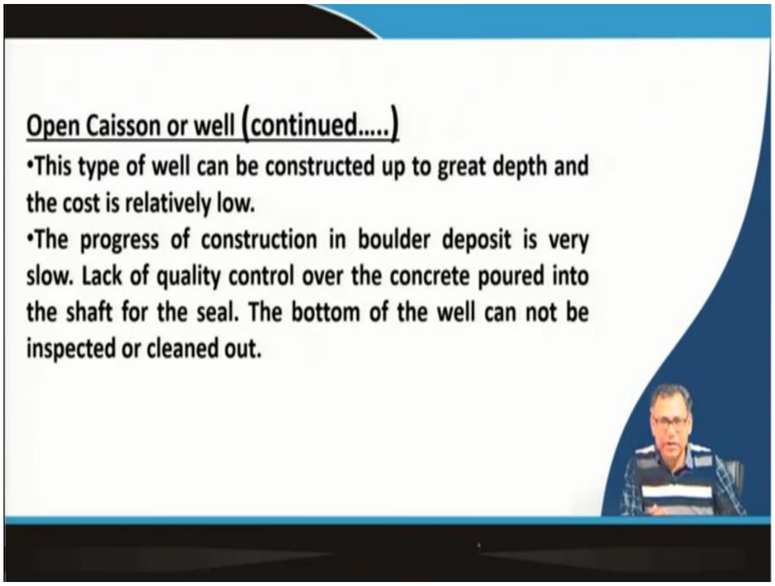

Now this inside portion is filled with sand. Now, this type of well can be constructed up to a great depth, any depth and its cost is relatively low. The progress of construction in boulder deposit is very slow. So, the advantage is that it can be installed up to any depth but cost is very low. But the disadvantages are the progress of construction in boulder deposit is very slow, the lack of quality control over the concreting, because now concreting is done underwater.

So, quality control is very difficult for this type of construction. So, the quality control over the concrete poured into the shaft for the seal is very difficult the bottom of the well cannot be inspected or cleaned out. So, these are bottom surface. So, it cannot be inspected properly and cleaned out. So, one day it is filled by the sand in the top plug or the top portion is concrete is done and then it is sealed. So, this is the total construction process for the open caisson. So, it has some advantages and the limitations also.

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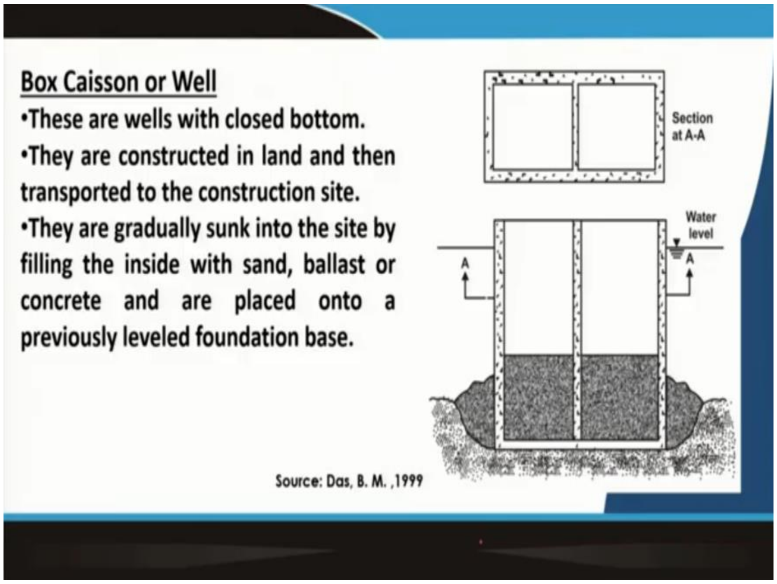

So, the next one is the box caisson where the bottom portion is closed, but top portion is still open. And they are constructed in the land and then transported to the construction site, the previous one was constructed in the site itself, but here it is constructed in the land and then transported to the construction site. And they are generally sunk into the site by filling inside the sand, ballast or concrete because now the bottom is sealed.

So, these are sunk into the water by placing sand or ballast or concrete inside that shaft and placed up to the required depth where there should be a previously leveled foundation base, because if the foundation base is level, then this type of caisson can be useful or can be installed. So, these are placed on previously levelled foundation base.

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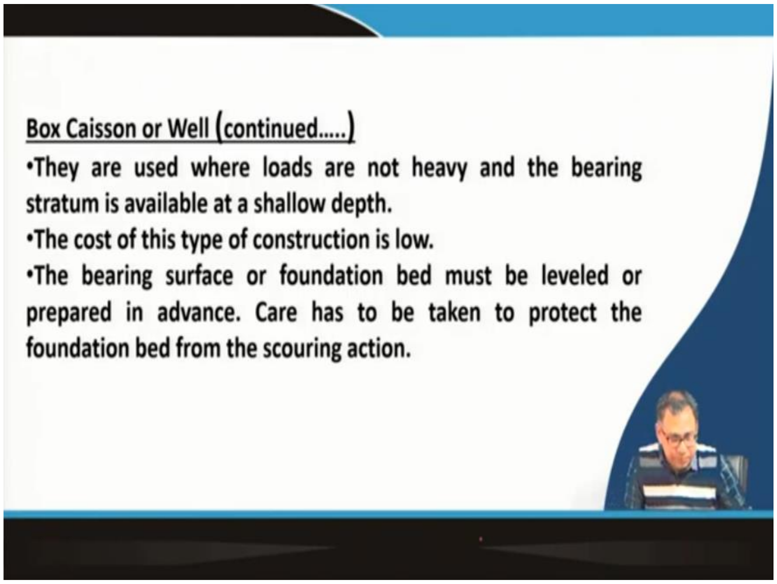

So, these are used where loads are not heavy and bearing strata is available at a shallow depth, the advantage is the cost of this type of construction is low and the disadvantages are the bearing surface or foundation base must be level or should be levelled before it is installed then care has to be taken to protect the foundation bed from the scouring action.

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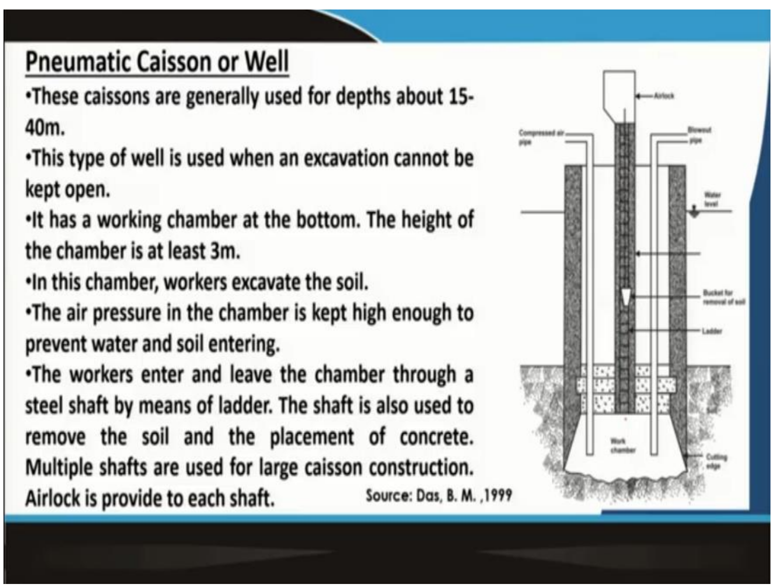

The next one is the pneumatic caisson or the well. So, these types of caisson are generally used for up to a depth of 15 m to 40 m. So, this type of well is used when the excavation cannot be kept open because what is the difference between these one and the first one, in the first one both bottom and top are open. So, sometimes it is not possible that the excavation cannot be open because soil can enter or water can enter. So, in such case this type of caisson can be done or caisson well can be used.

So, here there will be a construction or working chamber. So, this is working chamber, where worker can work within that chamber. So, height of the chamber is at least 3 m. So, these chamber workers excavate the soil because now here because it is difficult to keep the excavation part open because in the first open caisson the excavation is done, but that the bottom is still open.

But sometimes it is very difficult to do that or if it is not possible then you go for this type of caisson. So, in this working chamber these workers excavate the soil and then air pressure in the chamber is kept high enough to prevent water and soil entering. So, as I mentioned that there is a possibility of entrance of soil and water within the excavation, so that means here high air pressure is maintained within the working chamber. So, that water and the soil cannot enter within the working chamber.

So, that is why we have to take care of the health issue of the workers and if required there will be rotation of the workers within the working chamber they cannot work for long time within that chamber. So, there will be a shorter duration of the working period for the worker because if we provide the very high pressure within the working chamber. So, now there is a shaft and within the shaft there is a ladder.

So, these workers can leave and enter the chamber through the shaft by means of ladder, this shaft can be also used to remove the soil and placement of the concrete. So, multiple shafts are used for large caisson and consequently construction and air lock are provided to each step obviously, because worker has to be work inside the chamber. So that means here when soils are excavated those soils are removed by the shaft. And later on, these will be used for the concreting purpose also.

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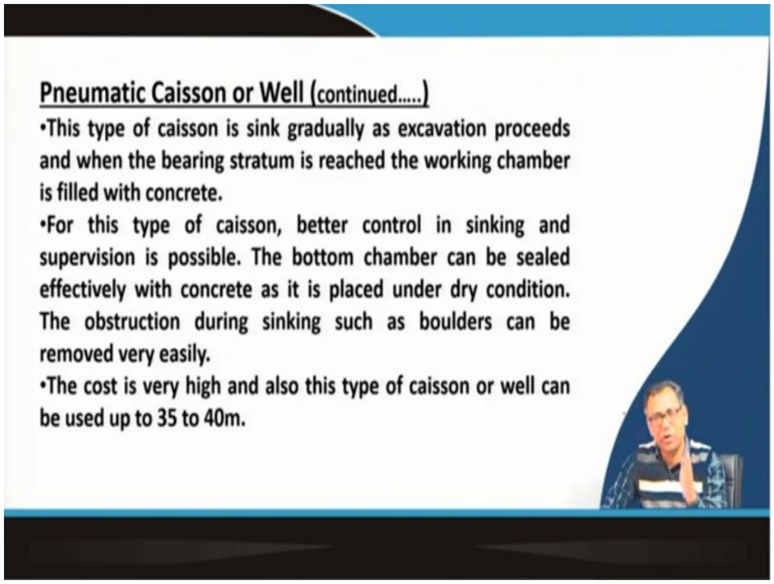

So, now this type of caisson is sunk gradually as excavation proceeds and when the bearing strata is reached the working chamber is filled with concrete. So that is acting as a bottom plug. So that working chamber is sealed. Now for this type of caisson, better control in sinking and the supervision is possible. Now bottom chamber can be sealed effectively because now there is no water when the concrete is in done for the seal of the bottom plugs because it is done under dry conditions.

So, better quality control during the concreting is possible and obstruction during the sinking such as boulders which is a problem in the open caisson can be also removed because that worker can excavate the soil within the working chamber so that issues can be solved. So, but the disadvantages are this is a very costly method and this type of well can be used up to 30 m to 40 m. And for the open caisson and it can be used for great depth for even for more than 40 m also.

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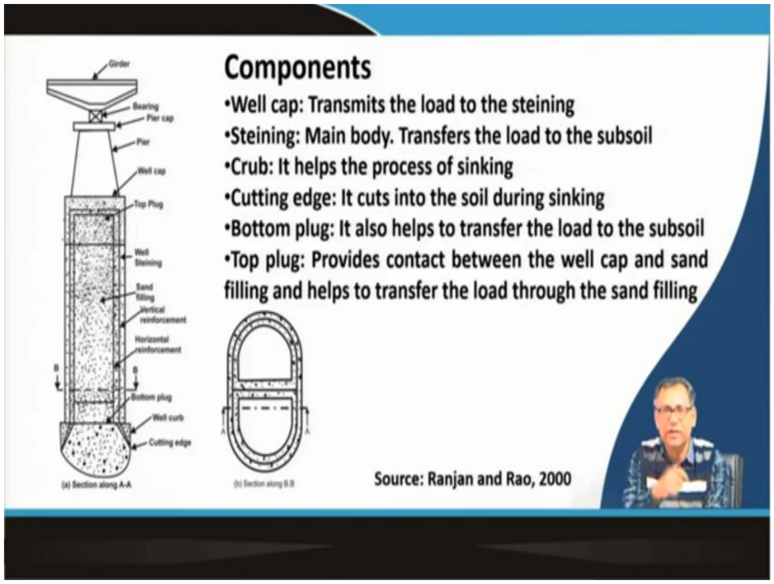

So, these are different components of well. So, this is as I was talking about this is the bottom plug. So, this is the bottom concreting this is the sand filling then again, the top plug and the well cap. So, this is the plan and this is the section, this is the well and this is the pier, bearing and then the girder. So, this is a bridge construction. So, what are the different components this well cap is generally monolithically cast with the steining. So, this well cap is transmitting the load to the steining.

Now, what is steining? Steining is basically the main body of this well. So, that shaft we are talking about, so this is the steining which is the side concreting walls, this is the main body of the shaft. So, these steining and the top well cap are cast at a time and the purpose of this steining is to transfer the load to the subsoil. Then the curb is this one this is a well curb. So, this is the curb. So, this helps to process the sinking.

Cutting edge, it cuts into the soil during the sinking, then bottom plug. So, this is the bottom plug it also helps to transfer the load to the substructure then top plugs. So, this is the top plug and in between bottom plug and the top plug this is the sand filling. So, top plug provides contact between the well cap and the sand filling and help to transfer the load to the sand filling. So, these are the different components.

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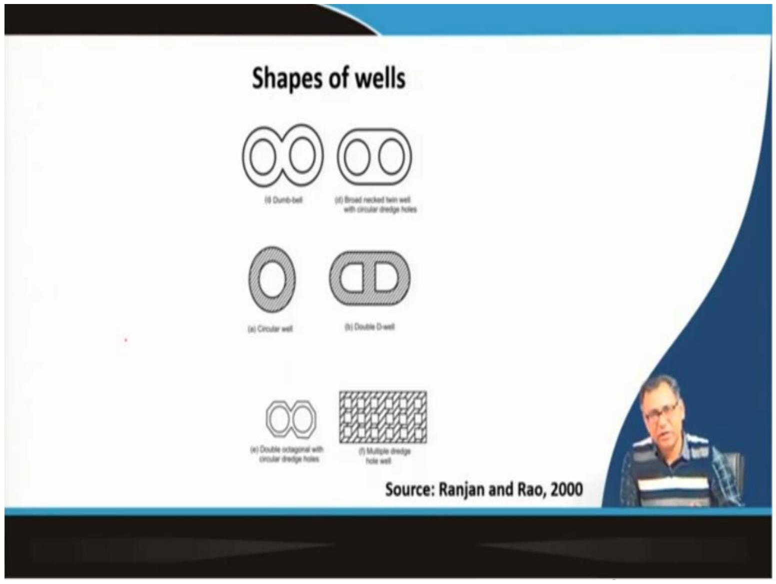

And then what are the different shapes of the well. So, circular shape is the most common shape of the well in addition to that there is rectangular shape of the well and other shapes are also described here. So, these are the different shapes of well.

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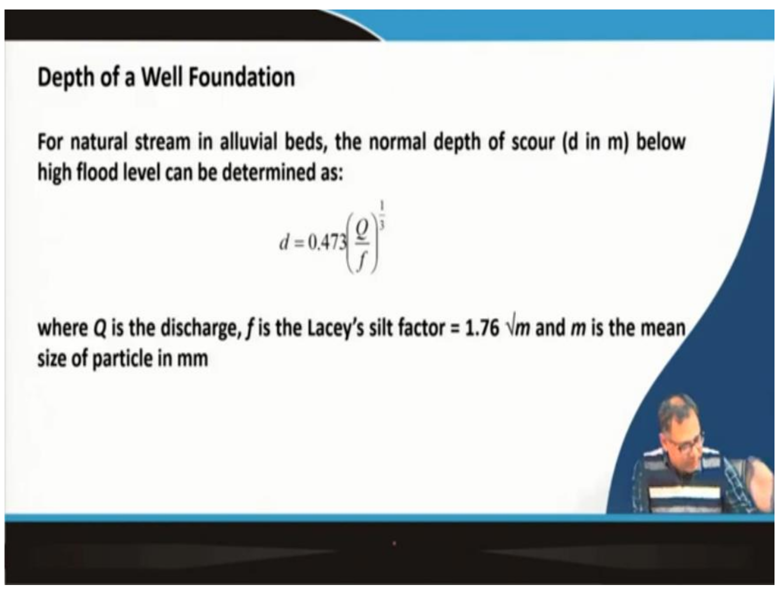

So, now, we are talking about how we can determine the depth of a well? How we will decide that, so to know that we have to determine what would be the scour depth for a particular site, so that scour depth we can determine by Lacey's formula, so d is the scour depth. So, Q is the discharge and f is the Lacey's silt factor, which is generally $1.76\sqrt{m}$, m is the mean size of the particles in mm, Q is the discharge. So, now, by using this equation you will get the scour depth

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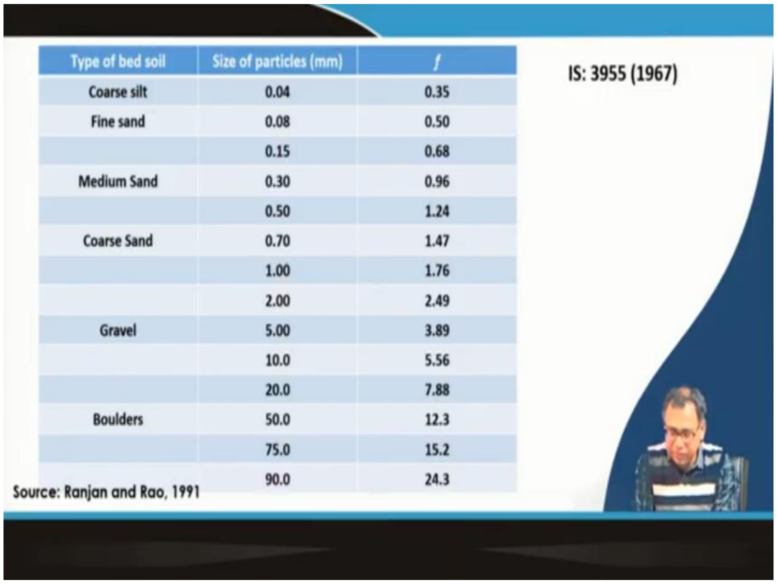

And we have a chart by which also we can get this *f* value which is Lacey's silt factor directly depending upon the particle size and the type of soil bed. So, that mean medium sand if the particle size is 0.3 mm then the *f* is 0.96, if it is 0.5 then *f* is 1.24 similarly, boulders if it is 90 mm then it is 24.3. So, that *f* also directly I can use based on these particle size or if you have a different particle size you can determine that *f* also by using this expression.

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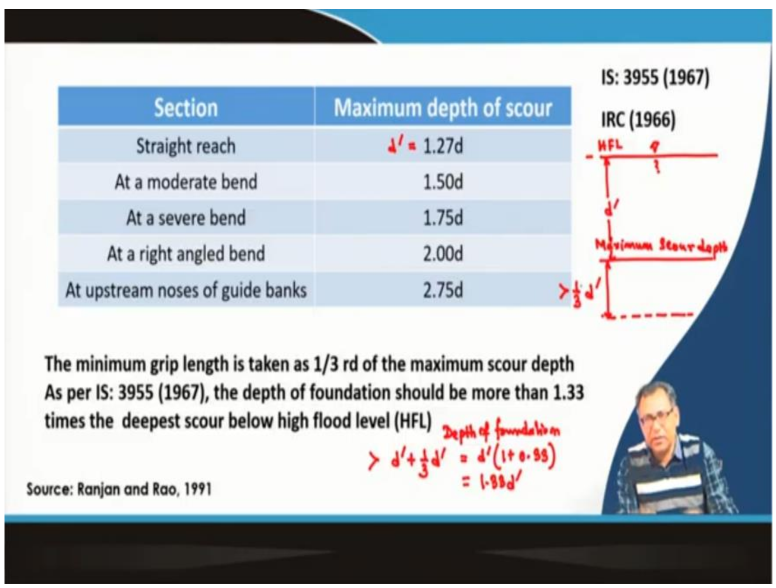

Then once I get the scour depth, so that mean this code has given, so there are two codes in the IRC and in the IS code. So, they recommended to increase the scour depth or the maximum scour depth by this amount depending upon the different types of sections. Suppose if it is a straight reach, so that scour depth that you will get some maximum scour depth will be 1.27 times of that *d* then at a moderate bend. So, this will be 1.5 times of *d*.

At a severe bend it will be 1.7 times of *d*, at a right angle bend it will be 2 times of *d*, at upstream noses of guide banks it will be 2.7 times of *d*. So, first you determine the *d* value, scour depth then you will determine the maximum scour depth. Now, we have to determine what will be the grip length? So, minimum grip length is one third of maximum scour depth. So, that is the recommendation.

So, that means, as per IS : 3955 (1967) the depth of foundation should be more than 1.33 times the deepest scour below the high flood level. So, that means, suppose this is your high flood level HFL and then first you calculate the scour depth then you calculate the maximum scour depth. So, by this recommendation, so this is the maximum scour depth. Now the grip length will be at least your depth of foundation will be at least here.

So, suppose this maximum scour depth is a d'. So, this one should be more than $\frac{1}{3}d'$. So, that means, you should say that if this is the maximum scour depth or that is also d' from the high flood level. So, the total depth of foundation should be greater than $d' + \frac{1}{3}d'$. So, that will be equal to this is your d' this is I should say $d'(1 + 0.33)$, so this is $1.33d'$, so that is the highest recommendation.

That your depth of foundations should be greater than 1.33 of the maximum scour depth below the HFL high flood level. So, that means, if the scour depth is d' from the high flood level, then you have to provide at least $\frac{1}{3}d'$ as the grip length and then the depth of foundation will be at least $1.33d'$, that is the minimum requirement. So, generally it is more than that, so and this is recommendation is given. So, based on that we have to design our well and then remember that this one $\frac{1}{3}d'$ is the grip length. So, $\frac{1}{3}d'$ is the minimum requirement of the grip length.

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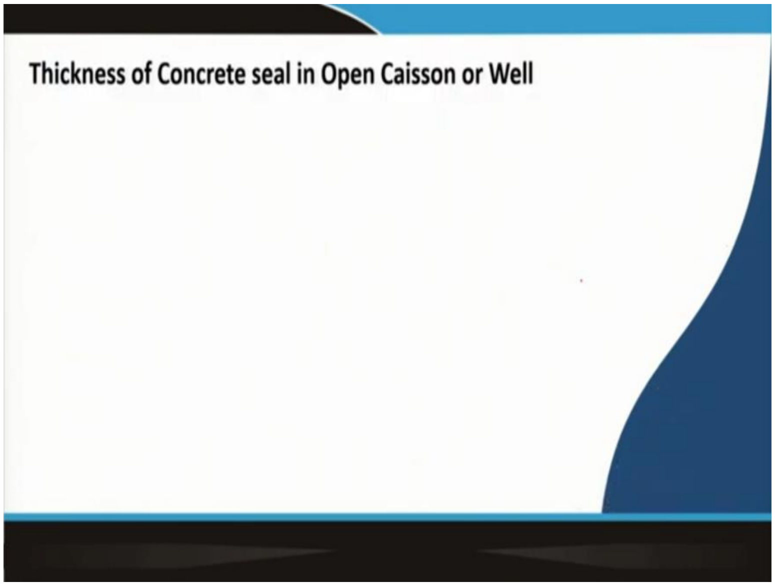

So, in the next class I will discuss that what will be the thickness of the concrete seal in open caisson or well. So, because if you see the one particular cross section of a caisson, so here the construction techniques are discussed that first these once it is reached the bearing strata then the concreting is done and underwater, even for pneumatic caisson and also the working chamber is filled with the concrete. So, for the open caisson this concrete is done under water.

So, that means, what would be the thickness of these bottom plug or what is the thickness of these concreting? Because, when concreting is done, there will be buoyancy force which is acting in the upward direction at the bottom of the shaft. So, you have to provide sufficient thickness of these concrete, so that force can be taken care otherwise, it will go in the upward direction. So, how this binds the force can be taken care.

So, those things we will be discussing the next class because then based on that, we have to decide what will be the required thickness of these concrete for the open caisson. So, that I will discuss in the next class, the thickness of the concrete sealed which is applied during the open caisson so that we can prevent that buoyancy force. And then we will provide the other issues also. So, those will be discussed in the next class. Thank you.