Prestressed Concrete Structures

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Lecture - 40
Circular Prestressing, Conclusion

Welcome back to prestressed concrete structures. This is the sixth lecture of the ninth module on special topics and this is concluding lecture of this course.

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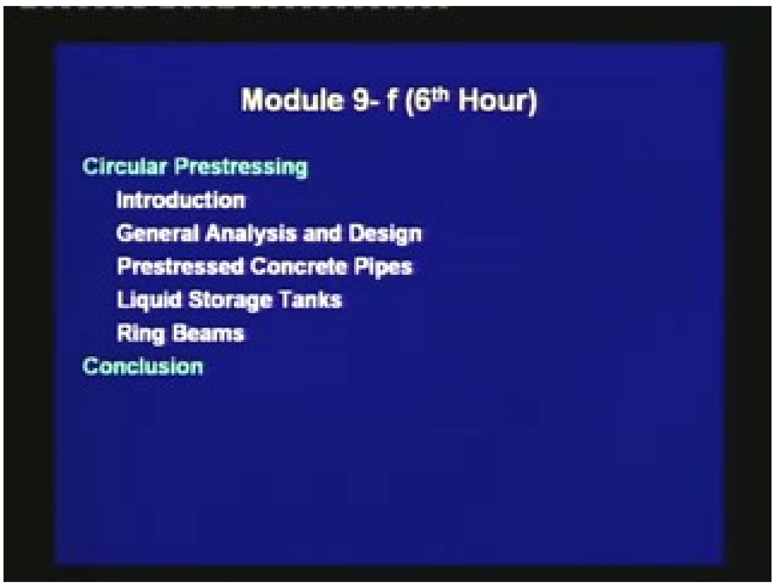

First, today we shall learn about circular prestressing. After the introduction we shall study the general analysis and design. We shall then study specifically about prestressed concrete pipes, liquid storage tanks and ring beams. Finally, we shall conclude.

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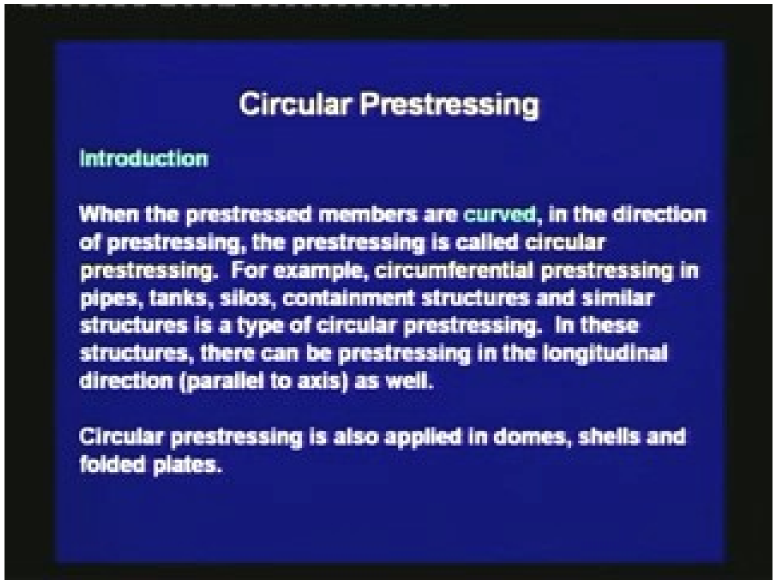

When the prestressed members are curved, in the direction of prestressing, the prestressing is called circular prestressing. For example, circumferential prestressing in pipes, tanks, silos, containment structures and similar structures is a type of circular prestressing. In these structures, there can be prestressing in the longitudinal direction, which is parallel to axis, as well. Circular prestressing is also applied in domes, shells and folded plates. Here, we have to be clear that if a tendon is passed through a curved profile within a linear member it is not called as circular prestressing. The member itself has to be curved to term the prestressing as circular prestressing.

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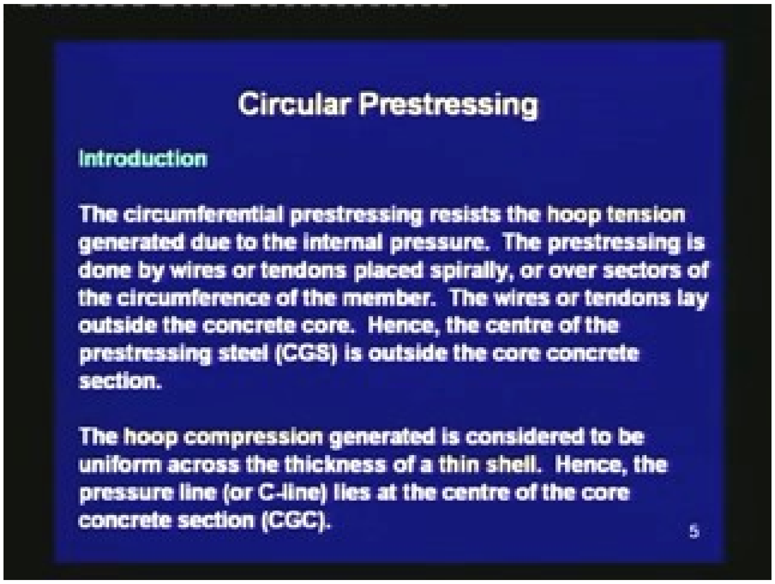

The circumferential prestressing resists the hoop tension generated due to the internal pressure. The prestressing is done by wires or tendons placed spirally or over sectors of the circumference of the member. The wires or tendons lay outside the concrete core. Hence, the centre of the prestressing steel, which we shall denote as CGS, is outside the core concrete section.

The hoop compression generated is considered to be uniform across the thickness of a thin shell. Hence, the pressure line or C line lies at the centre of the core concrete section, which we shall denote as CGC. Thus, in circumferential prestressing, the prestressing wires or tendons lay outside a concrete core shell and it creates a hoop compression to resist the hoop tension that generates due to internal pressure. The CGS that means the centroid of the prestressing steel lies outside the concrete section and also we assume that for thin shells the stress across the thickness of the shell is uniform. Thus, the hoop compression that is generated coincides with the center of the concrete section.

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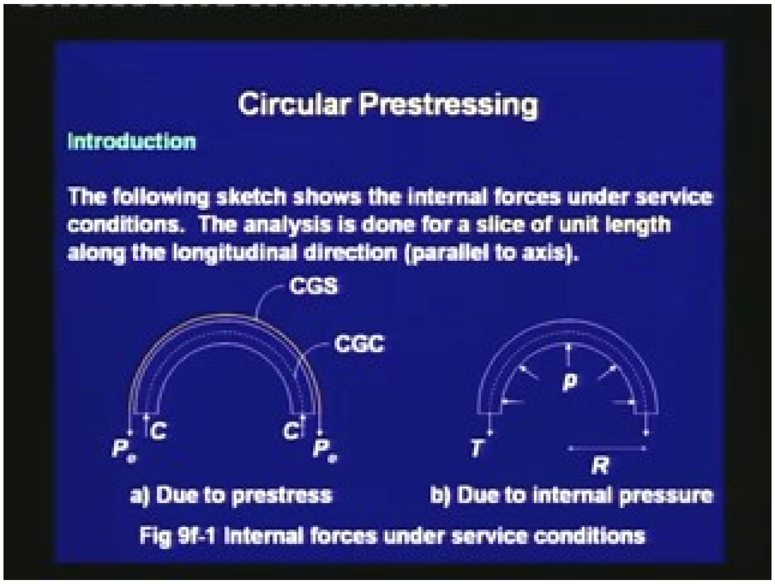

The following sketch shows the internal forces under service conditions. The analysis is done for a slice of unit length along the longitudinal direction, which is parallel to the axis of the member. In this sketch, the prestressing tendon is lying outside the shell and it is creating a hoop compression, where the compression is lying at the mid-plane of the shell, which is the CGC. Due to the internal pressure P, there is hoop tension which is also lying at the centre of the section.

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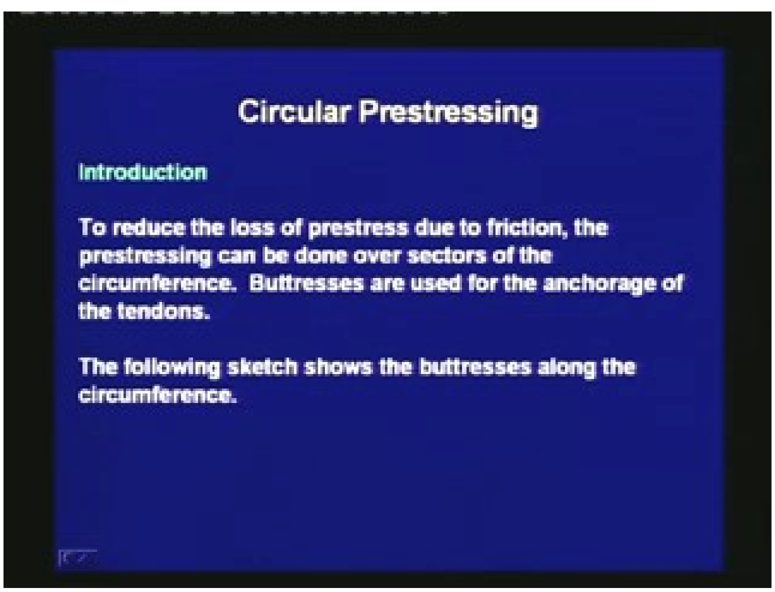

To reduce the loss of prestress due to friction, the prestressing can be done over sectors of the circumference. Buttresses are used for the anchorage of the tendons. The following sketch shows the buttresses along the circumference.

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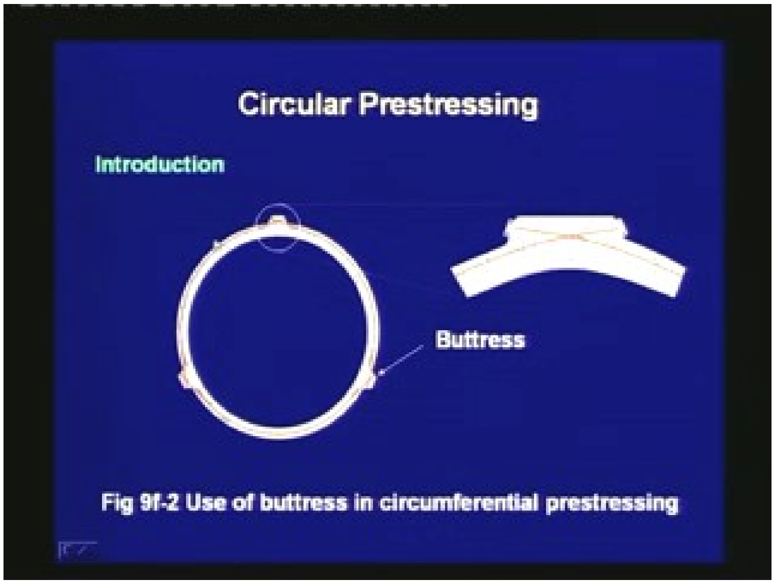

Here, you can see that the prestressing tendon is not continuous throughout the circumference. It has been broken up into sectors and it has been anchored in this buttresses. This reduces the friction loss that occurs during the circumferential prestressing. A closer view of buttresses shows that one tendon is anchored at the left end, which can be the dead end and the other tendon is anchor at right end, which can be the stretching end.

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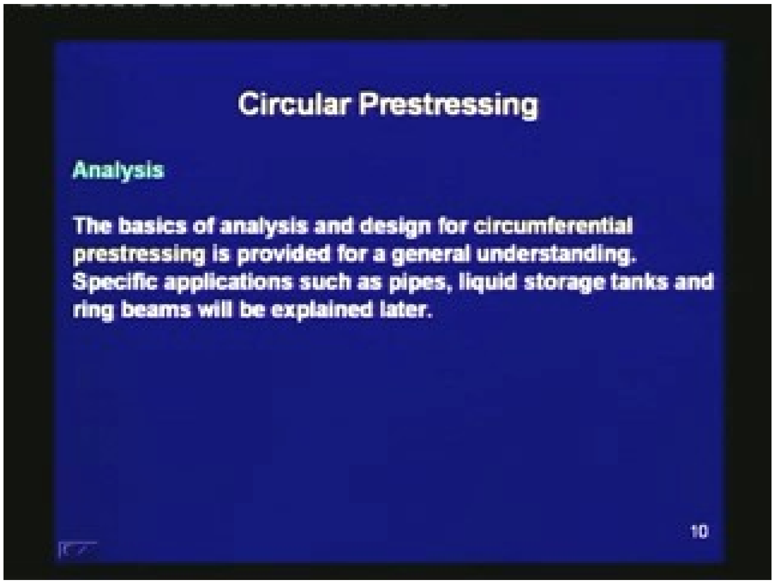

Next, we move on to the analysis and design under circumferential prestressing for general conditions. The basics of analysis and design for circumferential prestressing, is provided for a general understanding. Specific applications such as pipes, liquid storage tanks and ring beams will be explained later.

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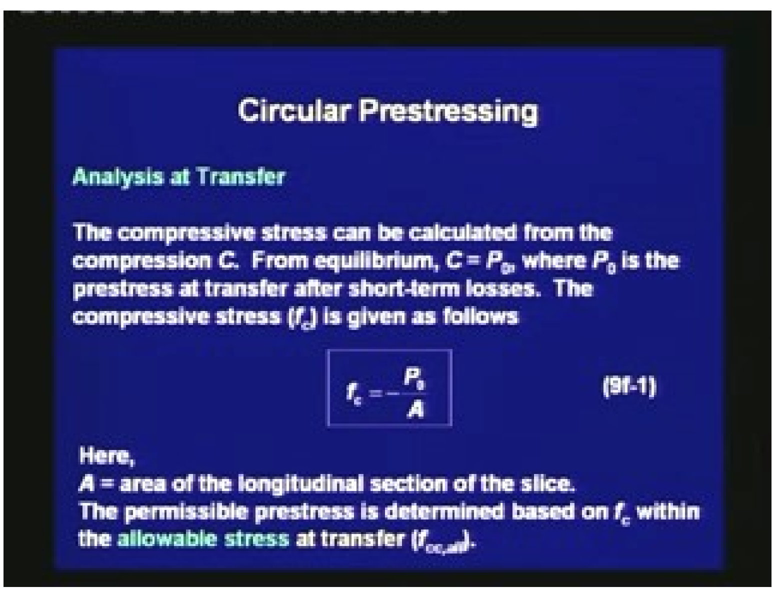

Analysis at transfer - the compressive stress can be calculated from the compression C that generates due to the prestressing force. From equilibrium, C is equal to P_0, where P_0 is the prestress at transfer after short-term losses. The compressive stress f_c is given as follows: f_c, is equal to minus P_0 by A, where A is the area of the longitudinal section of the slice. The permissible prestress is determined based on f_c within the allowable stress at transfer, which can be denoted as $f_{cc,all}$. Thus, assuming the hoop compression is uniform across the thickness, we are able to find out an expression of the compressive stress that generates due to the circumferential prestressing. At transfer, this stress has to be less than the allowable compressive stress in the concrete at transfer.

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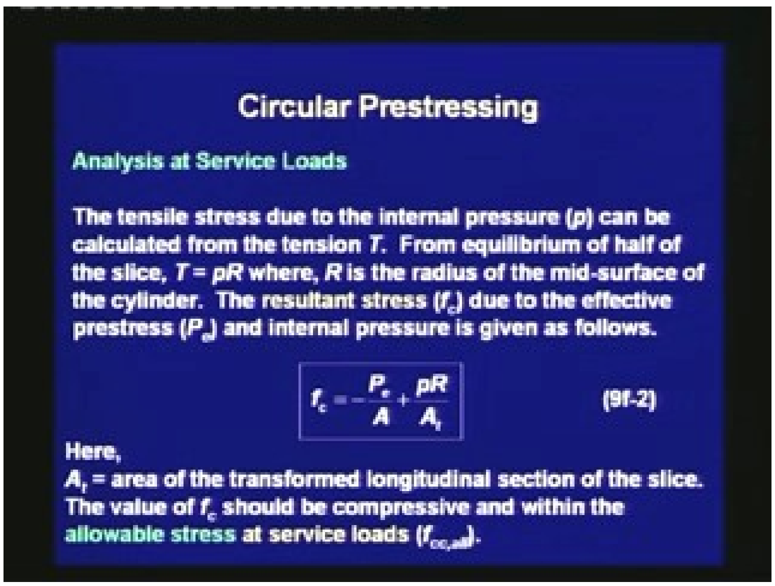

Next, we move on to analysis at service loads. The tensile stress due to the internal pressure p can be calculated from the tension T. From equilibrium of half of the slice, T is equal to pR where, R is the radius of the mid-surface of the cylinder. The resultant stress f_c due to the effective prestress, which is denoted as P_e and internal pressure, is given as follows: f_c, is equal to minus P_e by A plus p times R divided by A_t. Here, A_t is the area of the transformed longitudinal section of the slice. The value of f_c should be compressive and within the allowable stress at service loads, which we are denoting as $f_{cc,all}$.

Thus, under service conditions the hoop tension adds up to the hoop compression and the total stress has two components: one due to the prestressing force, which is compressive and another due to the internal pressure, which is tensile. The resultant stress should be compressive and it should be within the allowable compressive value for service loads.

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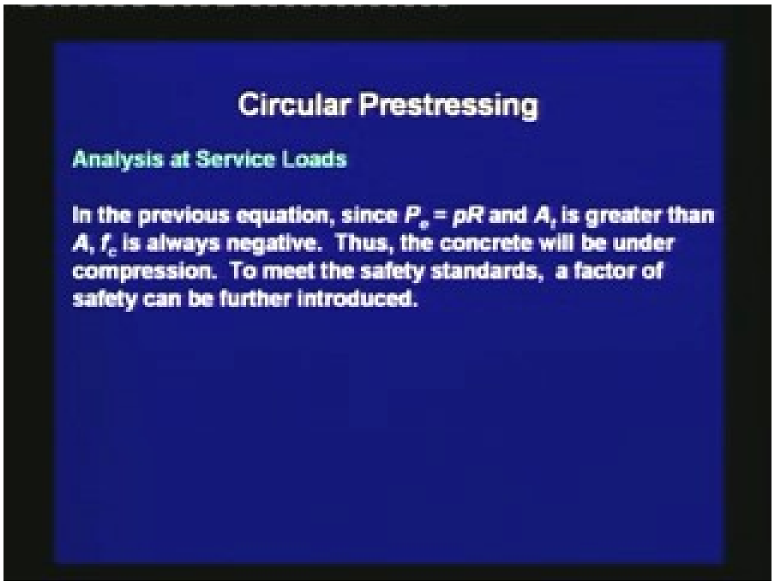

In the previous equation, since P_e is equal to pR and $A_{t,}$ is greater than A, f_c is always negative. Thus, the concrete will be under compression. To meet the safety standards, a factor of safety can be further introduced. From the previous expression, it can be noted that since the effective prestress is equal to p times R which comes from the equilibrium of half of the slice and the area A_t is greater than the concrete A, f_c will be always under compression. To this expression, a further safety factor can be used depending upon the usage of the structures.

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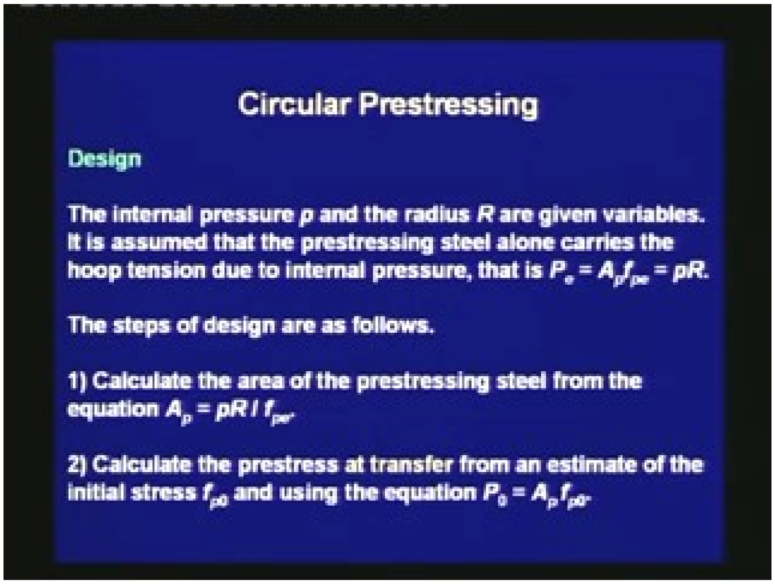

The internal pressure p and the radius R are given variables. It is assumed that the prestressing steel alone carries the hoop tension due to internal pressure that is P_e is equal to A_p times f_{pe} is equal to pR. Thus in design, first we are assuming that the internal pressure is resisted by the prestressing force alone. Then we are trying to find out suitable combination of the radius of the shell and the thickness of the shell, depending on the internal pressure p. The design steps are as follows: first calculate the area of prestressing steel from the equation A_p is equal to pR divided by f_{pe}. Thus given the assumption that P_e is equal to the internal pressure times radius, we find out the amount of prestressing steel required in the unit length of the slice and that is equal to A_p is equal to pR divided by f_{pe}.

Next, we are calculating the prestress at transfer from an estimate of the initial prestress $f_{p0,}$ using the equation P_0 is equal to A_p times f_{p0}. Thus, once we have calculated $A_{p,}$ we know that how much prestress we can apply initially. Based on that we are estimating $P_{0.}$ From that we can calculate the loss to get the effective prestress P_e.

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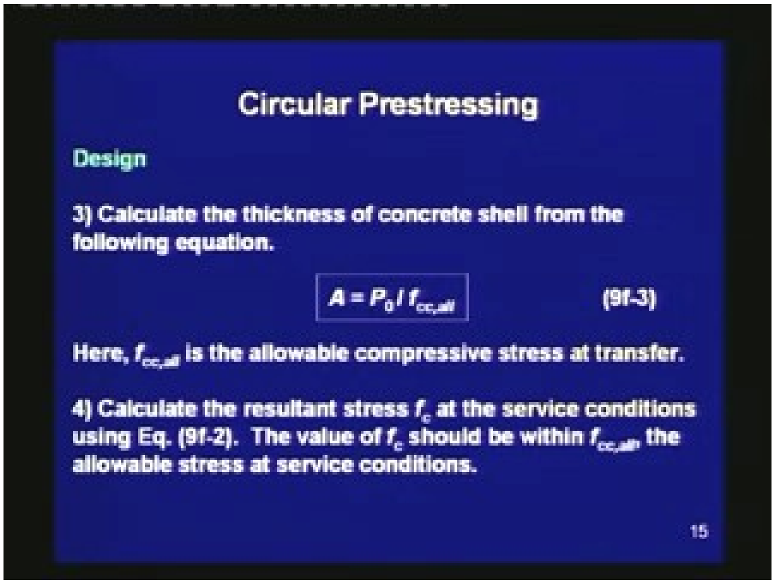

Third, calculate the thickness of the concrete shell from the following equation; A is equal to P_0 divided by $f_{cc,all}$, where f_{cc} is the allowable compressive stress at transfer. Thus, the thickness should be adequate to resist the compressive stress that is generated after the transfer of prestress to the shell. The fourth step is to calculate the resultant stress f_c at the service conditions, using equations 9f dash 2 the value of f_c should be within $f_{cc,all,}$ the allowable stress at service conditions. Thus, once we have designed the section and the prestressing steel, we need to check the stress under service conditions and make sure that this stress is within the allowable value for the service conditions.

With this general introduction, we are moving on to specific applications. First we shall study about prestressed concrete pipes. The prestressed concrete pipes are suitable when the internal pressure is within 0.5 to 2 Newton per millimeter square.

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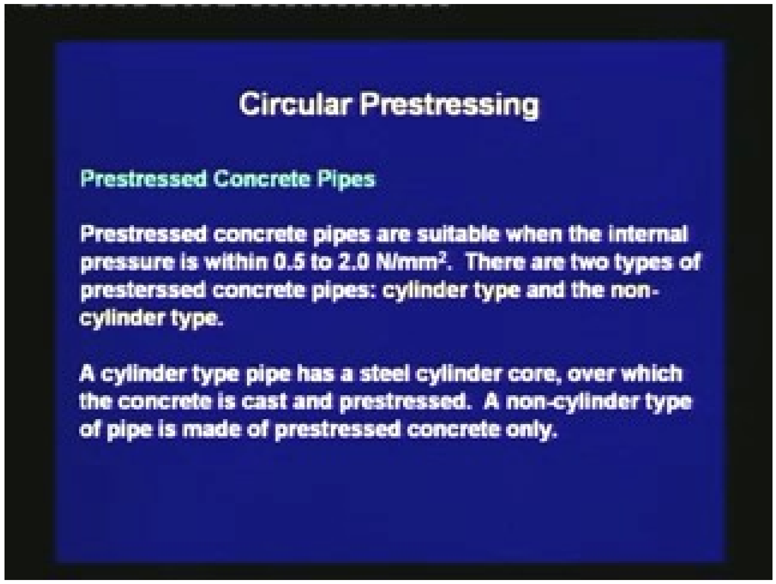

There are 2 types of prestressed concrete pipes: first the cylinder type and second the non-cylinder type. A cylinder type pipe has a steel cylinder core, over which the concrete is cast and prestressed. A non-cylinder type of pipe is made of prestressed concrete alone. Thus, there are two types of prestressed concrete pipes. In the first type, in the cylinder type, we first provide a steel cylinder over which the concrete is cast and it is prestressed. For a non-cylinder type, we are not providing any steel cylinder inside; it is the concrete itself that constitute the section of the pipe.

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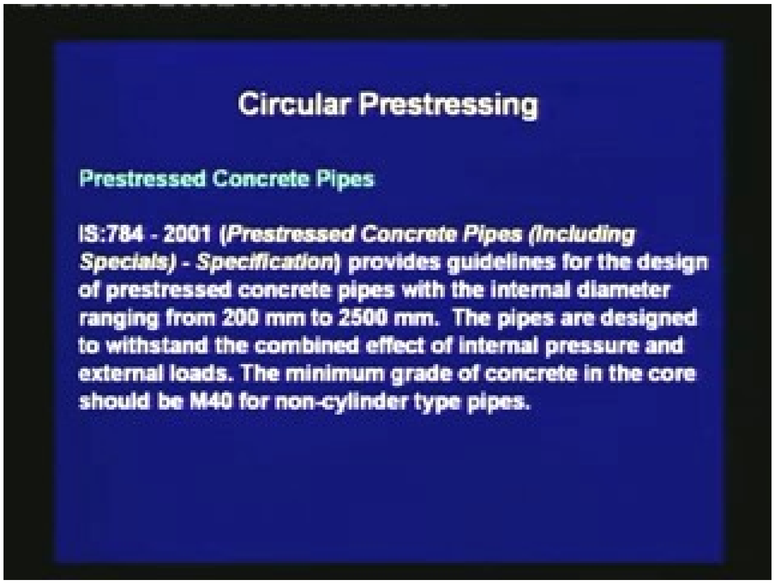

IS: 784 - 2001, title is prestressed concrete pipe, including specials, - specifications, provides guidelines for the design of prestressed concrete pipes, with the internal diameter ranging from 200 millimeter to 2500 millimeter. The pipes are designed to withstand the combined effect of internal pressure and external loads. The minimum grade of concrete in the core should be M40 for non-cylinder type pipes. Thus, there are some guidelines given in IS: 784 for the design of prestressed concrete pipes and depending upon the type of pipe that we select.

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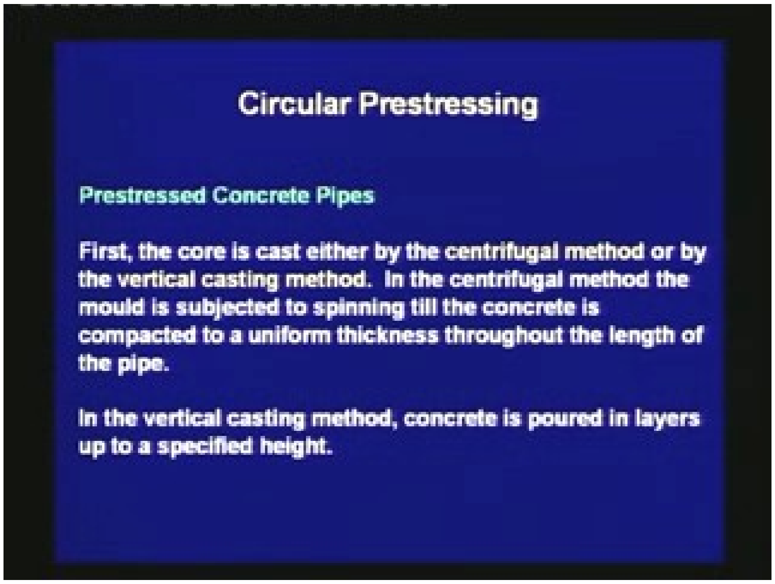

First, the core is cast either by the centrifugal method or by the vertical casting method. In the centrifugal method the mould is subjected to spinning till the concrete is compacted to a uniform thickness throughout the length of the pipe. In the vertical casting method, concrete is poured in layers up to a specified height. The casting process of concrete itself can be of two types: one is based on the spinning, where due to the centrifugal force the concrete spreads around the circumference and this process is carried out till the thickness is uniform through out the length of the pipe. The second procedure of casting the concrete is the vertical casting method, where concrete is cast in layers, depending upon the grade of concrete and depending upon the chances of segregation of the materials of concrete.

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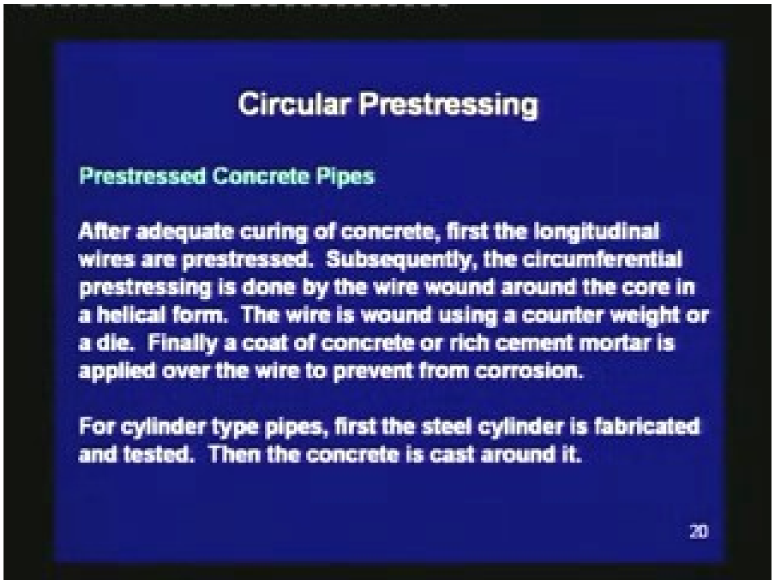

After adequate curing of concrete, first the longitudinal wires are prestressed. Subsequently, the circumferential prestressing is done by the wire wound around the core in a helical form. The wire is wound using a counter weight or a die. Finally a coat of concrete or rich cement mortar is applied over the wire to prevent from corrosion. For cylinder type pipes, first the steel cylinder is fabricated and tested. Then the concrete is cast around it. Thus, depending upon the type of the prestressed concrete cylinder, we select the manufacturing process and the manufacturing process has to be strictly controlled for quality to get the best properties of the prestressed concrete pipes.

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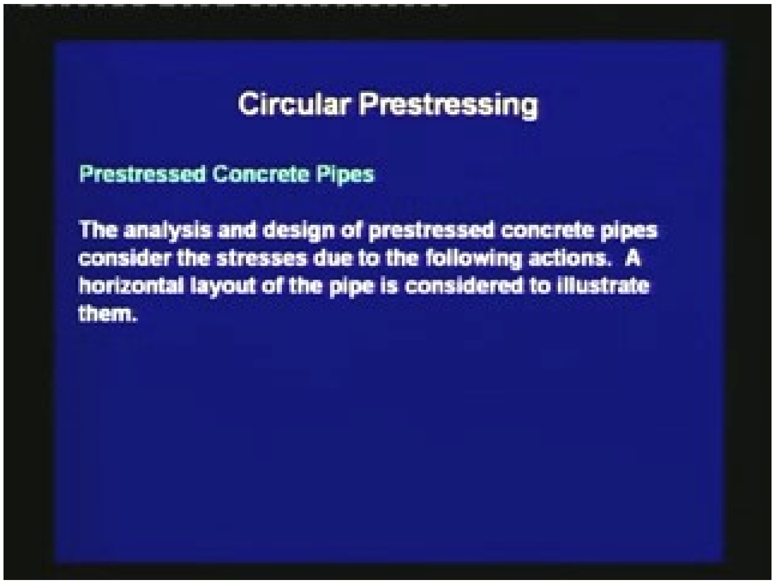

Next, we move to analysis and design of prestressed concrete pipes which considers the stresses due to the following actions. A horizontal layout of the pipe is considered to illustrate them.

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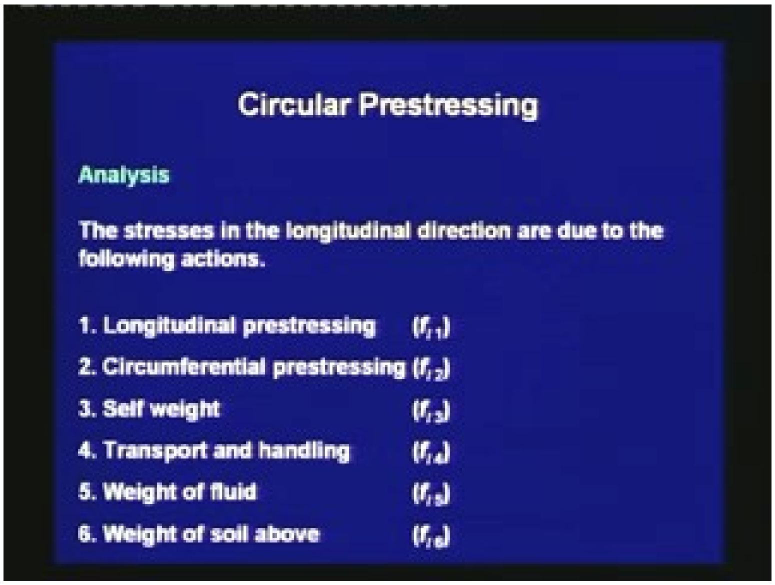

The stresses in the longitudinal direction are due to the following actions: first longitudinal prestressing, which will be denoted as f_{l1}, second circumferential prestressing, which will denoted as f_{l2}, third self weight, which is denoted as f_{l3}, then stresses due to transport and handling, which is denoted as f_{l4}, the stress due to weight of fluid inside the pipe, which is denoted as f_{15} and finally weight of soil above in case of pipes embedded in ground, which will denoted as f_{l6}.

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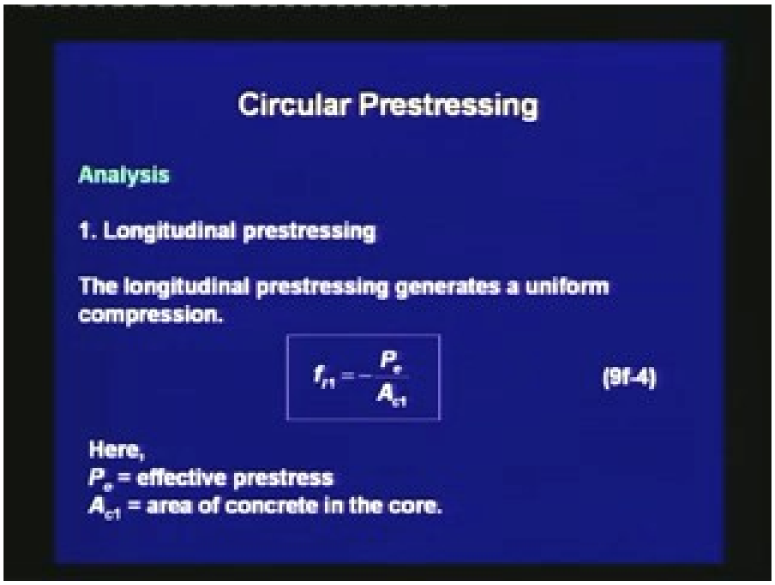

First is the longitudinal prestressing. The longitudinal prestressing generates a uniform compression which is given as f_{l1} is equal to minus P_e divided A_{c1}, where P_e is the effective prestress under service conditions and A_{c1} is the area of the concrete in the core.

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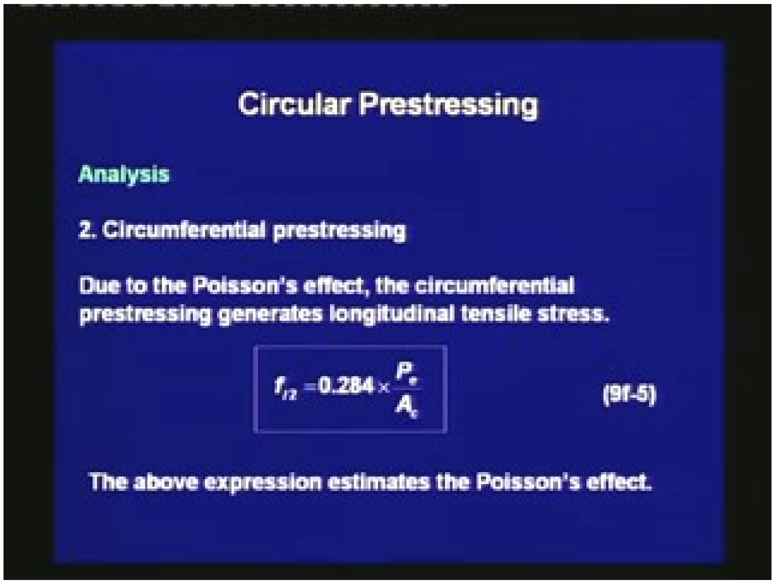

Second is the circumferential prestressing. Due to the Poisson's effect, the circumferential prestressing generates longitudinal tensile stress. It is given as f_{l2} is equal to 0.284 times P_e divided by A_c. The above expression estimates the Poisson's effect.

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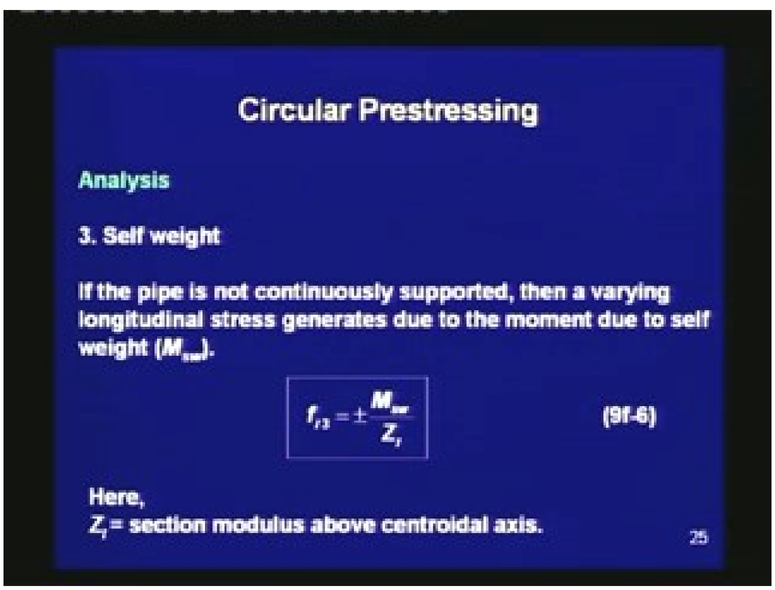

Third due to the self weight, if the pipe is not continuously supported, then a varying longitudinal stress generates due to the moment due to self weight, which we shall denote as M_{sw}. Thus, f_{l3} is equal to plus or minus M_{sw} divided by Z_l, where Z_l is the section modulus above the centroidal axis.

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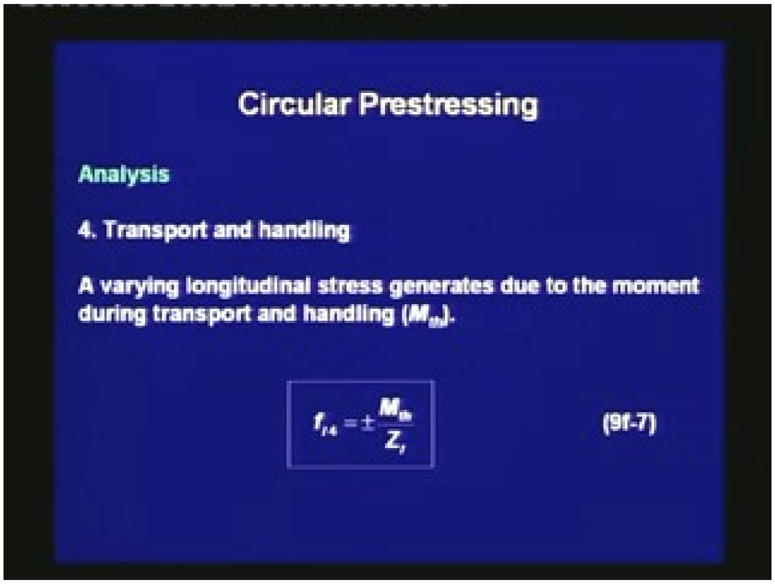

Fourth is transport and handling. A varying longitudinal stress generates due to the moment during transport and handling, which is denoted as M_{th}. M_{th} can be determined based on the support points of the pipe. Thus, once the M_{th} is determined we can find out the stress, which is given as f_{l4} is equal to plus or minus M_{th} divided by Z_l.

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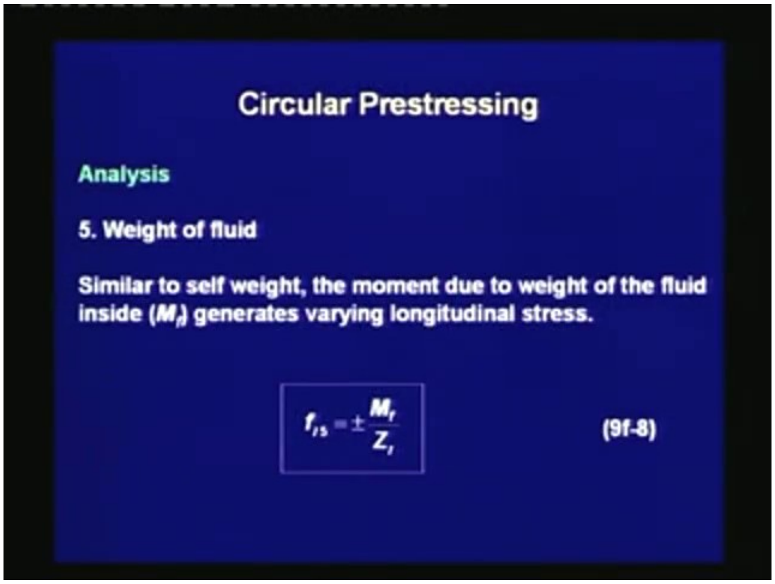

Fifth is the weight of fluid. Similar to self weight, the moment due to weight of the fluid inside, which is denoted as M_f generates varying longitudinal stress and f_{l5} is equal to plus or minus M_f divided by Z_l.

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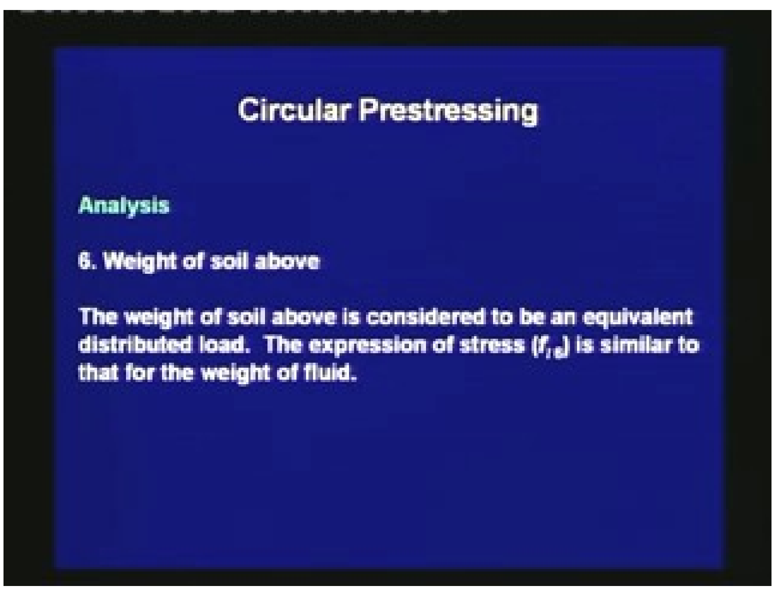

Finally, the weight of the soil above is considered to be an equivalent distributed load. The expression of stress f_{l6} is similar to that for the weight of the fluid.

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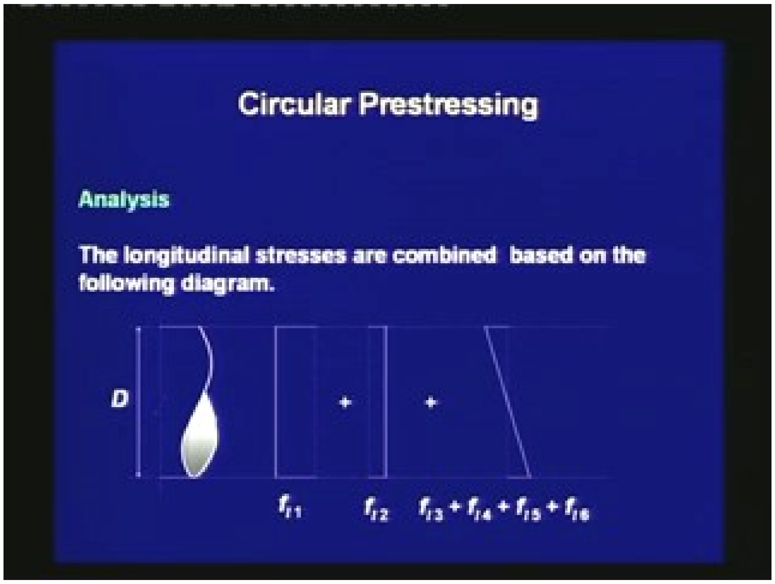

The longitudinal stresses are combined based on the following diagram. On the left hand side, we are having a section of the pipe laid horizontally. The f_{l1} is the uniform compressive stress due to the prestressing force, f_{l2} is the effect due to the circumferential prestressing and this is generated due to the Poisson's effect and that is also uniform throughout the section. Then we have the varying stresses due to the moments, due to the several causes. One is the self rate, second is the weight of the fluid, third is the transport and handling and finally, if there is some soil above then the buried pipes. All this should be considered, to calculate the bending stresses that generate due to the flexure of the pipe.

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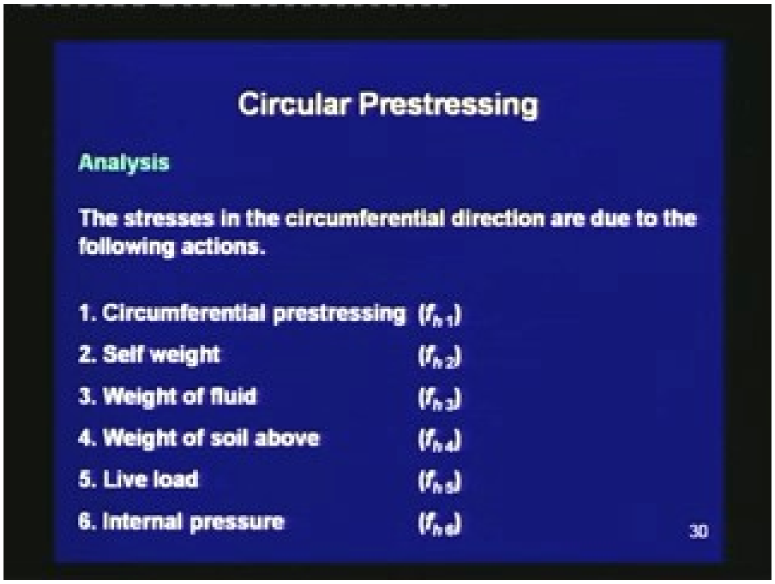

The stresses in the circumferential direction are due to the following actions: first-circumferential prestressing, second - self weight, third - weight of the fluid, fourth -weight of soil above, fifth - live load, sixth - internal pressure and these are denoted as f_{h1} to f_{h6}.

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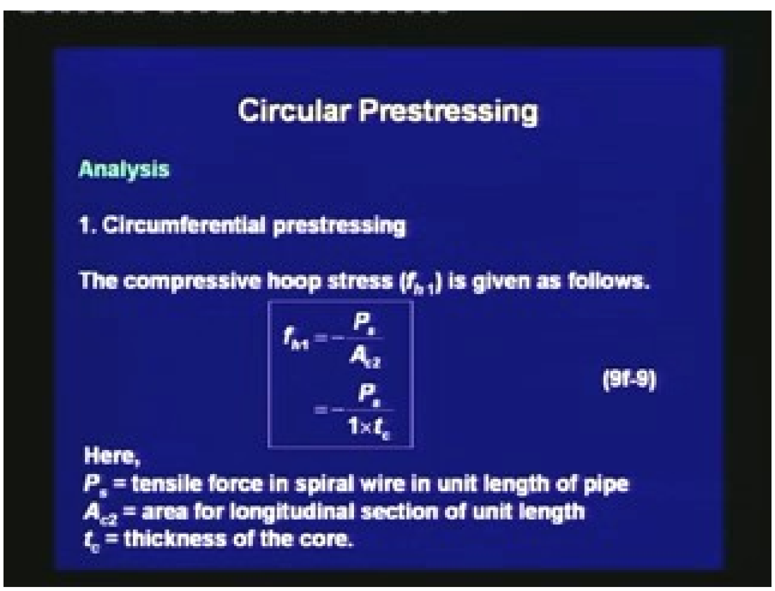

First is the circumferential prestressing. The compressive hoop stress, which is denoted as f_{h1} is given as minus P_s divided by A_{c2}, where P_s is the tensile force in spiral wire in unit length of pipe. Note that this is different from the longitudinal prestressing. A_{c2} is the area of longitudinal section of unit length and this is equal to 1 times the thickness of the core. Thus, given the circumferential prestressing, we can find out what is the stress generated in the circumferential direction.

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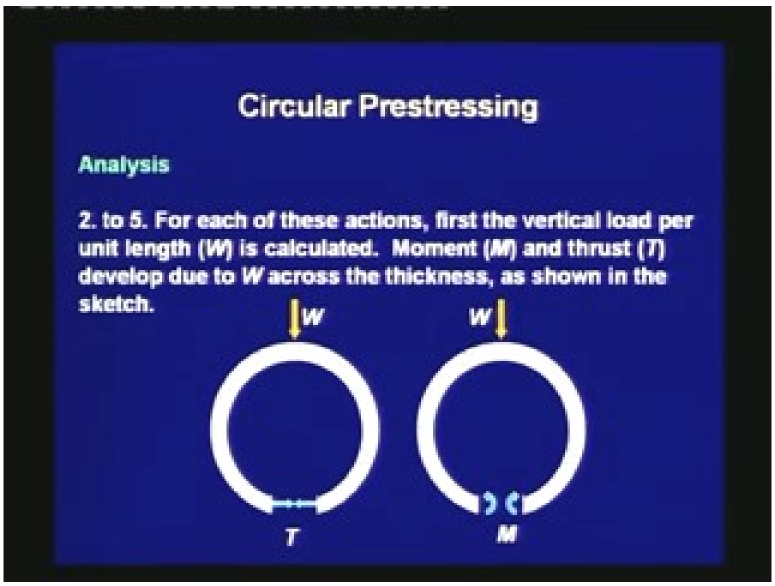

For the other causes, we should understand that due to a vertical load a thrust and a moment is generated in the circumferential direction. For 2 to 5 for each of these actions, first the vertical load per unit length, which is denoted as W, is calculated. The moment M and thrust T develop due to W across the thickness, as shown in the sketch. Thus it is due to the distortion of the pipe that we get the thickness, the thrust and the moment.

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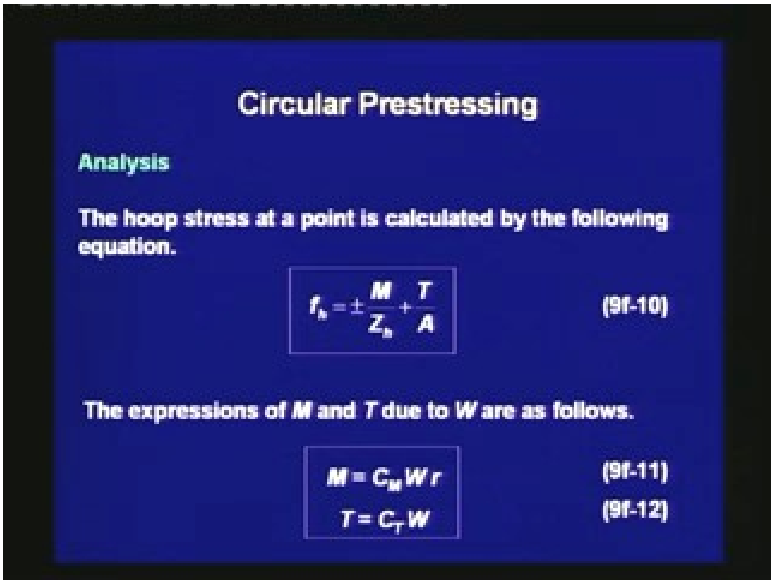

There are expressions to get the moment and the thrust depending on the value of W. The hoop stress at a point is calculated by the following equation: f_h is equal to plus or minus M divided by Z_h plus T divided by A. The expression of M and T due to W are as follows. M is equal to C_M times W times r; T is equal to C_T times W. Thus, what we find is that from the distortion of the section, we can calculate what the moment is and the thrust that generates due to a vertical load. From the moment and the thrust we can find out what is the circumferential stress generating. Now the coefficients C_M and C_T are tabulated in the code.

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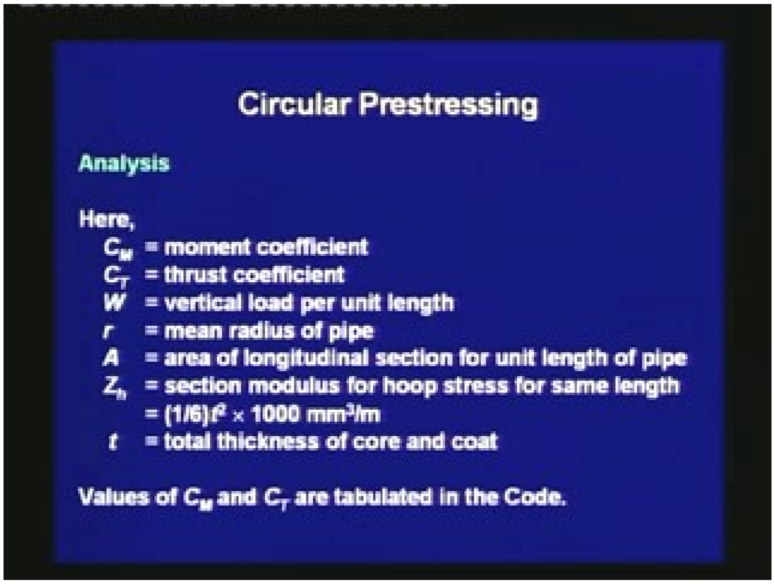

In the previous equation C_M is the moment coefficient, C_T is the thrust coefficient, W is the vertical load per unit length, r is the mean radius of pipe, A is area of longitudinal section for unit length of pipe, Z_h is the section modulus for hoop stress for the same length which is given as 1 by 6 t square times 1000 millimeter cube per meter and t is the total thickness of core and coat. Values of C_M and C_T are tabulated in the code.

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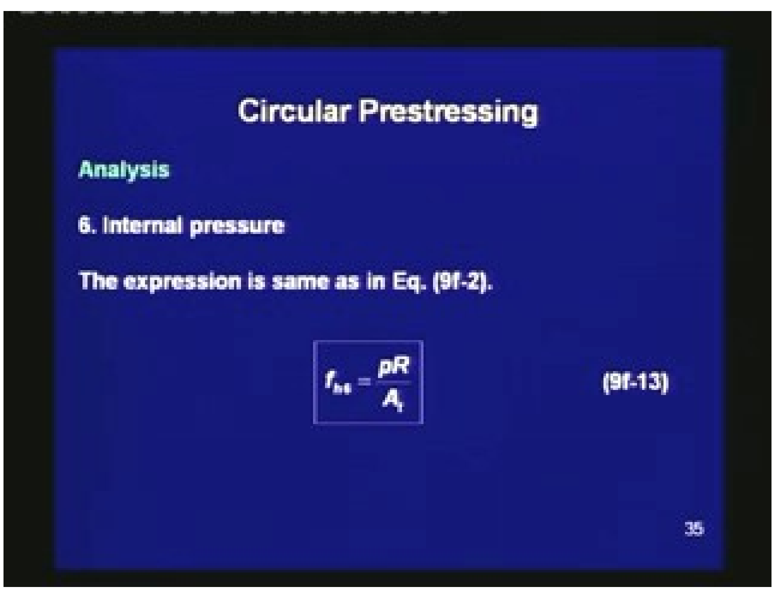

Finally, we come for the internal pressure. The expression of the hoop stress is same as given is equation 9f-2. f_{h6} is equal to pR divided by A_t, where p is the internal pressure and R is the mean radius.

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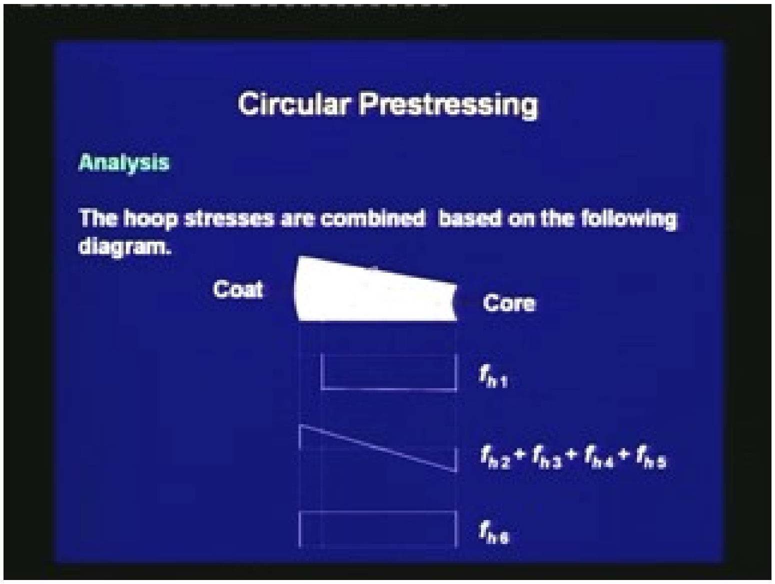

The hoop stresses are combined based on the following diagram. First, we have the effect of the circumferential prestressing, which is inside the core only. Next, we have the effect due to the vertical load and this generates a moment and a thrust; it gives a varying stress condition. Finally, we have the internal pressure and if you consider that the full section is resisting the internal pressure, then again it is uniform throughout the section. Thus, we can add up this individual stresses to get the final stress at a point.

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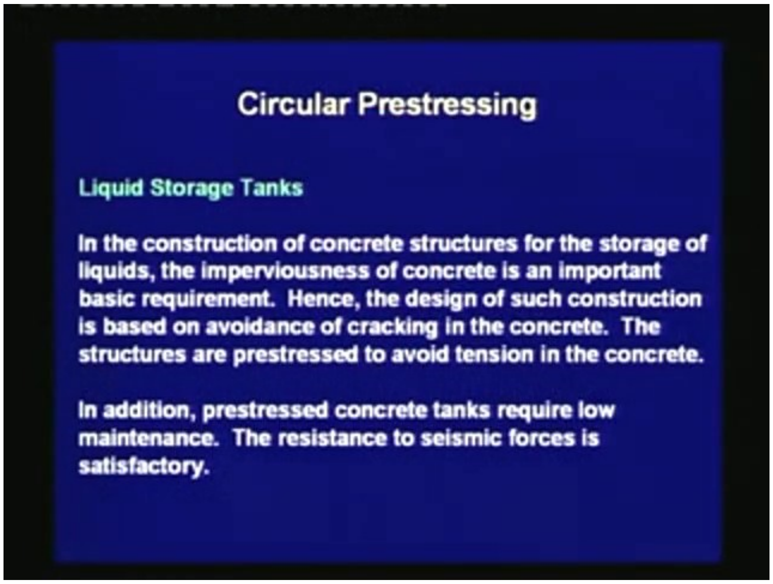

Next, we move on to the liquid storage tanks. In the construction of the concrete structures for the storage of the liquids, the imperviousness of concrete is an important basic requirement. Hence, the design of such construction is based on avoidance of cracking in the concrete. The structures are prestressed to avoid tension in the concrete. In addition, prestressed concrete tanks require low maintenance. The resistance to seismic forces is satisfactory.

The liquid storage tanks are prestressed primarily to avoid the cracking of concrete, which is the requirement for the liquid storage tanks. Also once cracking is avoided then the maintenance of such tanks is better and the performance and seismic forces is also satisfactory.

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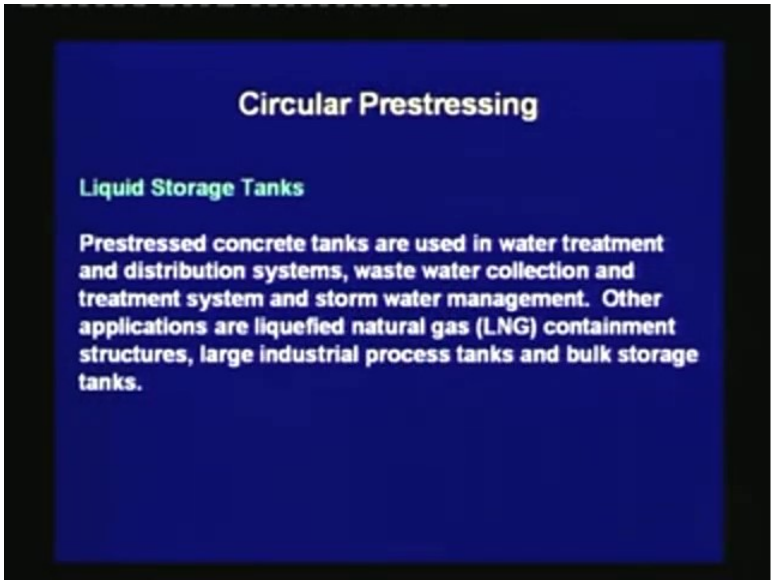

Prestressed concrete tanks are used in water treatment and distribution systems, waste water collection and treatment system and storm water management. Other applications are liquefied natural gas; in short LNG containment structures, large industrial process tanks and bulk storage tanks. Thus, the liquid storage tank has wide application starting from the use of water and waste water to other types of liquid storage which are used in the industrial processes.

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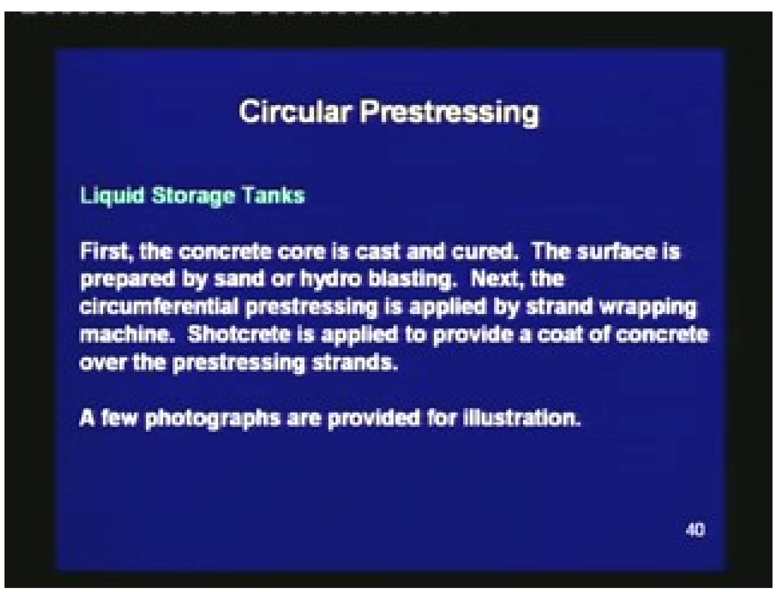

In this type of structures, first the concrete core is cast and cured. The surface is prepared by sand or hydro blasting; this is the outside surface. Next, the circumferential prestressing is applied by strand wrapping machine. Shotcrete is applied to provide a coat of concrete over the prestressing strands. A few photographs are provided for illustration.

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Fig 9f-3 Circumferential prestressing
(Courtesy: DYK Incorporated)

In the photograph, you can see the strand wrapping machine is providing the circumferential prestressing about this tank. The tank has been first cast and cured, after that, this strand wrapping machine is providing the circumferential prestressing around this tank and a close up view, shows the prestressing strand which is being wrapped around the tank.

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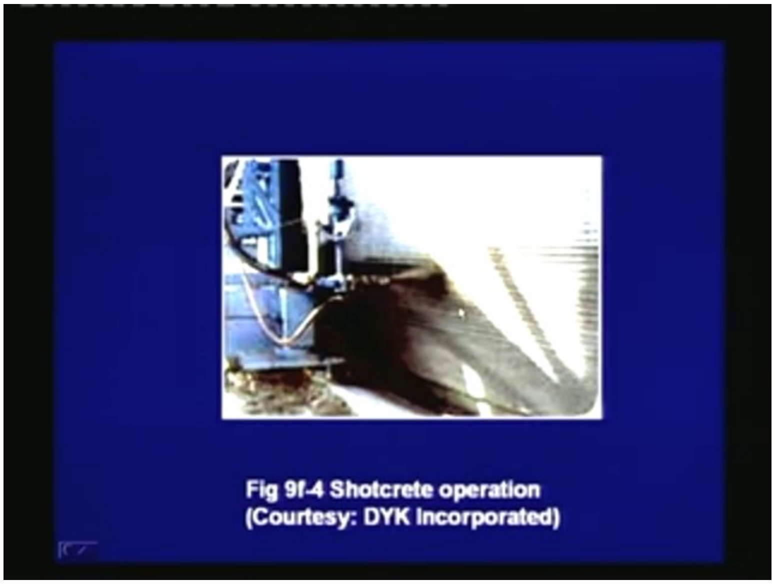

Next, a shotcrete machine is used to provide a coat of concrete over the prestressing strand, which checks for any corrosion of the prestressing tanks.

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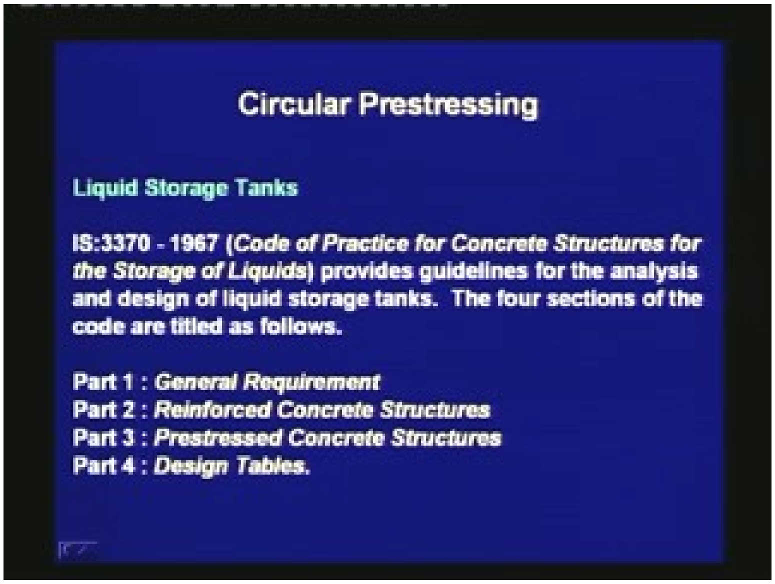

IS: 3370 – 1967; the title is Code of Practice for Concrete Structures for the Storage of Liquids, provide guidelines for the analysis and design of liquid storage tanks. The four section of the code are titled as follows: Part 1: General Requirement; Part 2: Reinforced

Concrete Structures; Part 3: Prestressed concrete structures and Part 4: Design Tables. Thus, IS: 3370 is specifically mentioned for liquid storage tanks. This code is divided in to four parts. Part 3 is for the prestressed concrete liquid storage tanks.

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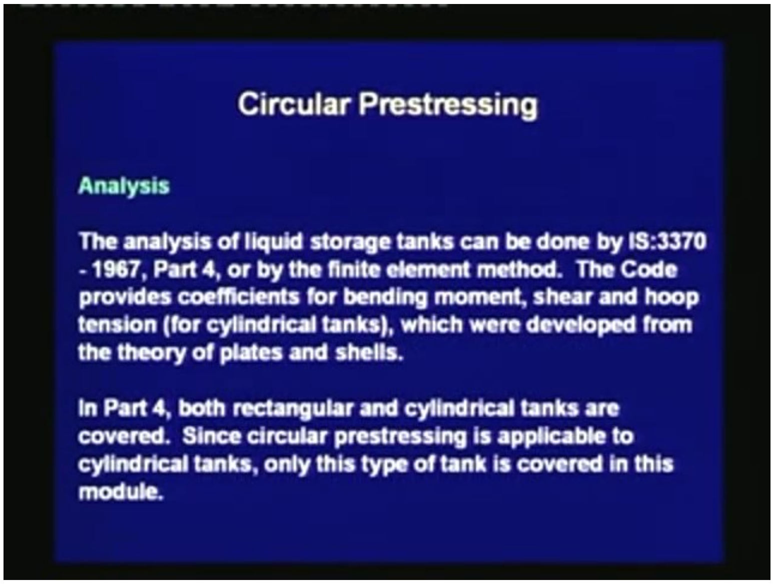

The analysis of liquid storage tank can be done by IS: 3370-1967, Part 4, or by the finite element method. The code provides coefficients for bending moment shear and hoop tension for cylindrical tanks, which were developed from the theory of plates and shells.

In Part 4 both rectangular and cylindrical tanks are covered. Since, circular prestressing is applied to cylindrical tanks, only this type of tank is covered in this module. Thus the Part 4 of IS: 3370 gives us guidelines for the analysis of the liquid storage tanks. There are guidelines for both rectangular and cylindrical tanks, but since circular prestressing for cylindrical tanks, we shall concentrate only on those type of tanks.

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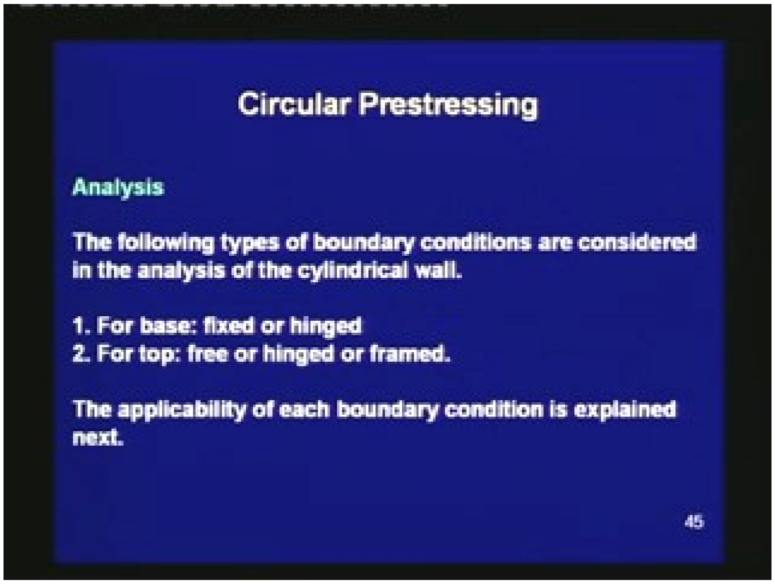

The following types of boundary conditions are considered in the analysis of the cylindrical wall. Number one, for base: fixed or hinged. For top: free or hinged or framed. The applicability of each boundary condition is explained next.

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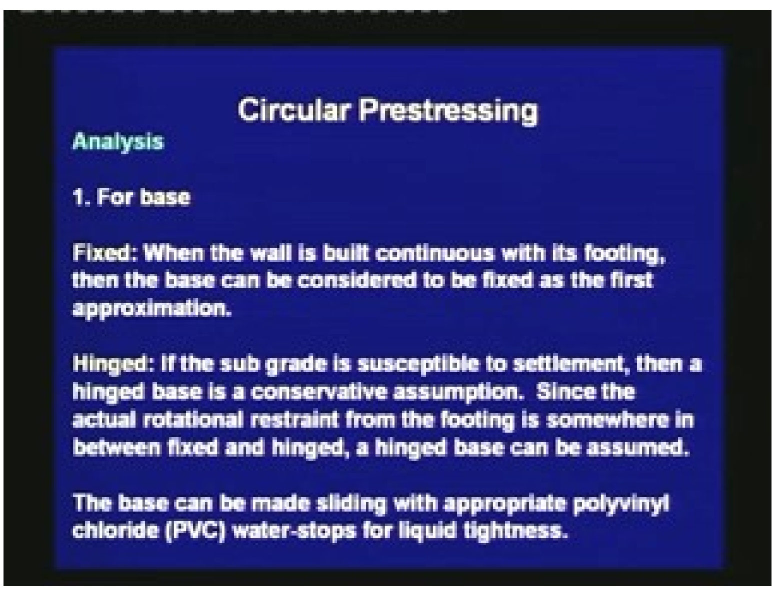

For base, when the wall is built continuous with its footing, then the base can be considered to be fixed as the first approximation. If the sub grade is susceptible to settlement, then a hinged base is a conservative assumption. Since the actual rotational restraint from the footing is somewhere in between fixed and hinged, a hinged base can be assumed. The base can be made sliding with appropriate polyvinyl chloride or PVC water-stops for liquid tightness. Thus, the two main types of the boundary condition at the bottom of the cylindrical wall is either fixed or hinged. If the soil is subjected to settlement, then a hinged assumption is a conservative assumption for the bottom of the cylindrical wall.

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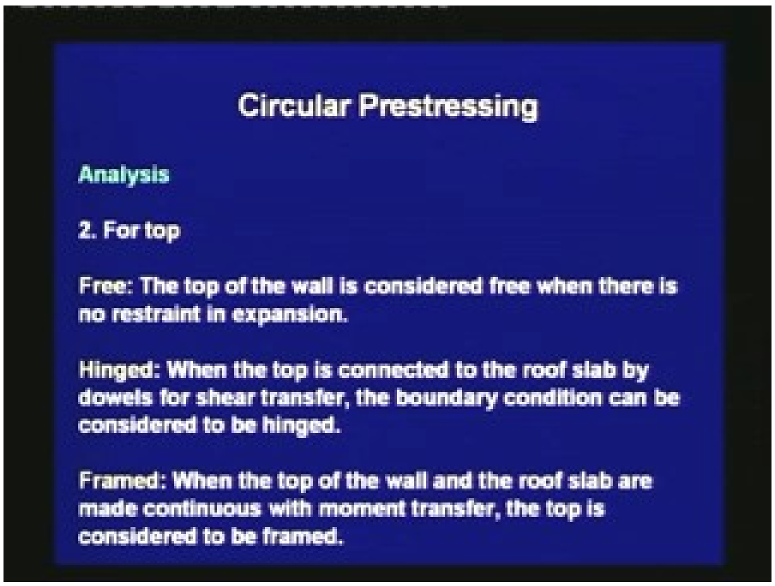

Next for the top, if the top of the wall is considered free, then there is no restraint in expansion. When the top is connected to the roof slab by dowels for shear transfer the boundary condition can be considered to be hinged. Finally, when the top of the wall and roof slab are made continuous with moment transfer, the top is considered to be framed. Depending upon the connection between the wall and the roof slab, we have to judge what the boundary condition is at the top, whether if it is free, hinged or framed.

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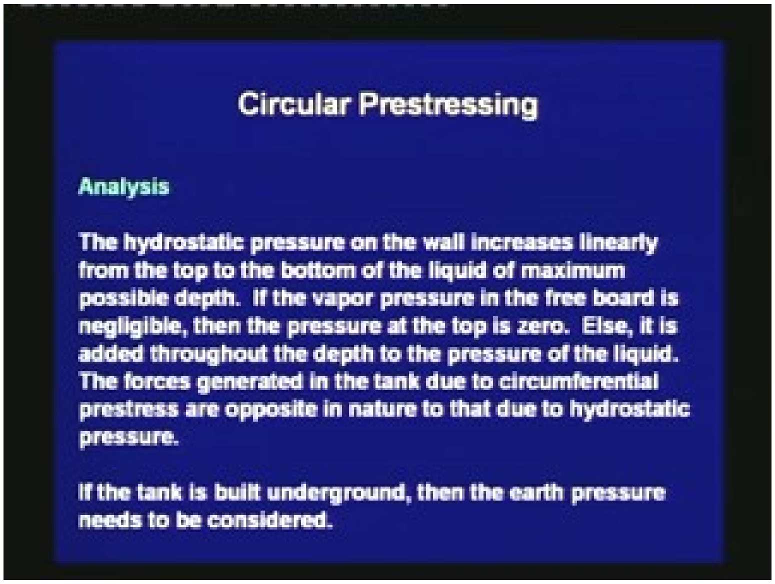

The analysis is based on the boundary conditions. The hydrostatic pressure on the wall increases linearly from the top to the bottom of the liquid of maximum possible depth. If the vapor pressure in the free board is negligible, then the pressure at the top is 0. Else, it is added throughout the depth of the pressure of the liquid. The forces generated in the tank due to circumferential prestress are opposite in nature to that due to hydrostatic pressure. If the tank is built underground, then the Earth pressure needs to be considered. Thus, hoop tension generates due to the hydrostatic pressure, due to the liquid stored in the tank.

The design is based on the maximum liquid that can be stored in the tank. The triangular hydrostatic pressure is used to calculate the hoop stress, if there is vapor pressure about the liquid free board, then that has also be included. Finally, if the tank is buried under ground, then the Earth pressure also has to be included. Now, the most severe condition should be used to design the tank, whether the empty condition or whether the full condition, all these conditions, has to be checked to find out the design stresses.

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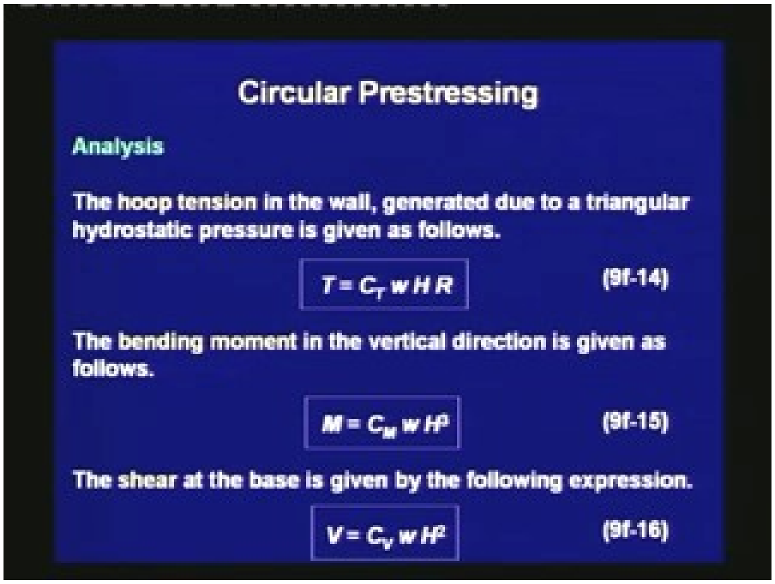

The hoop tension in the wall, generated due to triangular hydrostatic pressure is given as follows: T is equal to C_T times w times H times R. The bending moment in the vertical direction is given as follows: M is equal to C_M times w times H cube. The shear at the base is given by the following expression: V is equal C_V times w times H square.

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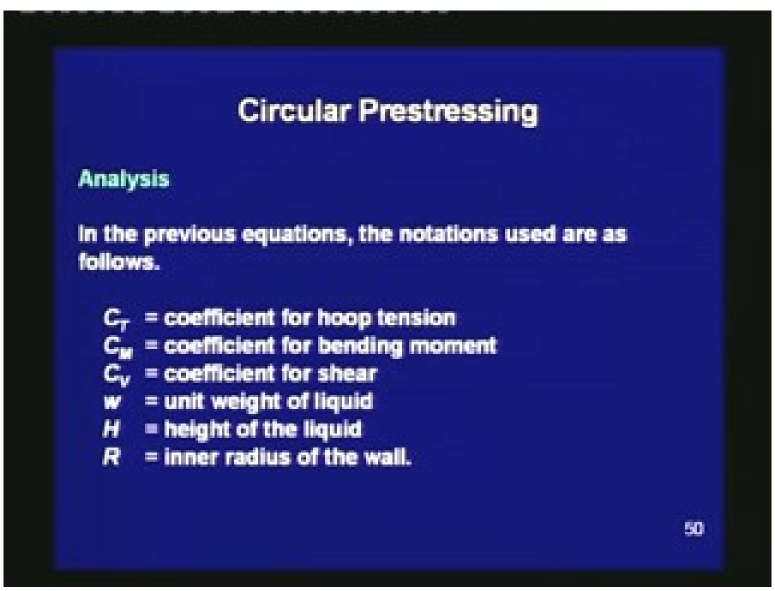

In the previous equations, the notation as follows: C_T is equal to coefficient for hoop tension, C_M is the coefficient for bending moment, C_v is the coefficient for shear, w is the unit weight of liquid, H is the height of the liquid, R is the inner radius of the wall. Thus, the analysis is based on the coefficient, that is given in IS: 3370 Part 4 and these coefficients are developed from the theory of plates and shells. Once the coefficient is known, we can calculate the hoop tension, the moment and shear that generates in the section of the tank.

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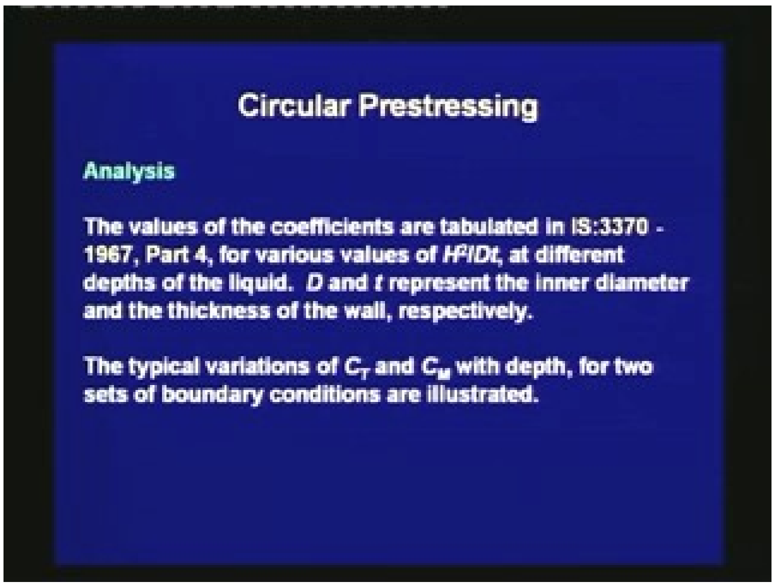

The values of the coefficient are tabulated in IS: 3370-1967, Part 4 for various value of H square divided by Dt, at different depth of the liquid. D and t represent the inner diameter and the thickness of the wall respectively. The typical variations of C_T and C_M with depth, for two sets of boundary conditions are illustrated.

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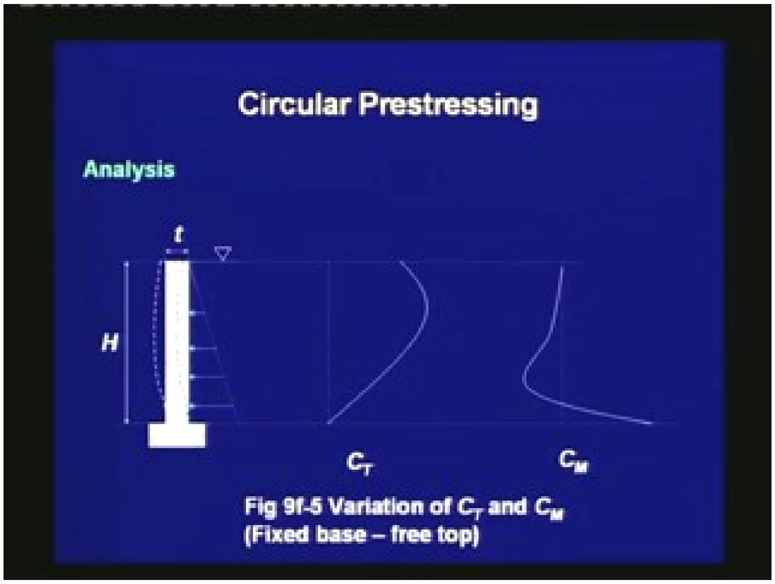

In this sketch, the tank section is fixed at the bottom and free to slide at the top. The hydrostatic pressure, if the tank is completely full is triangular. Then the variation of the coefficient for the hoop tension is as follows and the variation of the coefficient for the moment about the vertical direction is shown like this. Thus at the base we have a negative moment, whereas beyond that we have positive moment and the hoop tension also achieves maximum value in an intermediate height. The second case is for a hinged base, where the foundation may tilt; the top is free to slide and again due to the triangular hydrostatic pressure, we have the tabulated values of C_T and C_M. Note that in this case there is no negative moment at the base and the section is always under positive moment.

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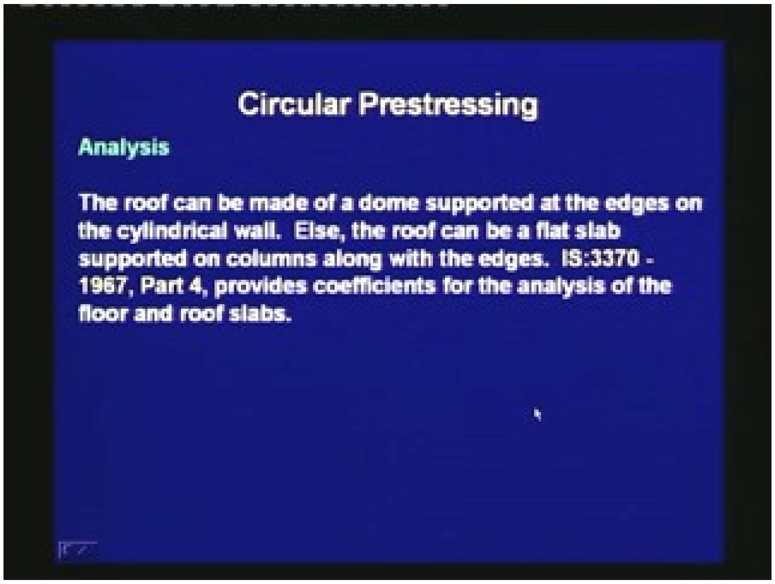

The roof can be made of the dome supported at the edges on the cylindrical wall. Else, the roof can be flat slab supported on columns along with the edges. IS: 3370 - 1967, Part 4, provides coefficients for the analysis of the floor and roof slabs. That means, similar to the analysis of the cylindrical wall, we can also analyse the floor and the roof slab based on the moment coefficient that is given in the code and once we get the moments we can design for the reinforcement and the prestressing steel like a conventional design.

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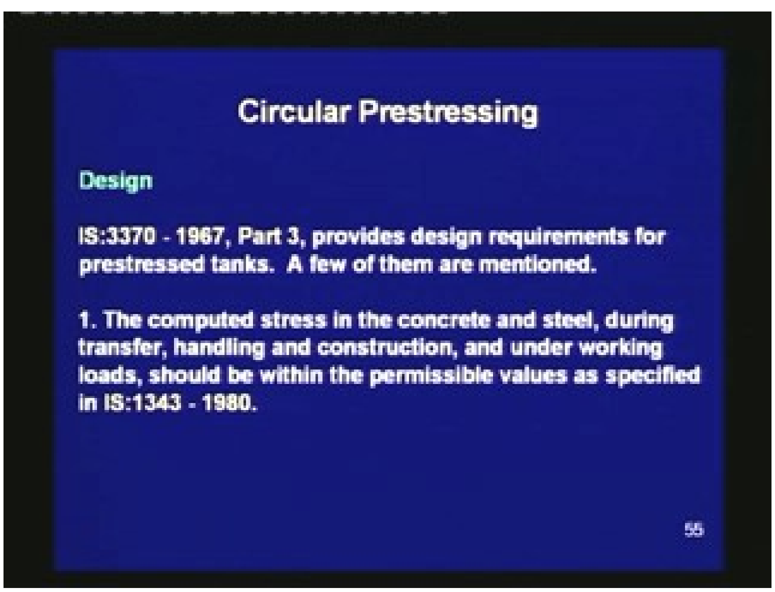

IS: 3370 - 1967, Part 3, provides design requirements for prestressed tanks. A few of them are mentioned. The computed stress in the concrete and steel, during transfer, handling and construction, and under working loads, should be within the permissible values as specified in IS: 1343 – 1980, which is the code for prestressed concrete.

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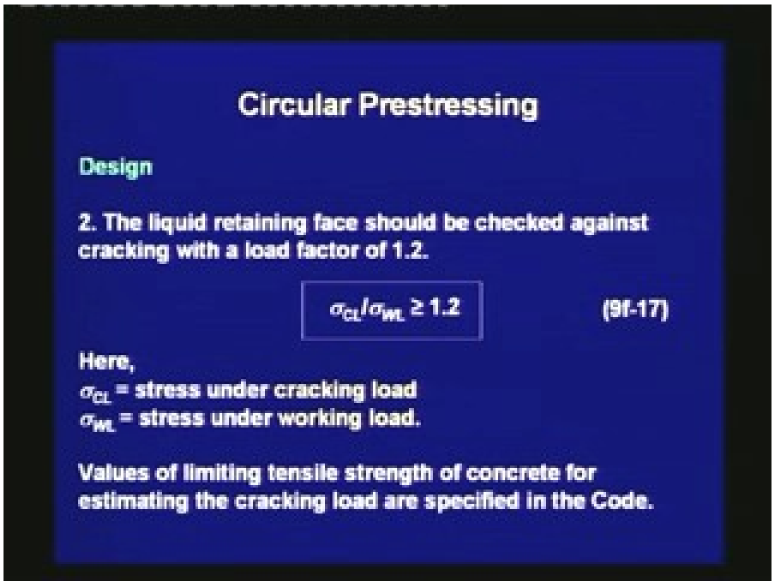

Second, the liquid retaining face should be checked against cracking with a load factor of 1.2. Thus, sigma$_{CL}$ divided by sigma$_{WL}$ should be greater than or equal to 1.2, where sigma$_{CL}$ is the stress under cracking load, and sigma$_{WL}$ is the stress under working load. Values of limiting tensile strength of concrete for estimating the cracking load are specified in the code.

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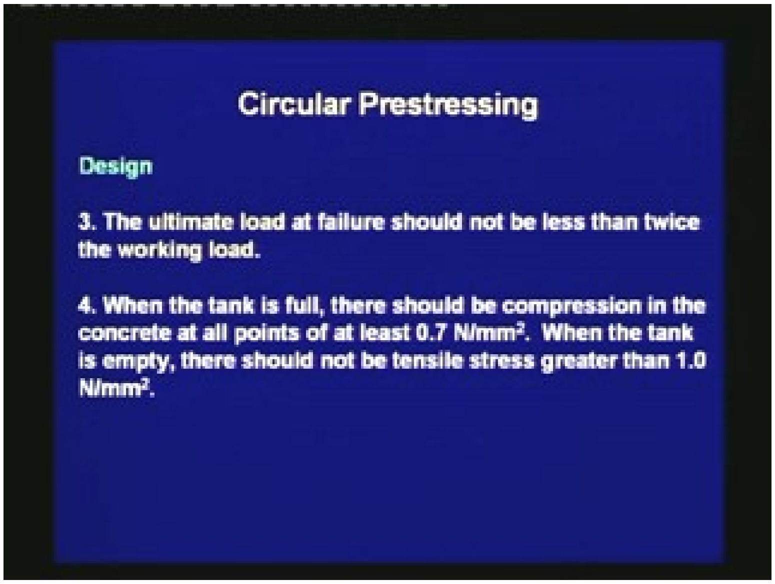

Third, the ultimate load at the failure should not be less than twice the working load. Fourth, when the tank is full, there should be compression in the concrete at all points of at least 0.7 Newton per millimeter square. When the tank is empty, there should not be tensile stress greater than 1.0 Newton per millimeter square. Thus, IS: 3370 Part 3 gives as guidelines specifically for prestress concrete tanks and these guidelines should be used during the design of the prestressed concrete tanks.

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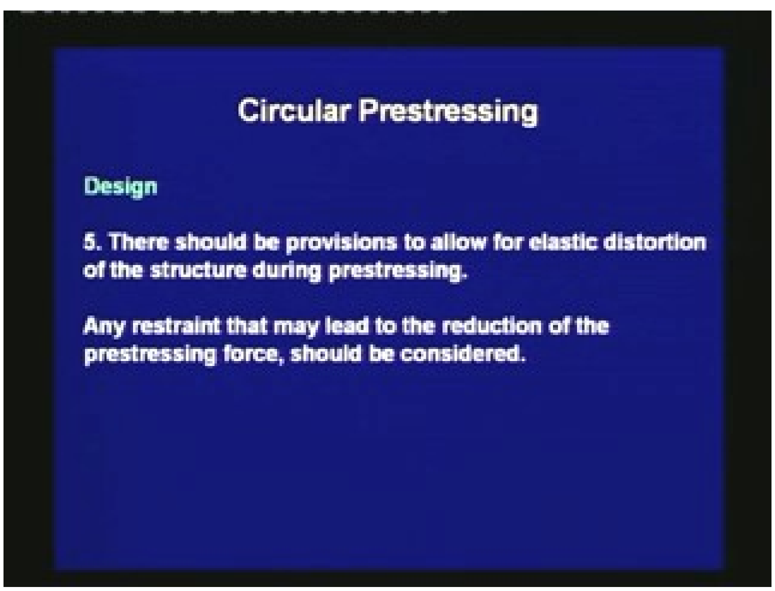

There should be provision to allow for elastic distortion of the structure during prestressing. Any restraint that may lead to the reduction of the prestressing force should be considered. Thus, when the prestressing is done, if there is some restrain, then there can be a drop in the prestressing force and that should be considered in the analysis and design of the prestressed concrete tanks.

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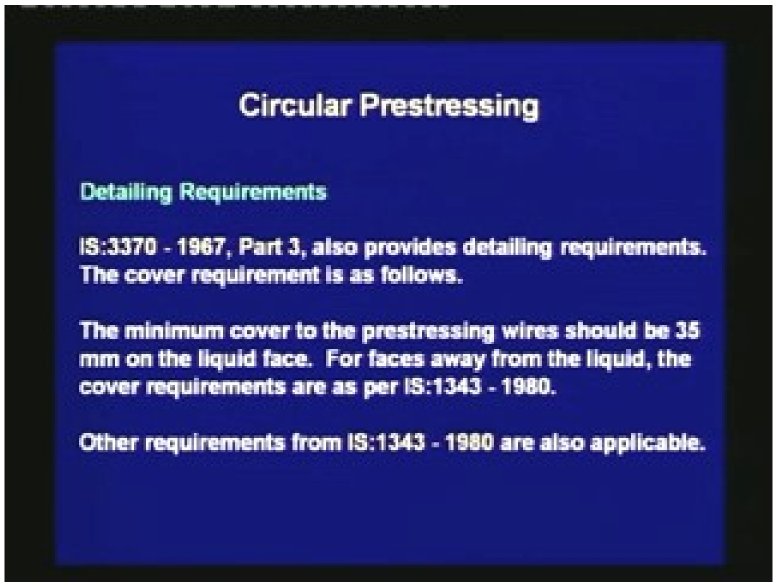

IS: 3370, Part 3 also provides detailing requirements. The cover requirement is as follows.

The minimum cover to the prestressing wires should be 35 millimeter on the liquid face. For faces away from the liquid, the cover requirements are as per IS: 1343. Other requirements from IS: 1343 are also applicable.

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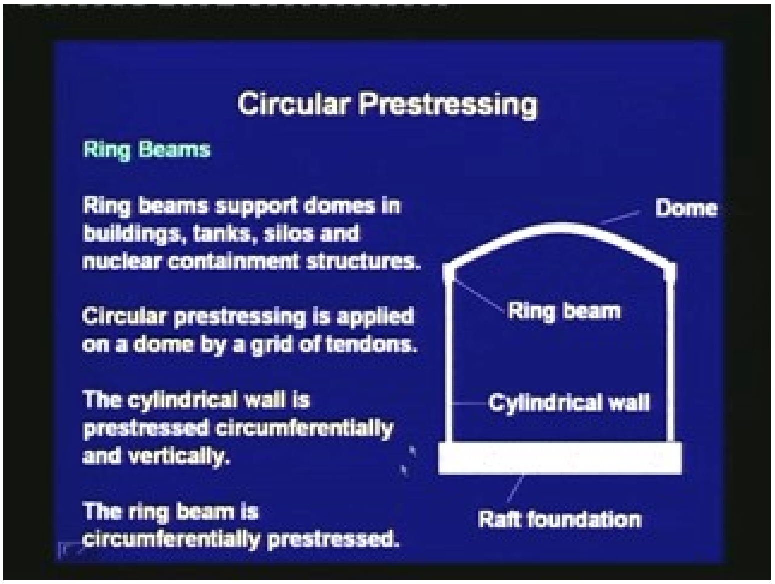

Next, we move on to the analysis of ring beams. The ring beams are used in presence of domes. We are showing this for a typical nuclear containment structure. In this sketch, the dome is the circular member at the top and this is supported on the ring beams. Then we have the cylindrical wall and this is supported on a raft foundation. Thus, ring beams support domes in buildings, tanks, silos and nuclear containment structures. Circular prestressing is applied on dome by a grid of tendons. The cylindrical wall is prestressed circumferentially as well as vertically. The ring beam is circumferentially prestressed. Thus in a nuclear containment structure, the dome, the ring beam, the cylindrical wall are all prestressed and even the raft foundation may be prestressed.

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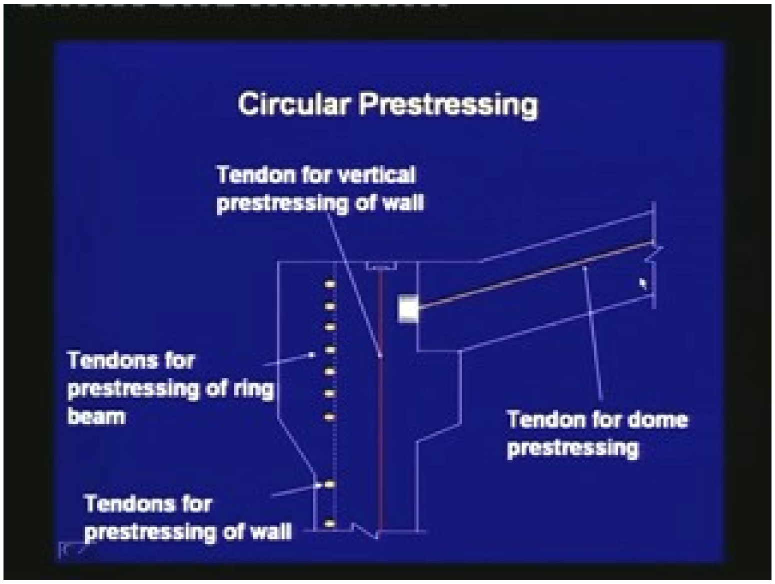

This sketch shows some details of the prestressing tendons. This is at the junction of the dome and the ring beam. The dome is circularly prestressed by tendons, which are first anchored. Then the cylindrical wall is prestressed in the vertical direction; the wall is also prestressed by tendons in the circumferential direction and the ring beam, which is at the base of this dome is also circumferentially prestressed.

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This figure shows a containment structure, from the Kaiga atomic power plant. Here you can see that the dome is supported on a ring beam and then the cylindrical wall is supported on the raft foundation.

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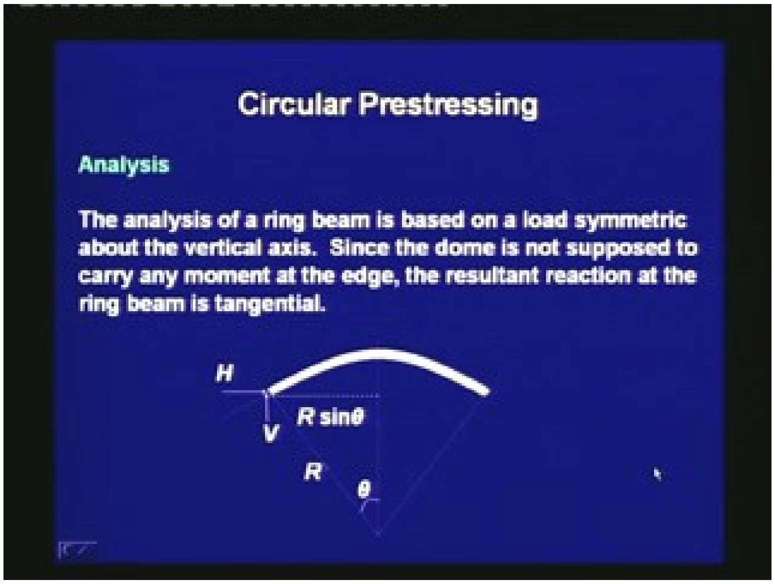

The analysis of a ring beam is based on a load symmetric about the vertical axis. Since the dome is not supposed to carry any moment at the edge, the resultant reaction at the ring beam is tangential. Thus, if we take a free body diagram of the dome, the reaction at the support is tangential. This relates the horizontal thrust on the domes and the vertical reaction on the dome. R is the radius of the dome and theta is half of the angle that is subtended by the dome.

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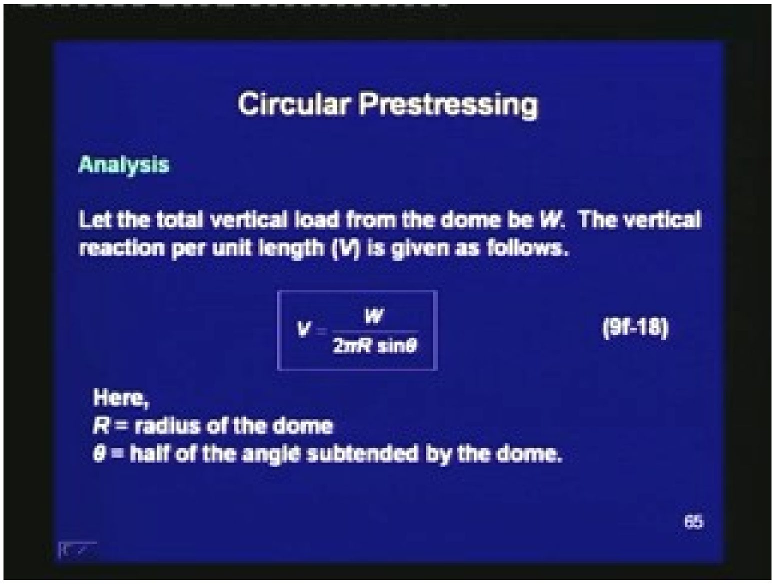

Let the total vertical load from the dome be W, the vertical reaction per unit length which is denoted as V is given as follows: V is equal to W divided by 2 pi times R sin theta. Here, R is the radius of the dome and theta is the half of the angle subtended by the dome.

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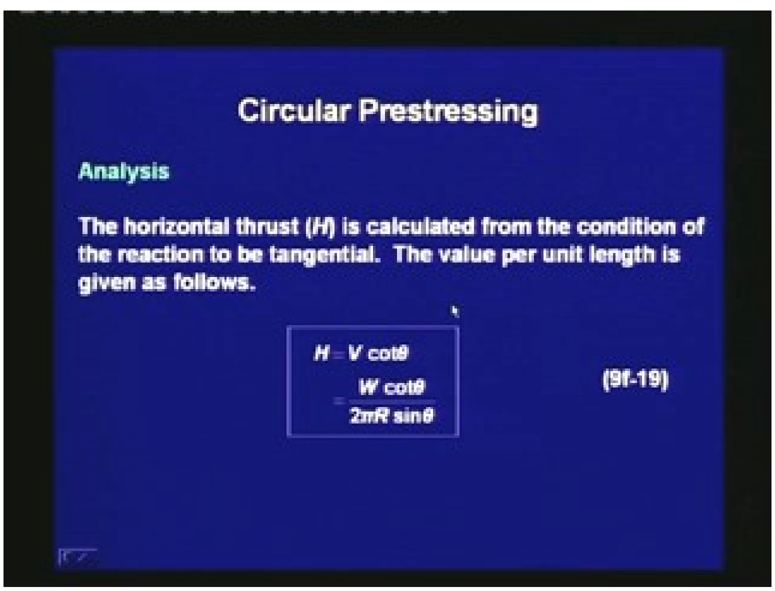

The horizontal thrust is calculated from the condition of the reaction to be tangential. The value per unit length is given as follows. H is equal to V cot theta is equal to W cot theta divided by 2 pi R sin theta.

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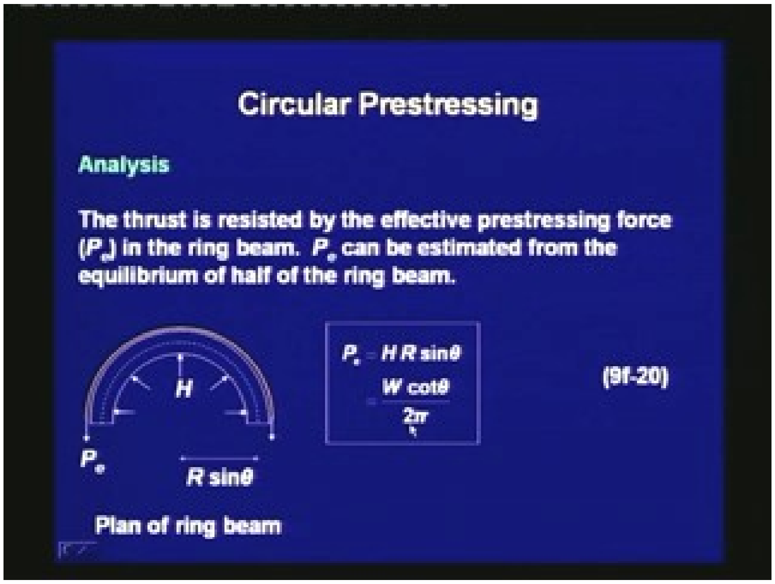

The thrust is resisted by the effective prestressing force P_e in the ring beam. P_e can be estimated from the equilibrium of half of the ring beam. Thus, given the internal pressure, which is due to the horizontal thrust from the dome, we are able to calculate what is the effective prestress? This P_e is given as h times R sin theta, which is similar to the general formula that we have seen earlier and once we substitute the value of h we get the effective prestress that is required in the ring beam to support the dome and P_e is given as W cot theta divided by 2 pi. Thus, we have seen the ring beam can be designed based on the thrust that the dome applies on the ring beam. The analysis for the dome and the cylindrical wall is based on the requirements of the nuclear containment structure and these structures have to be analyzed by the special methods like the finite element method. Then, once we determine what are the forces and stresses coming in the domes and in the wall, we will be able to design the prestressing steel for them.

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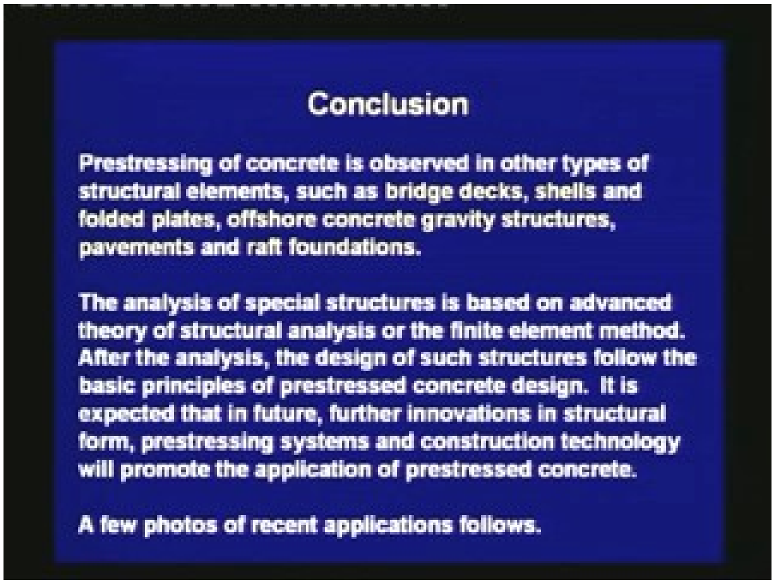

Finally, today we are concluding this prestressed concrete course. The prestressed concrete is observed in other types of structural elements, such as bridge decks, shells and folded plates, off shore concrete gravity structures and raft foundations.

The analysis of special structure is based on advanced theory of structural analysis or the finite element method. After the analysis, the design of such structures follow the basic principles of prestressed concrete design. It is expected that in future, further innovations in structural form, prestressing systems and construction technology will promote the application of prestressed concrete. Thus, what we covered in this course gives you a beginner impression of prestressed concrete. We had covered from the actually loaded members, then we moved on to the flexure, then we moved on to the shear and torsion. We also studied about the losses in prestress, the material properties and we looked into the designs of the end zones of prestressed members.

Then we moved on to the special topics. We studied about the composite construction, we also studied about the two way slab and one way slab; we studied about the compression members and finally today we studied about the circular prestressing. Thus, the application of prestressed concrete is wide and in future with the development of different prestressing systems, structural forms and bold design, we are expected to see more and more application of prestress concrete. The analysis of special structures needs the understanding of theory of plates and shells and the use of finite element method by a robust software package. Once we can analyze this sophisticated structures, then the design of the prestressing tendons and the reinforcement follows the principle that we have studied in this course. We also have to be aware of the material properties and the local stresses that generates near the anchorage.

The losses of prestress is also important which needs to be studied for any type of prestressed concrete structures. Thus, in future we will be able to design even better and more economic and efficient structural forms, by the use of prestressed concrete. A few photos of recent applications of prestressed concrete are shown.

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In this photograph, you can see a cement silo. This is a shell type of structure which stores cement. Similar type of silos can be used for storing food grains or any other granular material. This industrial structure can be analysed either by a conventional analysis or by the finite element method. Once we analyze this shell, then we can design the prestressed concrete section, as per the fundamental principles that we have learnt in this course.

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This figure is that of a curved box girder bridge. We have discussed about the applications of prestressed concrete structures in bridges. Although, in this course we have studied only prismatic sections and that to straight I-girders, but prestressed concrete is also used for curved box girder bridges. This type of box girders needs special analysis and we need to also consider the effect of distortion of the box girders. Once we have analyzed the curved box girders, then the design for the prestressing steel follows based on the fundamental principles of prestressed concrete. These curved box girders are very elegant and they are signature structures in a metropolitan environment.

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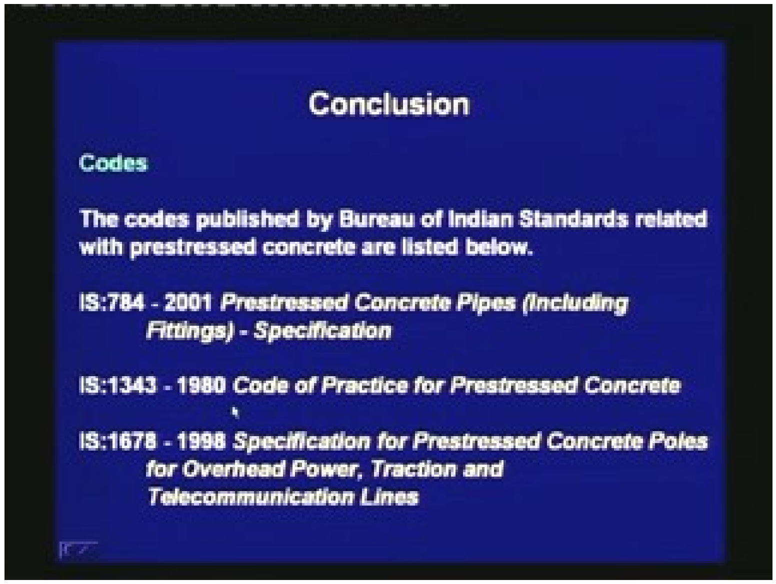

Before we end I mentioned, the different code related with prestress concrete that is published by the Bureau of Indian Standards: first is the IS: 784 - 2001, which is the Prestressed Concrete Pipes including fittings-Specifications; IS: 1343 – 1980, Code of Practice for Prestressed Concrete. This is the code that we followed mostly in our course. Next is IS: 1678 – 1998, Specification for Prestressed Concrete Poles for Overhead Power, Traction and Telecommunication Lines.

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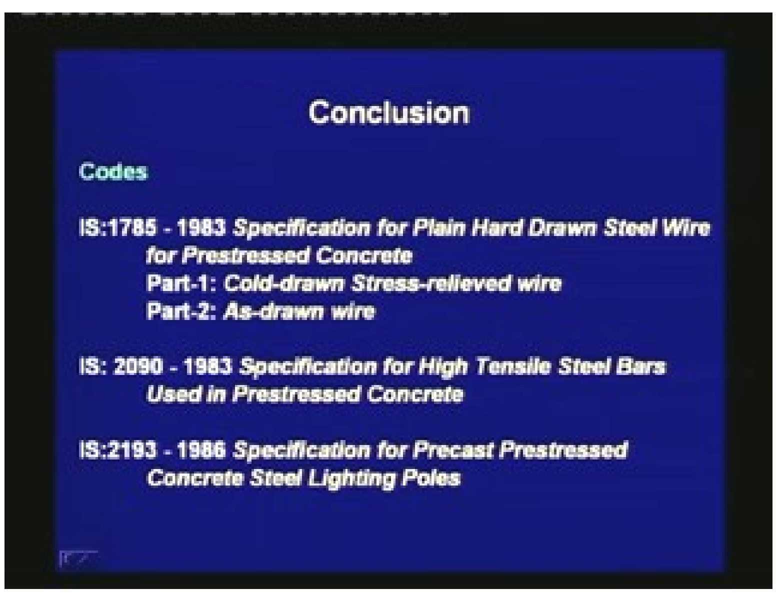

IS: 1785 – 1983, Specification for Plain Hard Drawn Steel Wire for Prestressed Concrete, Part 1 – Cold-drawn Stress-relieved wire, Part - 2 As-drawn wire. IS: 2090 – 1983, Specification for High Tensile Steel Bars Used in Prestressed Concrete; IS: 2193 – 1986, Specification for Precast Prestressed Concrete Steel Lighting Poles.

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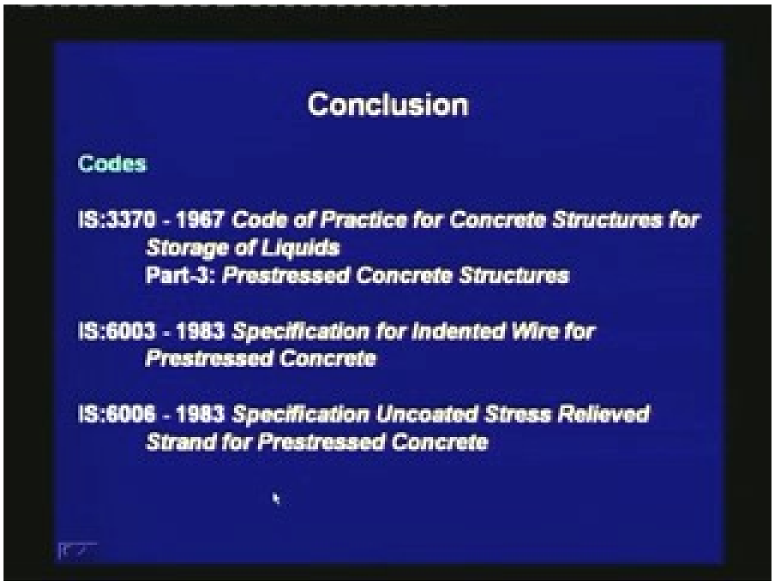

IS: 3370 – 1967, Code of Practice for Concrete Structures for Storage of Liquids. Here, Part-3 is the one which is specifically used for the prestressed concrete structures; IS: 6003 – 1983, Specification for Intended Wire for Prestressed Concrete; IS: 6006-1983, Specification for Uncoated Stress Relieved Strand for Prestressed Concrete.

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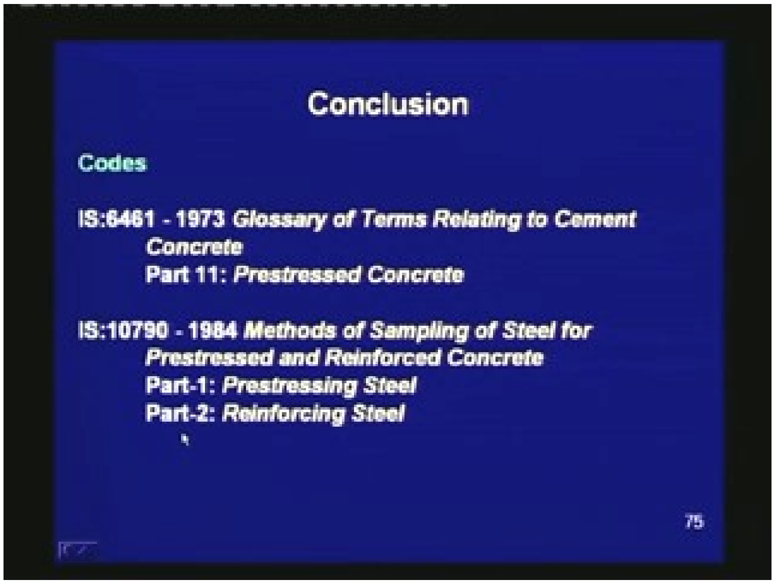

IS: 6461 – 1973, Glossary of Terms Relating to Cement Concrete of which Part-11 is related with Prestressed Concrete. IS: 10790 – 1984, Methods of Sampling of Steel for Prestressed and Reinforced concrete, Part-1 is the Prestressing Steel, Part-2 is the Reinforcing Steel.

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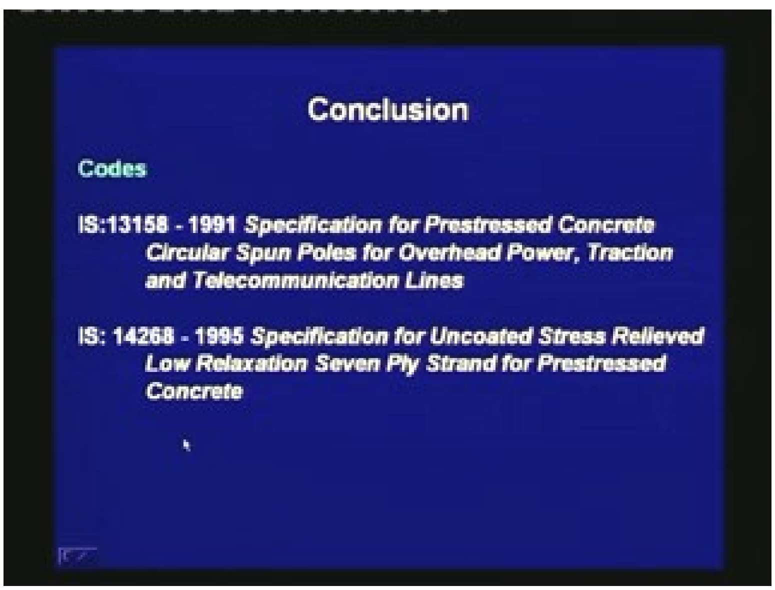

IS: 13158 – 1991, Specification for Prestressed Concrete Circular Spun Poles for Overhead Power, Traction and Telecommunication Lines; IS: 14268 – 1995, Specification for Uncoated Stress Relieved Low Relaxation Seven Ply Strand for Prestressed Concrete.

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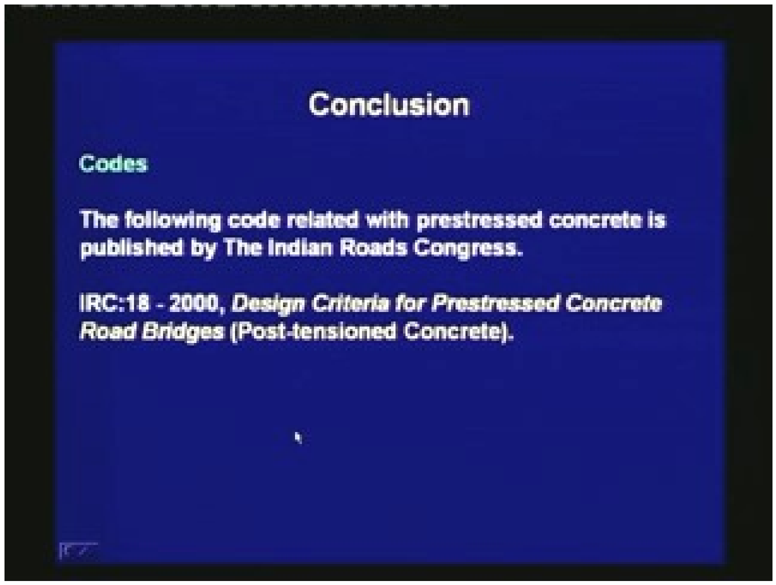

The following code related with prestressed concrete is published by the Indian Roads Congress: IRC: 18 - 2000, Design Criteria for Prestressed Concrete Bridges and Post tensioned Concrete. This code is the one, which is specifically used for prestressed concrete. There are other codes published by Indian Road Congress which is related with the analysis and design of road bridges. When you are moving into the career, you have to learn the use of these codes depending upon where you are using the knowledge of prestressed concrete.

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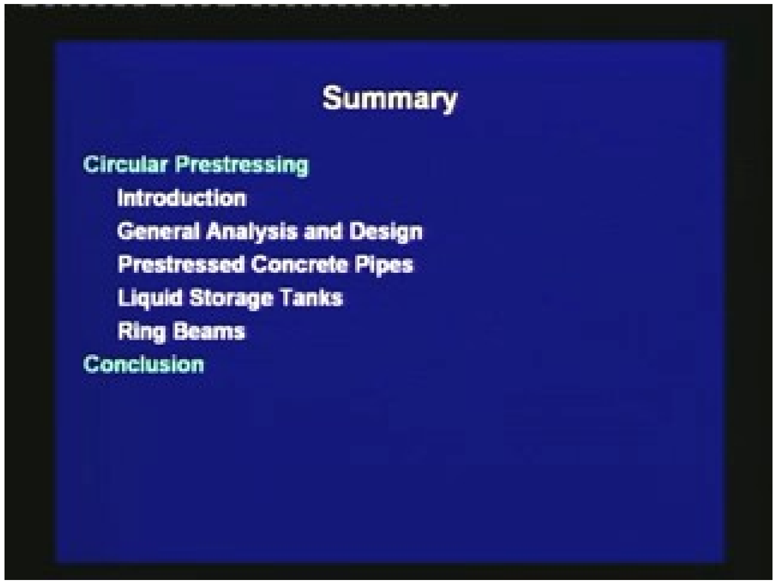

Thus, in today's lectures, we first gave an introduction of circular prestressing. We understood what is the necessity of circumferential prestressing is and then we learnt the general analysis and design principles for circumferential prestressing. Next, we studied some special applications. First, we studied prestressed concrete pipes; next, we studied liquid storage tanks and finally, we studied ring beams. We got familiar with the codes that are related with prestressed concrete structures and we hope that you had of wonderful time with these codes. Thank you.