

# PRESTRESSED CONCRETE STRUCTURES

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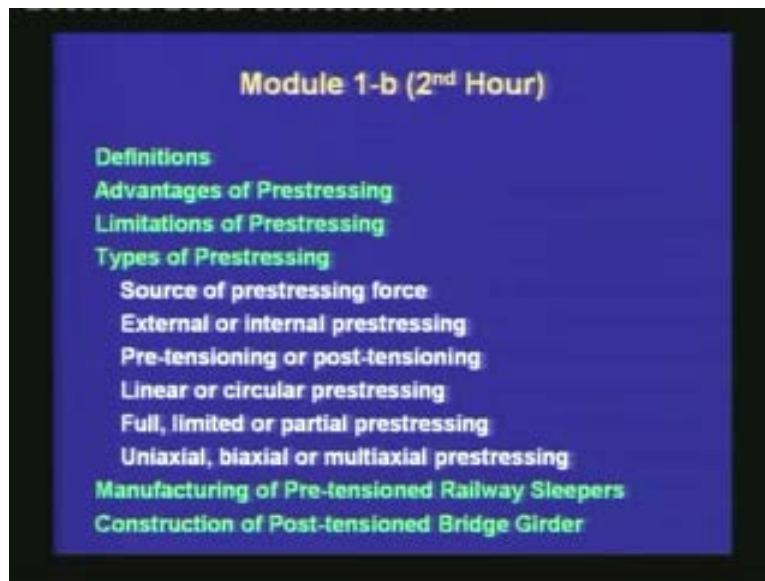
**Indian Institute of Technology Madras**

## **Module – 1: Introduction, Prestressing Systems and Material Properties**

### **Lecture – 2: Advantages, Limitations and Type of Prestressing**

Welcome back to Prestressed Concrete Structures. This is the second lecture of the first module on Introduction, Prestressing Systems and Material Properties.

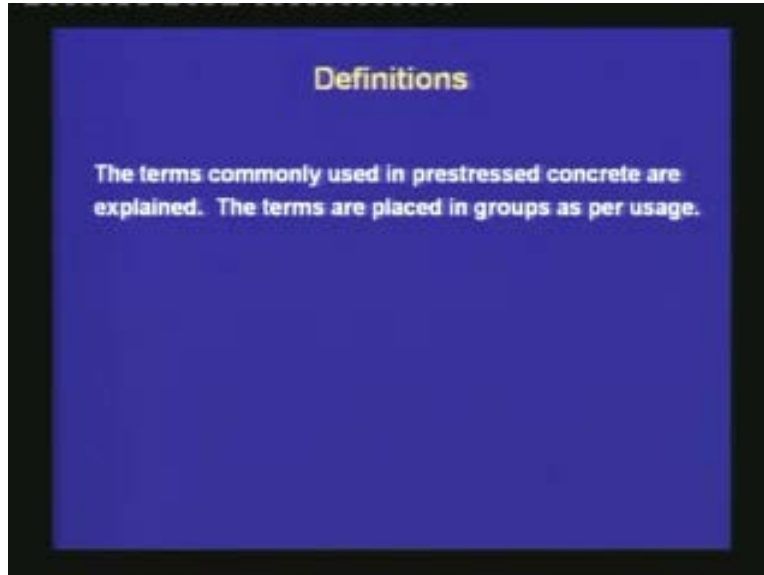
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In this lecture, first we shall learn some definitions of terms which are used in prestressed concrete. Next, we shall learn about the advantages of prestressing; after that we shall move on to the limitations of the prestressing. Under the types of prestressing there can be various classifications: first, we shall study about the sources of prestressing force; next, we shall study about the external or internal prestressing; the next classification will be pre-tensioning or post-tensioning; then, linear or circular prestressing; full, limited or partial prestressing; finally, we shall see uniaxial, biaxial or multiaxial prestressing. After that, we shall see some photographs of manufacturing of prestressed concrete products.

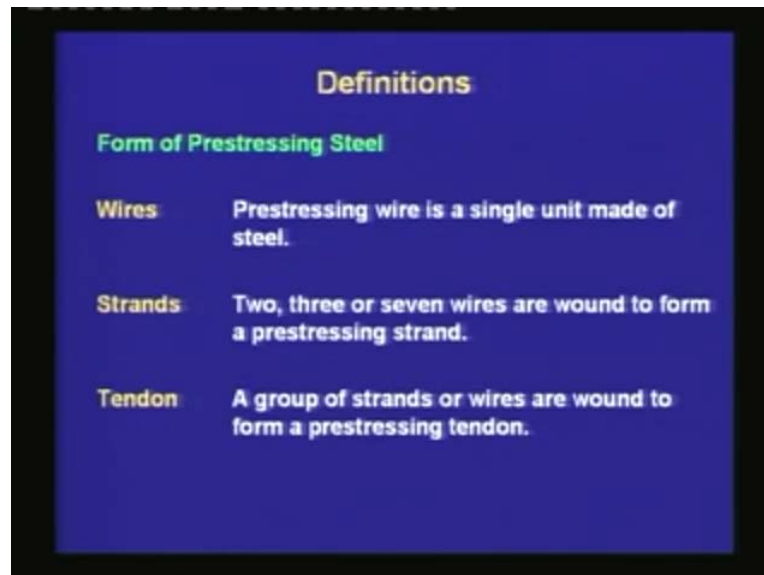
First, we shall see about railway sleepers and then we shall see the construction of bridge girders.

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The terms commonly used in prestressed concrete are explained. These terms are placed in groups as per the usage.

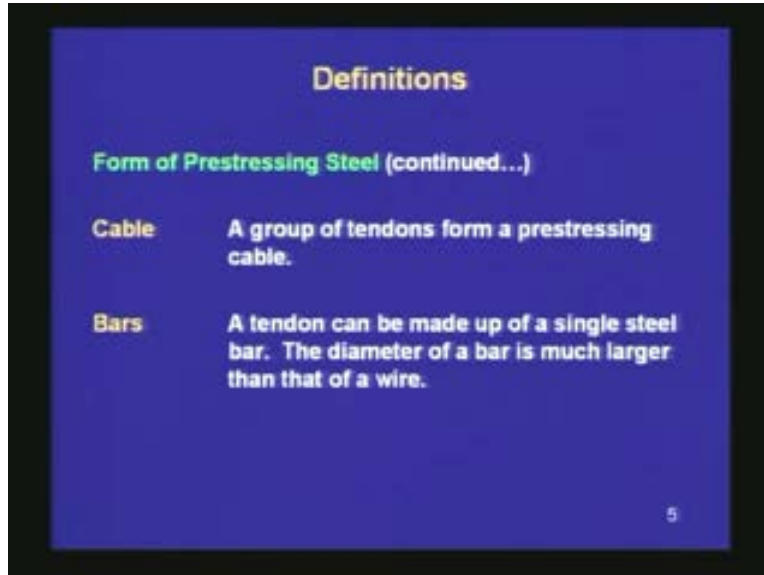
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We are discussing about the forms of prestressing steel. *Wires* are a single unit which is made up of steel. *Strands* are two, three or seven wires, which are wound to form a

prestressing strand. A *tendon* is a group of strands or wires which are wound to form a single prestressing tendon.

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Similarly, we can have a *bar* which is a single unit. A *cable* is a group of tendons forming a prestressing cable. Note that the diameter of a bar is much larger than the diameter of a wire.

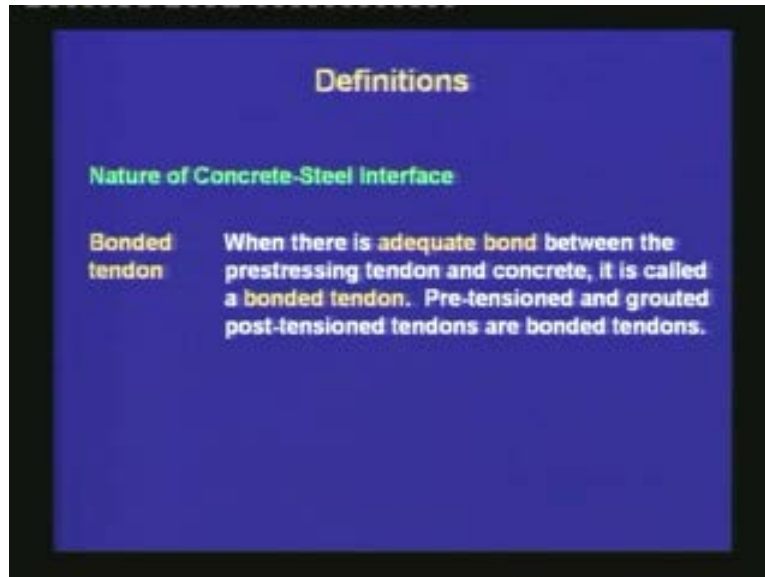
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In this sketch, you can see the various forms of prestressing steel. On the top left is a seven-wire strand, and you can see that six wires have been wound around a central wire.

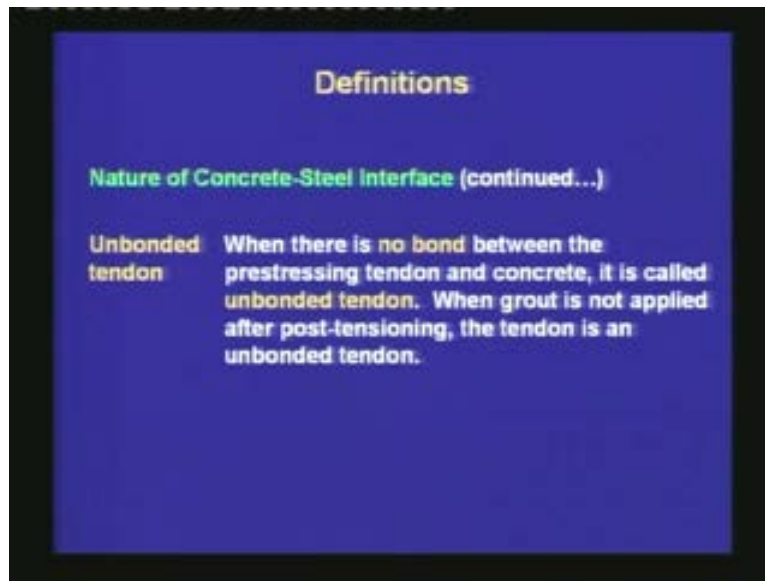
On the top right, we can see how the tendons are attached by the anchoring system. We have the anchor block, the guide, and these jaws or the wedges which hold on to the tendons at the end. On the bottom left, we can see a single bar; note that the diameter is much larger than the wire. On the right hand side, we can see the anchoring of individual wires by the button heads.

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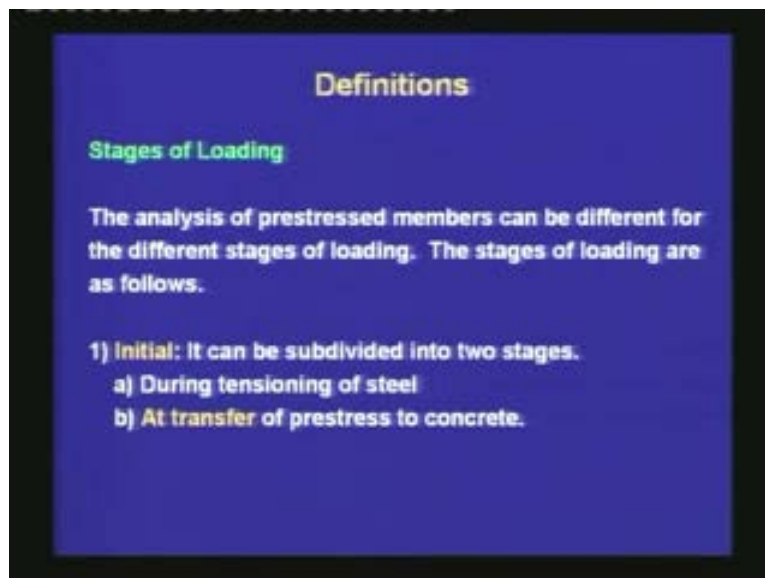
Next, we are studying about the nature of concrete to steel interface. When there is adequate bond between the prestressing tendon and concrete, it is called a *bonded* tendon. Pre-tensioned and grouted post-tensioned are bonded tendons. That means, if there is concrete all around the tendons then it is called a bonded tendon. For a pre-tensioned member, the tendon is always bonded; but for a post-tensioned member, if it is fully grouted then it is a bonded tendon.

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When there is no bond between the prestressing tendon and concrete, it is called *unbonded* tendon. For a post-tensioned member, if grout is not passed through the duct then the tendon remains an unbonded tendon; that means the concrete does not come in direct contact with the tendon.

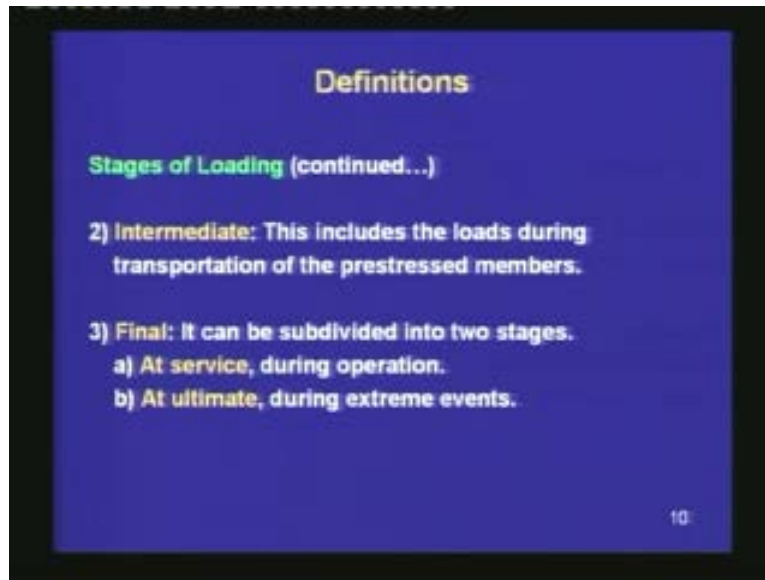
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Next, we are studying about the stages of loading. The analysis of prestressed members can be different for the different stages of loading. The stages of loading are as follows: first is *initial*; it can be subdivided into two sub-stages: (a) *during tensioning* of steel, and

(b) *at transfer* of prestress to concrete. The purpose of studying the stages of loading is to understand the transfer of forces to the steel and to the concrete. In the initial stage, first, the stress is transferred to the steel and then from the steel, the stress is transferred to the concrete.

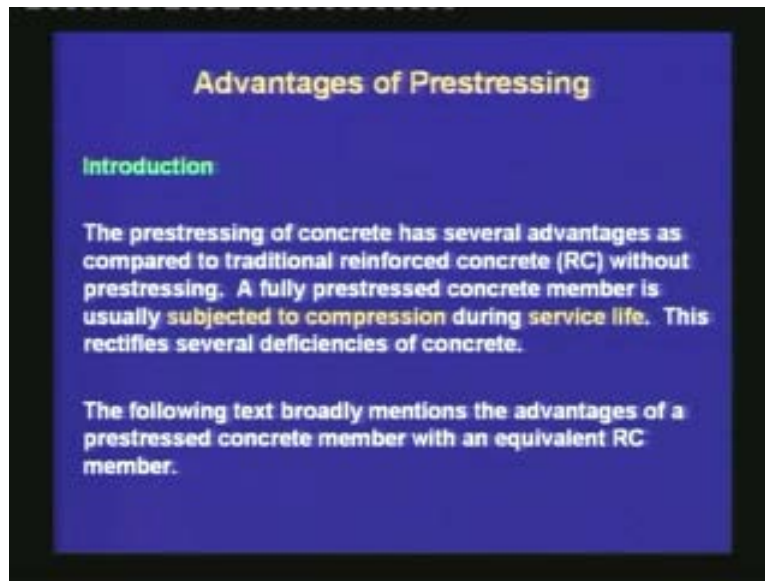
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The next stage is an *intermediate* stage; this includes the loads during transportation of the prestressed members. If the prestressed members are precast somewhere else and they are transferred to the site, then there will be some stresses during this transportation and the members have to be analyzed for the stresses during this transportation. Finally, we have the *final* stage. This also can be subdivided into two: (a) *at service*, when the member is under operation, and (b) *at ultimate* stage refers to an extreme event where the member can reach its final strength.

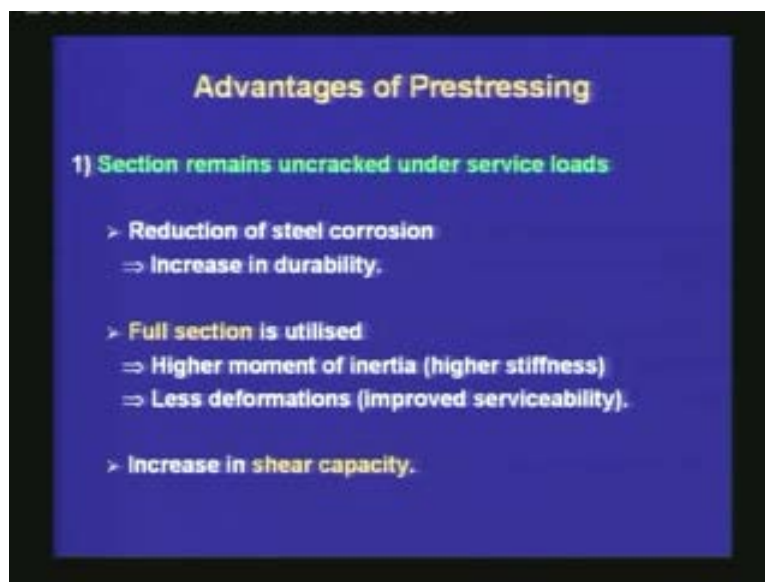
Next, we are studying the advantages of prestressing.

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The prestressing of concrete has several advantages as compared to traditional reinforced concrete without prestressing. A fully prestressed concrete member is usually subjected to compression during service life. This rectifies several deficiencies of concrete. The following text broadly mentions the advantages of a prestressed concrete member with respect to an equivalent reinforced concrete member.

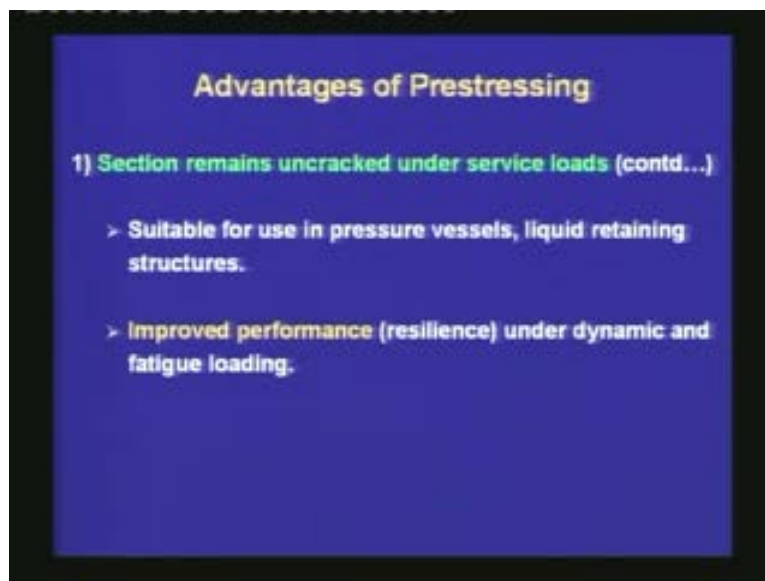
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A main deficiency of reinforced concrete members is the cracking of concrete. But the prestressing overcomes the cracking. For a fully prestressed member, the concrete

remains uncracked under the service conditions, and this leads to several advantages of prestressed concrete. If the concrete is uncracked, the primary advantage that we get is the reduction of deterioration and corrosion. The reduction of steel corrosion leads to increased durability of precast and prestressed member. The next advantage is that the full section is utilized. That means, the section will have a higher moment of inertia, which will give higher stiffness. This will lead to less deformation, which in turn will have improved serviceability. Since the section is uncracked, there is also an increase in the shear capacity.

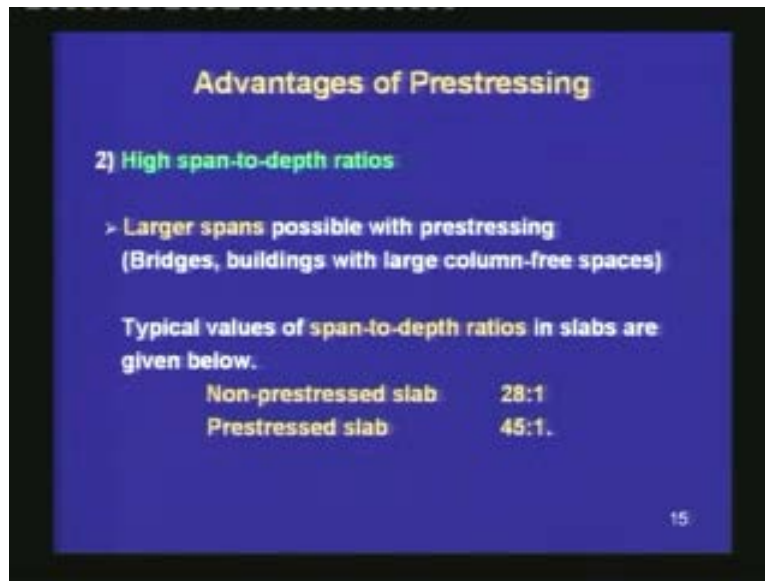
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An uncracked member is suitable to be used in pressure vessels and in liquid storage tanks. Because in these types of structures, we do not want cracks through which the liquid can seep out or, which can create a hazard. Hence, prestressing is applied in these types of structures. And also, we can see that there is an improved performance due to resilience under dynamic and fatigue loading. Big structures can undergo several cycles of loading which can induce fatigue in a member; but when the member is prestressed, then its behaviour gets better.

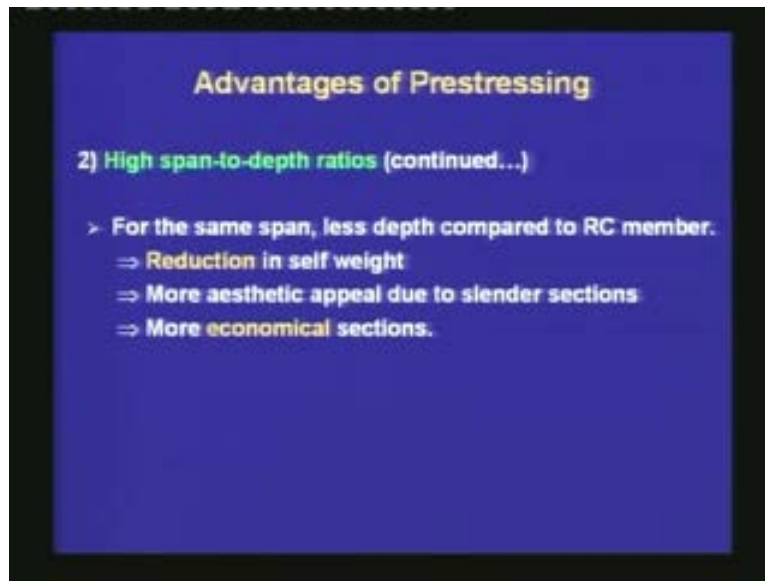


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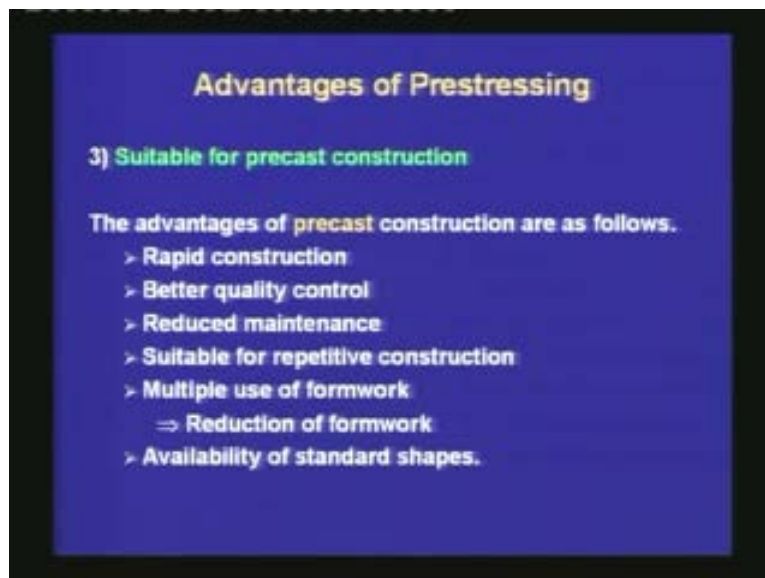
Next, we are studying the high span-to-depth ratios for prestressed concrete members. Since the span-to-depth ratio can be high, prestressing is applied for large spans like bridges, buildings with large column free spaces as we can see in godown structures. Typical values of span-to-depth ratios in slabs are as follows: for a non-prestressed slab, the span-to-depth ratio can be 28:1; for a prestressed slab, the ratio can increase to 45:1. That means, as we are prestressing the slab, the clear span can be much larger compared to an equivalent reinforced concrete (RC) slab, and this helps in the future use of the building.

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For the same span, the depth of a prestressed member is less than the corresponding RC member. It leads to reduction in self weight, more aesthetic appeal due to slender sections, and finally it gives a more economical section because the amount of concrete used is much less.

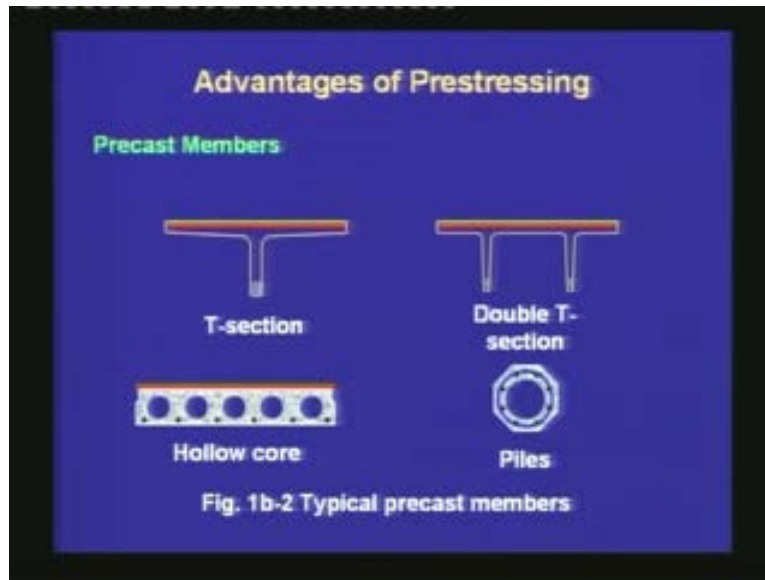
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The next advantage of prestressing is that, it is very much suitable for precast construction. The advantages of precast construction are as follows: it is a rapid construction; there is better quality control, reduced maintenance; it is suitable for

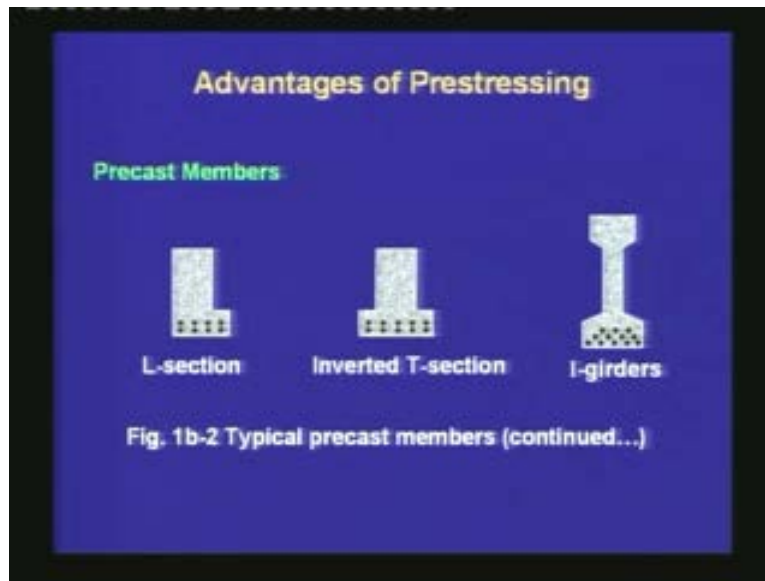
repetitive construction; multiple use of formwork, which leads to reduction of formwork, and availability of standard shapes. Thus, prestressing goes very much hand-in-hand with precast construction. The advantages of precast construction can be fully utilized, and this leads to a much better and faster construction.

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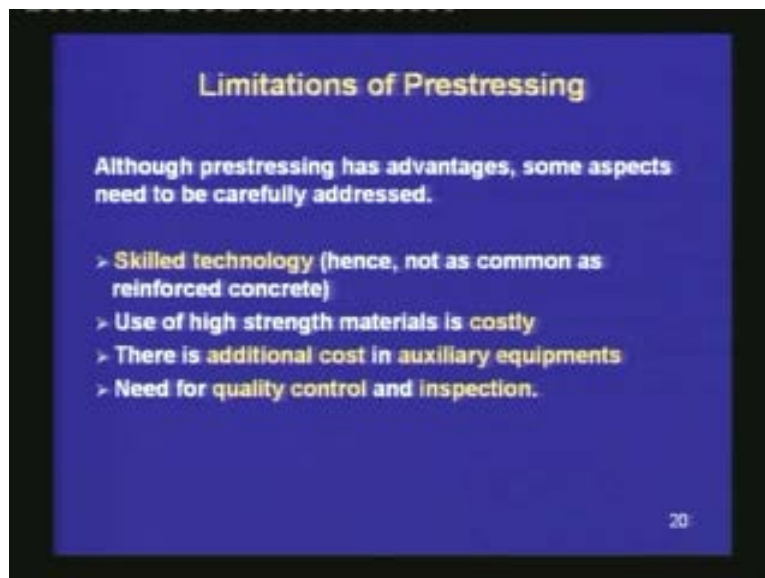
Here, we can see some typical examples of precast members. In the top left, we see a T-section which can be used in buildings; second, we can see a double T-section which can be used in buildings or bridges. In the bottom left, we see a hollow core section which can be used in bridges or industrial buildings; and on the bottom right, we see a typical pile which can be used for the foundation of buildings or bridges.

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These are some other examples of precast members, like an L-section, which can be used to support other members; an inverted T-section, where the flanges are used to support other members; and on the right most side, we see the I-girders which are very typical in bridge construction.

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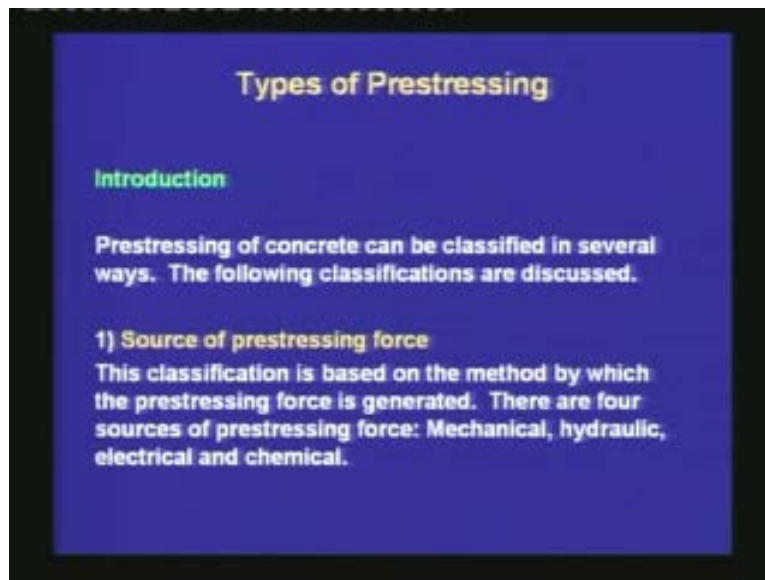


We are moving on to the limitations of prestressing. Although prestressing has advantages, some aspects need to be carefully addressed. First, it needs skilled technology. Hence, it is not as common as reinforced concrete. Next, use of high strength

materials is costly. Then, there is an additional cost in auxiliary equipment. Finally, there is need for better quality control and inspection. Although we have many advantages of prestressing, we have to be cautious because the additional advantages bring in responsibilities. We need to have good technology to implement the prestressing. There should be good quality control, so that the advantages that we are expecting will be materialized. Hence, care should be taken in manufacturing prestressed concrete products.

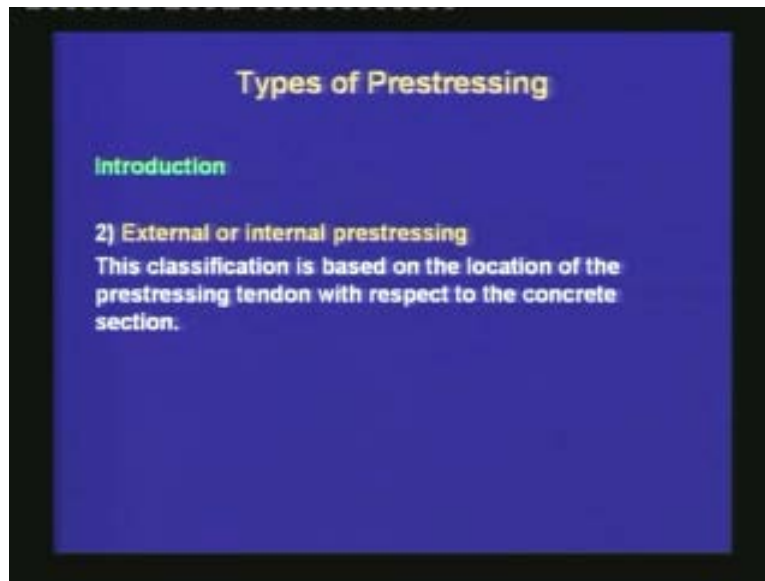
Next, we are moving on to the different types of prestressing.

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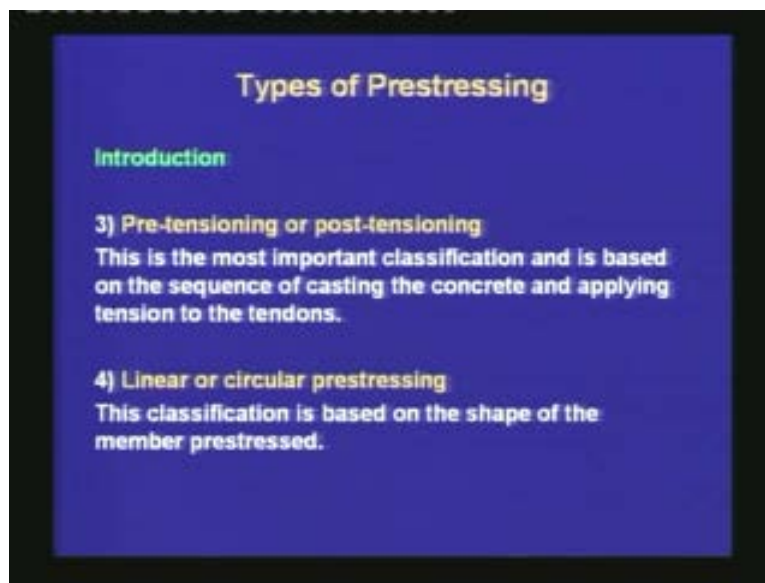
Pre-stressing of concrete can be classified in several ways. The following classifications are discussed. The first classification is based on the source of prestressing force. This classification is based on the method by which the prestressing force is generated. There are four sources of prestressing force: mechanical, hydraulic, electrical and chemical.

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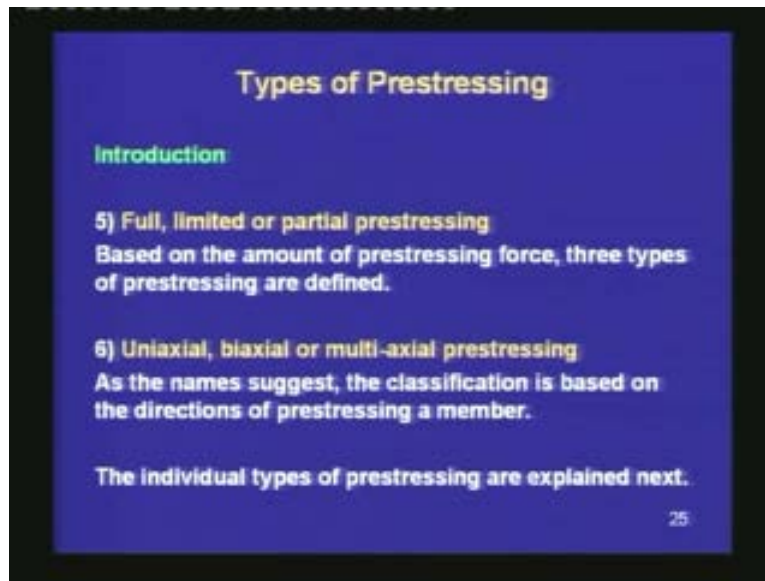
The next classification is external or internal prestressing. This classification is based on the location of the prestressing tendon with respect to the concrete section.

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The third classification is the pre-tensioning or post-tensioning. This is the most important classification and is based on the sequence of casting the concrete and applying tension to the tendons. The fourth classification is linear or circular prestressing; this classification is based on the shape of the member prestressed.

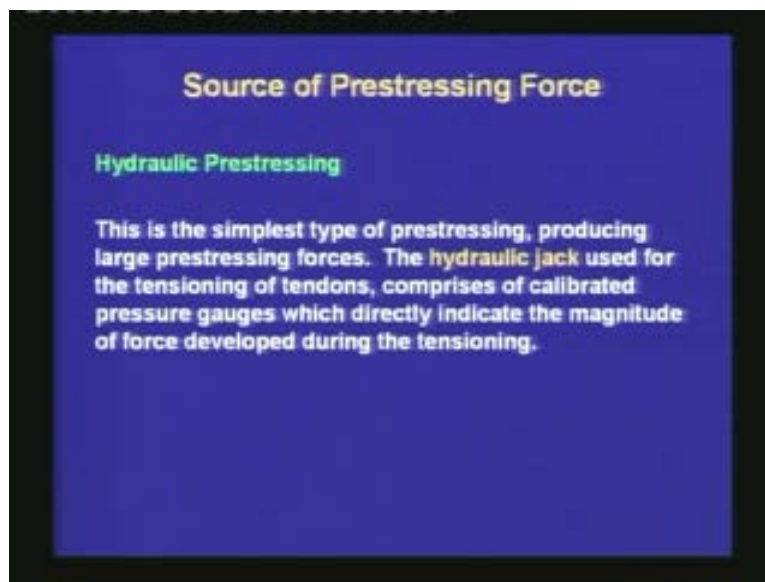
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The fifth classification is full, limited or partial prestressing. Based on the amount of prestressing force, the three types of prestressing are defined. Finally, the sixth classification is uniaxial, biaxial or multi-axial prestressing. As the names suggest, the classification is based on the directions of the prestressing member.

The individual types of prestressing are explained next.

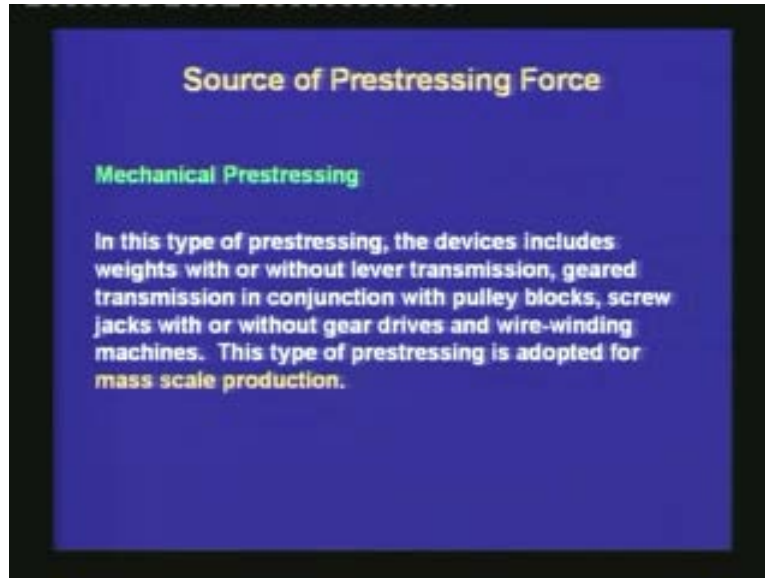
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Hydraulic prestressing: This is the simplest type of prestressing producing large prestressing forces. The hydraulic jack used for the tensioning of tendons comprises of

calibrated pressure gauges, which directly indicate the magnitude of force developed during the tensioning. This is the most common form of applying the prestress to the steel, which is then transferred to the concrete. Hydraulic jacks which operate based on oil pressure, are used to apply the prestress.

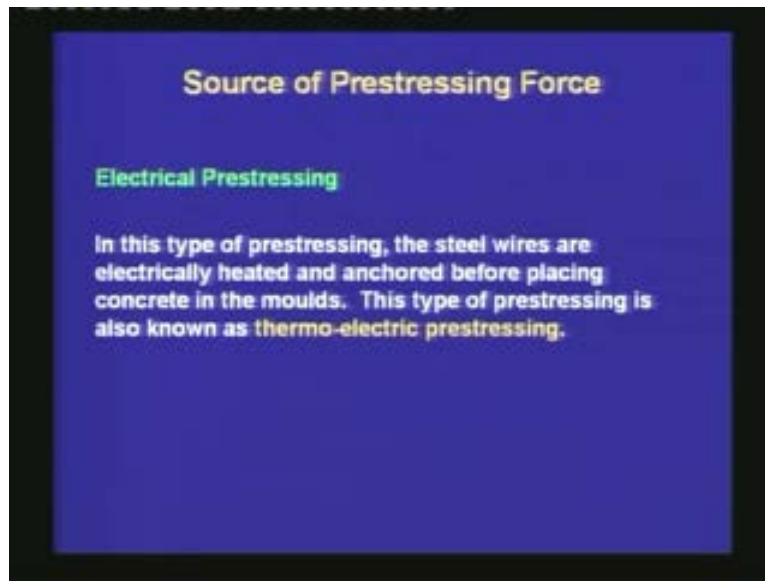
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Next is the mechanical prestressing. In this type of prestressing, the devices include weights with or without lever transmission, geared transmission in conjunction with pulley blocks, screw jacks with or without gear drives, and wire-winding machines. This type of prestressing is adopted for mass scale production. Thus, the mechanical prestressing is based on equipments with mechanical components, and these equipments are more popular when mass scale production of prestressed members is adopted.

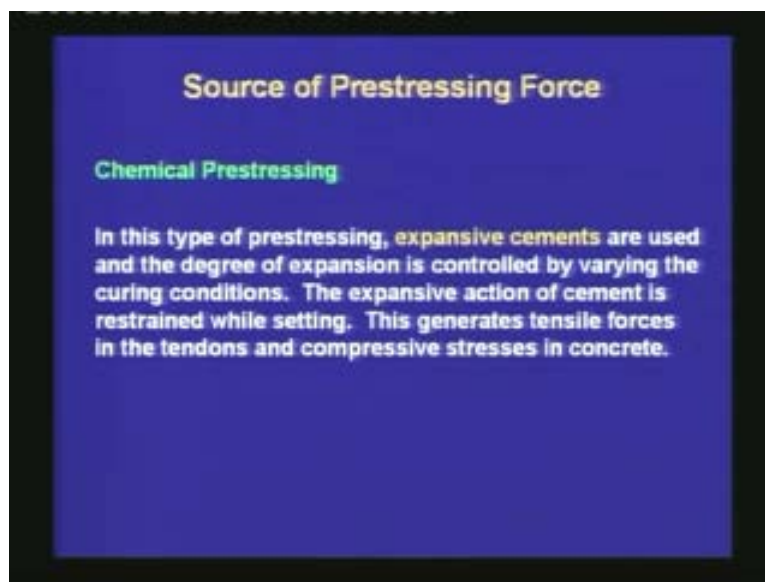


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The third type is the electrical prestressing. In this type of prestressing, the steel wires are electrically heated and anchored, before placing concrete in the moulds. This type of prestressing is also known as thermo-electric prestressing. That means, when the wires are heated they expand, and then they are allowed to cool down, which transfers the prestress to the concrete.

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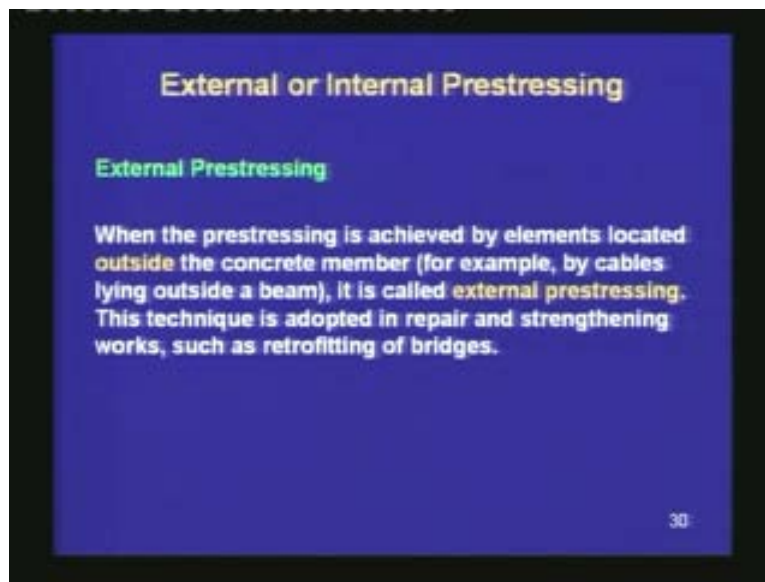


The fourth form is the chemical prestressing. In this type of prestressing, expansive cements are used, and the degree of expansion is controlled by varying the curing

conditions. The expansive action of cement is restrained while setting. This generates tensile forces in the tendons and compressive stresses in concrete. This chemical prestressing is relatively rare, but it can be used in order to transfer prestress to the concrete.

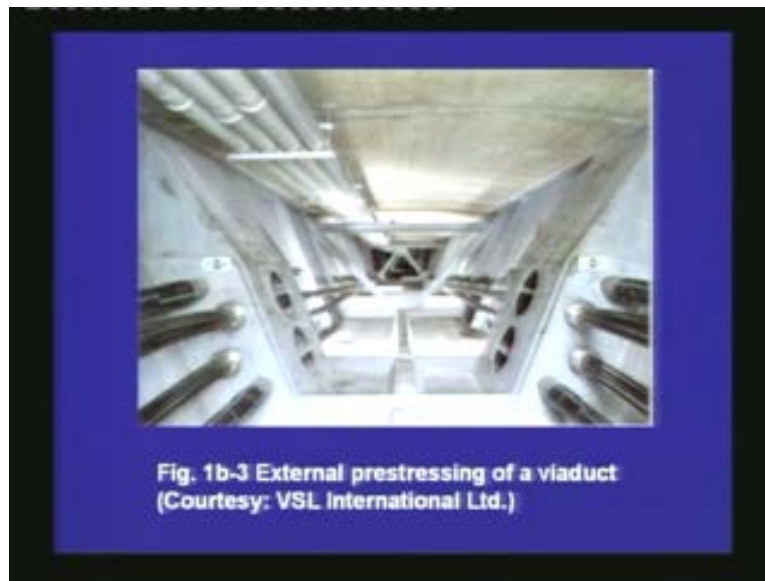
We are moving on to the second group of classifications.

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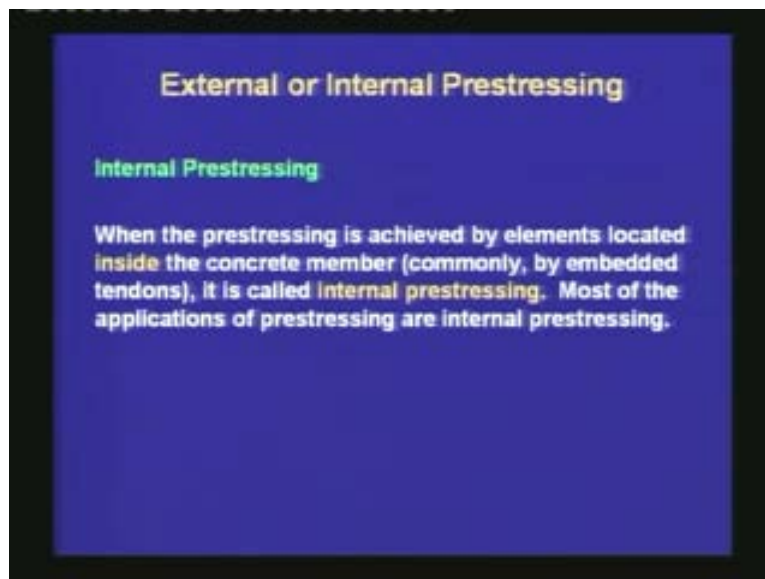
When the prestressing is achieved by elements located outside the concrete member, for example, by cables lying outside a beam, it is called external prestressing. This technique is adopted in repair and strengthening works, such as retrofitting of bridges.

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This photograph shows that the tendons are lined inside the box girder of a bridge. Here, we can note that on the left and on the right side, the prestressing tendons have been anchored to the haunches in the box girder.

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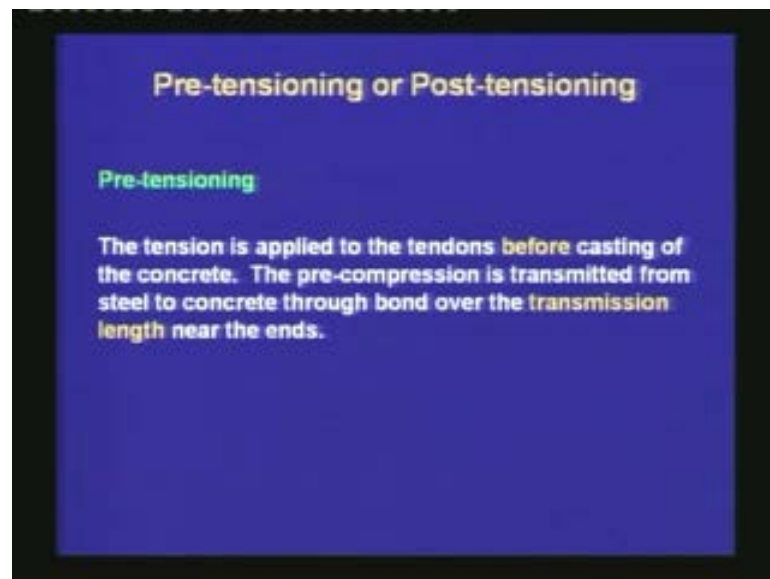
When the prestressing is achieved by elements located inside the concrete member commonly by embedded tendons, it is called internal prestressing. Most of the applications of prestressing are internal prestressing.

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In this photograph, we can see that the tendons are located inside the member. Once the concrete is cast, these ducts and the tendons will be concealed by the concrete and it cannot be seen from the outside. Thus, internal prestressing is different from external prestressing based on the location of the tendon with respect to the concrete.

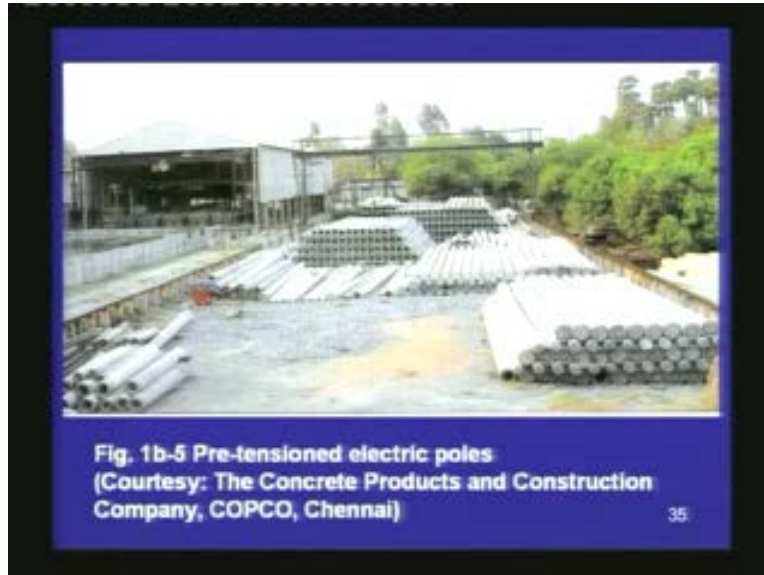
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The next classification is the most important. When the tension is applied to the tendons before casting the concrete, it is called pre-tensioning. The pre-compression is

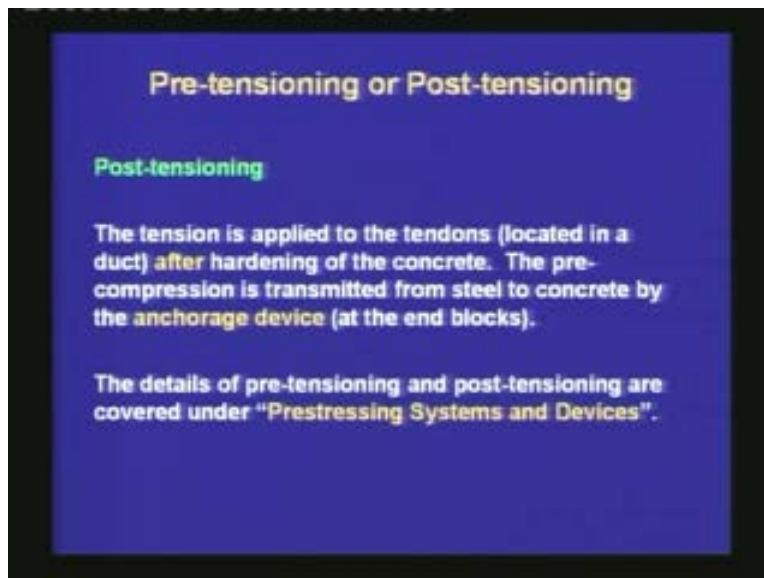
transmitted from steel to concrete through bond over the transmission length near the ends.

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Here, we can see electric poles which have been pre-tensioned. The steel wires had been tensioned before the concrete was placed. After the concrete had hardened, the steel wires were cut and at that time, the prestress was transferred from the steel to the concrete. The other type of prestressing is the post-tensioning.

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The tension is applied to the tendons after hardening of the concrete. The pre-compression is transmitted from steel to concrete by the anchorage device at the end blocks. The essential difference of post-tensioning with respect to pre-tensioning is that, the tension is applied to the steel after the concrete is hardened. Once the steel is tensioned, the wedges are placed. The jack is then released, and the steel sets on the concrete member through the anchorage blocks, which thus transfers the prestress to the concrete. The details of pre-tensioning and post-tensioning will be covered under the lectures on Prestressing Systems and Devices.

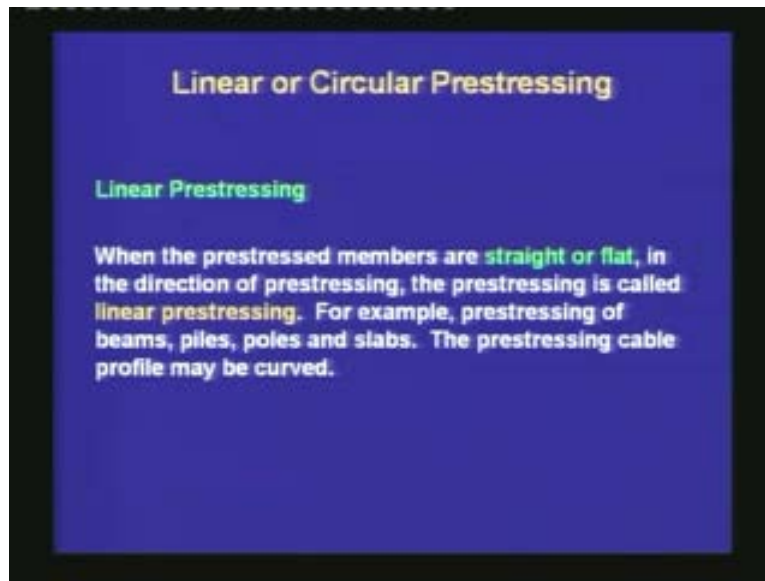
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This photograph shows a post-tensioned box girder bridge. Here we can see that some of the tendons have been stretched. It has been fixed by the anchor blocks, and thus some prestress has been applied to the sections.



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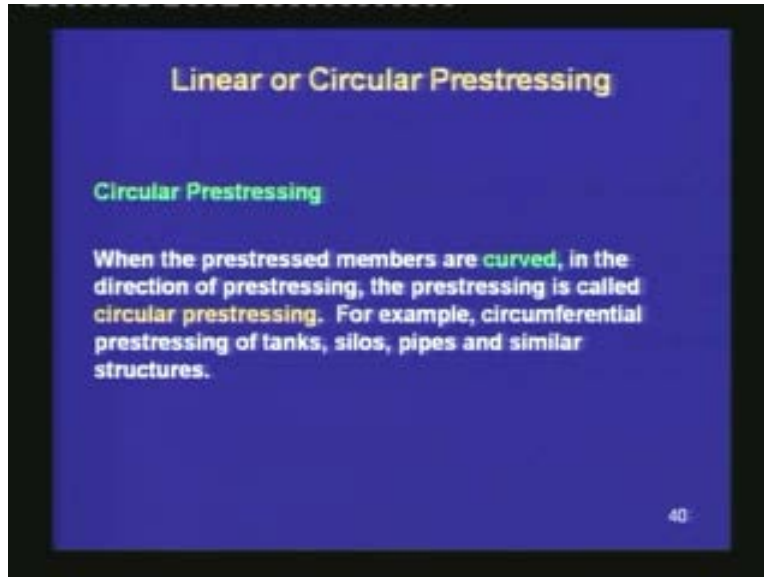
The next classification is based on the direction. When the prestressed members are straight or flat in the direction of prestressing, the prestressing is called linear prestressing. For example, the prestressing of beams, piles, poles and slabs. The prestressing cable profile may be curved. That is, if the prestressing tendons are along the line of the member then it is called linear prestressing.

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In this photograph, we can see that railway sleepers are stacked. These are examples of linear prestressing because the prestressing tendons are in line with the longitudinal axis of the sleepers.

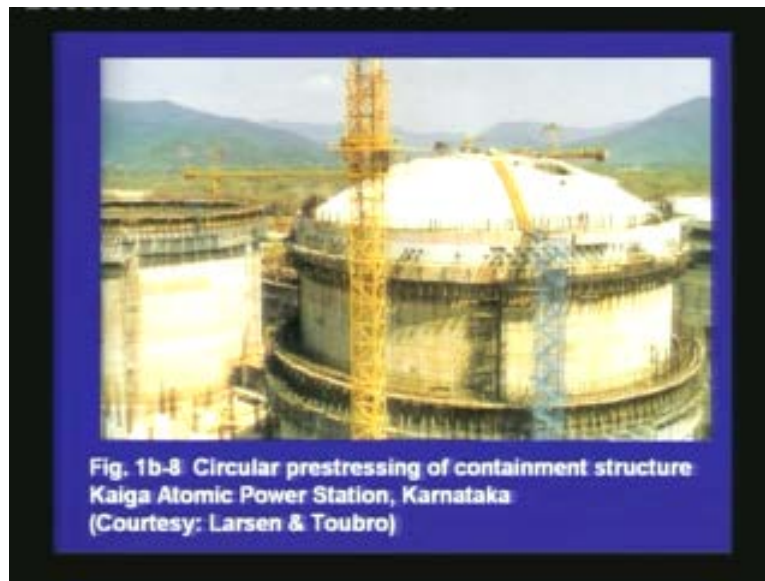
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The next type is the circular prestressing. When the prestressed members are curved, the direction of prestressing also changes and this prestressing is called the circular prestressing. For example, circumferential prestressing of tanks, silos, pipes and similar structures.

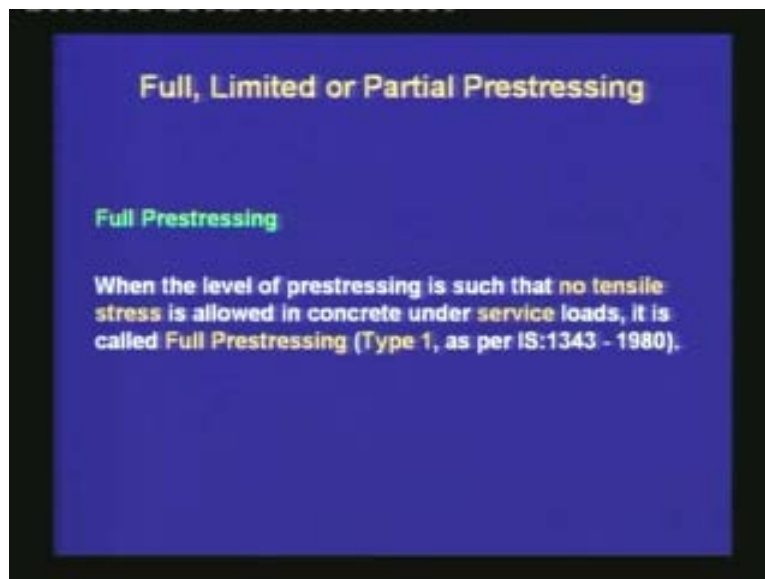


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This photograph is of a containment structure. Here, the prestressing wires were wound around this containment structure and hence, this is called circular prestressing. It is different from the more conventional linear prestressing.

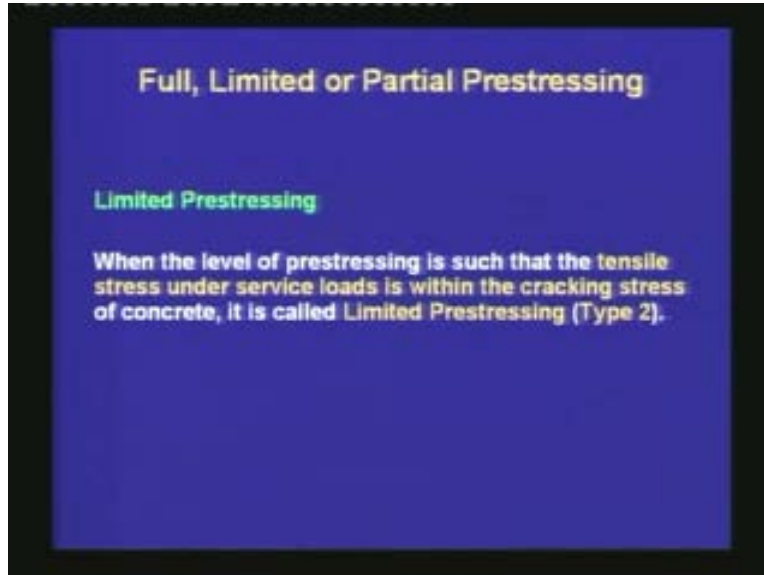
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The next classification is related with the amount of prestressing. When the level of prestressing is such that no tensile stress is allowed in the concrete under service loads, it is called full prestressing. It is referred to as Type 1 in the code IS: 1343 - 1980. Thus, in

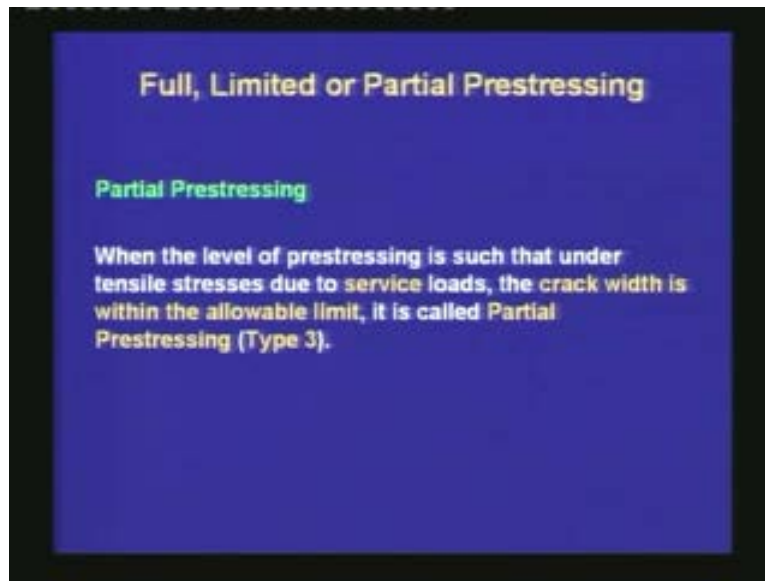
a fully prestressed member, there cannot be any tension in the concrete during the service life.

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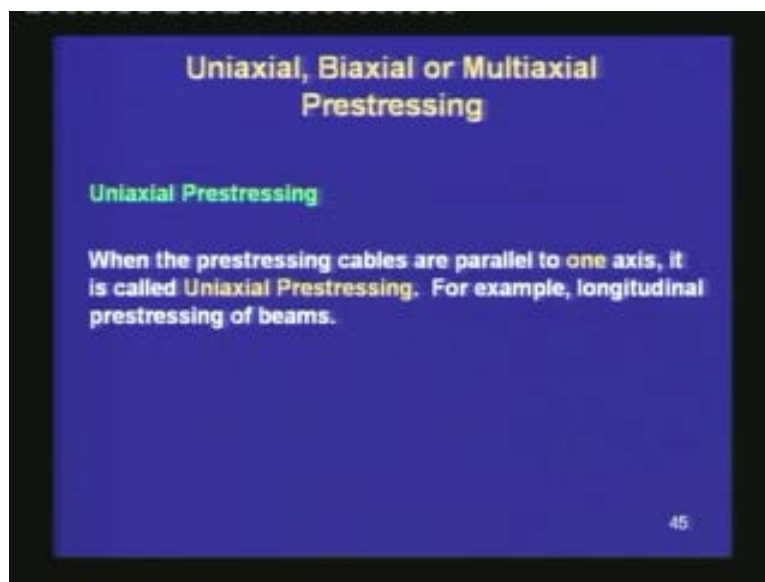
When the level of prestressing is such that the tensile stress under service loads is within the cracking stress of concrete, it is called limited prestressing and it is designated as Type 2. Thus in a limited prestressed member, tension is allowed in concrete but it is made sure that it is lower than the tensile strength of the concrete. Hence, cracking will not develop within the concrete. These types of members are referred to as Type 2 members in the code IS: 1343.

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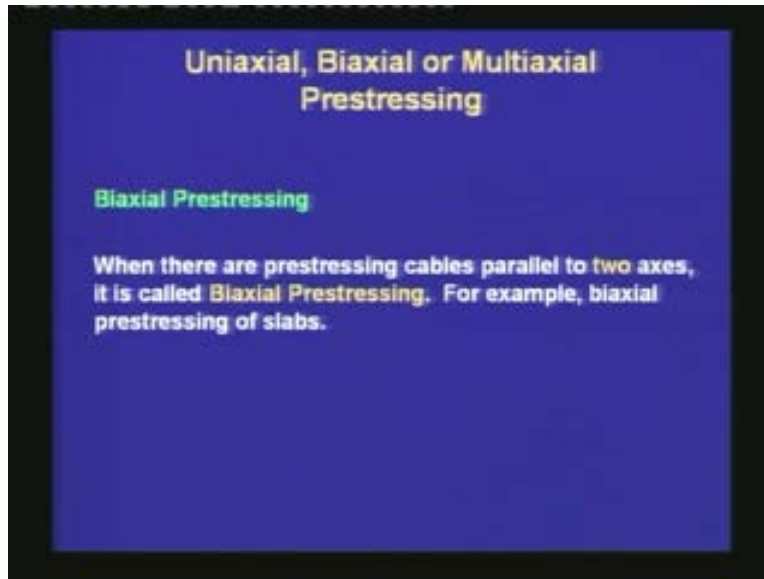
The partial prestressing means the level of prestressing is such that under tensile stresses due to service loads, there can be cracking and the crack width is limited within some allowable values. It is referred to as Type 3 in the code. Thus, in partial prestressing we allow not only tensile stresses but also cracking of the concrete. The crack width will be limited within allowable values.

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The next type of classification is based on the different directions of prestressing. When the prestressing cables are parallel to one axis, it is called uniaxial prestressing, for example, longitudinal prestressing of beams.

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When there are prestressing cables parallel to two axes, it is called biaxial prestressing; for example biaxial prestressing of slabs.

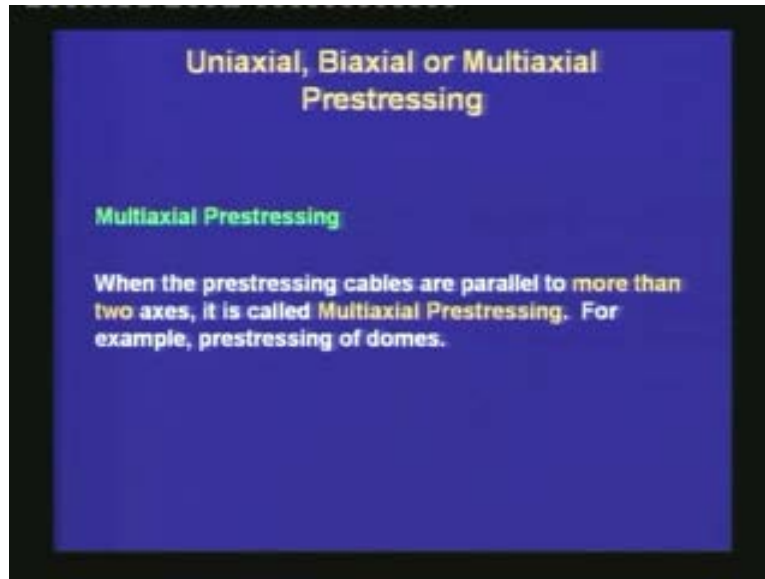
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In this photograph, we can see that the slab has been prestressed in two directions. We can note the ducts running in two directions and in addition to the ducts, there are also

non-prestressed conventional reinforcement to take account of shrinkage and thermal stresses. Thus, this is an example of biaxial prestressing as compared to uniaxial prestressing for beams.

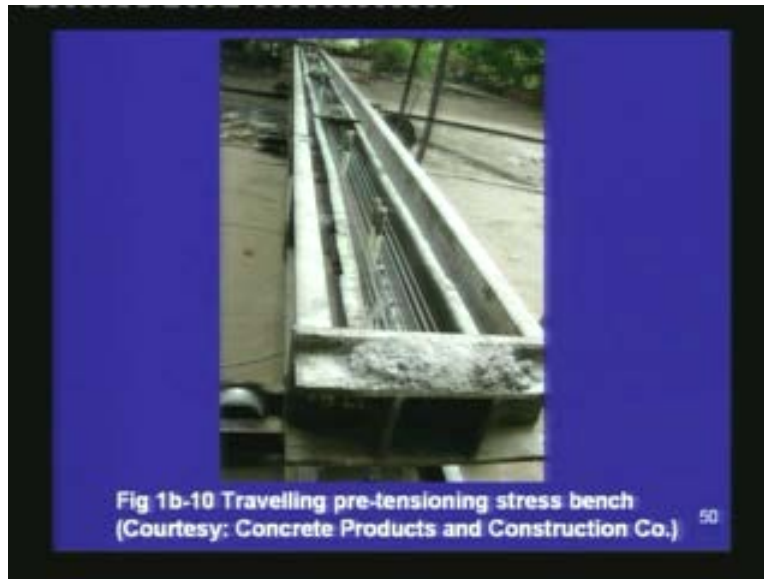
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When the prestressing cables are parallel to more than two axes, it is called mutiaxial prestressing; for example, prestressing of domes. In domes of some big structures, prestressing can be done in more than two directions and in that case, it is called a multiaxial prestressing.

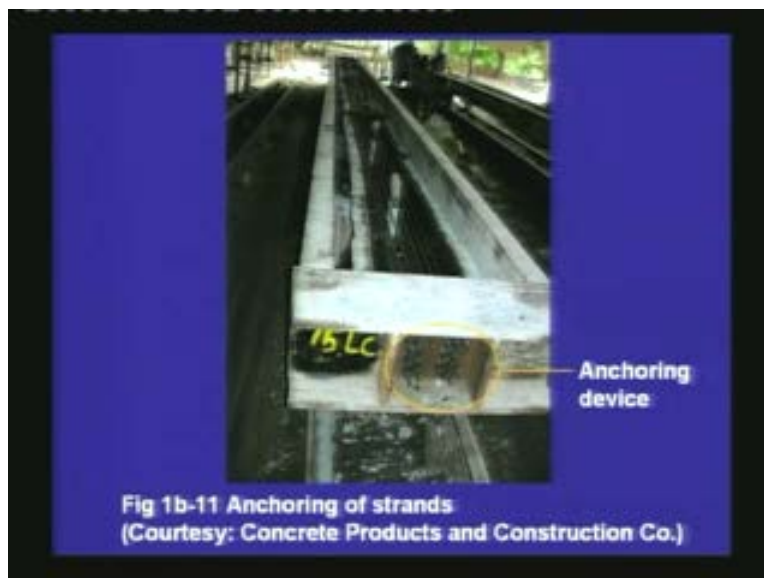
Next, we are moving on to the manufacturing of pre-tensioned railway sleepers. Note that we shall see the sequence of the pre-tensioning operation.

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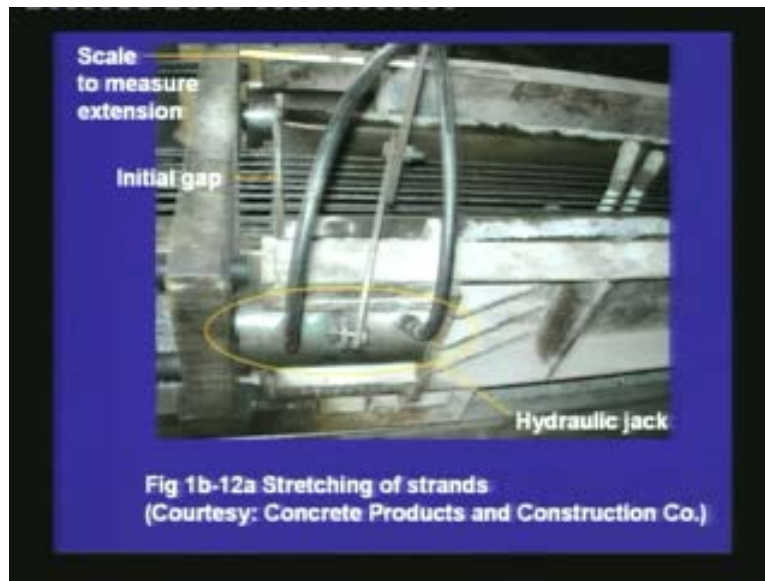
This is a travelling pre-tensioning stress bench. It is called a stress bench because the tendons are anchored to this unit, and this unit can move from one place to another on the rollers which are placed in rails. Hence, this is called a travelling pre-tensioning stress bench.

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Once the steel is placed in this stress bench, these are anchored at the end. This anchoring is done by wedges. One side it is anchored, and the other side the tension is applied.

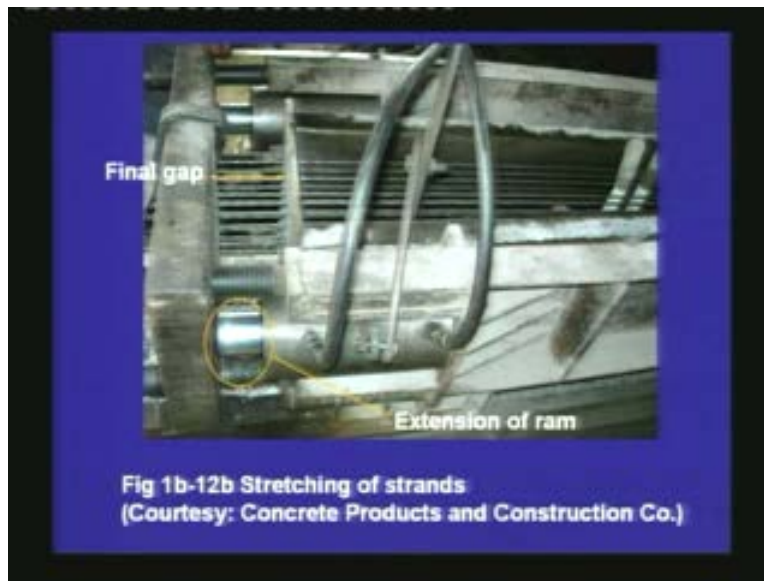
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This is the other end where the strands are fixed to a steel plate, which is being moved out by hydraulic jacks. This is called the stretching end as compared to the dead end of the other side of the stress bench. Note, that there is an initial gap between the end of the stress bench and the plate to which the tendons are attached. There is a scale to measure the extension after the tensioning operation is carried out. This scale measures the movement of the end plate with respect to the end of the stress bench. The hydraulic jack is a double acting jack where oil is pumped through one pipe and it moves out through the other pipe.

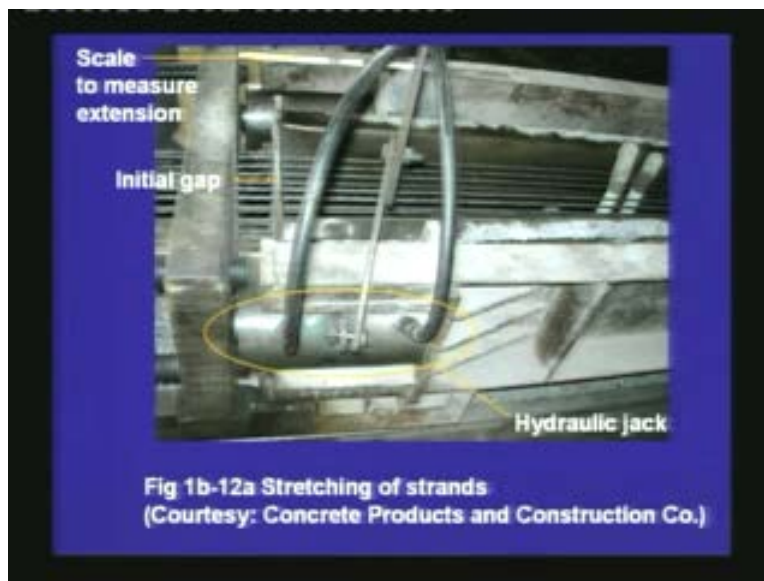


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This is the situation after the tendons have been stretched. Note that the piston of the jack has come out. It has pushed the end plate to extend the tendons. The gap between the end plate and the end of the stress bench has increased.

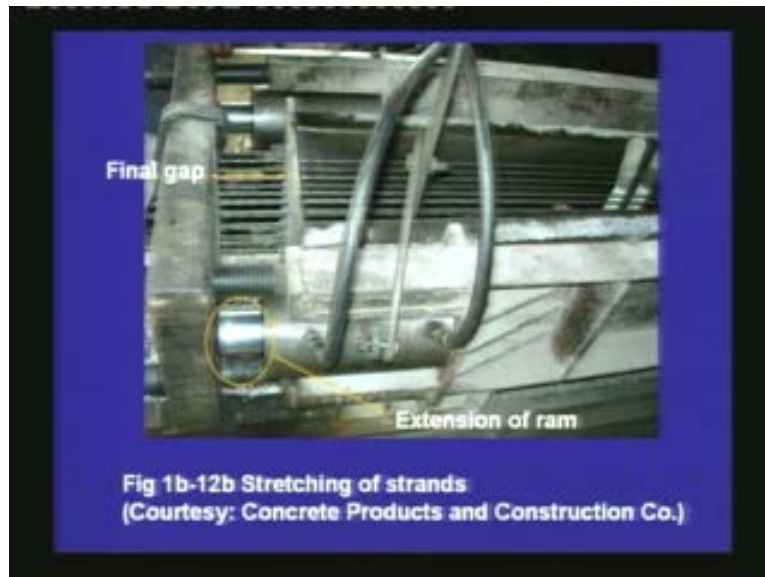
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Compare this figure once again with the previous figure. Initially, we had a smaller gap

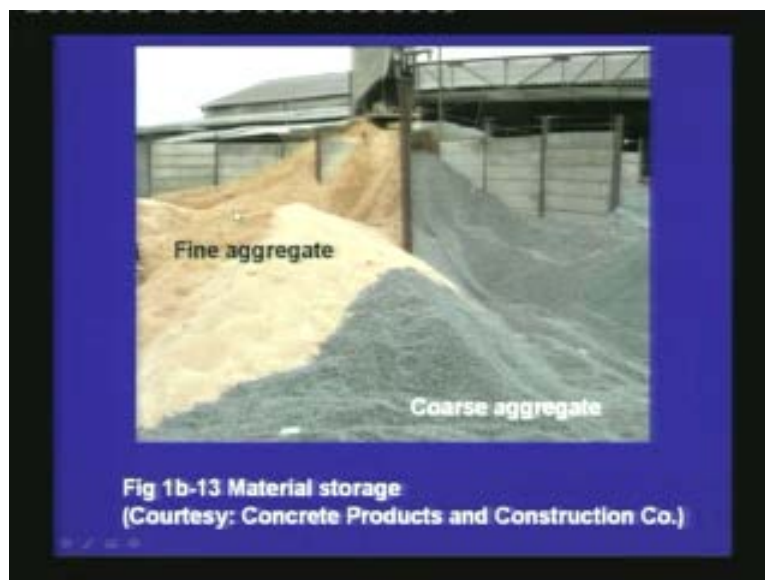


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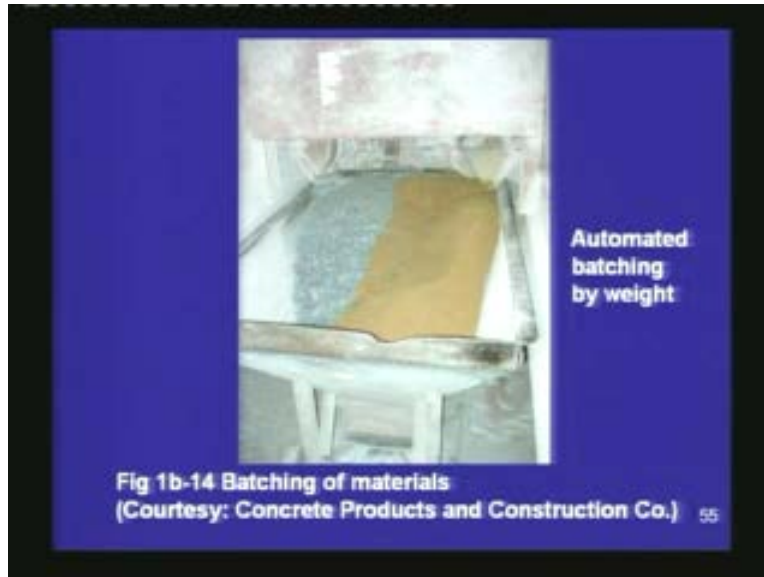
and then after stretching the tendons, we have a bigger gap. Now the tendons are under tension. This gap is being monitored by the scale which records how much extension the tendons have been subjected to. Once the tendons are stretched then we are ready to cast the concrete. The ingredients of concrete are stored in the yard.

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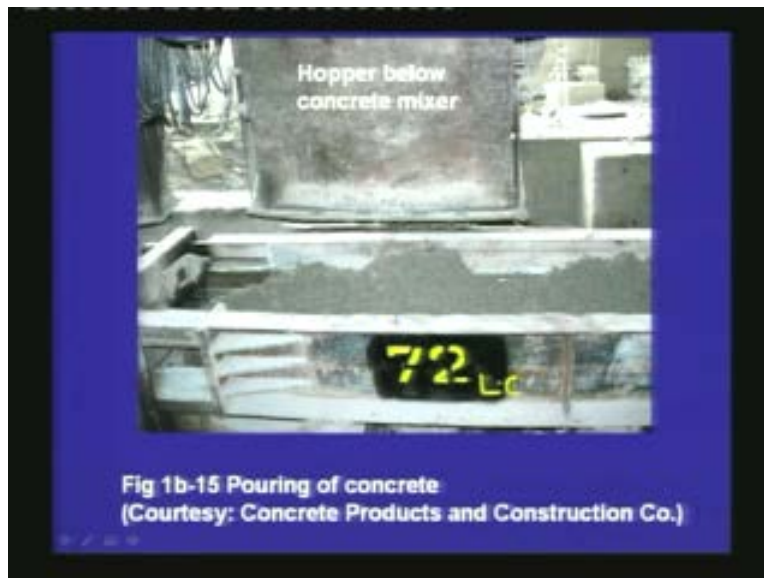
In this photograph, we can see that the coarse aggregate which are gravels and the fine aggregate which is the sand, have been kept separately in the storage yard.

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The material is brought and is weighed by an automatic batching machine. It is measured exactly how much amount of the coarse and the fine aggregates have to be mixed.

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Once the ingredients are mixed in a mixture, then the concrete is dropped by a hopper in to the stress bench. Note that, this is the green concrete where the fine aggregate, the

coarse aggregate, the cement and the water have been mixed. Some admixtures are also added. Now the concrete is in green stage, and it has been dropped within the stress bench.

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After the concrete is dropped, it is vibrated. In this case, the mould itself is vibrated. There is some vibration done by needle vibrators so as to make sure that the concrete is well compacted without voids. After that, the finishing is done properly to make sure that it is a smooth finish at the top after the concrete has been cast.

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Once the concrete has been cast, it needs to be cured. Remember that prestressed concrete needs good quality control. In order to have proper curing of the concrete, a steam chamber has been made. From the stress bench, the mould is directly pushed inside the steam chamber and it is kept there for 24 hrs for the initial curing under controlled environment. There is steam running inside the chamber which helps in rapid curing of the concrete in the mould.

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After 24 hours, the mould is brought out. From the mould, each sleeper is now ready to be taken out. Before the sleepers are taken out, the wires are cut. We get four sleepers from one stress bench. Once the wires are cut, the prestress is transferred to the concrete. That is, first the steel was under tension; then the concrete was cast. The concrete was cured enough to get a minimum strength, and then the wires were cut. Once the wires are cut, they try to shrink and that transfers the prestress to the concrete. The prestress is transferred to the concrete by the bond over a certain length, which is called the transmission length, at the two ends of the member.

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Once the wires are cut, the sleepers are ready to be taken out from the mould. Here, we can see that a sleeper is being taken out from the mould.

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Next, the sleepers are being stacked. From one stress bench we are getting four sleepers. We can see that at the end of the sleepers the wires have been cut, and these sleepers are now prestressed.



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For further curing, these sleepers are taken to a water tank, and there they are cured for a substantial period, so that the concrete gains its final strength. This process is expedited by the travelling formwork. Since the travelling stress bench can move from one place to another on wheels, the whole process is very fast. The construction is a fast track construction, and the production of railway sleepers can be at a high rate. Here, we can see that many sleepers have been stacked and they are ready for dispatching to the railways.

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In the above photograph, we can see that from the stacking yard, the sleepers are being loaded onto wagons. These will be transported to the site where they will be placed beneath the rails. Thus, the pre-tensioning operation is a very fast track construction, and it is suitable for mass production of prestressed elements like railway sleepers, poles and other smaller units. This is done in a controlled environment with proper quality control and precise tensioning of the tendons.

We are moving on to the construction of a post-tensioned bridge girder.

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As compared to a pre-tensioned member, in a post-tensioned member first the reinforcement cage is made, the duct is placed and then the concrete is cast. The steel tendon is then passed through the ducts. After the concrete has cured sufficiently, tension is applied on the tendons by hydraulic jacks, and then the tendons are held by anchorage blocks which gradually apply the prestress to the concrete. The essential difference between pre-tensioning and post-tensioning is that, in the pre-tensioning the steel was stretched before the casting of the concrete, but in post-tensioning the steel will be stretched after the casting of the concrete.

In the above photograph, we can see an I-girder where the reinforcement cage has been fabricated. Once the reinforcement cage has been fabricated, the ducts through which the

tendons will be passed are placed. Now, the placement of the duct is based on analysis which we shall cover later. Once the duct is placed and the side formworks are placed, then the concrete is cast. After the casting of the concrete, it will be cured for a substantial period till it gains strength.

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Then through the ducts, the steel tendons are passed. The tendons are right now projecting out from the end of the members. These tendons will be stretched by hydraulic jacks.

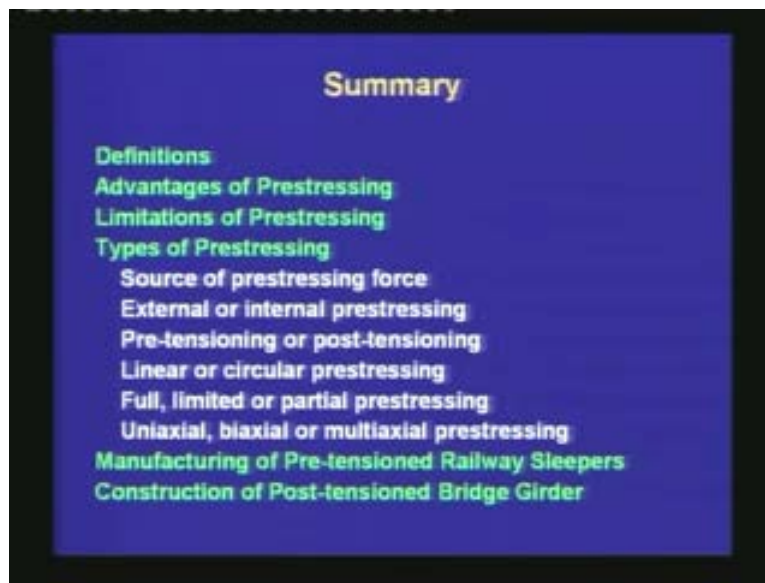
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In this photograph, we can see at the bottom that the jack is stretching the tendons. Once the tendons are stretched, wedges are placed in the anchor blocks and then the jack can be released. When the jack is released, the tendons sit on the anchor blocks through the wedges, and the prestress is transferred to the concrete girder. This operation has to be done very carefully because, unless the stretching is controlled, there can be early cracking in the concrete member, if the concrete has not gained enough strength. Hence, in a post-tensioning operation, one has to be extremely careful during the stretching of the steel because that is the testing time for the prestressed member. Once the stretching operation is done properly, then the member is ready for the service loads. The member can be precast in a different place and it can be transported to site; or it can be placed in the final location and the post-tensioning operation can be done at the final location.

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In today's lecture, we have covered many definitions of the prestressing system. The first sets of definitions were related with the type of steel that is used in the prestressing systems. It can come in the form of individual wires, it can be in the form of strands, or it can come in the form of a bar. Individual wires are wound to form a strand, several strands can be placed in a tendon and again several tendons can form a cable. Thus, depending upon the type of application, the prestressing steel is selected.

We learned about the definitions related to the stages of prestressing. There are three main stages. The first one is the initial stage, where the steel is tensioned and then the

stress is applied to the concrete. The second stage is the intermediate stage for precast members, where the stresses that generate during transportation need to be checked. Finally, we have the final stage. That can be sub-divided into two stages. One is the service stage which is for the period for which the structure is being used. There can be an ultimate stage which occurs from extreme event, when the load can be substantially high and the member can reach its final strength. Depending upon the stages, the analysis has to be done considering the strength of the concrete and the allowable stresses for each stage.

After the definitions, we moved on to the advantages of prestressing, as compared to reinforced concrete. We have seen that there are several advantages of prestressed concrete, out of which the primary advantage is that the concrete stays uncracked for most of the prestressed concrete members. Cracking is a big disadvantage for reinforced concrete because that leads to corrosion, and the section is not fully utilized. Whereas, in a prestressed concrete member, since cracking is avoided, the full section is utilized; we have higher moment of inertia, thus higher stiffness, and we have reduced deflection. The biggest advantage is that the deterioration of the steel is reduced because of the absence of cracks.

The second advantage is the increased span-to-depth ratio. For prestressed concrete members, the span can be substantially large as compared to an equivalent reinforced concrete member. This is to an advantage for bridge construction and for building construction, where we need large column free space, such as in commercial buildings and office spaces. This is possible when we prestress the slabs. The reduced depth also helps to reduce the weight, and this makes a prestressed concrete member to have less concrete as compared to an equivalent reinforced concrete member.

The third advantage is that prestressed concrete is a good quality product. The service life can be more. Provided it is made properly, the serviceability of a prestressed concrete member is better than a reinforced concrete member. It has a higher resilience, with which it has a better fatigue behavior as compared to a reinforced concrete member.

But along with advantages we also have limitations of prestressing because, it brings us additional responsibility in the manufacturing of the prestressed concrete product. First,

we need skilled technology and we need the auxiliary equipments to have prestressing in the member. Next, both the concrete and the steel have to be of good quality, and hence the cost increases. The process of prestressing should be extremely careful because, unless there is proper quality control of prestressed concrete, there can be cracks during the prestressing operation. If the concrete is not cast properly that will lead to corrosion, which can lead to reduction of the strength of the prestressed concrete members. Hence, a prestressed concrete member demands better quality control and inspection during the manufacturing process.

After this, we had moved on to the different types of prestressing. We had seen that the prestressing can be classified based on different methods of classification. The first classification was based on source of prestressing force. The prestress can be applied by a hydraulic jack or it can be applied mechanically in a mass production unit. It can also be applied by an electrical system or a chemical system. The most common are the hydraulic jacks which operate based on the oil pressure, and they are used to stretch the tendons. The second classification is based on the location of the prestressing tendon with respect to the concrete. If the tendon is outside the concrete, it is called external prestressing, as is used in bridge girders. If the tendon is concealed within the concrete then it is called an internal prestressing. Most of the prestressed concrete members are internally prestressed; ducts are laid out within the concrete for a post-tensioned member and the steel remains within the ducts.

The third classification and which is the most important classification was the pre-tensioning or post-tensioning. This classification is based on the sequence of stretching the steel and the casting of the concrete. If the steel is stretched first before the casting of the concrete, this is called pre-tensioned concrete. If the steel is stretched after the casting and curing of the concrete, it is called post-tensioned concrete. Thus, the pre-tensioning and the post-tensioning are based on the sequence of stretching of the steel and the casting of the concrete.

The next classification was related with the direction of prestressing. Beams, sleepers, poles, pipes are all linearly prestressed, where the prestressing tendon is along the axis of the member. Whereas tanks, silos and containment structures are circularly prestressed.

That is, the prestressing tendons are wound around the circumference of the member. Based on the direction of prestressing, it can be classified as linear or circular prestressing.

The next classification was related with the amount of prestressing: full, limited or partial. A fully prestressed member refers to a member which does not have any tensile stress during its service life. A limited prestressed member refers to a member which can have a tensile stress, but the tensile stress is limited to the cracking strength of the concrete. Thus, we do not expect any cracks under the service loads. The third type is the partial prestressing where we not only have tensile stress, but can also have cracking. But the crack width is limited to check corrosion. Thus, based on the amount of prestressing we can have a member fully prestressed which is referred to as Type 1, or limited prestress which is referred to as Type 2, or a partially prestressed member, which is referred to as Type 3. The analysis also should take account of these types, so that the strength calculations are done appropriately. The final classification was related with how many directions of prestressing are being done.

A uniaxial prestressing is done for a linear member like beams, sleepers, piles and poles. Biaxial prestressing is done for a two dimensional member like a slab, where the prestressing can be done in two directions. Multiaxial prestressing is done for elements like domes, where the prestressing can be done in more than two directions.

After this classification, we had moved on to the manufacturing of pre-tensioned railway sleepers. In this section we had observed how a mass production of railway sleepers is undertaken. This is a pre-tensioned concrete, which means, the steel is stretched before the concrete is cast. The concrete is cast in a stress bench which is a self-straining member, and a travelling stress bench is used for the fast track construction. Within the stress bench, first the steel is anchored at one end which is called the dead end and then it is stretched at the other end by hydraulic jacks.

Once the stretching operation is over, then the concrete is cast. The coarse aggregate, the fine aggregate, the cement, water and admixtures if any, are mixed in the mixer and it is dropped in the mould of the stress bench. There it is vibrated for proper compaction. Once it is properly compacted, the surface is finished and the stress bench is inserted

within a curing chamber. The controlled curing under steam helps to gain the strength of the concrete quickly. Within 24 hours it gains substantial strength to have the prestress transferred from the steel to the concrete. After 24 hours, the moulds are taken out and then the wires are cut. When the wires are cut, the pre-tension is transferred to the concrete. After this, the sleepers are taken out from the moulds, they are stacked in the water tank and then they are cured until the concrete has gained the final strength. Once the curing is over, they are stacked in the yard from which they are dispatched on the wagons for the construction of the railway tracks. Thus, the manufacturing of railway sleepers is done in a very controlled environment with fast track construction, so that the production of railway sleepers can meet the demand of the railway tracks.

Next, we had seen the post-tensioning operation of a bridge girder. First, the reinforcement cage is made, through which the duct is laid. Once the duct is laid properly, the side formworks are built. It is made sure that there is adequate cover around the reinforcement cage. Then the concrete is cast. The concrete should be of good quality, and it has to be properly compacted so as not to have any voids within the concrete. Once the concrete is cured to gain substantial strength, the strands are passed through the ducts. At one end, a strand is anchored by an anchorage device, on the other end it is stretched by a hydraulic jack. Once the stretching operation is done, wedges are attached to the strands, and the jacks are gradually released by which the tension in the steel gets transferred to concrete as compression. This is the post-tensioning operation, which also needs great care to have the operation done properly. With this we are ending this chapter on the advantages, limitations and the different types of prestressing.

Thank you.