Prestressed Concrete Structures

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Lecture - 31

Post - tensioned Members

Welcome back to prestressed concrete structures. This is the second lecture on the module seven on transmission of prestressed. In today's lecture, we shall cover post-tensioned members. We shall see how to design the end zone reinforcement for a post-tensioned member and also how to design the bearing plate for a post-tensioned member.

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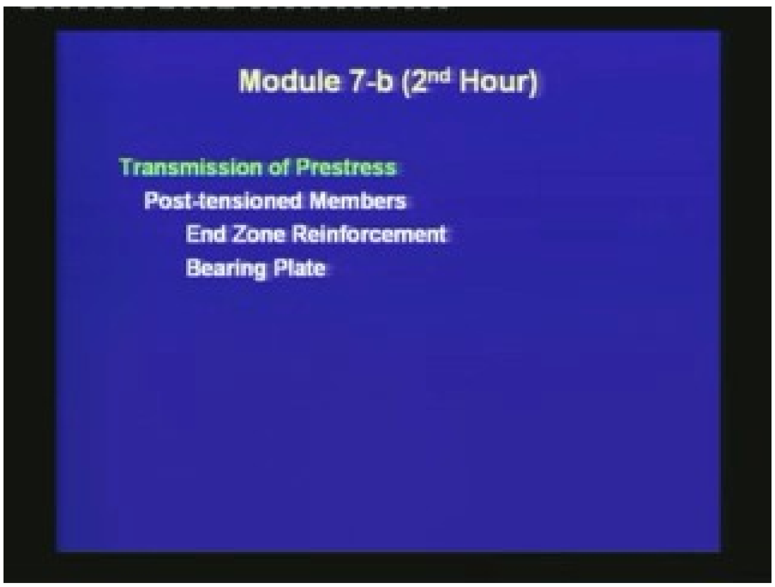

Unlike in a pre-tensioned member without anchorage, the stress in the tendon of a post-tensioned member attains the prestress at the anchorage block. There is no requirement of transmission length or development length.

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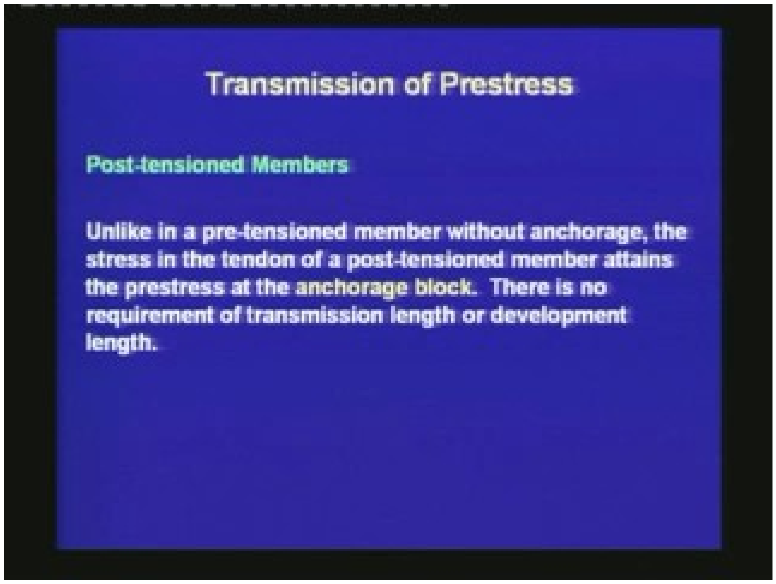

Previously, we have learnt that in a pre- tensioned member the stress at the end of the tendon is zero. It develops to the effective stress over a length, which is called transmission length. The stress needs to develop upto the ultimate value at the location of the maximum moment. Unlike a pre-tensioned member, in a post-tensioned member the stress develops right at the anchorage block because the strands are anchored by wedge. Hence, the stress at the end is not zero, but it is equal to the pre-stress. In a post-tensioned member, we do not talk about transmission length of the development length. This is one primary difference between the transmission of prestress between the pre-tensioned member and the post-tensioned member.

In a pre-tensioned member, the prestress is transferred to the concrete over a certain length whereas in a post-tensioned member the prestress is transferred right at the end. The anchorage device and the bearing plate transfers the stress in the concrete at the end.

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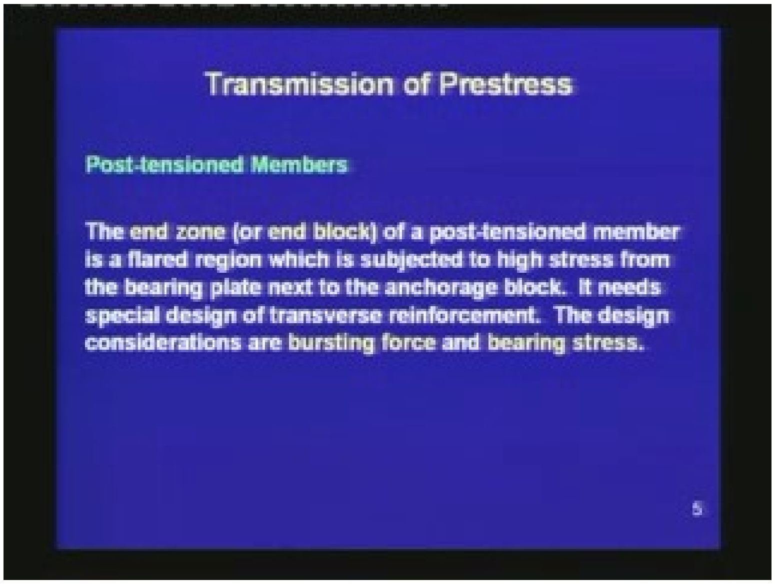

The end zone (or end block) of a post-tensioned member is a flared region which is subjected to high stress from the bearing plate next to the anchorage block. It needs special design of transverse reinforcement. The design considerations are bursting force and bearing stress. Unlike, in a pre-tensioned member, where the prestress is transferred gradually, in a post-tensioned member, the stress is transferred at the end. Hence, the end region of a post-tensioned member, which is called the end zone (or the end block) is subjected to much higher stress concentration. To reduce the effect of stress concentration for an I section, the end is made into a rectangular section by bearing the web, so that the thickness at the end zone is much larger than the thickness of the web in the intermediate region. Thus, the end zone of a post-tensioned member is usually a rectangular section. This part of the rectangular section is carried over a certain distance within which there is a high stress concentration. Beyond that end zone region, the width of the web is reduced and for the intermediate region, it is narrowed down with the design width of the web.

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Fig 7b-1 End zone of a bridge I-girder
(Courtesy: Larsen & Toubro)

The photograph for the end zone of a post-tensioned member shows the anchorage block to hold the prestressing tendons. We observe, when the strands are stretched, the jack gets the reaction against the member itself. This creates quite substantial amount of stresses in the end region. The end region is rectangular, whereas in the span, the beam is an I section. This is the end zone of a bridge I-girder. You can observe the anchorage blocks, which have been used to apply the prestress from the tendon to the concrete.

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Fig 7b-2 End zone of a bridge box girder
(Courtesy: Cochin Port Trust, Kerala)

This is another photograph of a bridge box girder. Here, you see that the anchorage blocks have been placed at the end zone. This creates substantial amount of stresses in the end zone and the strands develop the prestress at the anchorage block itself.

The stress field in the end zone of a post-tensioned member is complicated. The compressive stress trajectories are not parallel at the ends, they diverge from the anchorage block till they become parallel. Based on Saint Venant's principle, it is assumed that the trajectories become parallel after a length equal to the larger transverse dimension of the end zone.

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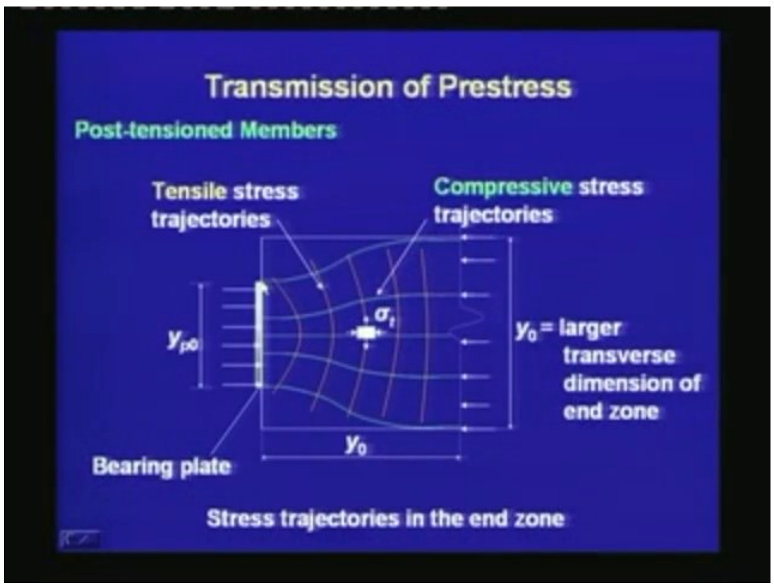

This sketch helps us understand the effect of stress concentration, the cause and the effect of stress concentration in the end zone region. The bearing plate next to the anchorage block applies the concentrated stresses at the end of the member, y_{p0} is the dimension of the bearing plate. After the stress is transferred to the concrete in this bearing region, the compressive stress trajectories which are denoted by green lines, expand and over a certain length they become parallel. It is assumed that the distance within which it becomes parallel is equal to the larger dimension of the end zone. Thus, y_0 is the larger transverse dimension of the end zone within which the stress concentration effect gets reduced. Beyond y_0, the stress distribution is uniform, if the pre-stressing tendon is concentric and we do not have the effect of stress concentration beyond the length y_0.

Thus, the length of the end block is equal to the larger dimension of the end zone that is the ransverse dimension.

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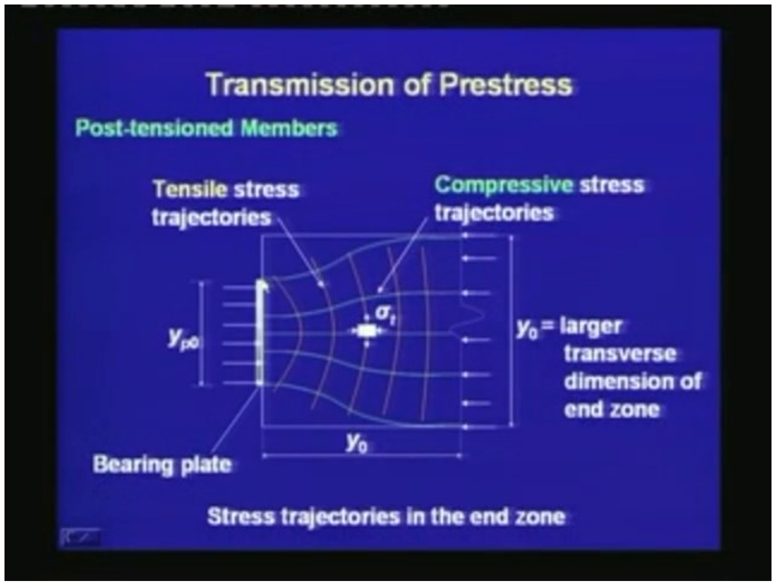

The tensile stress trajectories are also shown by the orange lines. Here also, you can see that these lines are bent and gradually they become parallel as we move towards the end of the end zone. Since the stress trajectories are not parallel, it generates tensile stresses and compressive stresses within the end zone. If you look into an element at the level of CGC, we observe that, axially there is a compressive stress whereas, in the transverse direction we have a tensile stress that transfers tensile stress and denoted as $sigma_t$. This is the stress which we shall consider in designing of the end zone reinforcement. Thus, understanding the stress trajectories is important to understand the reason of providing end zone reinforcement in a post-tensioned member.

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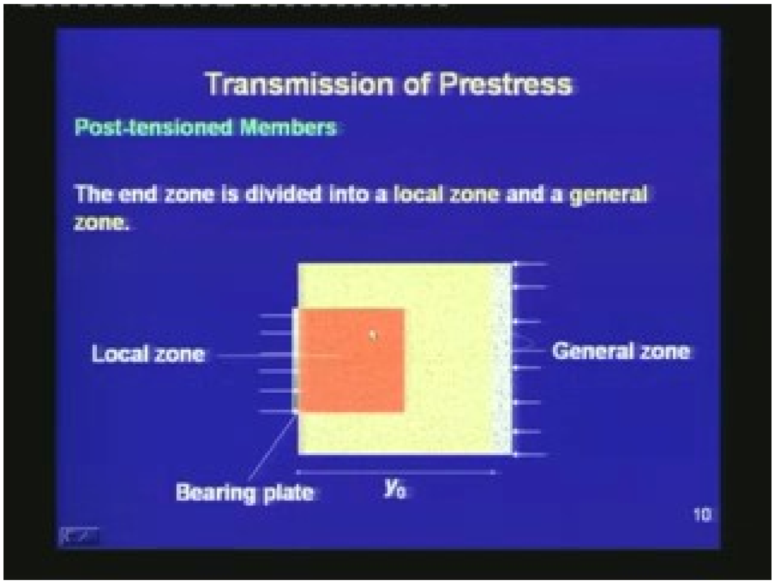

The end zone is divided into a local zone and a general zone. The local zone is a prism, right behind the bearing plate, it is subjected to very high stress concentration and to the tensile stresses sigma$_t$, which we take into account in designing reinforcement for the local zone. The region outside the local zone is denoted as general zone. In fact, the local zone is considered to be a part of general zone. The general zone also has stress concentration, but not as much as the local zone but it has some other effects, like spalling of concrete in the region outside the bearing plate. The general zone is reinforced by the end zone reinforcement to check the bursting effect of the tensile stresses.

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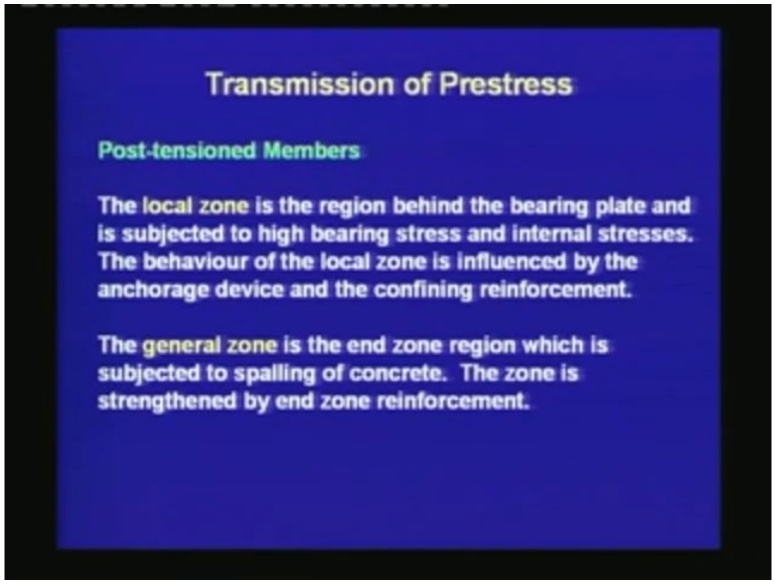

Thus, the local zone is the region behind the bearing plate and is subjected to high bearing stress and internal stresses. The behaviour of the local zone is influenced by the anchorage device and the confining reinforcement.

The general zone is the end zone region which is subjected to spalling of concrete. It is strengthened by end zone reinforcement. We do provide special reinforcement in both the local zone and general zone region.

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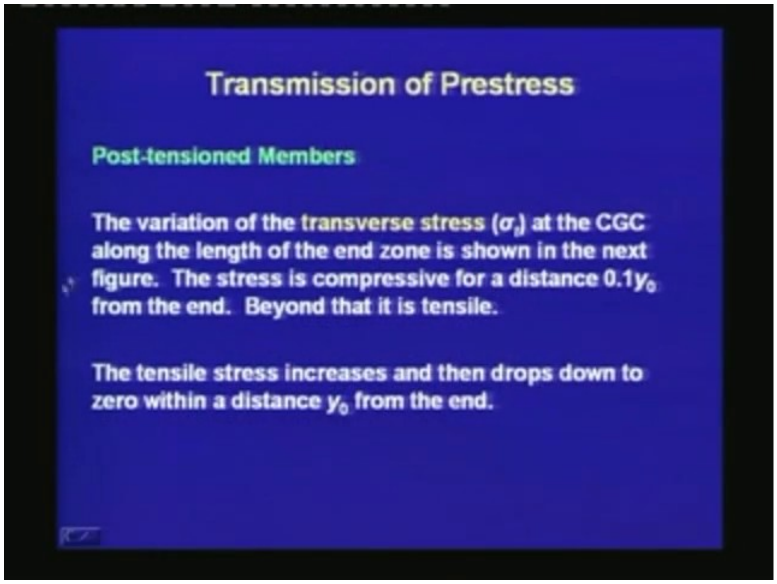

The variation of the transverse tensile stress sigma$_t$, at the level of CGC along the length of the end zone is shown in the next figure. The stress is compressive for a distance $0.1y_0$ from the end. Beyond that it is tensile. The tensile stress increases and then drops down to zero within a distance y_0 from the end.

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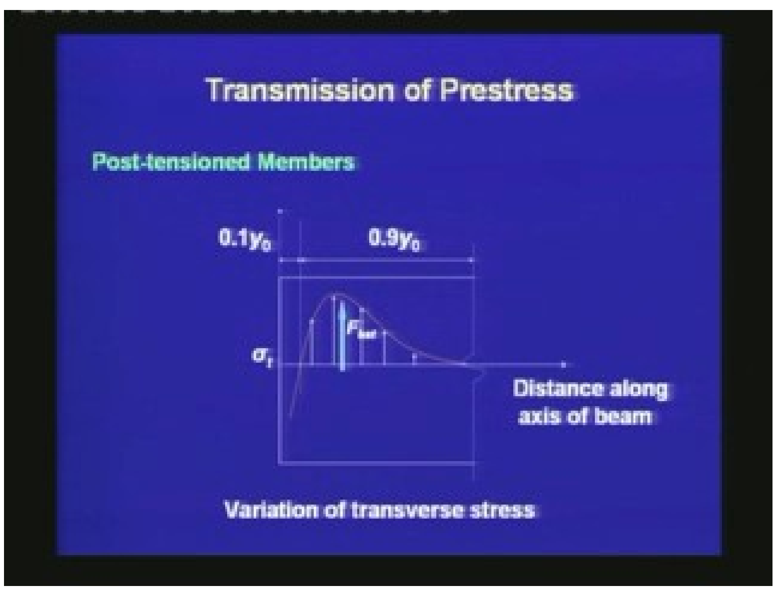

If you plot the variation of the transverse stresses at the level of CGC and along the axis of the beam, we observe that right behind the bearing plate, the transverse stresses are compressive. After a distance of about one tenth of the length of the end zone, the stresses become tensile and it increases up to a maximum value then it decreases and becomes negligible towards the end of the end zone. We are more concerned about the tensile stress that occurs between the regions, $0.0y_0$ to y_0. It is 90% of the length of the end zone is of concern because of the transverse tensile stress. This transverse tensile stress acts in a radial direction with respect to the axis, which means, it is neither vertical nor horizontal but it acts in a radial direction with respect to the axis of the beam.

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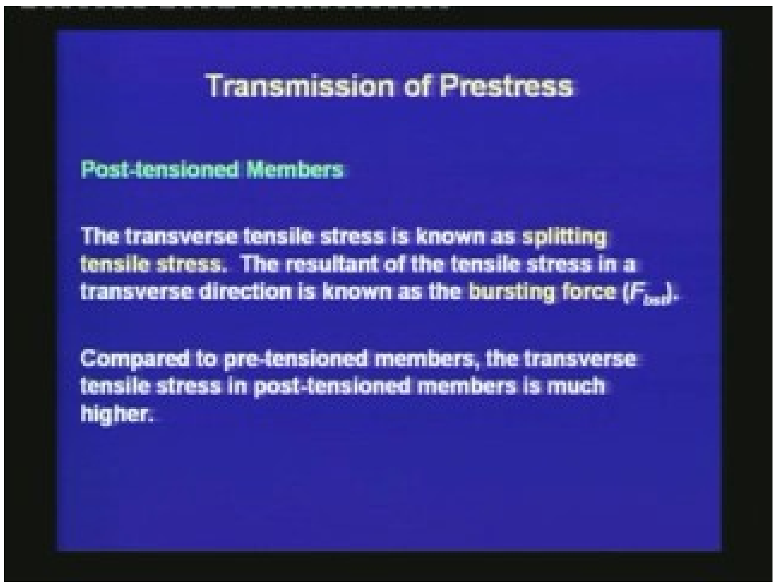

The transverse tensile stress is known as splitting tensile stress. The resultant of the tensile stress in a transverse direction is known as the bursting force.

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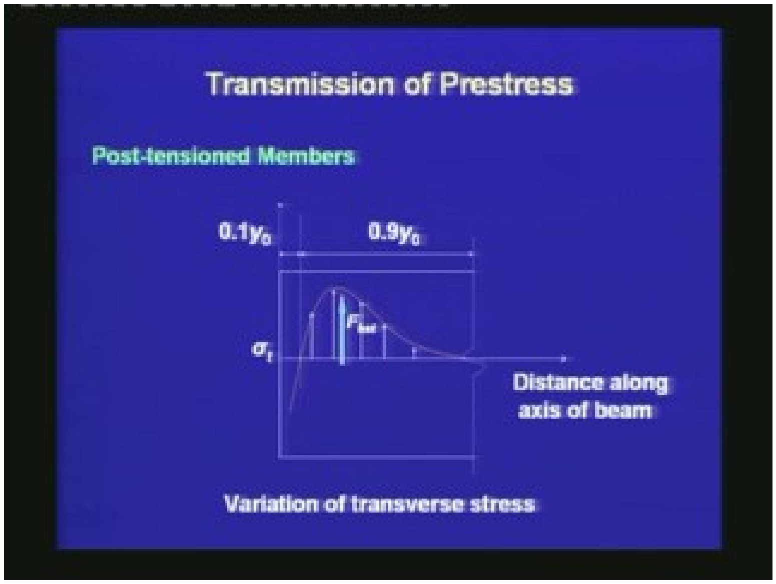

In our previous sketch, we have denoted the resultant of stresses by a force, which we denote as F_{bst} and this term is referred to bursting force. This force creates horizontal crack unless it is properly reinforced. This is called the splitting of the concrete. That means, splitting of the concrete refers to the horizontal crack that generates due to the stress concentration.

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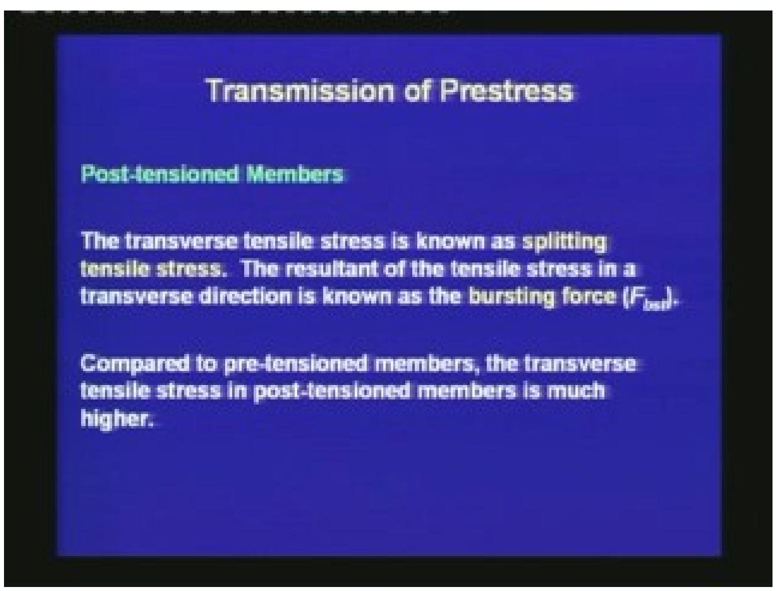

Compared to pre-tensioned members, the transverse tensile stress in post-tensioned members is much higher.

During our lecture on pre-tensioned member, we observed that there is a transverse tensile stress in the pre-tensioned member. But, the transverse tensile stress in the end zone of a post-tensioned member is much higher as compared to the pre-tensioned member. Hence, the end zone of a post-tensioned member needs special attention regarding the design of end zone reinforcement.

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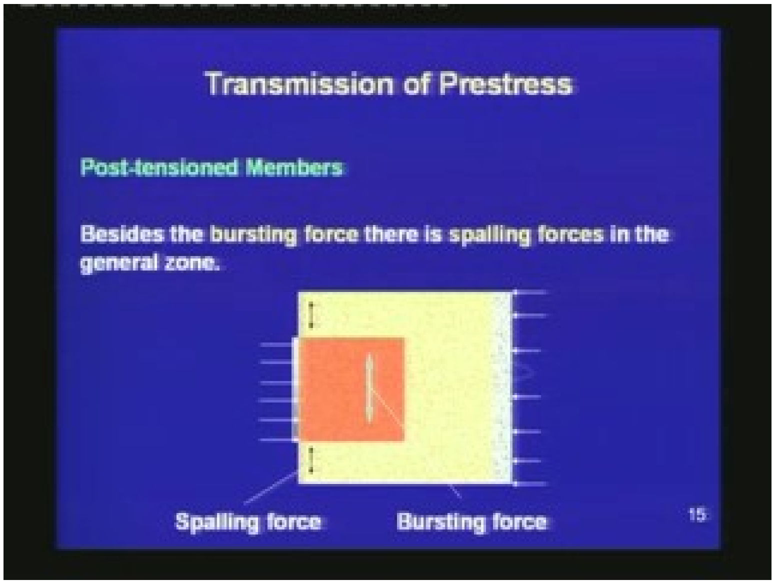

Besides the bursting force, there is spalling forces in the general zone. We not only have the bursting force in the local zone and stress peel over to the general zone, but we also have some other forces which create spalling of concrete and this is outside the bearing plate region. This force which causes spalling of concrete is termed as a spalling force.

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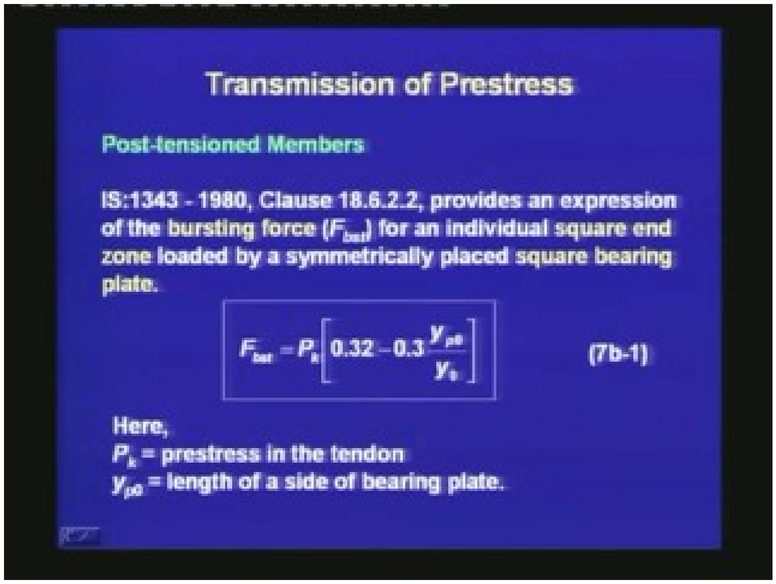

IS: 1343-1980, Clause 18.6.2.2 provides an expression of the bursting force F_{bst} for an individual square end zone loaded by a symmetrically placed square bearing plate. Thus, the expression that is given in IS 1343 is for an end zone whose cross-section is squared and with the bearing plate is also squared. This bearing plate is concentric with the end zone. That means the axis of the bearing plate is same as the axis of the end zone. The expression of F_{bst} is equal to P_k times 0.32 minus 0.3 times y_{p0} divided by y_0. Here, P_k is the prestress in the tendon that means if you have a larger bursting force in prestress and also the bursting force is a function of the ratio of the dimension of the bearing plate to the dimension of the end zone. y_{p0} is the length of a side of bearing plate that is parallel to Y_0.

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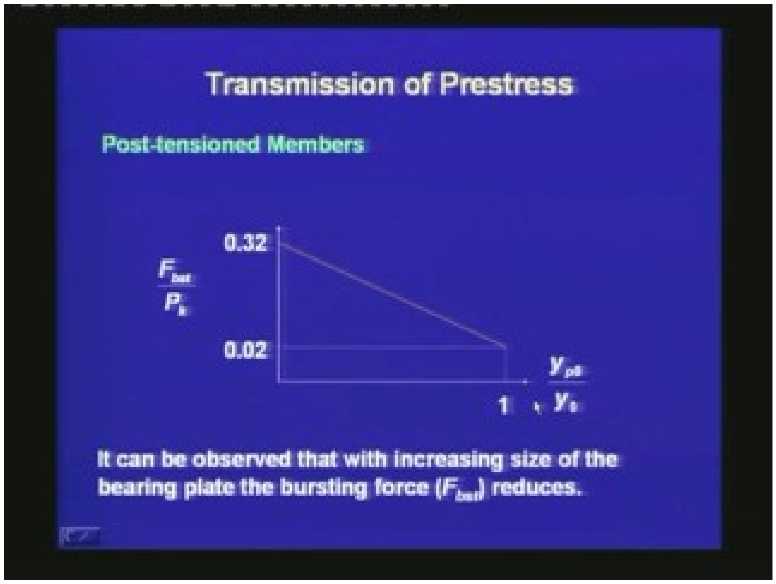

If you plot the variation of the bursting force normalized with respect to the prestress in the tendon, we observe that the bursting force reduces as the size of the bearing plate increases. The equation is the linear equation if have negligible plate, then the bursting force is about 32% of the prestress. As the plate increases to the end zone dimension, the bursting force drops down to about 2% of the prestressing force. Thus, we can observe that if we increase the size of the bearing plate, the bursting forces are reduced.

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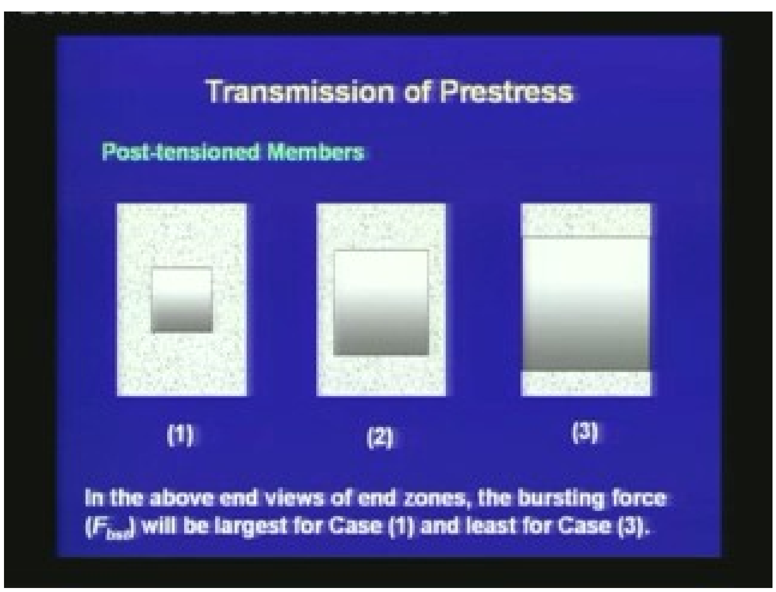

In this figure, we are observing that for the same prestress member, if we have three different sizes of the bearing plates: for one, it is a very small bearing plate, for two we have a larger bearing plate, for three we have a bearing plate which covers the width of the end zone. For these three cases, we observe that the bursting force is largest for case 1, which has a small bearing plate and is least for case 3 which has the largest bearing plate. Thus, one way to reduce the effect of bursting forces is to increase the size of the bearing plate so that it applies a more uniform stress at the end of the post-tensioned member.

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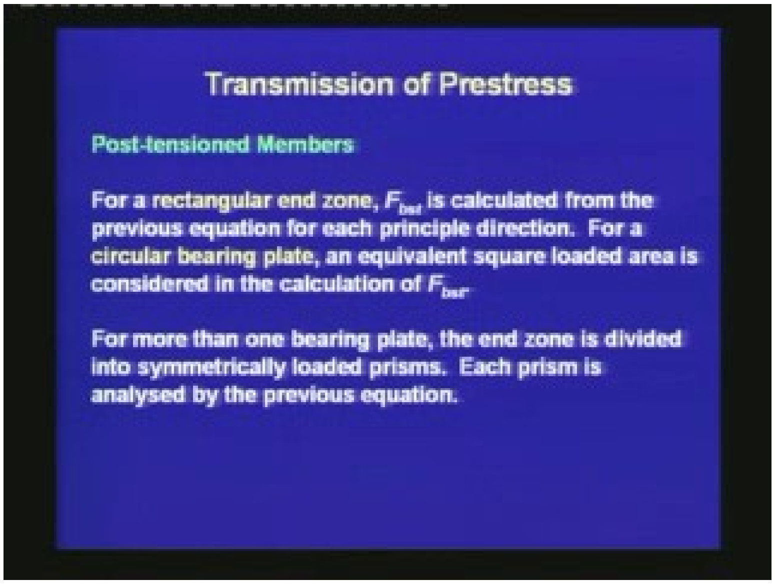

For a rectangular end zone, F_{bst} is calculated from the previous equation for each principle direction. That means, if the end zone and the bearing plate are rectangular, then we apply the previous equation for the horizontal and vertical direction separately and we calculate the two bearing forces, one in the horizontal direction and one in the vertical direction. If the bearing plate is circular, an equivalent square loaded area is considered in the calculation of F_{bst}. Thus, for a circular bearing plate, we consider an equivalent square bearing plate, whose area is same as that of the circular bearing plate and then we apply the expression that is given earlier. Again, the expression of the bursting force is a function of the prestress in the tendon, it is a function of the ratio of the dimension of the bearing plate to the dimension of the end zone and both these dimensions are in the same direction. We observe that as the ratio of the dimension increases the bursting force comes down. If you have more than one bearing plate then the end zone is divided into symmetrically loaded prisms. Each prism is analysed by the previous equation.

As you have observed, we may have more than one bearing plate. In that case, we divide the end zone into regions which are tributary to each bearing plate, the region for one bearing plate is placed symmetrically about its center. Then, we apply this expression for each region of the end zone separately.

Next, we are moving on to the design of the end zone reinforcement.

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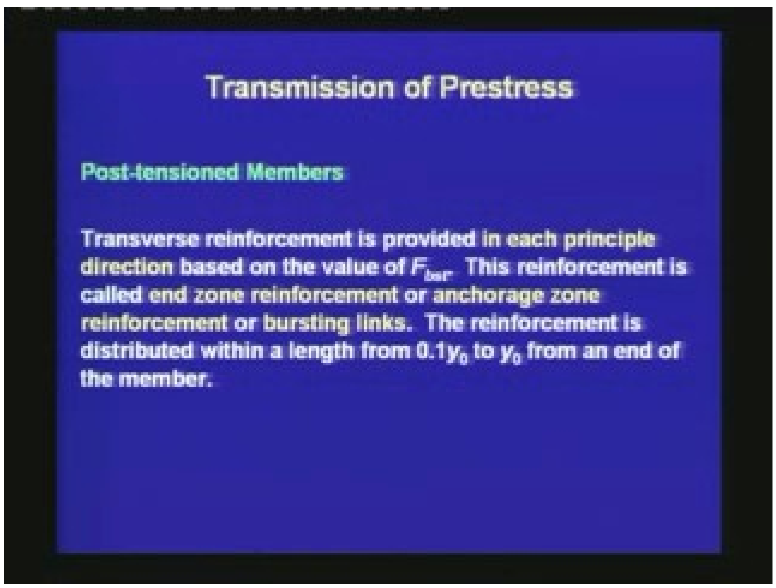

The transverse reinforcement is provided in each principle direction based on the value of F_{bst}. We have calculated till now is the bursting force. If it is a square bearing plate, with a square end zone, then the bursting force is same in both the horizontal and the vertical direction. If it is the rectangular bearing plate and if the proportion of the dimensions of the bearing plate to the end zone is different in the two directions, then we shall have two values of the bursting force: one for the horizontal direction and another for the vertical direction. We select the higher of the two and design the end reinforcement for the bursting force. End zone reinforcement is also called anchorage zone reinforcement or bursting links. The reinforcement is distributed within a length from $0.1y_0$ to y_0 from an end of the member.

The end zone reinforcement is started from a distance $0.0y_0$ because there the transverse stresses become tensile and the end zone reinforcement is continued up to a distance y_0 from the end. Beyond that, the transverse tensile stress becomes negligible. Hence, the end zone reinforcement is placed in a distance of $0.9y_0$. This end zone reinforcement is also called anchorage zone reinforcement or bursting links.

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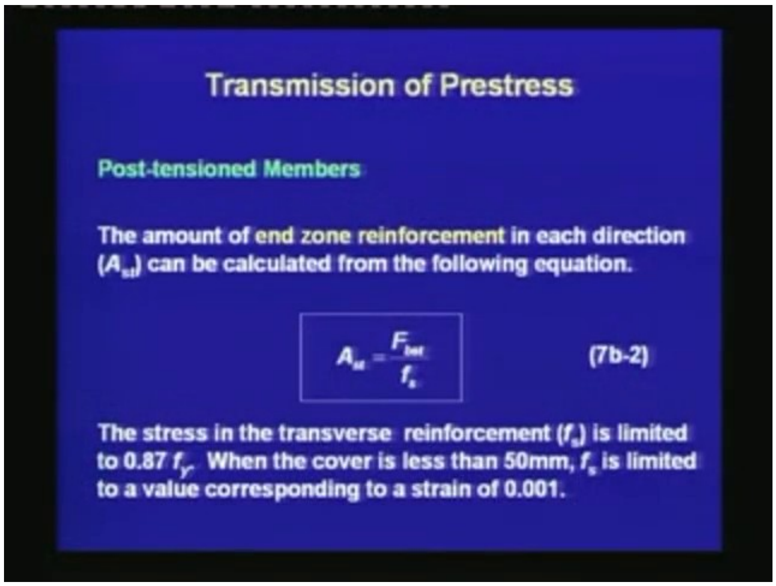

The amount of end zone reinforcement in each direction shall be denoted as A_{st} and can be calculated from the following equation: A_{st} is equal to F_{bst} divided by f_s. The stress in the transverse reinforcement f_s is limited to $0.87f_y$. When the cover is less than 50 millimeters, f_s is limited to a value corresponding to a strain of 0.001. Thus, when we are designing the end zone reinforcement, we are free to select the stress that we can allow in the transverse reinforcement. The maximum value is $0.87f_y$. If the cover of the concrete to the tendons is less than 50 millimeter, then the code recommends that we reduce the allowable stress in the transverse reinforcement to a value which corresponds to a strain of 0.001. Thus, f_s will be equal to the modulus of the transverse reinforcement times 0.001. With this value of f_s we calculate the amount of transverse steel here which is denoted as A_{st}.

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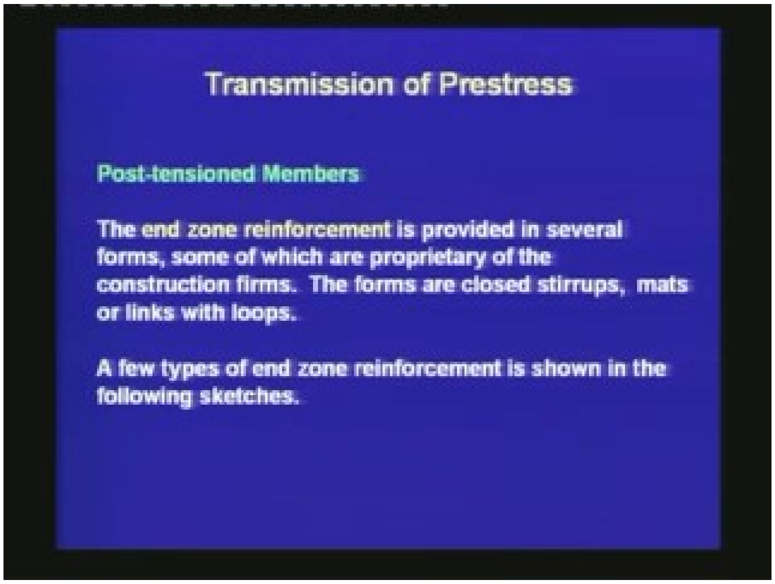

The end zone reinforcement is provided in several forms some of which are proprietary of the construction firms. The forms have closed stirrups, mats or links with loops. A few types of end zone reinforcement are shown in the following sketches.

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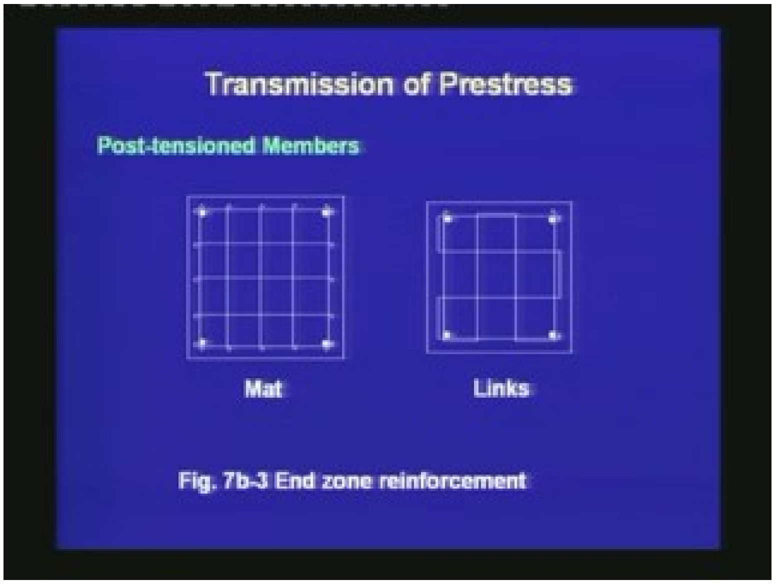

End zone reinforcement can be of several types and are usually designed by the post-tensioned firms and they have proprietary designs. A few of them are shown; on the left, we can observe a mat of reinforcement and here you see that we are providing both horizontal reinforcement and vertical reinforcement. We can also provide the reinforcement in the form of links, instead of providing individual horizontal or vertical reinforcement, we can provide the reinforcement by having links in them. The simplest form of the end zone reinforcement is to have closed stirrups, so as to confine the concrete of the end zone.

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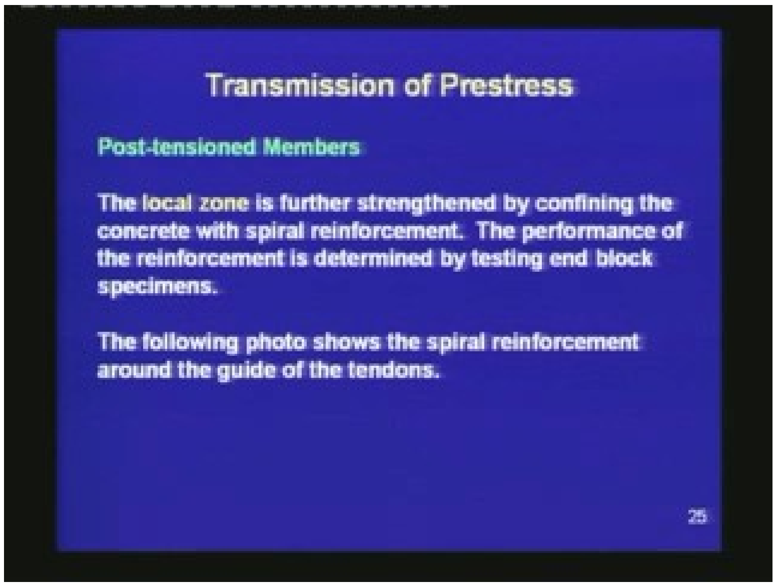

The local zone is further strengthened by confining the concrete with spiral reinforcement. Performance of the reinforcement is determined by testing end block specimens. The following photo shows the spiral reinforcement around the guide of the tendons.

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As I mentioned before, the local zone is subjected to severe stress concentration. In order to increase the strength of the concrete, confining reinforcement is placed in the local zone in the form of spirals or helical reinforcement. Most of the reinforcement is proprietary of the firms manufacturing the anchorage blocks and the end devices. Performance of this type of reinforcement is usually determined by test of the end blocks. In this photograph, you can observe that the prestressing strands after it has passed to the guides, has been anchored at the end block through the wedge and anchorage block. A part of the guide has been cut open to show the strands which passed through the guide to the anchorage block and outside the guide a spider reinforcement has been provided to confine the concrete to increase its strength, so as to resist the internal stress concentration. There is also a pipe for the grouting of the ducked after the post tensioning operation has been done. Thus, this type of special confining reinforcement is provided in the local zone so as to reduce the effect of the stress concentration. The end zone may be made of high strength concrete. Use of dispersed steel fibres in the concrete reduces the cracking due to the bursting force. Thus, we may have special type of concrete for the end zone, one option is a high strength concrete. We can also have fibre reinforcement concrete, where steel fibres are dispersed within the concrete in the end zone. This helps to check the growth of cracks in the end zone. Pertinent designs have been made for the concrete in the end zone region.

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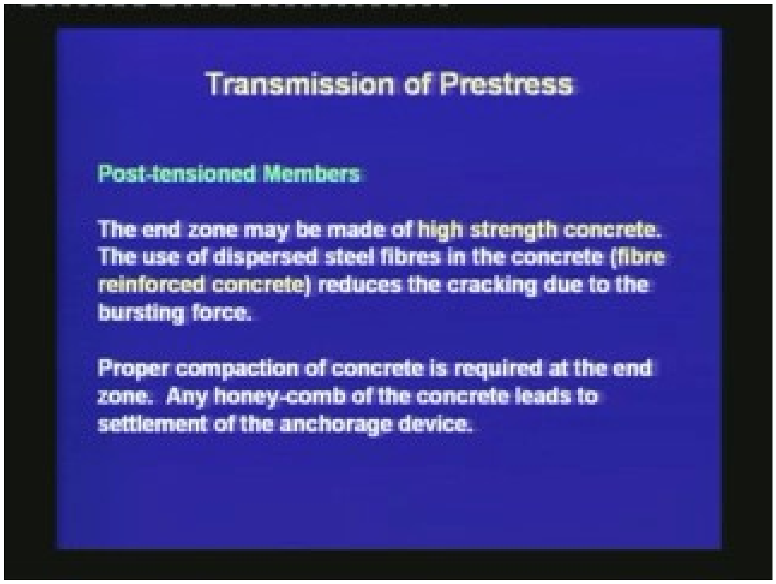

Proper compaction of concrete is required at the end zone. Any honey comb of the concrete leads to settlement of the anchorage device. Thus, during concreting, attention has to be paid towards the quality of casting, proper compaction has to be done in the end zone. If there is any honey comb left, that will lead to the sinking of the anchorage block and that may also lead to any accident during the post-tensioning operation. Thus, the post tensioning operation is a testing time to make sure that the post-tensioned beam has good quality concrete. Especially, the end zone has a concrete which is sufficient to sustain the stress concentration in the end zone.

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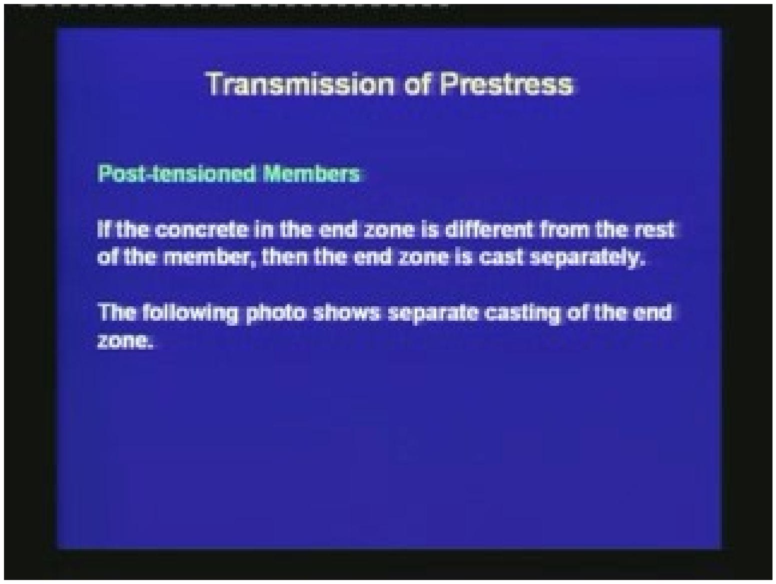

If the concrete in the end zone is different from the rest of the member, then the end zone is cast separately. The following photo shows separate casting of the end zone.

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For this bridge girder, you can observe that the end zone has been cast prior to the casting of the rest of the member. The end zone is a high strength concrete and there was strict quality control during the casting of the end zone concrete. Thus, this will ensure that the effect of the stress concentration will be reduced and the end zone will be able to sustain the stresses which arise during the post tensioning operation. Observe that the tendons will pass through these ducts and they will be fixed by anchorage blocks behind these bearing plates.

The next important aspect is to design the bearing plate for the end zone.

In this lecture, we are not designing the thickness of the bearing plate which is based on the conventional steel design. We are more interested to design the dimension of the bearing plate, the height and the width so that the effect in the concrete is minimized. The design of the bearing plate refers to designing the length and the width of the bearing plate such that the bearing stresses in the concrete are within the allowable value.

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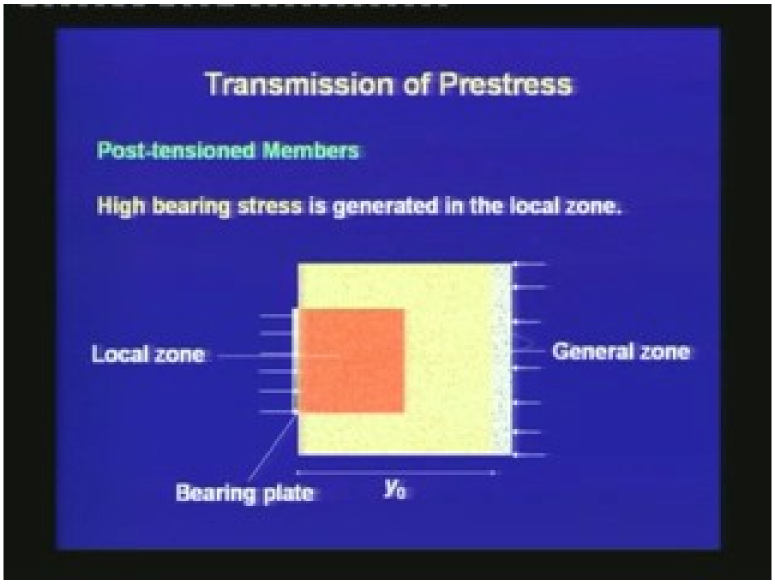

High bearing stress is generated in the local zone.

You can observe from this figure that when the bearing plate is resting against the end zone and the post-tensioned is applied, substantial bearing stress is applied in the local zone of the end zone and we need to check the failure of concrete due to the bearing.

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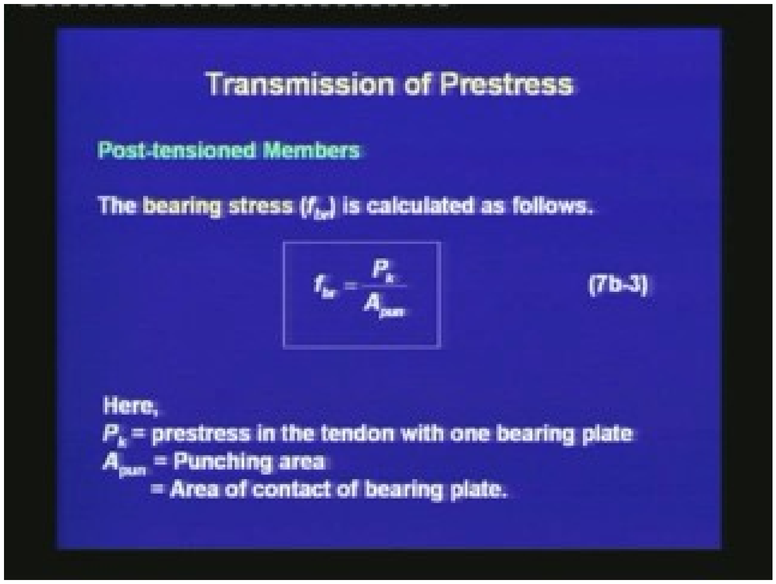

The bearing stress which is denoted f_{br} is calculated from the following equation: f_{br} is equal to P_k divided by $A_{punching}$, where P_k is the prestress in the tendon with one bearing plate and $A_{punching}$ is the punching area which is the area of contact of bearing plate. Thus, the bearing stress is the ratio of the prestressing force in one particular tendon within single bearing plate divided by the area of the bearing plate. We are assuming a uniform bearing stress to occur over the bearing area.

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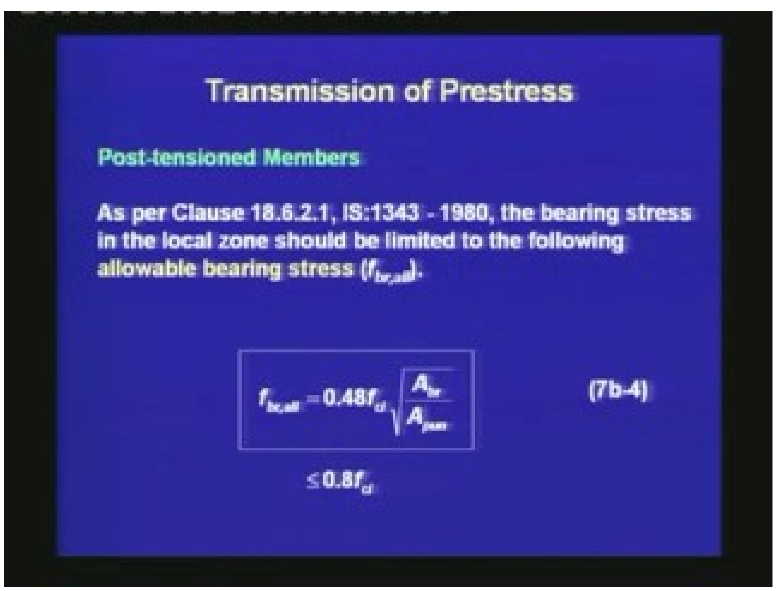

As per clause 18.6.2.1 of IS 1343-1980, the bearing stress in the local zone should be limited to the following allowable bearing stress, which is denoted as $f_{br,allowable}$. It is equal to 0.48 f_{ci} times root over A_{br} divided by $A_{punching}$. The allowable bearing stress should be limited to 80% of f_{ci}.

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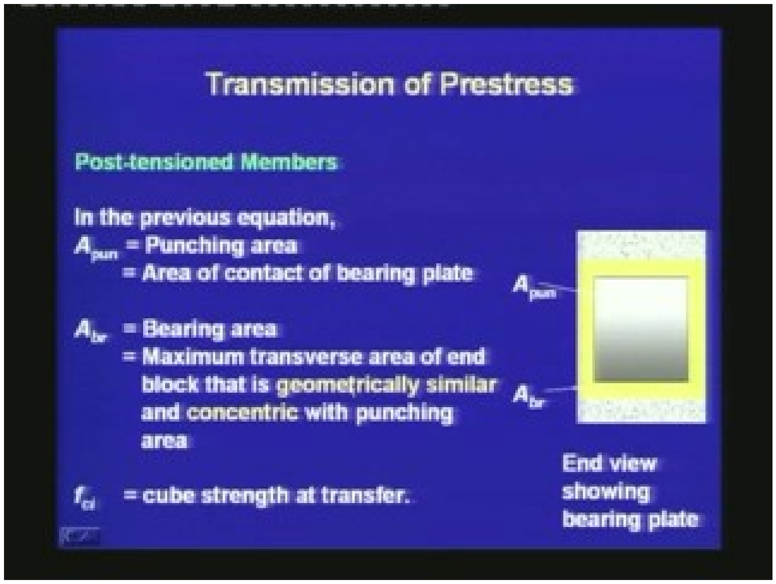

In this equation, $A_{punching}$ is the area of contact of the bearing plate which is shown as the gray shaded area and $A_{bearing}$ is the bearing area which is equal to the maximum transverse area of end block that is geometrically similar and concentric with the punching area. We shall explain the A bearing in the subsequent slide. Before that, let us mention that f_{ci} is the cube strength at transfer. This is sketch of the end view showing the bearing plate resting against the post-tensioned member. Thus, the code recommends are limiting bearing stress and this bearing stress is a function of the cube strength at transfer. It is the function of two areas: one is the punching area, which is the area of the bearing plate and another is the bearing area, which is the area in the concrete that is similar to the punching area and concentrically located with the punching area. If we have to reduce the bearing stress, or in other words if you are trying to increase the allowable bearing stress, then we should have adequate concrete strength. The post-tensioning operation can be done only when the concrete achieves the minimum strength as specified in the design calculations. Only then we shall have a high value of f_{ci} which will give a high value of the allowable bearing stress. If the ratio f_{br} divided by $A_{punching}$ increases, then we can increase the allowable bearing stress. Now, let us try to understand the concept of the A_{br} which is the bearing area in the concrete resisting the bearing stress.

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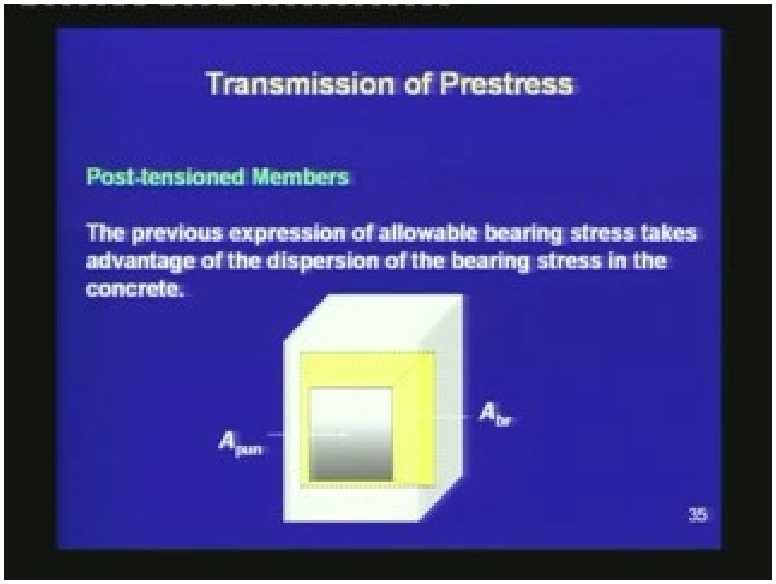

The previous expression of allowable bearing stress takes advantage of the dispersion of the bearing stress in the concrete. $A_{punching}$ is the area where the bearing stress is applied and after that the bearing stress gets dispersed in the end zone to an area which can be placed within the end zone, this is geometrically similar to $A_{punching}$. Thus, A_{br} and $A_{punching}$ are the two ends of a frustum which can be placed within the end zone.

The purpose of having a larger A_{br} as compared to $A_{punching}$ is that the bearing stress gets dispersed in the concrete which has been adequately strengthened by providing end zone reinforcement. Thus, if the end zone reinforcement is there, we are taking advantage of the dispersion of the bearing stress and considering of factor which is larger than one, this helps us to increase our allowable bearing stress.

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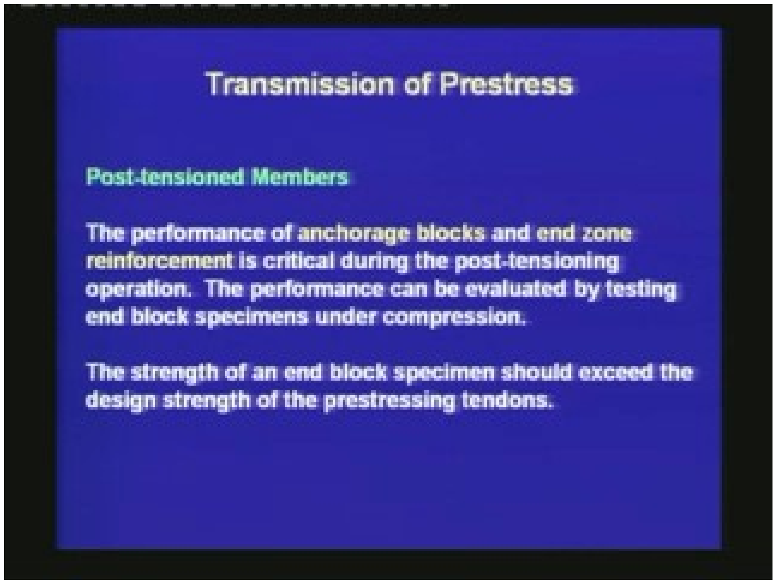

The performance of anchorage blocks and end zone reinforcement is critical during the post-tensioning operation. The performance can be evaluated by testing end block specimens under compression. The strength of an end block specimen should exceed the design strength of the prestressing tendons. As I mentioned before, the post-tensioning operation itself is the testing time for a post-tensioning member. The anchorage block and the end zone have to perform during the post-tensioning operation. Now, these regions are tested separately in a laboratory to check their capacity and the capacity of an end zone should be larger than the maximum prestressed that is coming in the tendon. Hence, we ensure that there will not be failure in the end zone and the stress will be transferred to the post-tensioned member.

The following photos show the manufacturing of an end block specimen.

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Fig 7b-5 Fabrication of end zone reinforcement
(Courtesy: Indian Institute of Technology Madras)

This is the end zone reinforcement for an end block specimen. For this reinforcement, the anchorage block will be coming on the right side. Observe that the end zone reinforcement is larger sized and closely spaced towards the end of the post-tensioned member. The end of the post-tensioned member will be on the right side and the reinforcement is of a smaller size and is largely dispersed, as we are moving out from the ends of the end zone. Thus, the end zone reinforcement is not uniformly placed along the length of the end zone. There is more reinforcement towards the end of the end zone near the anchorage block and there is less reinforcement toward the other half of the end zone. This is a more efficient way of placing the end zone reinforcement in the end block specimen.

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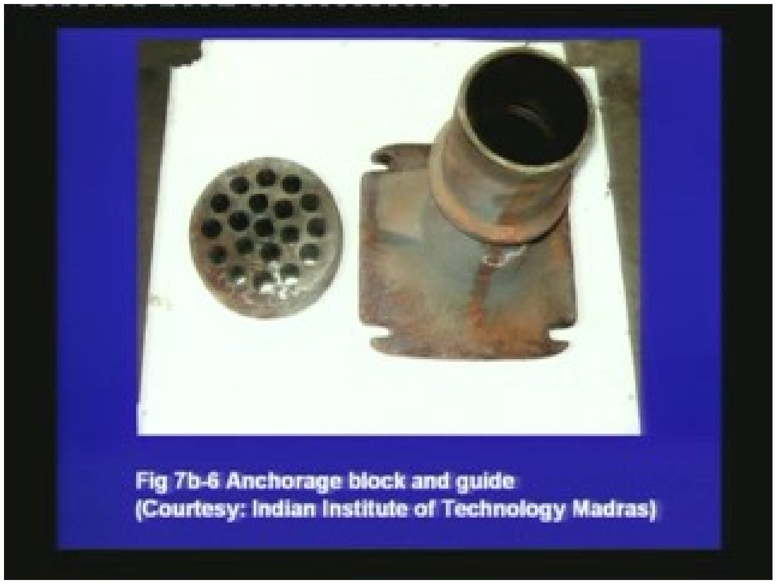

In this photo, we observe the guide through which the prestressing tendon will pass and the anchorage block where the prestressing tendons will be attached.

Once, this guide is placed within the reinforcement gauge, the concrete will be cast. We shall have a specimen as shown in this photograph.

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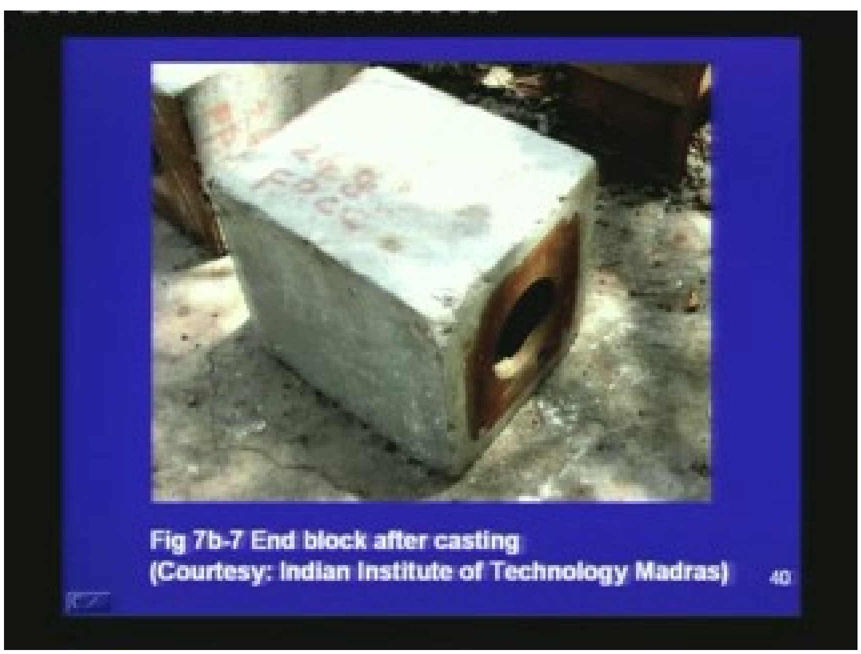

This is an end block specimen which will be tested to check its capacity. Here, you can observe that this is the bearing plate which is also a part of the guide and the space will provide us the requisite space to put the tendons. Once the tendons are placed, the anchorage block will be placed where the tendons will be attached. This type of specimen can be tested under compression to simulate the compression due to the anchorage blocks or it can also be tested for fertig to check the performance of the whole anchorage systems under varying load.

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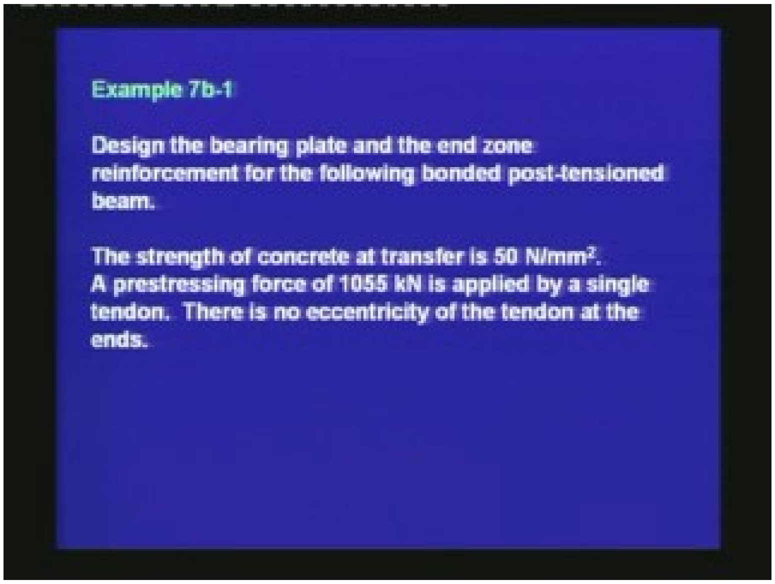

Let us now try to understand the design of the end zone reinforcement and the bearing plate by an example. Design the bearing plate and the end zone reinforcement for the following bonded post-tensioned beam. The strength of concrete at transfer is 50 Newton per millimeter square. A prestressing force of 1055 Kilonewtons is applied by a single tendon. There is no eccentricity of the tendon at the ends.

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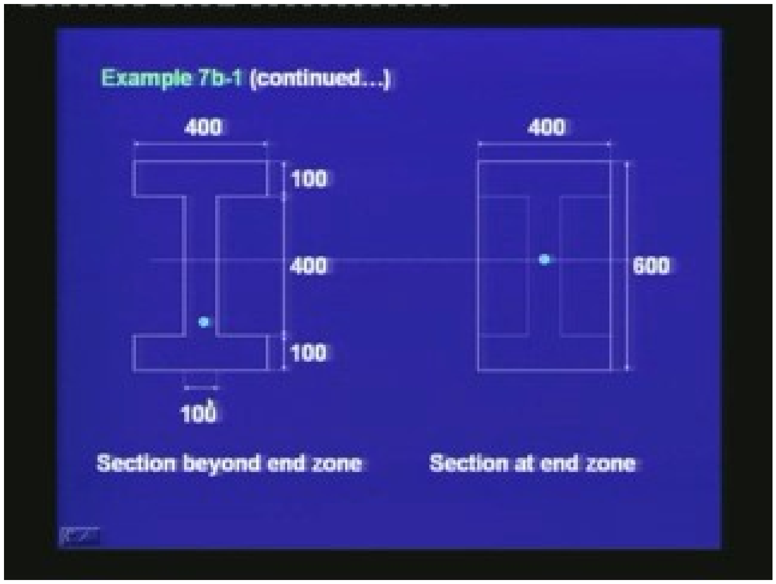

This section is as follows: in the span region, it is an I section which is 400 millimeter wide flanged. The depth of the flanges is 100 millimeter and it is a section which is symmetric about a horizontal axis. The tendon has an eccentricity with respect to CGC in the intermediate region. The width of the web is 100 millimeters and the total depth of the section is 600 millimeters. Now, when we are coming to the end, the width of the web has been flared so that we have an increased width of the end zone. The width of the end zone has been made equal to the width of the flange. That means, the end zone is of uniform width which is 400 millimeters and the depth of the section is 600 millimeters.

Thus, the end zone is a rectangular section, where as the section in the span region is an I section. Again, the purpose of flaring the end zone is to reduce the effect of the concentrated stresses.

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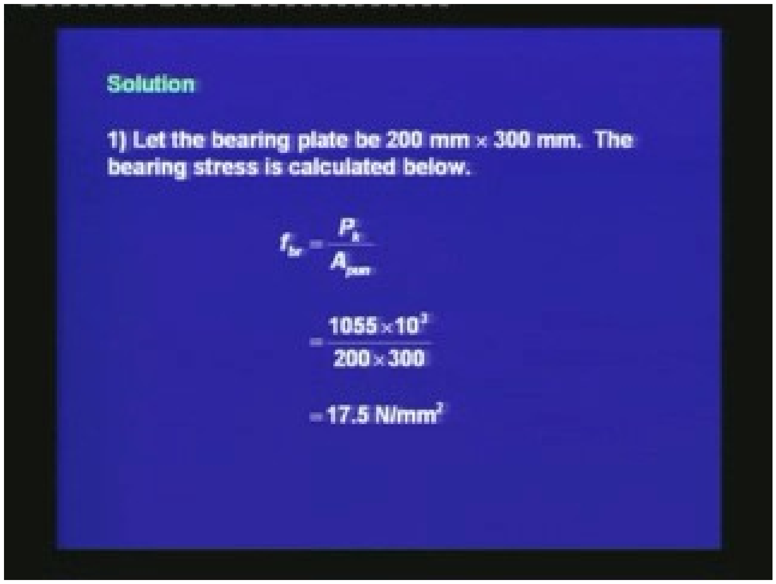

For this problem, there is only one tendon which does not have eccentricity at the end and the strength of the concrete at transfer has been given, which is 50 Newton per millimeters square. We can observe that this is substantially high value of the concrete strength. Now, before designing the end zone reinforcement, we are calculating the bearing stress that will come in the end zone. For that, we need to have a trail bearing plate and for this problem, we are selecting a bearing plate which is geometrically similar to the end zone section, its width is 200 millimeters which is half of the width of the end zone. The height of the bearing plate is 300 millimeters which is again half of the height of the end zone. We shall place the bearing plate concentrically with the end zone. The bearing stress is calculated by the following equation: f_{br} is equal to P_k, which is the prestressing force coming in the tendon divided by the $A_{punching}$, which is the area of the bearing plate. The value of P_k is given as 1055 Kilonewtons, which is 1055 times 10 to the power 3 Newton divided by $A_{punching}$ is equal to 200 times 300 millimeter square. Thus, we get a uniform bearing stress of 17.5 Newton per millimeter square in the local zone of the end zone of the post-tensioned member.

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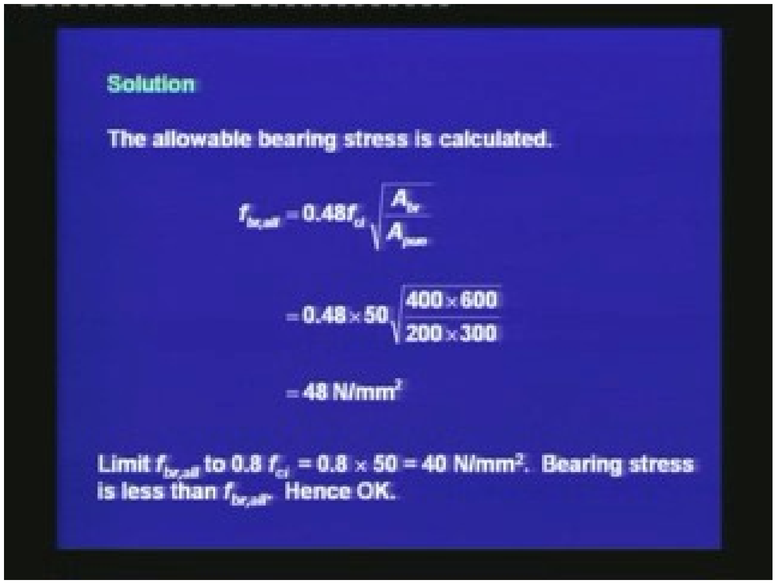

The allowable bearing stress as per the code is 0.48 f_{ci} times root over A_{br} divided by $A_{punching}$. f_{ci} is given as 50 Newton per millimeter square and A_{br} is a geometrically similar area in the end zone which can be placed. Since we have selected a bearing plate, which is geometrically similar to the cross-section of the end zone, we are able to utilize the full cross-section of the end zone as A_{br}. Thus, A_{br} is equal to 400 times 600 and $A_{punching}$ as before it is 200 times 300. We get the allowable bearing stress as 48 Newton per millimeter square. But we have to check the other limit of the allowable bearing stress. The allowable bearing stress should be limited to 80% of f_{ci}, which is 0.8 times 50 which is equal to 40 Newton per millimeter square. The bearing stress which we calculated earlier is less than f_{br} allowable and hence it is okay. Thus, what we have found, the allowable bearing stress is governed by the second provision that it can be maximum of 80% of the cube strength during transfer. Based on that, we found out that the allowable bearing stress is 40 Newton per millimeter square. Earlier, we had found out the bearing stress to be 17 Newton per millimeter square, which is less than the allowable value. Hence, the bearing plate is of adequate dimension which will help to have a stress which is within the allowable bearing stress of the concrete.

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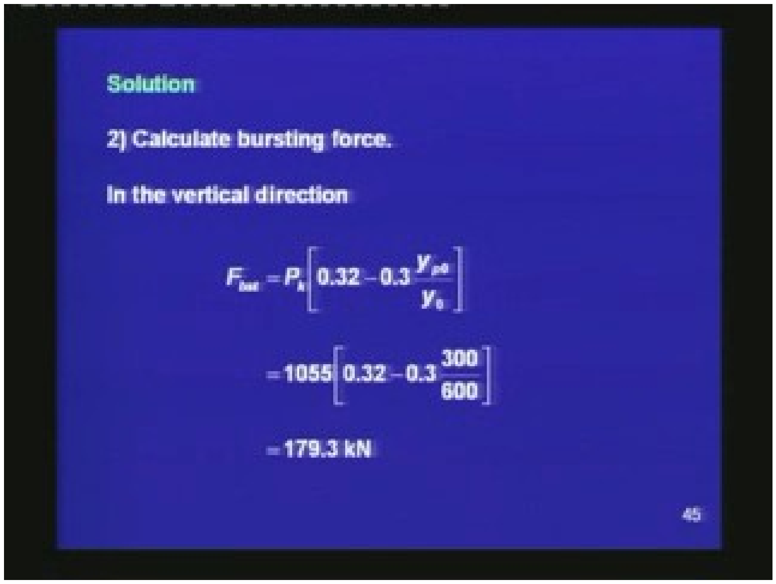

Second, we are calculating the bursting force. Since it is a rectangular section, we are calculating the bursting force in two directions: one in the vertical direction and one in the horizontal direction. For the vertical direction, F_{bst} is equal to P_k times 0.32 minus 0.3 times y_{p0} divided by y_0 and the values of y_{p0} and y_0 are the directions that are under consideration. P_k is equal to 1055 Kilonewtons, y_{p0} in the vertical direction is 300 millimeters, which means the dimension of the bearing plate in the vertical direction is 300 millimeters, y_0 is the dimension of the end zone for the vertical direction which we have as 600 millimeters.

Once, we substitute the values of y_{p0} and y_0 in this expression, we get F_{bst} is equal to 179.3 Kilonewtons. Thus, there is a bursting force of 179 Kilonewtons acting at the level of CGC in the vertical direction.

Next, we are calculating the bursting force in the horizontal direction: For that, P_k remains the same, whereas y_{p0} is now 200 because the horizontal dimension or the width of the bearing plate is 200 millimeter and Y_0 which is the width of the end zone is 400 millimeters. Since, we have cleared the end zone, we are having a uniform width of the end zone as 400 millimeters. Once, we substitute the value of y_{p0} and y_0 we get the same value of F_{bst} 179.3 Kilonewtons. The values of the bursting force in the horizontal and the vertical directions have come out to be same because we had selected a geometrically similar bearing plate with respect to the cross-section of the end zone. The cross-section of the end zone was 400 by 600 and our selected bearing plate was 200 by 300. Since, the ratio of the dimension of the bearing plate and the end zone was same for both the horizontal and vertical directions. We have got the same value of the bursting force for the two directions. Thus, design bursting force is 179.3 Kilonewtons.

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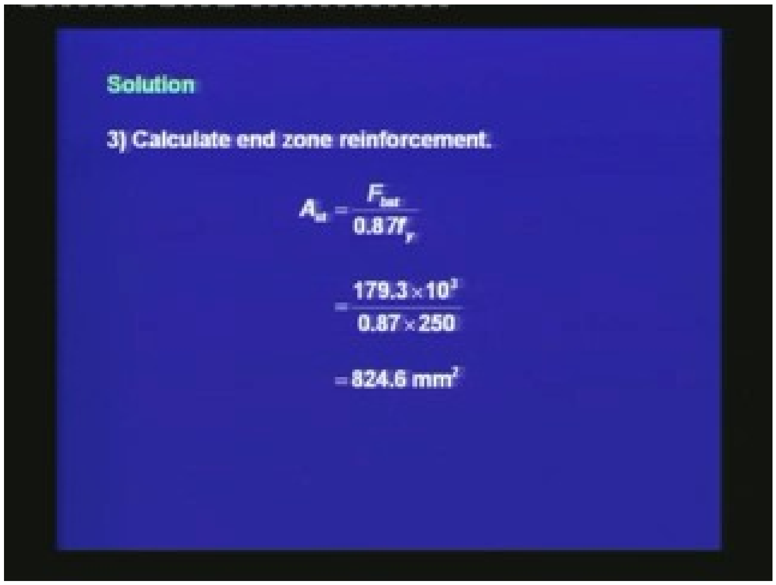

Next, we are calculating the end zone reinforcement: A_{st} is equal to F_{bst} divided by 0.87 f_y. Since, we have adequate cover around the tendon, we are selecting the maximum allowable stress which is 0.87 f_y so as to reduce our end zone reinforcement. We find that A_{st} is equal to 179.3 times 10 to the power 3 Newton divided by 0.87 times 250, which is the selected grade of end zone reinforcement and we find A_{st} is equal to 824.6 millimeter square. Thus, we have to provide confining reinforcement in the end zone which has an area of 824.6 millimeter square.

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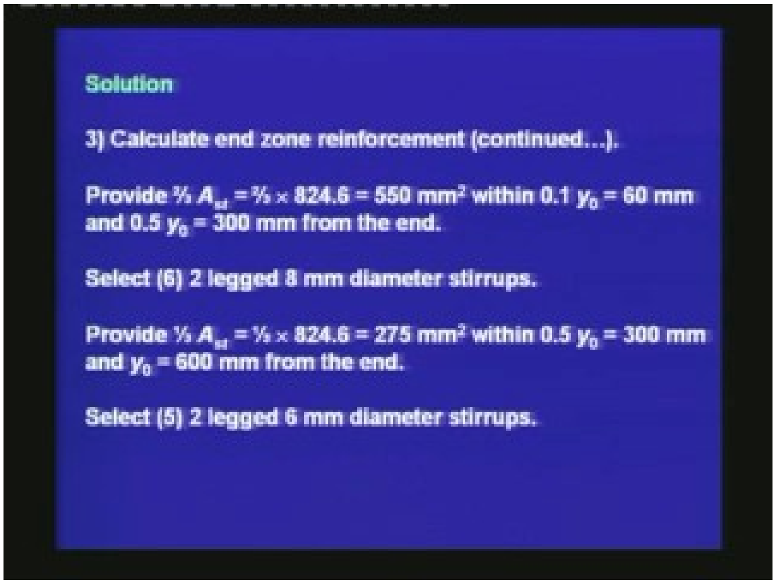

In order to design the end zone reinforcement, we are providing two third of A_{st} in the first half of the end zone. Thus, two third of A_{st} is equal to two third times 824.6 which is 550 millimeter square. This much of reinforcement we are placing within $0.1y_0$ which is equal to 60, here y_0 is the larger dimension of the end zone and 0.5 y_0 which is 300 millimeters from the end. Thus, within the distance of 60 millimeters and 300 millimeters from the end, we are providing two third of A_{st} which is 550 millimeter square. Select 6 number of 2 legged 8 millimeter diameter stirrups. Provide the rest one third of A_{st}, which is one third of 824.6, gives us 275 millimeter square within a distance $0.5y_0$ which is 300 millimeters and y_0 which is equal to 600 millimeters from the end. Thus, we are providing the rest one third of the end zone reinforcement in the second half of the end zone, which is a distance from 300 millimeters to 600 millimeters from the end of the post-tensioned member. Select 5 number of 2 legged 6 millimeters diameter stirrups. We observe that in the first half of the end zone which is closer to the bearing plate, we are selecting a larger diameter bar size and more number of bars, the spacing will also be closed, whereas for the second half of the end zone the bars size is smaller, the number is smaller and hence the spacing will also be larger for the second half.

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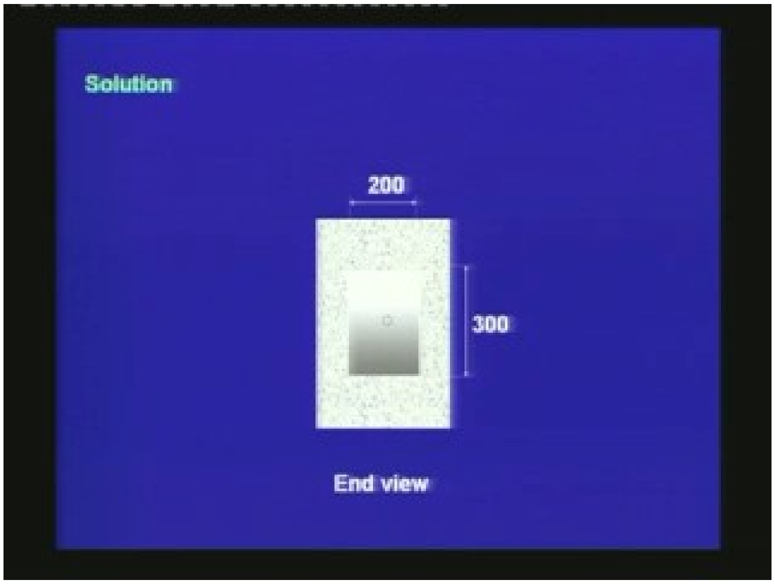

This is the design section for the bearing plate. The dimension of the bearing plate is 200 by 300 and it is placed concentrically with the end zone.

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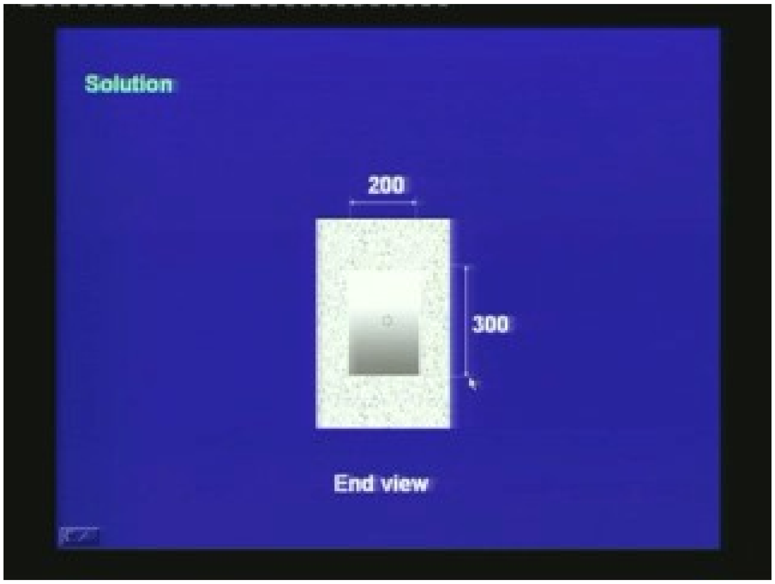

The end zone reinforcement is provided by closed stirrups. For a region from 60 to 300, from the end of the specimen we are providing (6) 8 millimeter diameter stirrups and these are closely spaced whereas, beyond 300 millimeters we are providing (5) 6 millimeter diameter stirrups that is up to a distance of 600 millimeters from the end. This end zone reinforcement is in addition to other shear reinforcement that we needed in the end zone region.

Since the end zone is substantially wide, the shear reinforcement recommend will be small as compared to the part with the reduced thickness of the web.

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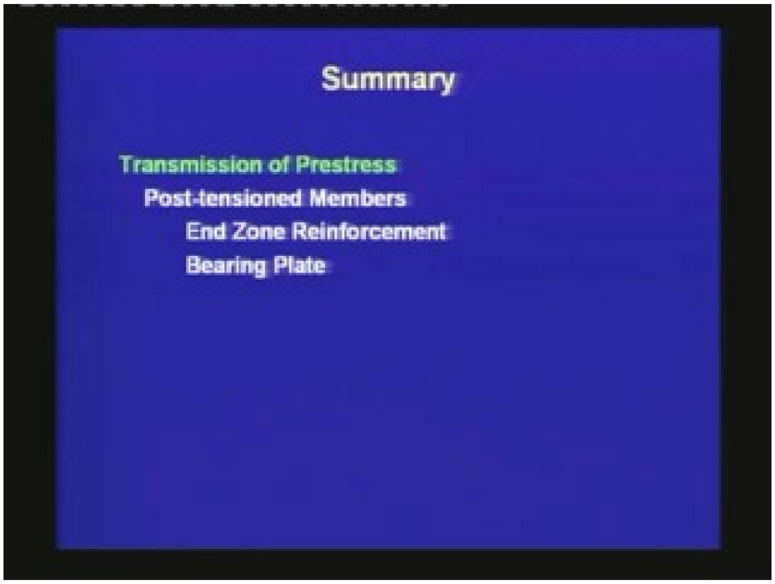

Thus in today's lecture, we talked about the transmission of prestress for a post-tensioned member. Unlike a pre-tensioned member, in a post-tensioned member the stress in the tendon develops right at the anchorage block and the prestress is transferred to the concrete by the bearing plate. In doing so, there is a huge amount of stress concentration at the end zone of the post-tensioned members which needs to be properly addressed to check the splitting of concrete at the horizontal plane and the spalling of concrete in the vertical surface which is outside the bearing plate region. We discussed about the bursting force and the design of end reinforcement to check the cracking due to bursting force. Then, we discussed about the bearing stress and how to design a bearing plate with adequate area such that the bearing stress is less than the allowable bearing stress for the concrete. In order to reduce the effect of bursting force, you should have a large bearing plate and we should transfer the prestress when the concrete has attained substantial strength.

With this we are ending the module of transmission of prestress. Thank you.