Foundation Engineering
Dr. Priti Maheshwari
Department Of Civil Engineering
Indian Institute Of Technology, Roorkee

Module - 02
Lecture - 17
Well Foundation - 1

Hello viewers, today we are going to start a new topic in this lecture series that is on well foundation. So, in this one first we will see, that what exactly are the well foundations, what are the various types of well foundation and what are the various Indian Standard Code provisions which are available for design and analysis of this well foundation. So, let us start with that what exactly is well foundation.

We all know that, when the loads from the super structure are quite high and the soil bearing stratum is not sufficient, it does not have the sufficient bearing then, we need to go for defoundation, so well foundation is one of that type of deep foundation.

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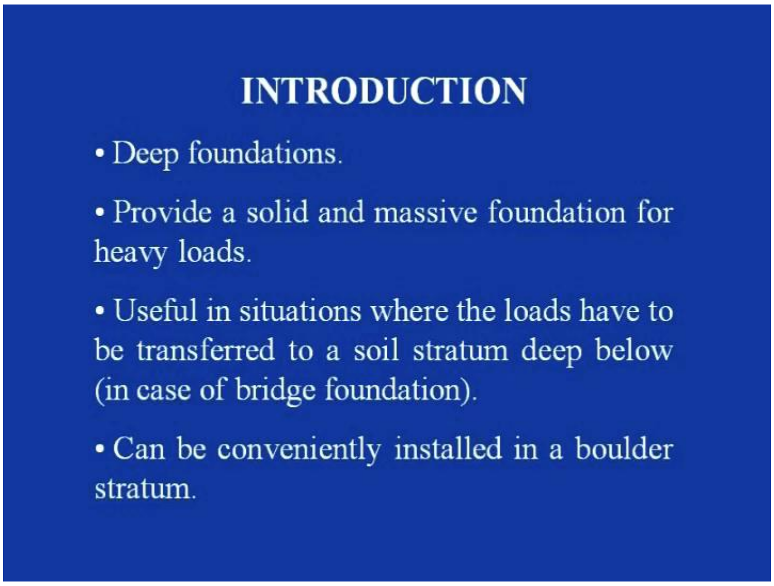

It provides the solid and massive foundation for very heavy loads, then it is useful in the situation where the loads have to be transferred to the soil stratum, which are deep below from the ground surface like in for example, in case of bridge foundation. Then this can be conveniently installed in a boulder stratum, which is usually found in case of bridge foundation. This is very widely used in India as foundation of bridge piers as well as the abutments.

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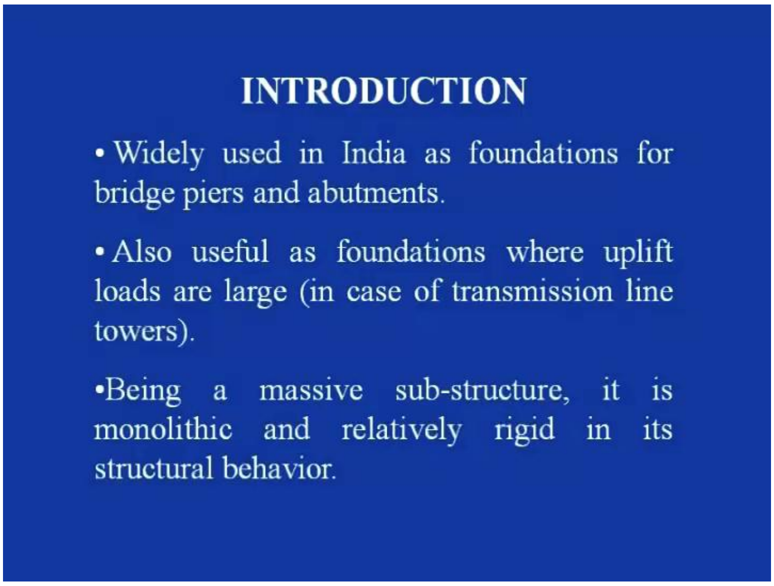

It is also useful as foundation where uplift loads are quite high, as you all know that in case of the transmission like towers, it is the uplift load which comes to the foundation and they are of very heavy in magnitude. So, in that case well foundation is quite useful, now being a massive sub structure it is monolithic and relatively rigid in its structural behaviour. Now, coming to the types and well types of well or it is called as case caisson, also there are three types of well.

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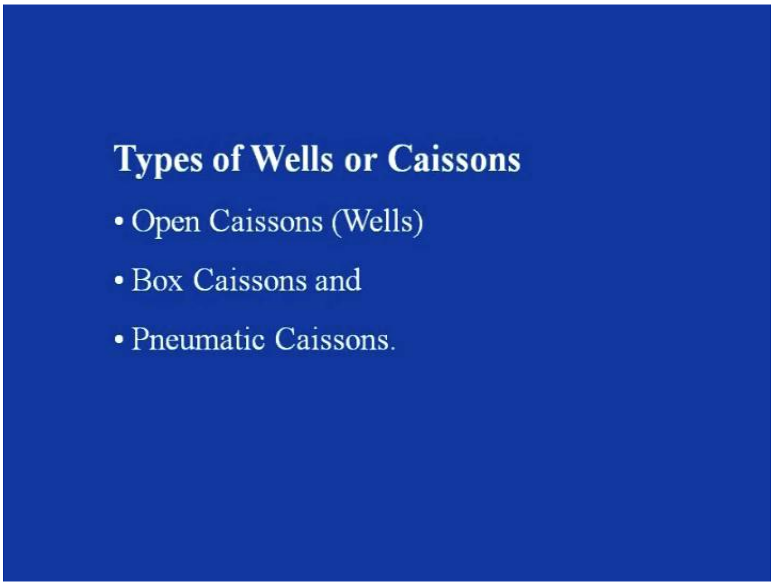

One is open well, second is box well and third one is called as pneumatic wells or pneumatic caisson. Now, we will discuss one by one that what exactly are these three types, what is the difference between these three types and when we go for the construction of these different type of well. What should be the caution that we should keep in mind while going for the construction, what is the advantage and disadvantage of these types of wells, so first let us start with the open wells.

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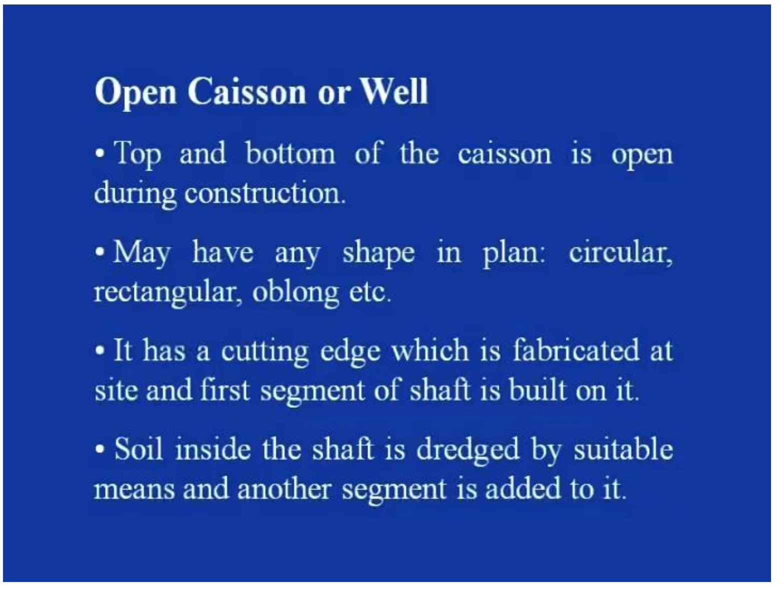

In case of this open caisson or open wells, top and bottom of the caisson is open during the construction, it can have any shape in plan that is, it can have it can be circular it can be rectangular or it can have oblong shape. Then it has a cutting edge, which is fabricated at the site and then the first segment of the shaft of the well is attached to it. Soil inside that shaft is being dredged out by some suitable means and once that soil within the shaft is being dredged out after that, another segment of the shaft is being added to this previous one.

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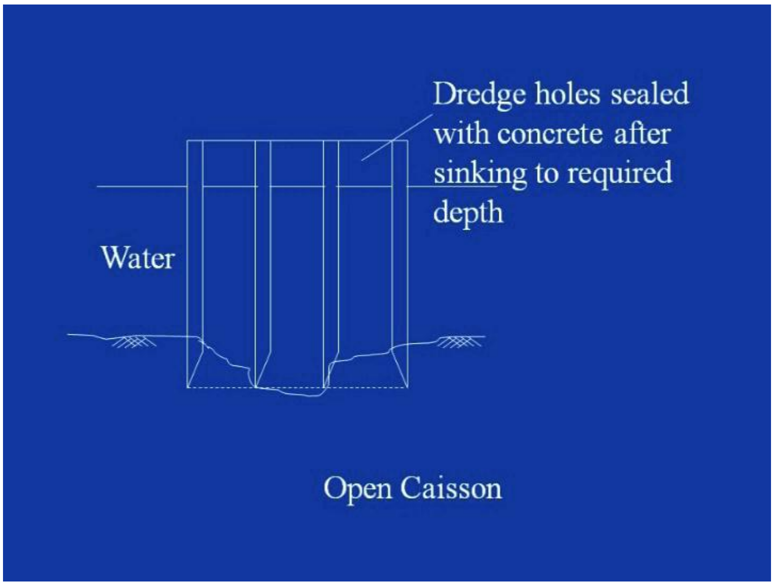

Here is a figure, where you can see the typical line diagram with respect to the open caisson. Here is the top and the bottom which both are open and the dredge holes, here you can see these are the dredge holes which are being created and the soil in these dredge holes, they are being excavated by some means, that is and after this well is reached to the required depth. These dredge holes, they are sealed with concrete, when it is being skunked to the required deft, now coming to the some of the features of this open caisson or well is that.

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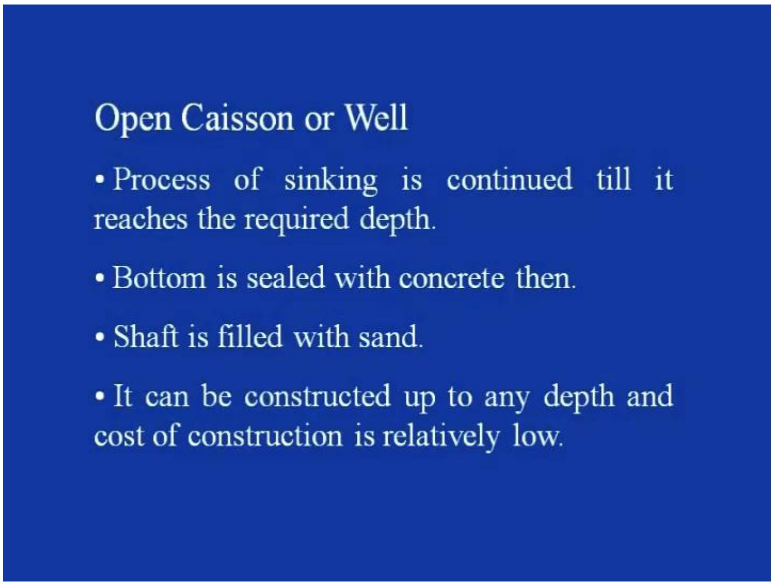

The process of sinking is continued till it reaches the required depth, that is what you have obtained from the refined consideration and the bearing capacity of the soil stratum.

Then once it is reached up to that particular level, the bottom of the well is being sealed with the concrete and the shaft, from where the soil has been taken out it is refilled or filled with sand. This type of well can be constructed up to any depth and cost of construction is relatively low, some of the disadvantages associated with an open wells.

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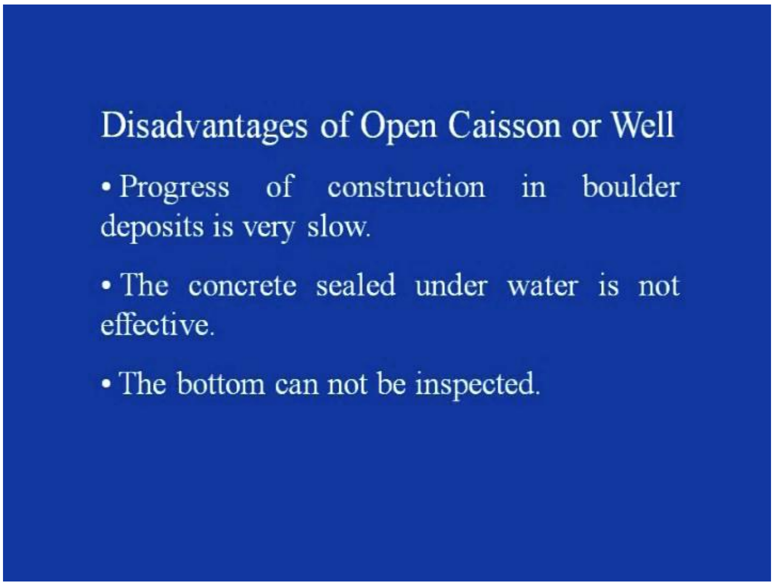

These are, that the progress of construction in bolder soil deposit is very slow, usually wherever this wells foundations, they are been provided, we encounter the bouldery strata. In case of the open wells, the construction in such stratum is quite low, so this is one of the main disadvantages of open wells. The concrete sealed is usually carried out under water and therefore, it is not very effective, another thing is the bottom of the well cannot be inspected.

So, these three are the main disadvantages of open caisson or well. Now, coming to the next type of a caisson is box caisson now, the main feature or how it is different from the open well is that, in case of the open well, the top as well as the bottom of the well, both were open, but in case of box caisson, it is open at the top but closed at the bottom.

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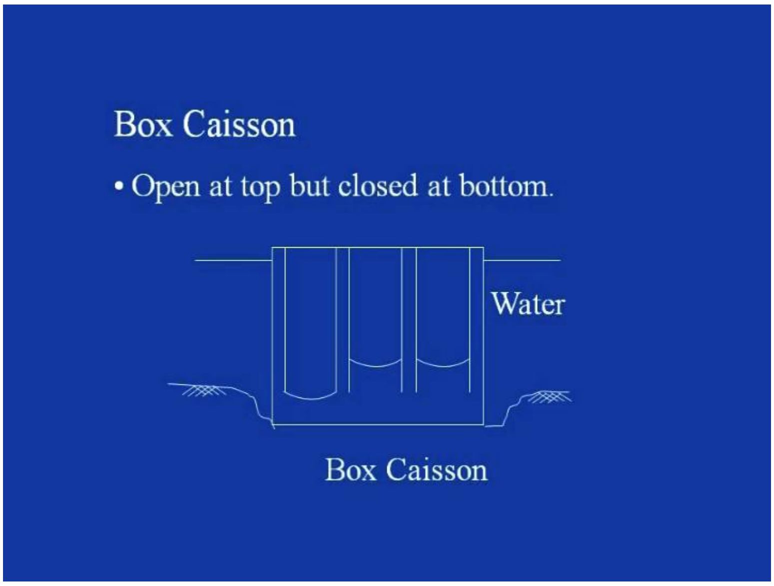

Here you can see the typical figure line diagram, explaining the box caisson features the top is open but the bottom is closed, these are some of the features of this type of caisson is that.

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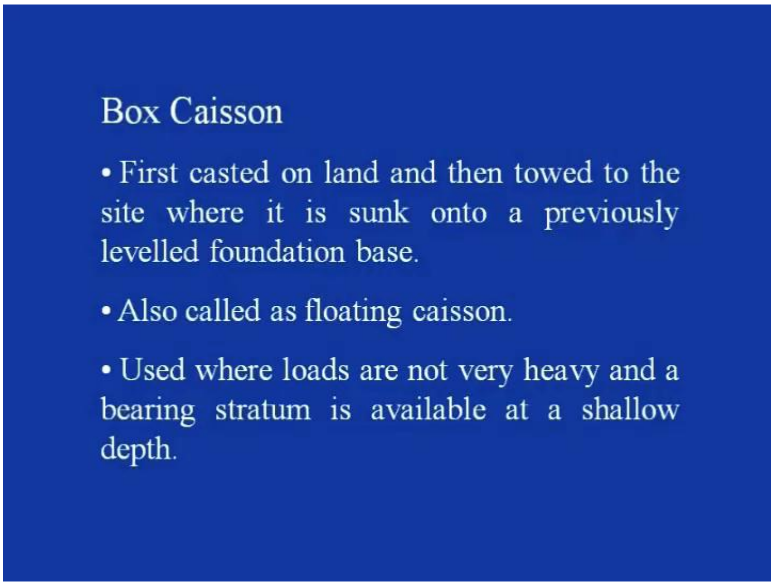

It is first casted on land and then towed to the site where it is sunk onto the previous level foundation base. So, the pre-requisite for the construction of this type of well is that, you have to have pre-levelled foundation base before you start sinking the well and this is to be first casted on the land and then it is transported to the site, where it is to be sunk.

And therefore, this is also called as floating caisson, where the loads are not though that heavy and the bearing stratum is available at the shallow depth, there these types of wells are quite useful. Some of the disadvantages associated with such type of well that is box caisson is that.

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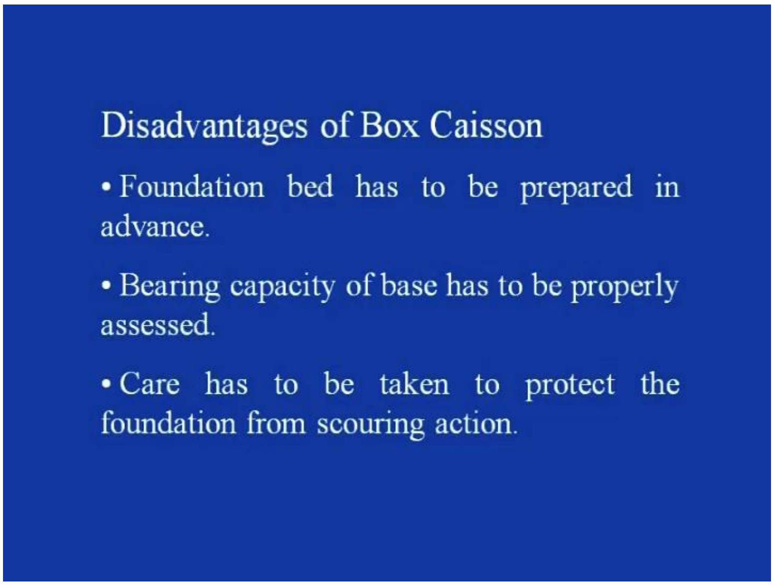

First thing is that because, it is the pre requisite that the foundation level or foundation bed has to be prepared in advance, so that becomes as one of the main disadvantage of such type of well. Then another thing is that, bearing capacity of this base has to be properly assessed, it should not happen that the bearing capacity which has been assessed and the actual bearing capacity they are not the same.

The proper care should be taken to protect this foundation from the scouring action in case, if the water is present. Coming to the third type of the caisson, it is the pneumatic caisson.

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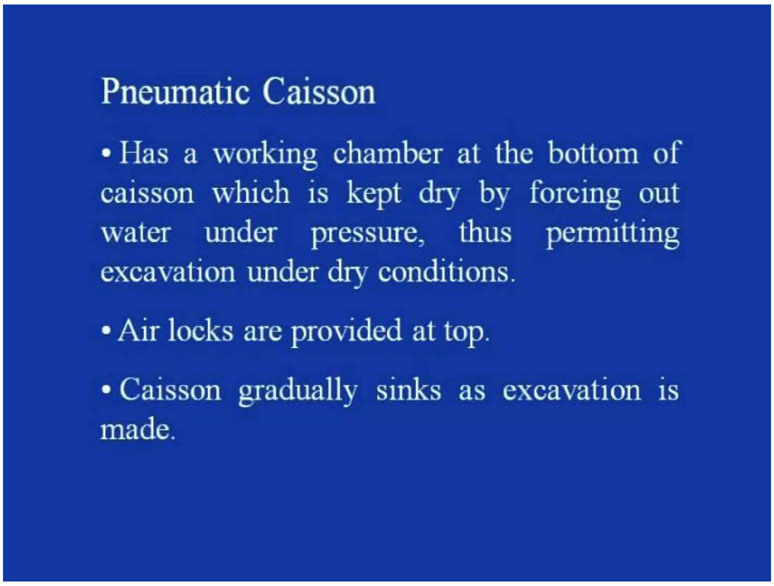

And, it has the working chamber at the bottom of the caisson, which is kept dry by forcing out water under pressure, and thus permitting the excavation under dry condition. So, in both the previous type of well, that is in case of the open well as well as the box well, the construction was being done in the presence of water. But in case of this pneumatic caisson, usually it is, basically it is done in, under the dry condition and you force out the water under pressure.

So, that you get the dry condition in the dredge hole and the construction of this type of caisson takes place. Air locks, they are provided at the top and the caisson, it gradually sinks at as the excavation is made. The typical line diagram showing, this pneumatic caisson is here.

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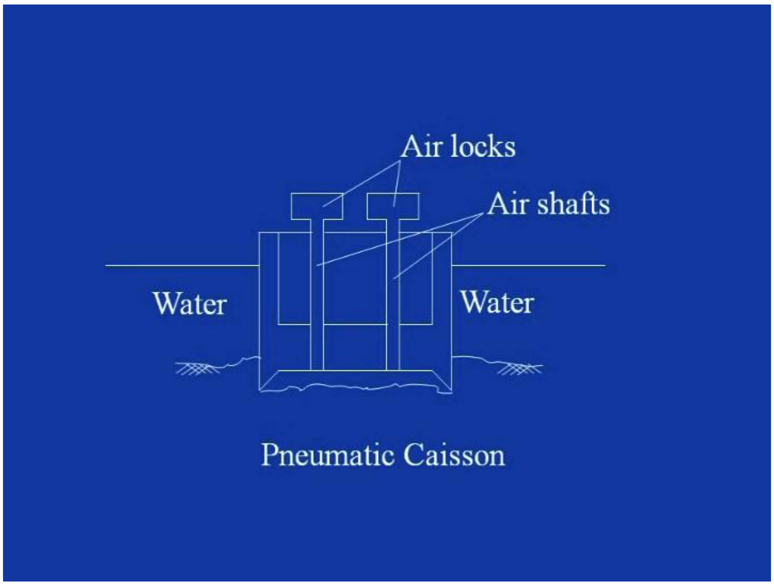

You can see here, that at the top two air locks are being provided, air shafts are being connected to this air lock and this goes inside the, it creates the pressure with the help of the air and that takes out the water and such that, here the dry condition is being carried out.

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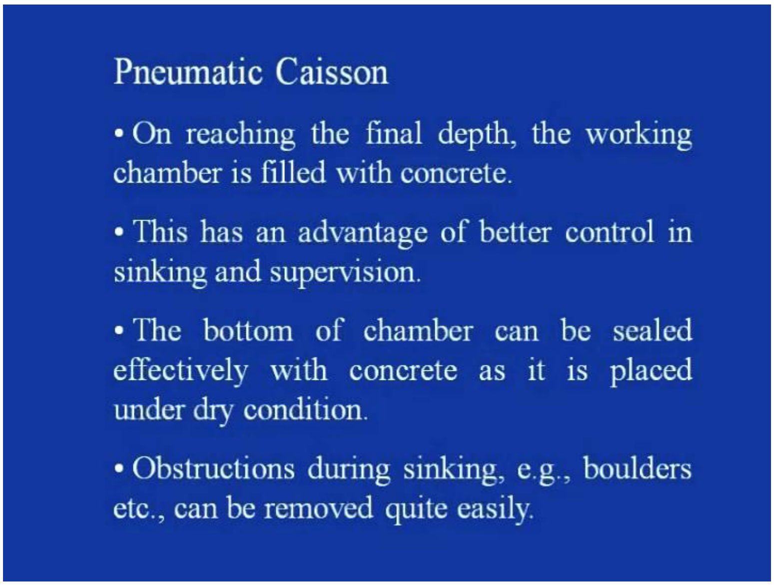

On reaching the final depth the working chamber of this pneumatic caisson is filled with the concrete. Now, this has the advantage of better control of sinking as well as the super vision because, manually one can go inside and do the supervision. The bottom of the chamber can be sealed effectively with concrete, as it is placed under dry condition, see in case of open well and box well, in both the cases, the sealing of the bottom or sealing at the bottom of the well, is done under wet condition.

However in case of this pneumatic well or pneumatic caisson, the sealing is done, under dry condition and therefore, it is much more effective as compare to the open well or box caisson. Obstruction during sinking for example, like boulders, they can be removed quite easily because, the excavation takes place, under the very high pressure, some of the disadvantages which are involved with pneumatic caisson.

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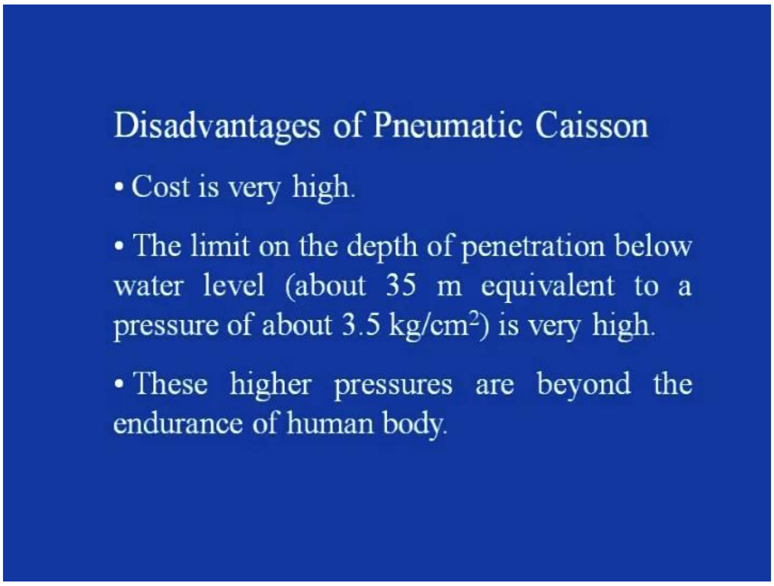

Is that, its cost is very high as compared to open well and box well. The limit, the second one is that the limit on the depth of penetration below water level is quite high, like if you take for example, about 35 meter of the depth of the well is equivalent to the pressure of about 3.5 kg per centimetre square and this high pressure, they are beyond the endurance of a human body.

Therefore such high pressures are there, the site conditions become very difficult for the manual supervision and the construction of the well. Now, these are, here we have discussed the three different types of the well that is, open well, box well and the pneumatic caisson.

Now, for any typical well, let us have a look on the component of well foundation, there are different components and associated with any type of well foundation. We will discuss them one by one, before we go for the analysis of well foundation.

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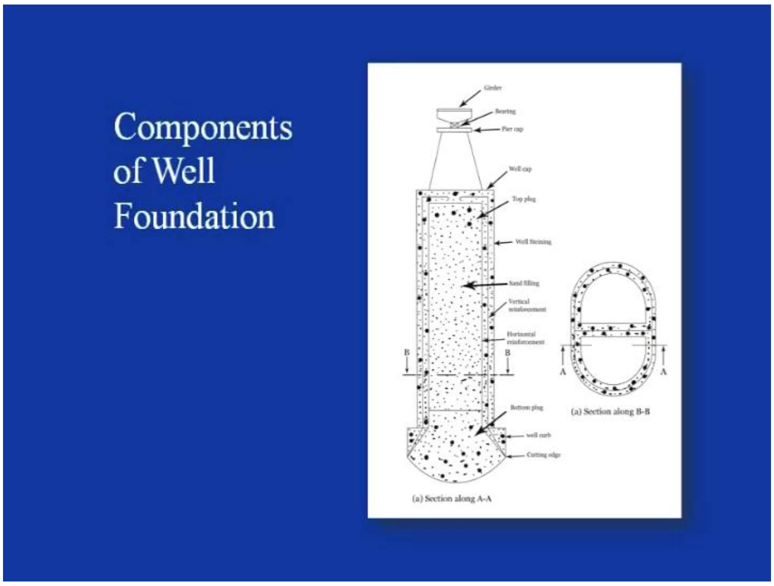

So, here is the different components of the well foundation, just you can have a look on this, that this top part that is the girder bearing pier cap and here is, this is the pier. These form, the super structure and the load from this, that is from the girder it comes to bearing, then the bearing transfers the load to pier cap and then it comes to pier. And just in contact with the pier, the first component of the well foundation comes, that is the well cap.

You can see here, that this is what is the well cap, below that, this well cap is connected to these vertical, you can see it, its sort of a shaft, that is called as well steining. This is connected to curb, that is a curb, curbed type of a structure that is called as well curbed and a cutting edge is connected at the bottom of the well curb, it facilitates the sinking of the well.

Now, some of the other components, they are like, here you can see it is bottom plug, here it is the sand plug and the top portion which is in contact with the well cap is the top plug. Now, let us discuss one by one, the various components of this well foundation.

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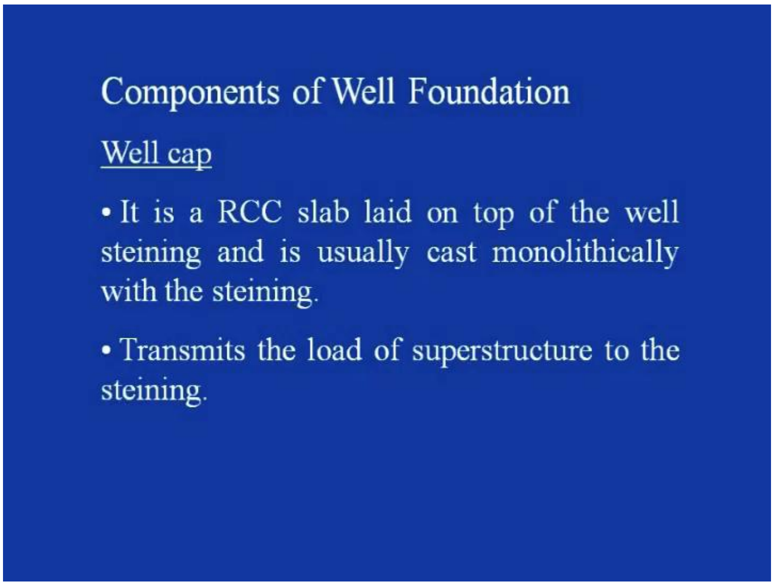

The first one as I just now discussed is well cap, this is a RCC slab which is laid on top of the well steining and is usually cast, monolithically with the steining, it transmits the load of superstructure to the steining. Now, again let us have a look on the, this particular figure and try to understand, that how it works or how the function of this well cap is there.

The load which is coming from here, it comes to well cap, this well cap is in contact with this well steining and it transfers the load, which is coming from the superstructure to the well steining. The second component, the most important one in case of the well foundation, is the well steining.

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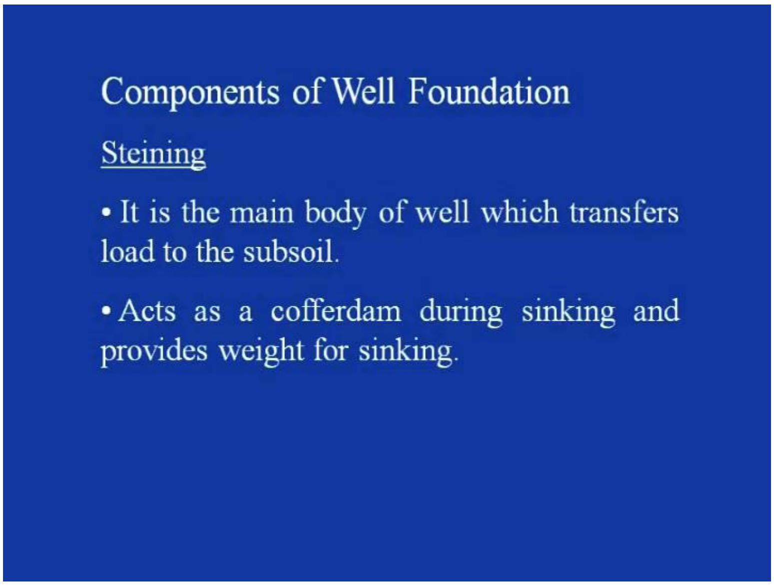

It comprises of the main body of the well, which transfers the load of to the subsoil, this acts as a cofferdam during sinking and provide the necessary weight for sinking. So, you see the sinking takes place under the weight of this steining. So, the thickness of this steining, becomes an important aspect, when you design the well foundation, coming to the figure again, you can see here, that this is having some particular thickness, the load which comes from the well cap it goes to well steining and then it gets transferred to the subsoil, the next component is the curb.

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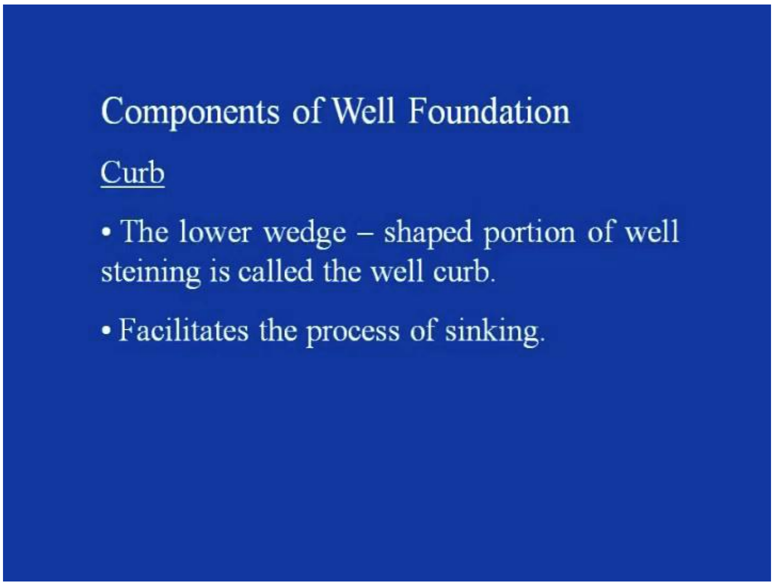

Which is the lower wedge shaped portion of the well steining and that is called as well curb, this facilitates the process of sinking. In the figure, you can see that, the bottom most portion of this well steining, which is running from this point to this point and there, you have this triangular kind of structure, that is the well curb and this facilitates the process of sinking.

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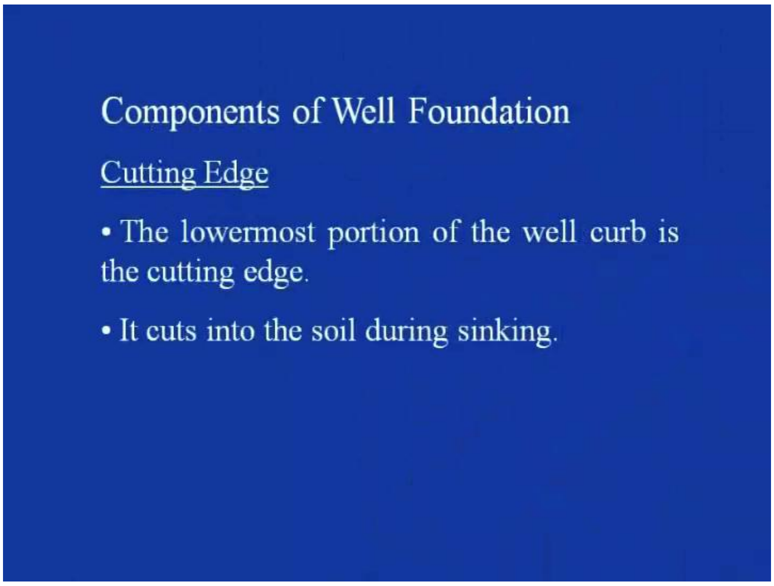

Next component is cutting edge, it is the lowermost portion of the well curb and that is the cutting edge, it cuts the soil during the sinking. You can see here, that here it is the, this is the cutting edge, so when the well sinks under its own weight, this cutting edge helps the well to get sunk. The next component is called as bottom plug, what is done is that you know beforehand that at what to, what depth the well is to be sunk, so once the well is reached to that required depth.

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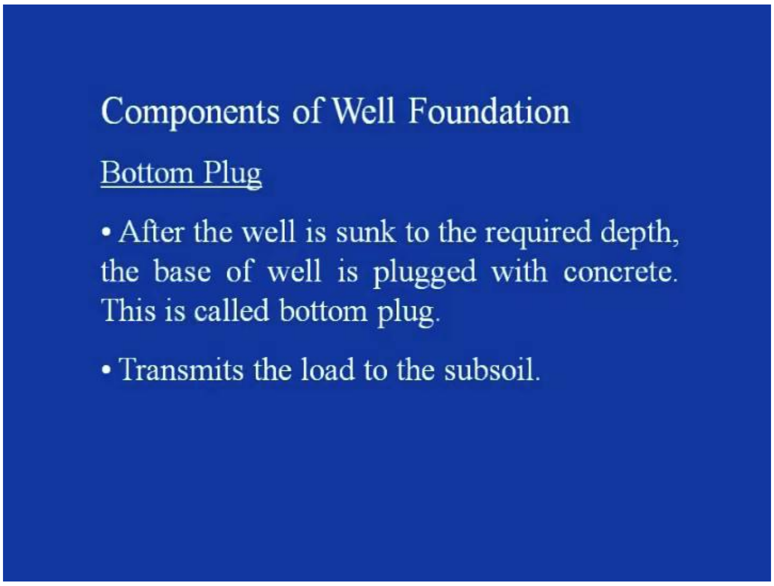

Then, the base of the plug a, the base of the well is being plugged with the concrete and that plug is called as the bottom plug. Now, this the function of this bottom plug is that, it transmits the load to the subsoil, you can see here that here, once this soil, once this well has reached to a particular depth, here this bottom portion of the well is being plugged with the concrete and this forms the bottom plug.

So, this is directly in contact with the subsoil. So, directly it transfers the load which is coming from the superstructure to the subsoil. The next component is dredge hole, now first we must understand that, what exactly is this dredge hole.

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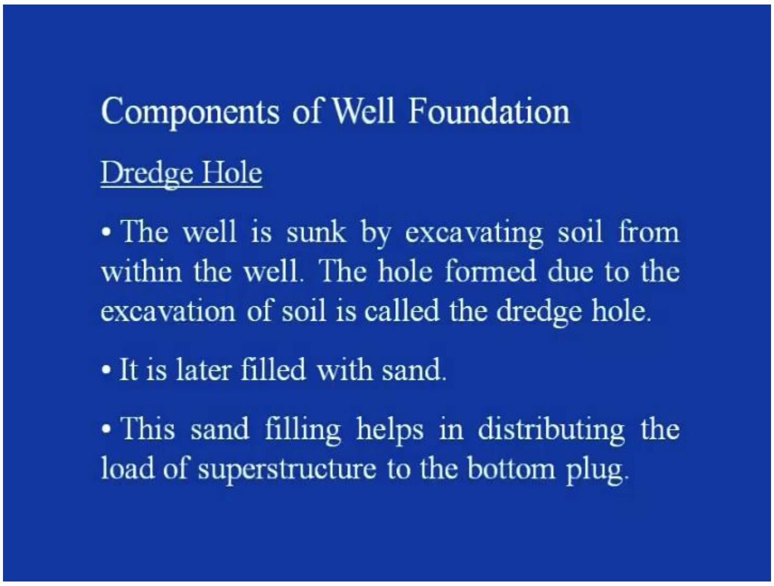

The well is sunk by excavating the soil from within the well the hole formed due to the excavation of this soil is called as dredge hole, so this makes a major component of the well. Now, once the well is reached at the desired or required depth, this dredge hole which has been created because, of the excavation of the soil within the well, it is filled with sand. Now, this sand filling helps in distributing the load of the superstructure to the bottom plug.

How we will just see in this particular figure see, when you have excavated this soil from this. So, here this will form the dredge hole and once the well is reached to the required depth, this hole is being filled with the sand and here you can see that, this particular part from this level and on to the top of this bottom plug is the sand filling, which is done and this helps in transferring the load from the superstructure and some of the load is being transferred to this sand filling and then to bottom plug. Coming to the next component, that is the top plug of the well foundation.

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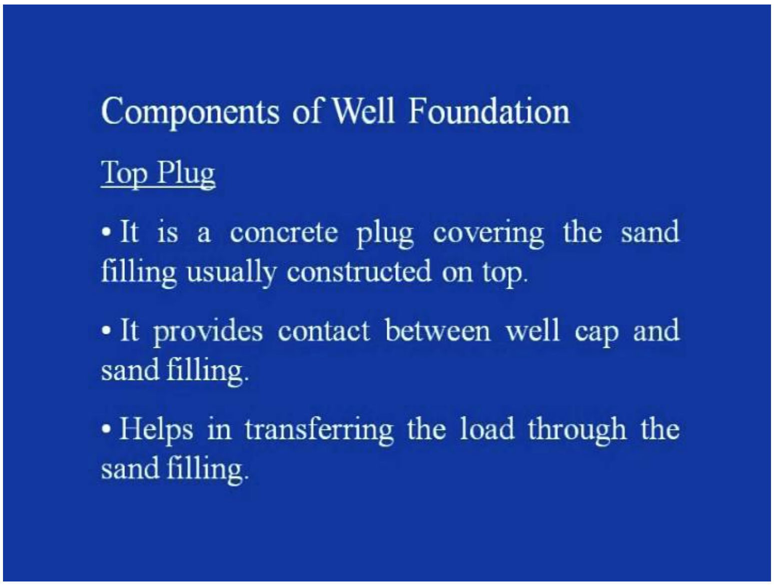

It is the concrete plug, which is covering the sand filling usually, which is constructed at the top of the well. It provides contact between well cap and sand filling and facilitate the transfer of the load from the superstructure, that is some part of the load from the superstructure to the sand filling and then to the bottom plug. You can see here, that up to this point is the sand filling and then the top portion is again being plugged with the concrete and this forms the top plug.

So, now you can see that, all the, all the components they are in contact with each other like, the well cap is in contact with the top plug, then the sand filling, then the bottom bottom plug. So, major load of the superstructure which comes to the well foundation is being transferred to the well steining, some of the load comes to this stop plug, then to the sand filling and then it goes to the bottom plug and then subsequently, the whole load goes to the subsoil.

Now, we saw that, the various components and their function of the well foundation, how the load gets transferred from the superstructure to ultimately to the subsoil. Now, let us have a look on different type of, or different type of shapes of the wells. We, there are many different shapes of the well, which are available, which are here you can see.

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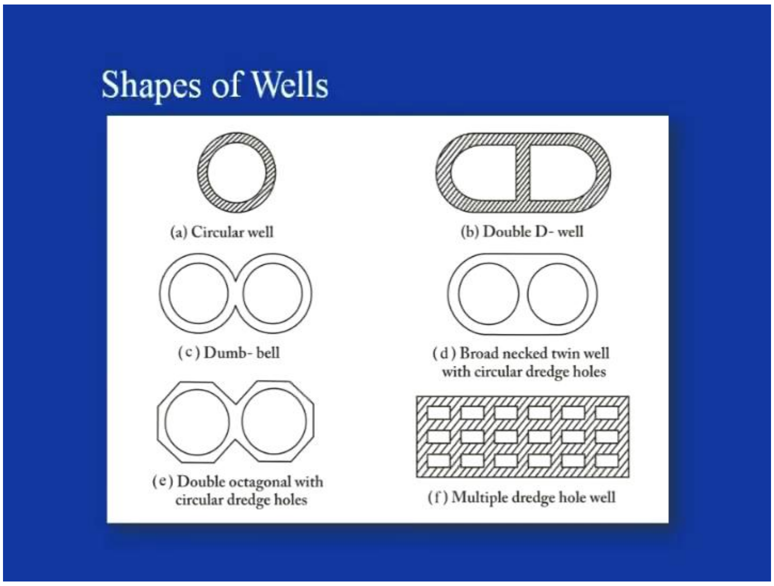

In this particular figure is the circular well, then the second one is double D-well, you can have dumb-bell shape, then fourth one is broad necked twin wells with circular dredge holes, double octagonal with circular dredge holes, then the last one is multiple dredge hole well. Now, let us see that the, what are the advantages and disadvantages of these different shape of well, in what condition these are preferred in what condition these are not employed.

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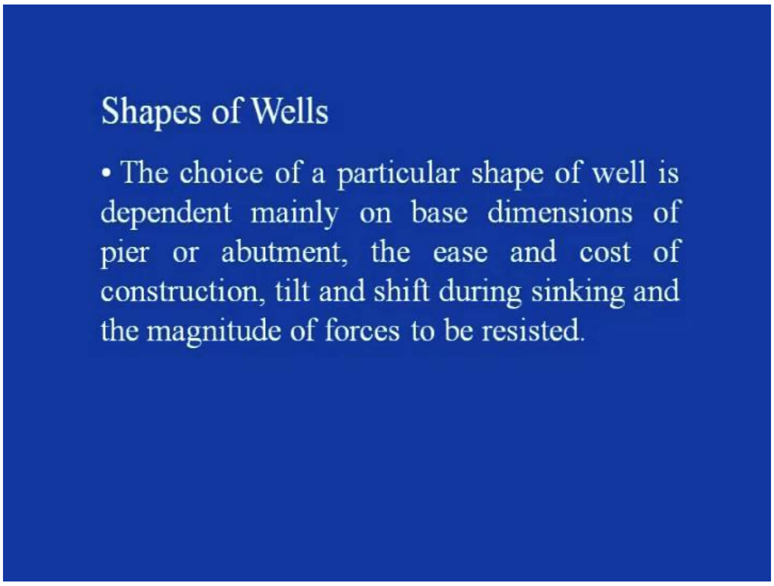

So, the choice of the particular shape of well is dependent mainly on the base dimension of pier or abutment. Another factor which really affects the choice of the shape of the well is, the ease and the cost of construction, the tilt and shift during sinking and the magnitude of forces that are to be resisted for this, for any particular well foundation.

So, taking all these factors like, base dimension of pier, ease and cost of construction, tilt and shift during sinking and the magnitude of forces, we need to take all these things into the consideration and then choose appropriate shape of the well. Some of the guidelines which are there, as per IS code and in general also.

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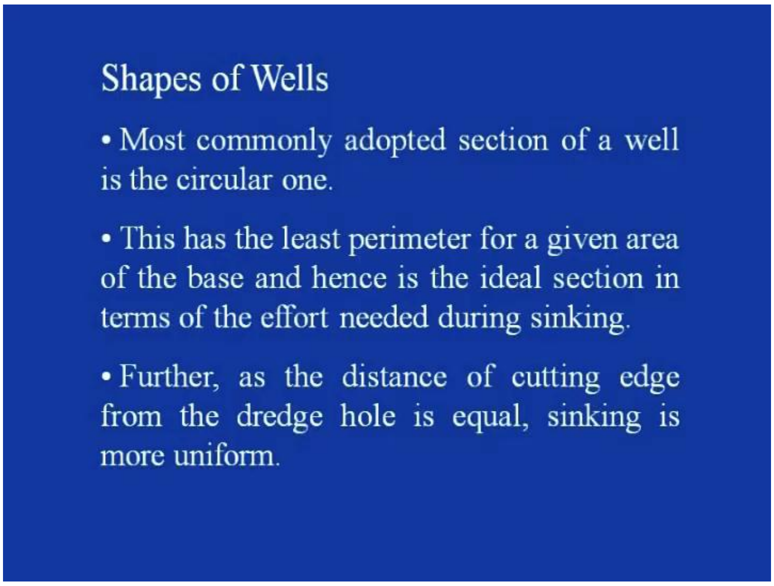

That the most commonly adopted section of the well is the circular one, why, because this has the least perimeter for a given area of the base and hence it is the ideal section in terms of effort, which is required during sinking of the well. Further, as the distance of cutting edge from the dredge hole is equal, being circular in section, the sinking of the well is more uniform. So, these are some of the, two of the main advantage of the circular well.

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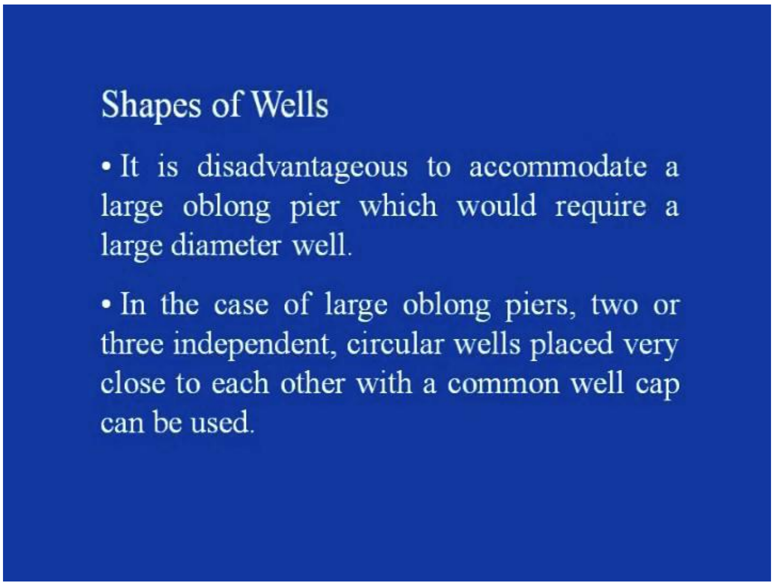

It is quite disadvantages to accommodate a large oblong pier, which would require very large diameter well. In case of large oblong piers, two or three independent circular wells, they are placed very close to each other with a common well cap see, usually this because, this oblong pier, they take very larger diameter of the well. So, it is better to replace such large diameters oblong well or pier, with the two or three circular well and those two or three circular well they are placed very close to each other and a common well cap is provided to all of these.

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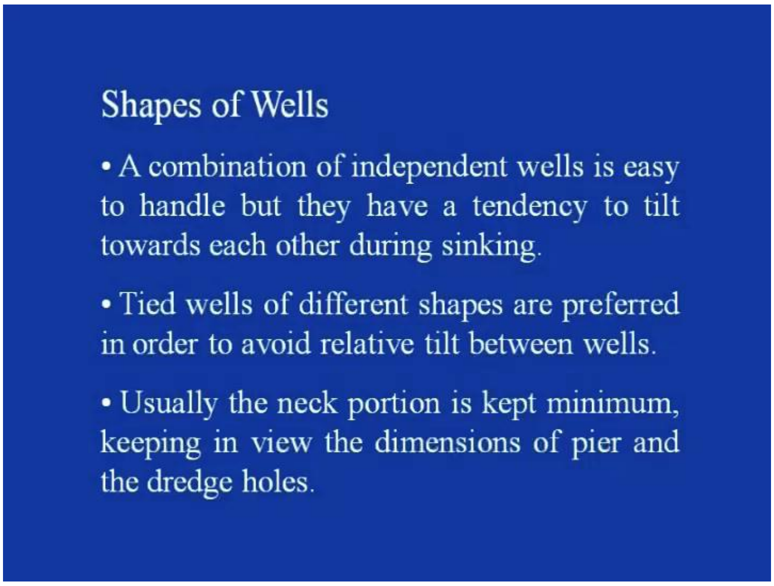

A combination of independent wells is easy to handle, but the disadvantage with such type of independent well is that they have the tendency to get tilted towards each other during the sinking process. Tied wells of different shapes are preferred in order to avoid relative tilts between wells. See, if you are going to provide the independent wells, they will have the tendency to tilt towards each other, during sinking.

So, to remove that particular disadvantage, usually these tide wells of various shapes, they are being used and in these tide wells, the tilts they are of within the permissible limit. Now, usually the neck portion of the well is kept minimum keeping in view the dimensions of pier and the, dredge hole.

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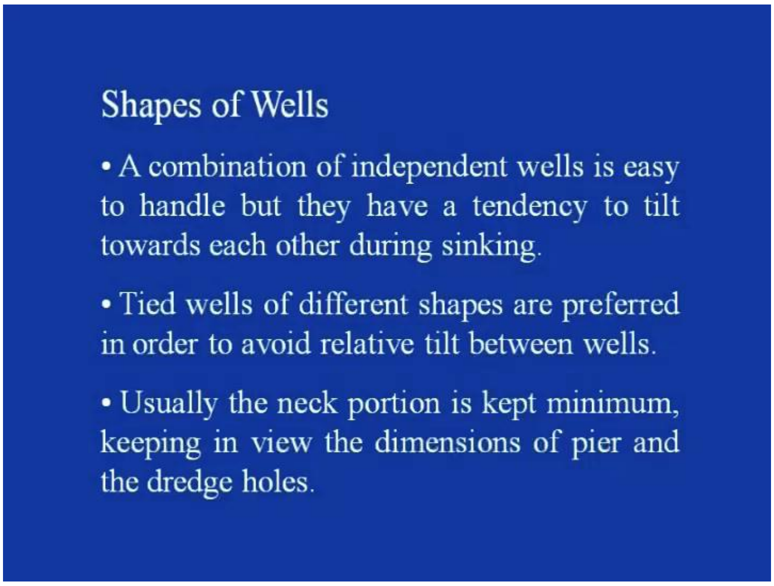

Then, coming to the other shapes of well, double D and dumb bell shapes are commonly used shapes of well, after the circular well. In case of double D wells, as the curved portion is much smaller as compared to the straight portion of the well, the lateral stability is considerably quite increase and that is the lateral stability of the well is increased, in the presence of double D wells.

However this is a straight portion, it makes the sinking process, a bit difficult as you we all know from the common sense is that, if a circular part is there then, the sinking will be more easy as compared to the straight portion of the well. So, this is a straight portion, it increases the resistance to sinking and it corners their corners, they pose problem in dredging.

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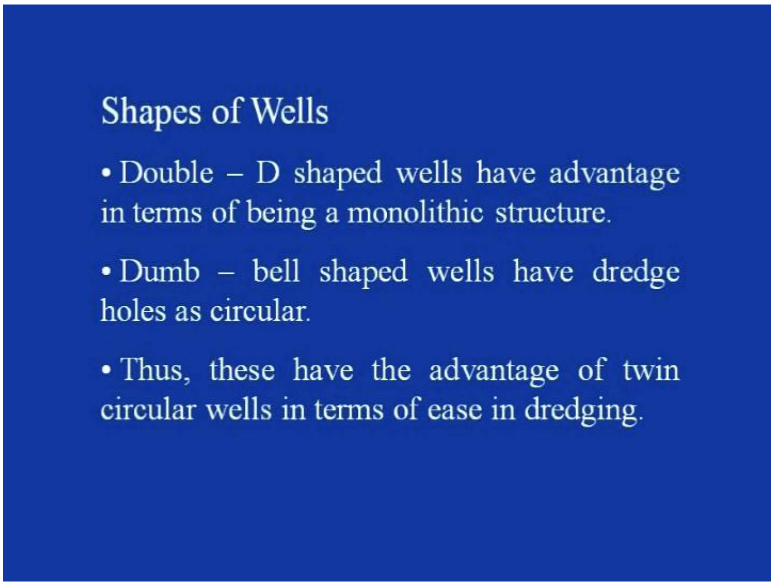

This double D shaped wells they have advantage in terms of being a monolithic structure. Double bell shaped wells they have holes dredge, dredge holes as circular, thus these have the advantage of twin circular wells, in terms of ease of dredging. So, you can go for the double bell shaped wells because, they are just equivalent to sort of two circular wells.

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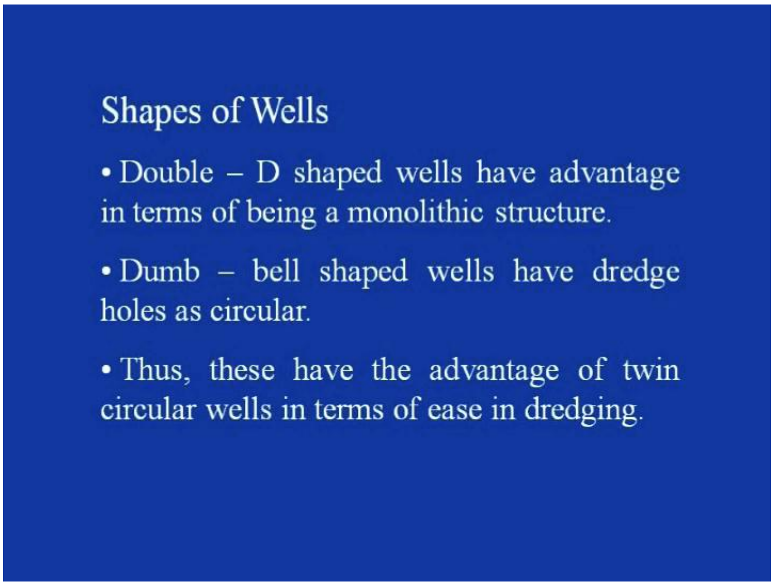

These double octagonal wells are not much in use, because of the difficulty in the construction because, the straight edges of the well foundation, it really causes difficulty during the sinking. Because, they offer greater resistant during sinking on account of increased surface area, see if the surface of the well is curved it offers lesser surface area and the lesser resistance. Coming to the next case that is for piers and abutments of very large size well, with there, this multiple dredge holes are being used.

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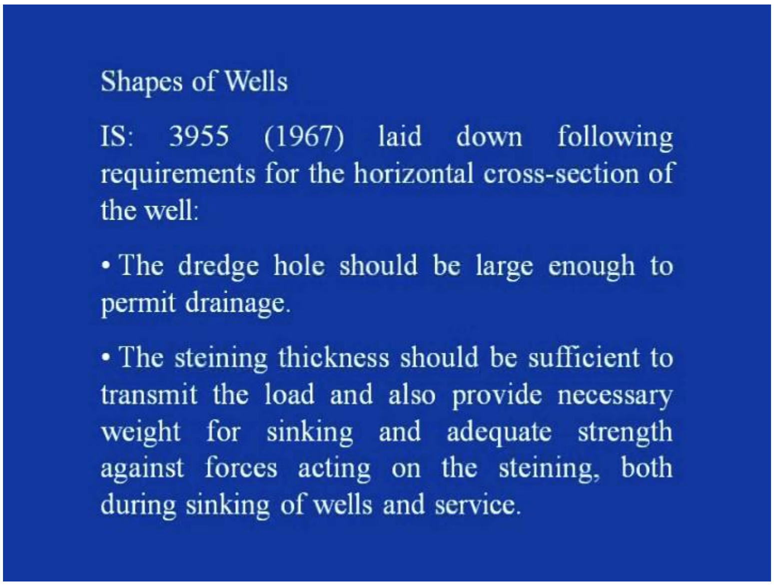

So, this is what is the shape of the well as for as the general guidelines are there, but some of the IS codes that is 3955 1967, it deals with the shape of well, it has laid down some of the requirement for the horizontal cross-section of the well, let us see what are the, those requirements. The first one is that the dredge hole should be large enough to permit the drainage. That is, first thing is that the dredge hole you have to decide upon the, based upon the size of the pier plus at the same time, it should be large enough to permit the drainage.

Now, the thick thickness of the steining is also one of the governing factor as far as the shape of the well is concerned, is that, the steining thickness should be sufficient to transmit the load. And also provide necessary weight for sinking and adequate strength against force, forces which are acting on the steining both during the sinking of the well and the service.

As I was mentioning when we were discussing the component of the well and we were discussing well is steining, there I mention to you that the thickness of the well is steining is an important aspect. As far as the design and the analysis of the well is concerned, the thickness should be adequate, that it provides the sufficient weight, which is useful in while during the sinking, plus at the same time the thickness should be adequate, that whatever loads are because, major part of the load is being transferred to this steining. So, that thickness of the steining should be able to resist, that much of the load which is coming to the well foundations.

So, while deciding the thickness of the steining, one needs to be very very careful from these two points. Then the next requirements which has been laid down by IS code is that, that the well should be able to accommodate the base of the structure and not cause ((Refer Time: 28:43)) obstruction to the flow of water. The fourth one is that, the overall size should be sufficient to transmit the load to the soil; that means the overall size of the well, it should be adequate, that it is able to transfer the whole of the load, on to the soil.

Now, another thing is that IS code has specified, some of the tilts and the amount of the permissible tilt and shifts which are, which can be permissible there in case of the well. So, the shape of the well should be in such a manner, that it should allow for the permissible tilts and shifts of the.

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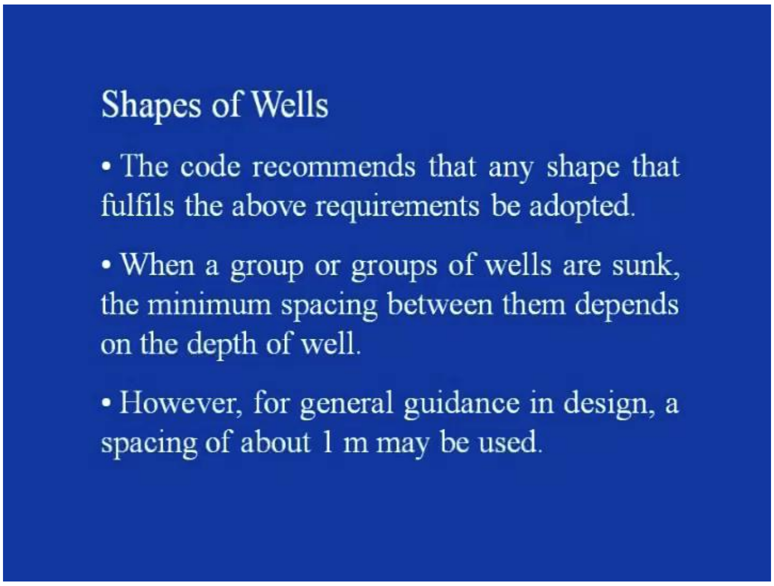

This, the IS codes further recommends that any shape that fulfils the above requirements, which I have just mentioned to you can be adopted. Now, in case, if the loads are quite high and it is required, that more than one well is to be provided, that is the group of wells are to be sunk or to be provided, the minimum spacing between them, it depends on the depth of the well. However, as far as the general guidelines, they are concerned in design, usually this is a spacing is taken to be 1 meter.

Now, this was all about the shape of the well, coming to the depth of the well foundation because, this is one of the main parameter, as far as the design or the analysis of the well foundation is concerned, that at what depth or what is the required depth for sinking the well as far as the loads are concerned.

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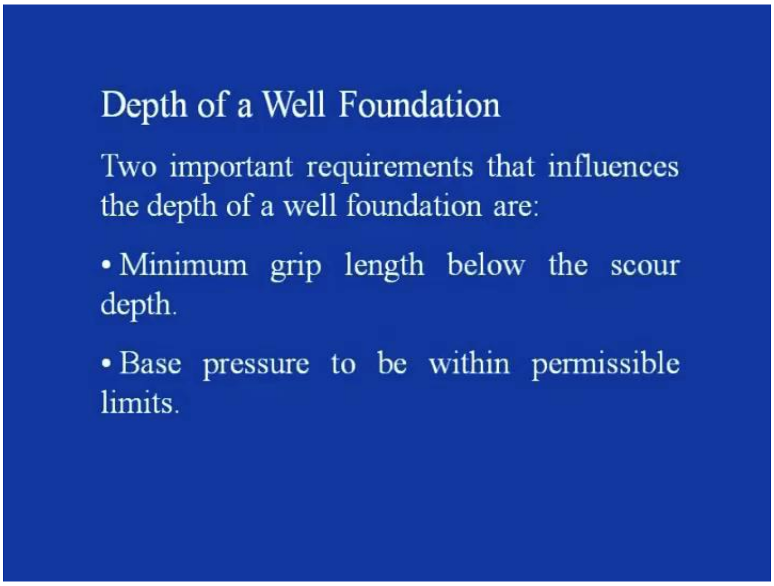

That, there are two important requirements, that influences the depth of the well foundation, the first one is minimum grip length below the scour depth and the second one is the base pressure which is to be, within the permissible limit. So, while deciding the depth of the well foundation, these two criteria has to be kept in mind and the both of, both of these has to be satisfied, that is the minimum grip length below this scour level has to be provided.

And whatever is the base pressure which is coming, which is there, because of the soil that should be within the permissible limit. Now, first let us see that, how we can find out the grip length of the well, so first of all before that, first we need to have a look on the scour depth, that what exactly do we mean by scour depth and then we will see that, what should be the grip length.

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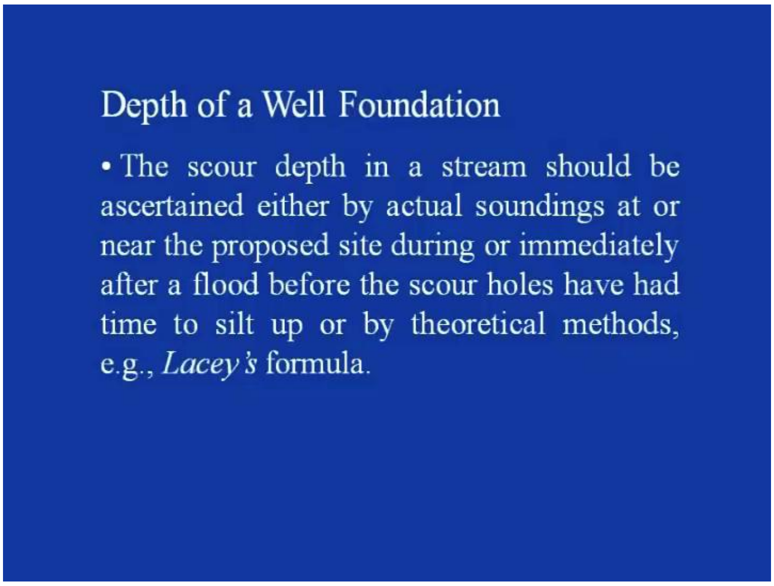

The scour depth in a stream, they should be ascertained either by actual sounding at or near the proposed site during or immediately after the flood, before the scour holes have had time to silt up or by theoretical methods, that is the Lacey's formula. So, either you conduct the test at the site, to know this scour depth or there are theoretical formula which are available for finding out the scour depth.

One of this formula is Lacey's formula, so here we are going to discuss the Lacey's formula and we are going to discuss that, how the scour depth is being evaluated using this.

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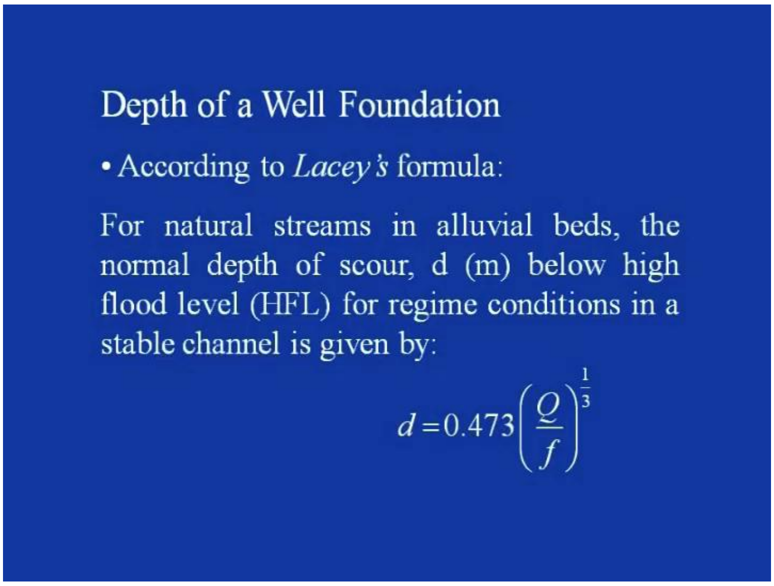

Now, as per this Lacey's formula, for natural streams in alluvial beds, the normal depth of a scour, which is represented as let us say d, which is in meter below high flood level for regime condition in a stable channel is given by this expression, which is d is equal to 0.473 Q by f to the power 1 by 3.

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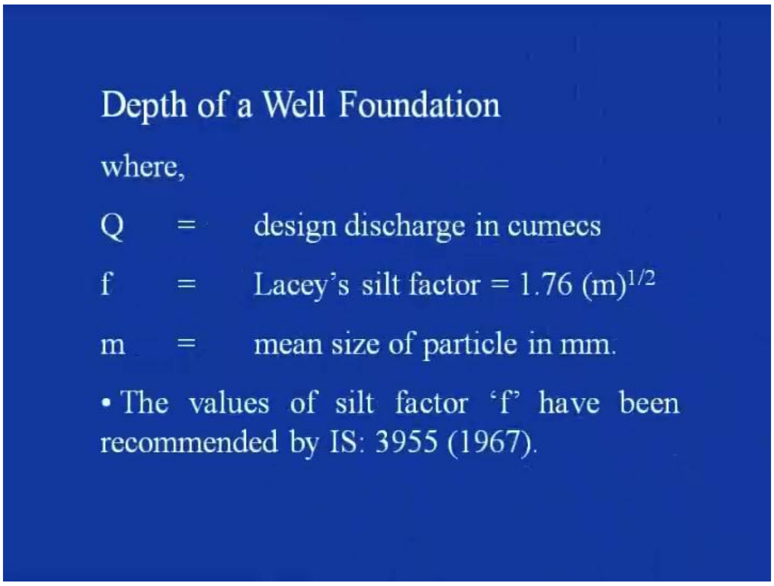

Where this Q is designed discharge in cumecs, that is meter cube per second, then f is the Lacey's silt factor, which is given by 1.76 m to the power half, m is the mean size of particle in millimetre. Now, how to decide upon these silt factor, IS code has given some of the guidelines for the choice of these silt factor, that is IS 39551967.

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Values of Lacey's silt factor:

Type of Bed Soil	Size of Particles (mm)	f
Coarse silt	0.04	0.35
Fine sand	0.08	0.50
	0.15	0.68
Medium sand	0.3	0.96
	0.5	1.24
Coarse sand	0.7	1.47
	1.0	1.76
	2.0	2.49

We will just have a look that, what exactly are these Laceys silt factor for different types of soil. You can see here, that the first column is dealing with the type of bed soil, the second one is with for size of particles, which are there in millimetre and third column give us the value of this Lacey's silt factor that is f. Now, here in this side, four types of soils are there in the subsequent one, we have some more types.

So, like in case here say, if the type of the bed soil is coarse silt, then the size of the particle is of the order of 0.04 millimeter and if this condition is prevailing at the site you can pick the value of f as 0.35. Like for example, in case if you are encountering the coarse sand as a type of bed soil and say the size of particle is of the order of, say 1 millimetre.

Then, you can use this particular table and pick the appropriate value of this Lacey's silt factor as 1.76, in case if you have encountered coarse sand as the type of bed soil and the size of the particle, is of the order of 1 millimetre. Now, in continuation of this particular table, here they are, there are the two other type of bed of a soil material, that is gravel and boulder.

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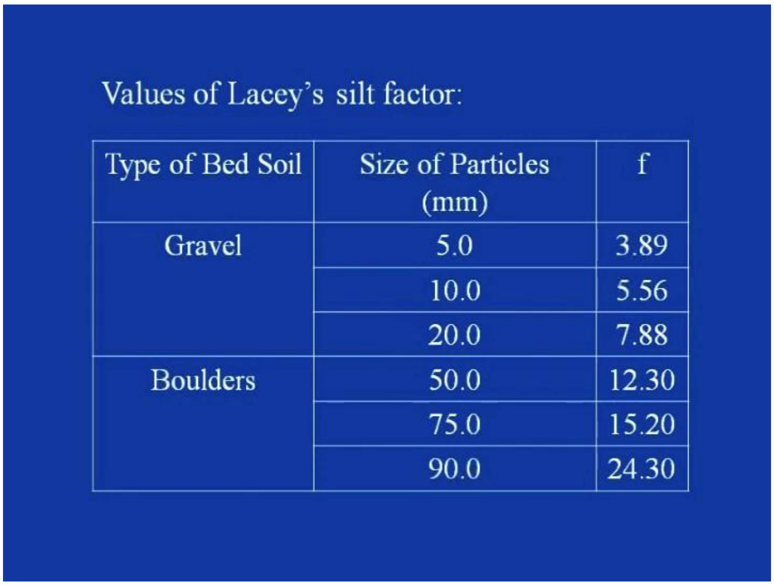
Values of Lacey’s silt factor:

Type of Bed Soil	Size of Particles (mm)	f
Gravel	5.0	3.89
	10.0	5.56
	20.0	7.88
Boulders	50.0	12.30
	75.0	15.20
	90.0	24.30

As we all know, that the size of the particles will keep on or will be quite high, in case of the gravel and boulder. So, let us say if the type of bed soil is say bouldery and the size of particles usually they are of the order of say seventy-five millimetre you can pick, pick an appropriate value of 15.20 as f which is the Lacey's silt factor. So, using this particular table, depending upon the type of bed soil and the size of particle, you can pick the appropriate value of Lacey’s silt factor f.

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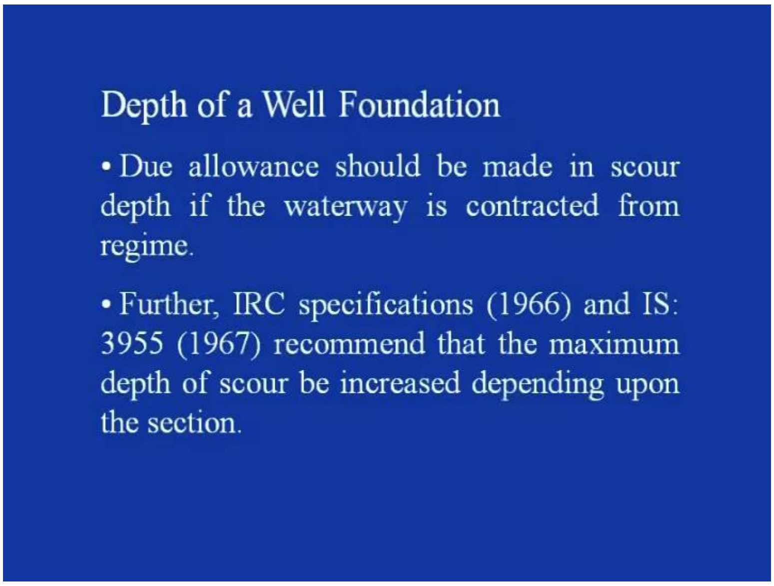

Now, due allowance should be made in scour depth, if the waterway is contracted from the regime. Now, further IRC specifications in 1966 and IS code, they recommend that the maximum depth of a scour, be increased depending upon the section. Now, codes they have given the provision or they have given as the idea that depending upon, what is the type of section to what extent, one should increase the scour depth, let us see here that this table has been taken from those codes and it gives us, the idea about the maximum depth of scour.

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Maximum depth of scour:

Section	Maximum Depth of Scour
In straight reach	1.27 d
At a moderate bend	1.50 d
At a severe bend	1.75 d
At a right angled bend or at noses of piers	2.00 d
At upstream noses of guide banks	2.75 d
In severe swirls	2.50 d

So, you can see here, that based upon the section, that is in the, if it is straight reach or if it is at a moderate bend or if you are providing the well foundation at a severe bend or if it is at a right angled bend or at the nose of the pier. They are corresponding to the condition, where you are providing the well foundation, d is the depth of the scour, which you have obtain from the Lacey's formula.

Now, that has to be increased to take care of any deviation from the regime, is that the maximum depth of the scour can be like 1.27 d, in case if it is the well foundation is being provided in the straight reach or let us say if it is at upstream noses of guide banks, then it can be, it has to be increased by a factor of 2.75 and likewise here, say if it is at a right angle bend or if you have the very sharp bends of cause, at there the scour will be more and. So, you have to provide some more maximum depth of square as 2 d, here we can see.

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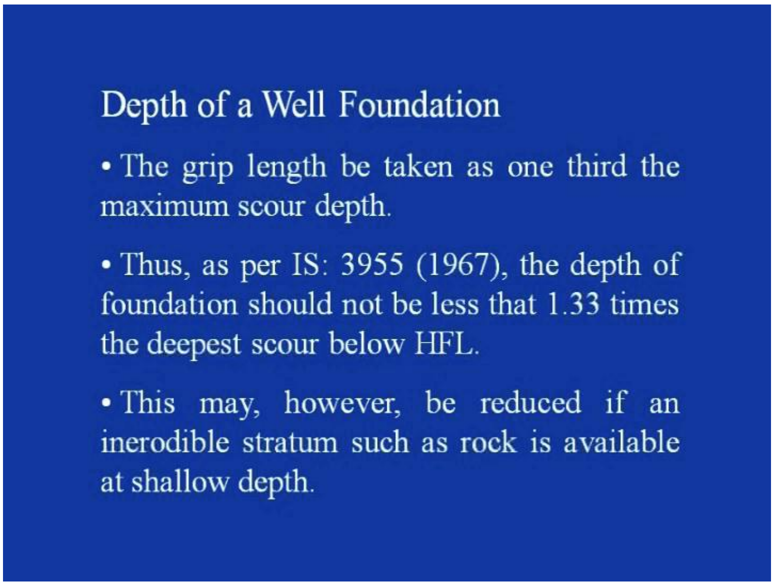

Now, these grip lengths of the well, it can be taken as one third of the maximum scour depth.

So, therefore, as per the IS code, the depth of foundation should not be less than 1.33 times, the deepest scour below high flood level that is HFL. So, first thing is that, we need to obtain the depth of scour from Lacey's formula then, we need to increase it depending upon the section, where you are providing the well foundation and the grip length is being then increased by 33 percent. So, whatever is the maximum depth of a square, you have to multiply that by a factor of 1.33 to know the grip length.

Now, this may; however, be reduced if and in erodible is stratum, such as rock is available at shallow depth. In case, if you have the rocky strata available at the shallow depth, this increase of the 33 percent can be reduced using your engineering judgement depending upon the condition at the site.

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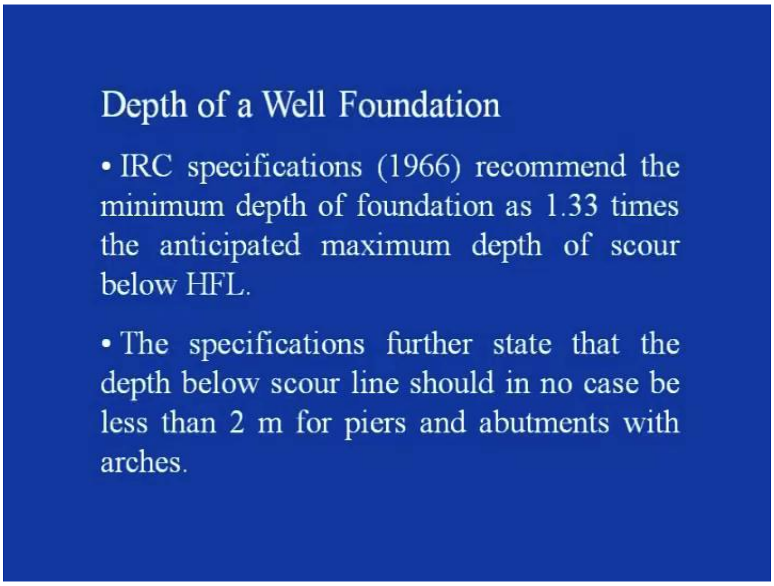

Now, this IRC specification, recommend the minimum depth of foundation as 1.33 times at the anticipated maximum depth of a scour below HFL, further the specification state, that depth below scour line should be in no case less than 2 meters for piers and abutments with arches. We need to consider, these two criteria and based upon this whichever is the larger grip length that, we get we need to provide that grip length.

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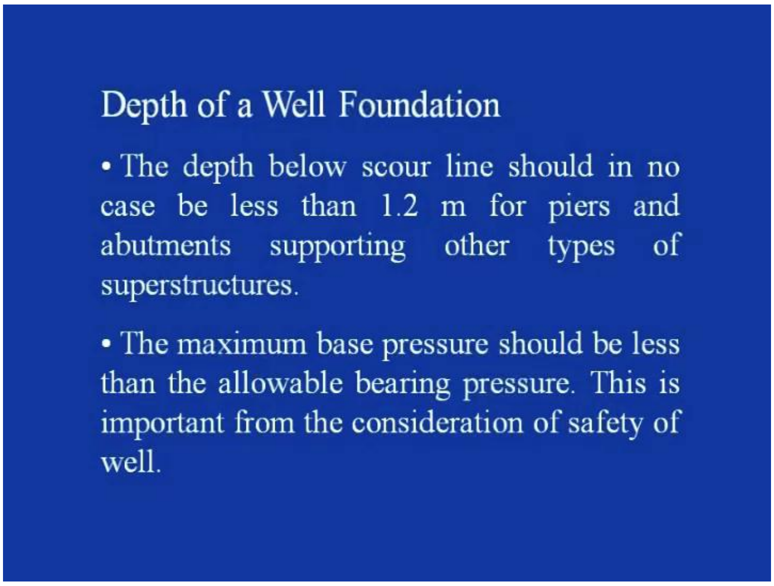

Now, the depth, below the scour line should in no case, be less than 1.2 meters for piers and abutment supporting other type of superstructure. If they are with respect to the piers and abutment with arches, the minimum depth below the scour line is 2 meters; however, for other supporting structures or other superstructures, it is 1.2 meters. So, this is the, how you have to decide upon the depth of the well foundation based upon the scour depth.

Now, you have to take into account, the base pressure and decide upon the depth of the well foundation, that is at the base of the well foundation whatever pressure which is coming, it should be less than the allowable bearing pressure. So, it is not only the scour depth, but the allowable soil pressure also, is one of the deciding factor of the depth of the well foundation.

So, today we have discussed about some of the fundamental or basic aspects, related to the well foundation, the first we discussed that, what are all the various type of well foundation, then we discuss the shape of the well foundation, different type of shapes, their advantages and disadvantages and then we saw that what all are the various components of the well foundation and their function and then we had an idea that, how one can decide upon the depth of the well foundation based upon the scour depth and the allowable soil pressure. Now, how this allowable soil pressure is being calculated that, we will be discussing in the next lecture.

Thank you.