PRESTRESSED CONCRETE STRUCTURES

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Module – 01: Introduction, Prestressing Systems and Material Properties

Lecture – 03: Prestressing Systems and Devices (Pre-Tensioning)

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

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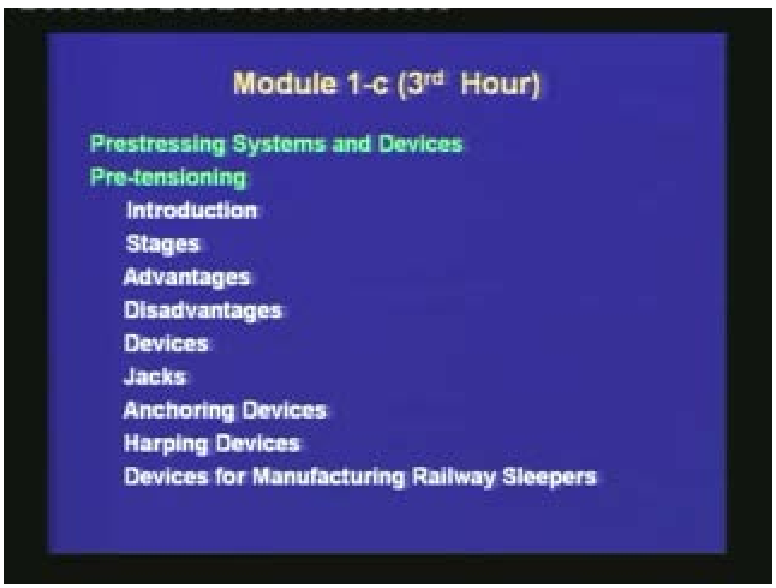

In this lecture, first, we shall study about some definitions in prestressing systems and devices. Then, we shall move on to the pre-tensioning systems and devices. We shall study about the equipments that are used in the pre-tensioning systems such as the jacks, the stress bench, etc. After the introduction, we shall study about the stages in the pre-tensioning process. We shall look into the advantages and disadvantages of pre-tensioning. Then, we shall further look into the devices such as jacks, anchoring devices, harping devices; and finally, we shall see some photographs of the devices used in the manufacturing of railway sleepers.

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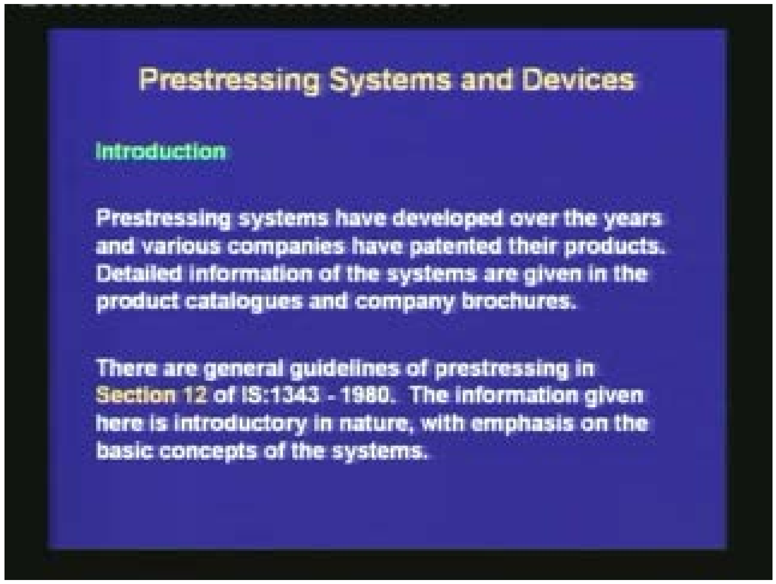

Prestressing systems have developed over the years and various companies have patented their products. Detailed information of the systems is given in the product catalogues and company brochures. Thus, in the field, the prestressing systems and devices that are available are patented by some manufacturers. At work, one has to get familiar with these devices from the production catalogues and the brochures. In this lecture, we shall discuss the systems and devices broadly, just to understand the principles based on which they work. There are general guidelines of prestressing in Section 12 of IS: 1343 – 1980. The information given here is introductory in nature, with emphasis on the basic concepts of the system.

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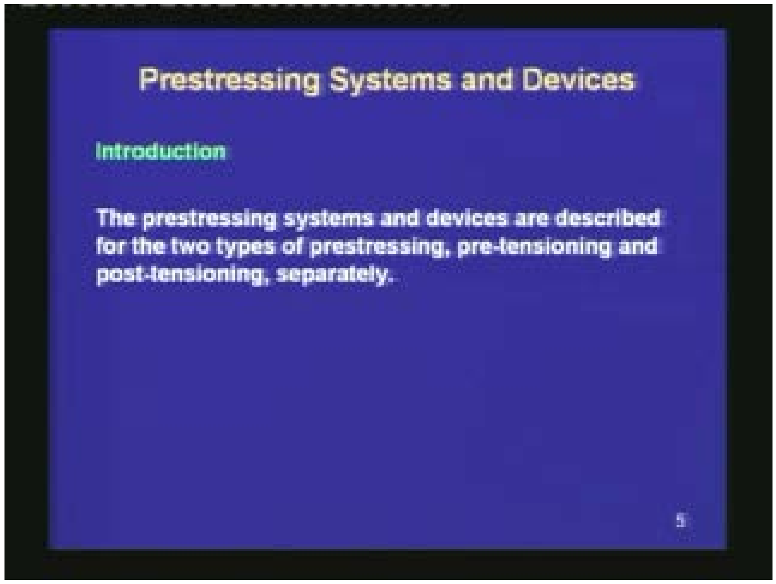

The prestressing systems and devices are described for the two types of prestressing, which are pre-tensioning and post-tensioning, separately. In the last lecture, we had studied this classification of prestressed concrete structures based on the sequence of tensioning the steel and casting the concrete. If the steel is tensioned first and the concrete is casted subsequently, that is called a pre-tensioned concrete structure.

On the other hand, if the concrete is cast first and then the steel is tensioned, that is called a post-tensioned concrete structure. Based on this classification, we shall study the prestressing systems and devices for each one of them separately.

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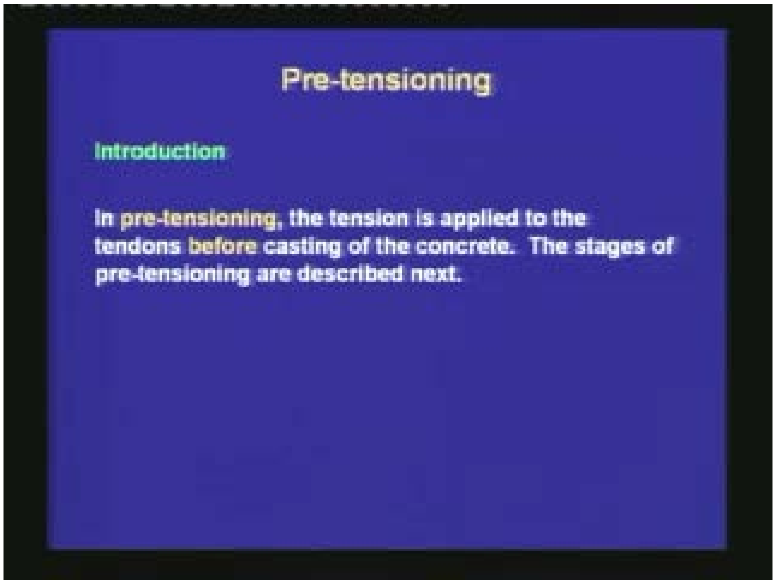

In pre-tensioning, the tension is applied to the tendons before casting of the concrete. The stages of pre-tensioning are described next.

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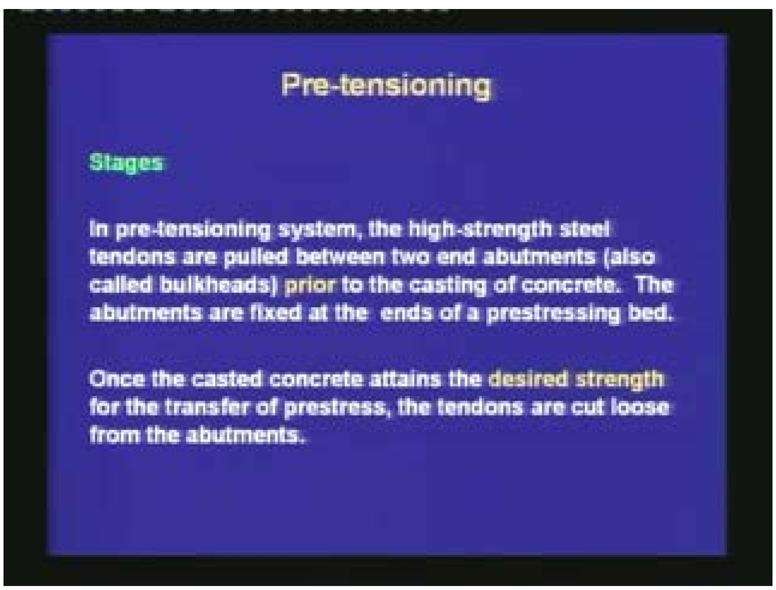

In pre-tensioning system, the high strength steel tendons are pulled between two end abutments (also called bulkheads) prior to the casting of the concrete. The abutments are fixed at the ends of a prestressing bed. Once the casted concrete attains the desired strength for the transfer of prestress, the tendons are cut loose from the abutments. Thus, first, the tendons are anchored at the bulkheads, which are provided at the ends of the prestressing bed, and then the concrete is cast. Sufficient time is given for the curing of the concrete. Once the concrete has attained substantial strength for the transfer of prestress, the tendons are cut and the prestress is transferred to the concrete.

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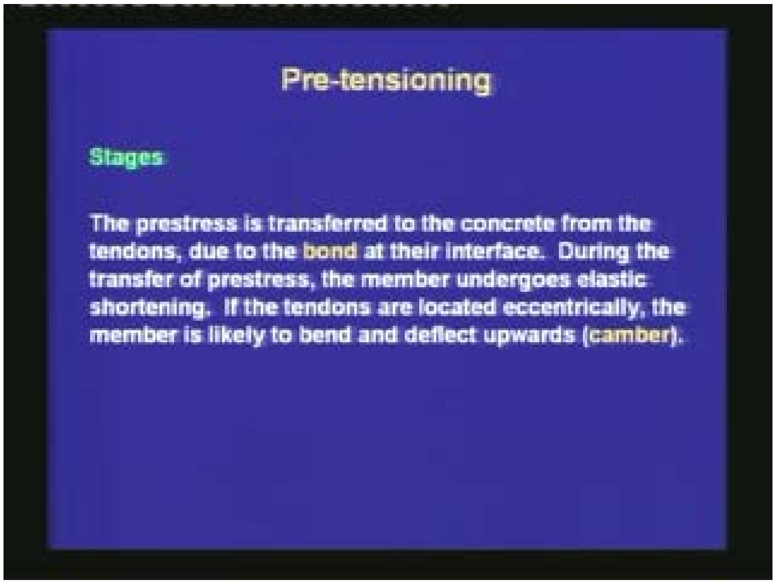

For the prestressed members, the prestress is transferred to the concrete from the tendons, due to the bond at their interface. During the transfer of prestress, the member undergoes elastic shortening. If the tendons are located eccentrically, the member is likely to bend and deflect upwards, which is called camber. When the prestress is transferred by cutting the tendons, the members tend to reduce in length, which is called elastic shortening. The prestress is transferred from the steel to the concrete by the bond at their interface over a certain length, which is called the transmission length at the ends of the prestressed members.

Once the prestress is transferred, the members are shortened. If the tendons are eccentrically located, that means the tendons are not along the axis of the member, then the member may deflect upwards which is called cambering of the member. After the member has cambered, then it is taken out from the mould and taken to the respective site.

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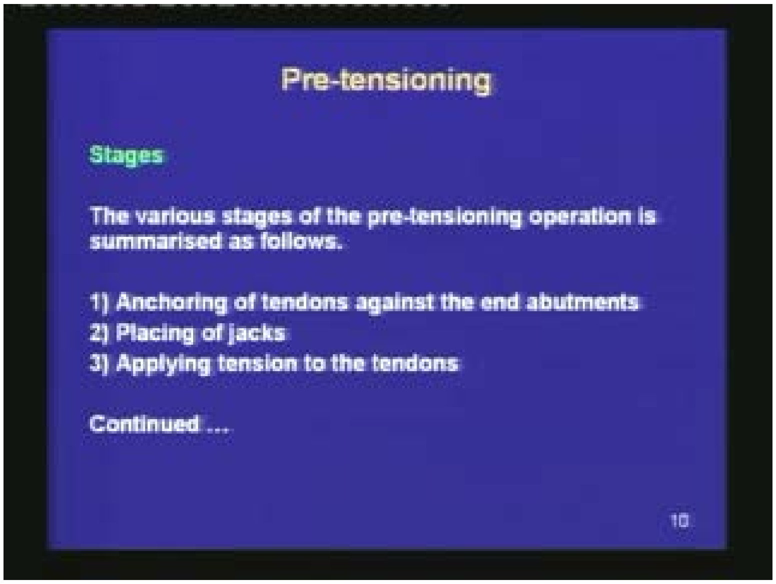

The various stages of the pre-tensioning operation are summarized as follows: First, anchoring of tendons against the end abutments; next, placing of the jacks at the end abutments; third, applying tension to the tendons. Up to this, the steel tendons are ready at their place under the tension. Next, we are moving on to the casting of the concrete.

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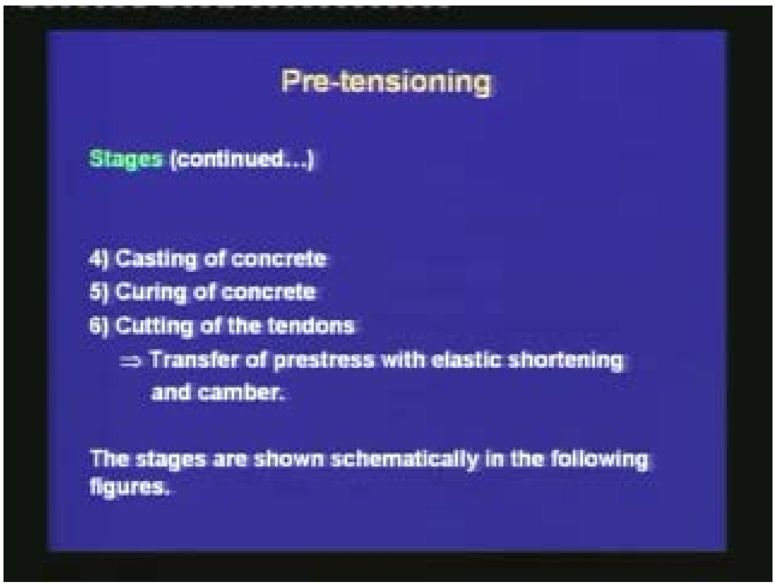

The fourth stage is the casting of the concrete. Then the concrete is cured sufficiently to attain the desired strength for the transfer of prestress, and the tendons are cut. When the tendons are cut, the transfer of prestress occurs along with elastic shortening and cambering. These stages are shown schematically in the following figures.

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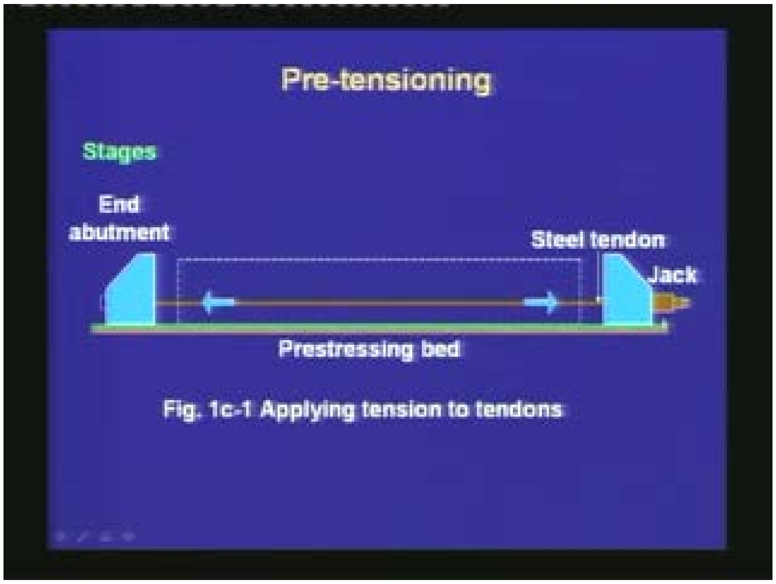

In this figure, we can see the prestressing bed over which the concrete will be cast. There are end abutments, which are fixed to the prestressing bed. Next, the tendon is placed which runs from one abutment to another abutment, and a jack is used to stretch the tendon.

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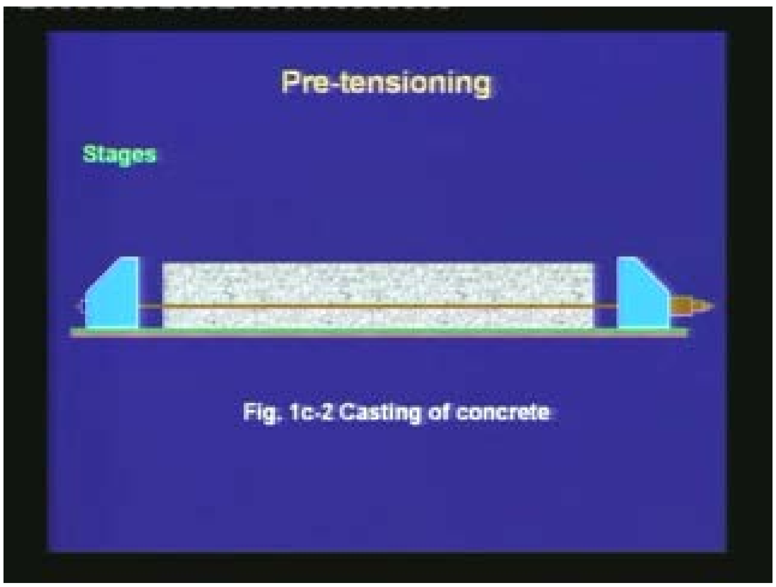

Once the tendons are stretched, we move on to the next stage, which is the casting of the concrete. There are moulds or shuttering which is used to shape the member and the concrete is cast and cured, to gain sufficient strength.

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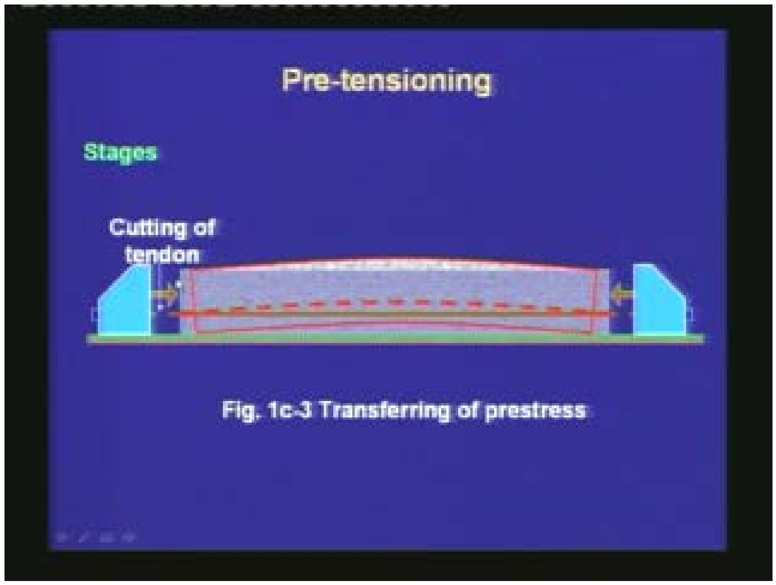

Next, the tendons are cut at the ends and once the tendons are cut, the member undergoes elastic shortening. In case of eccentric tendons, it deflects upwards which is called cambering of the member.

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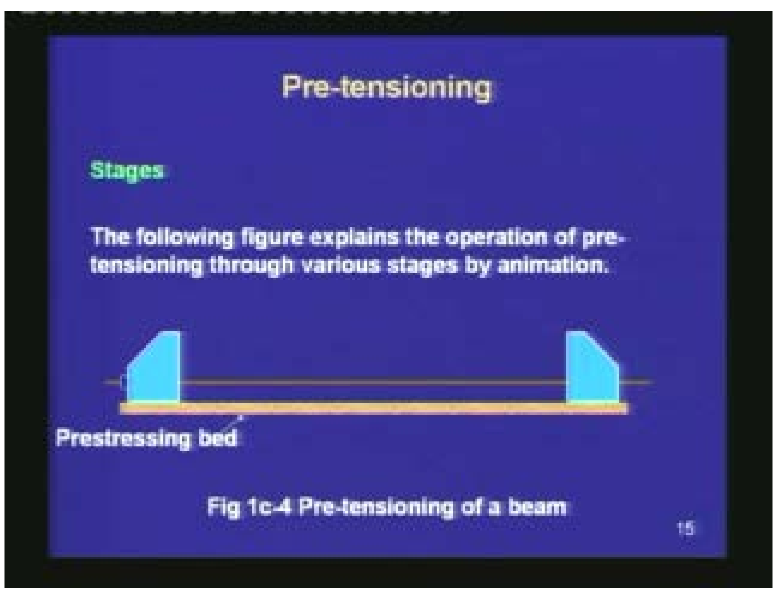

The above and following figures explain the operation of pre-tensioning through various stages of animation. Let us understand the process by this animated sketch. At present, the prestressing bed is ready with the tendons placed.

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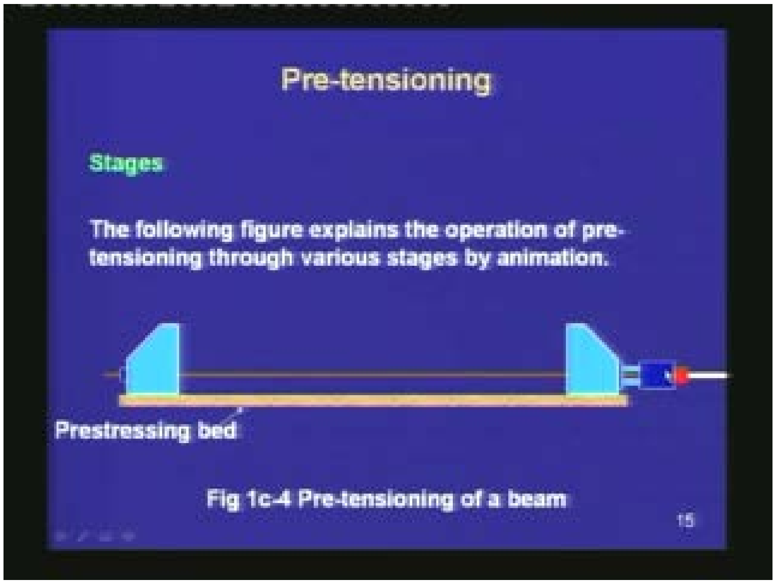

Next, the jack has been placed which will apply tension in the tendons.

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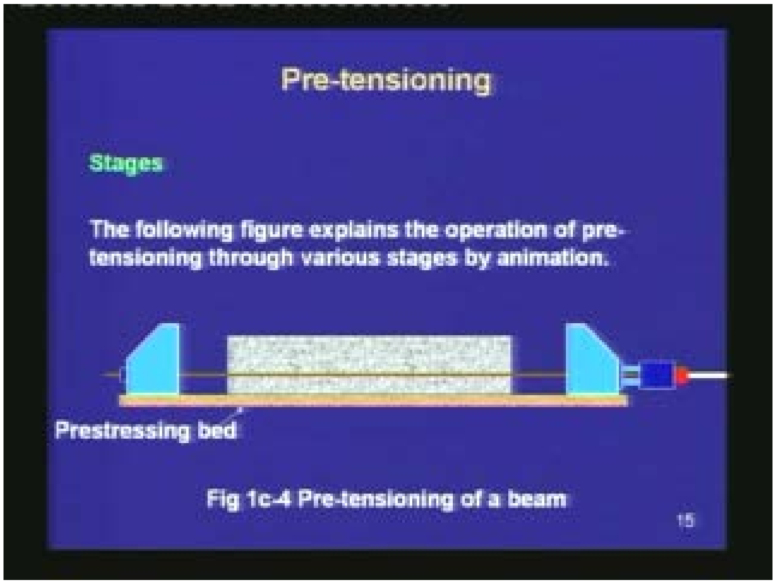

After this, the concrete is cast in the moulds and it is allowed to cure, to gain sufficient strength.

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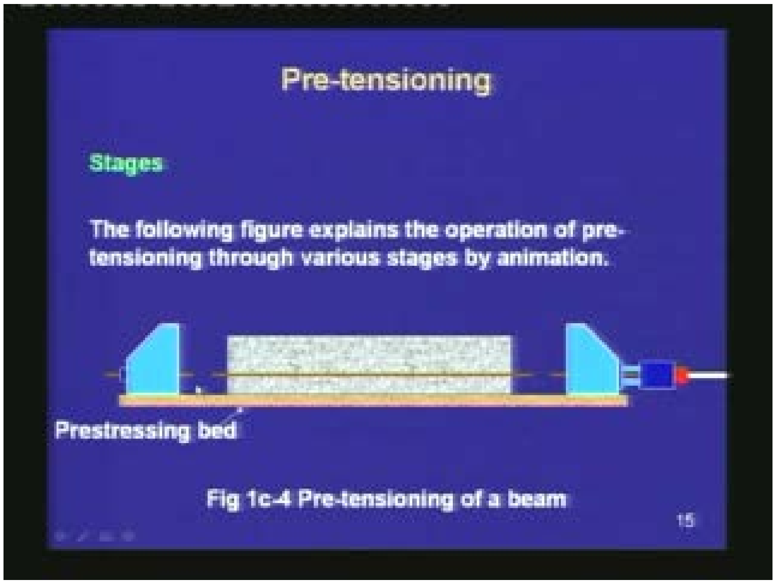

Next, the tendons are cut at the ends.

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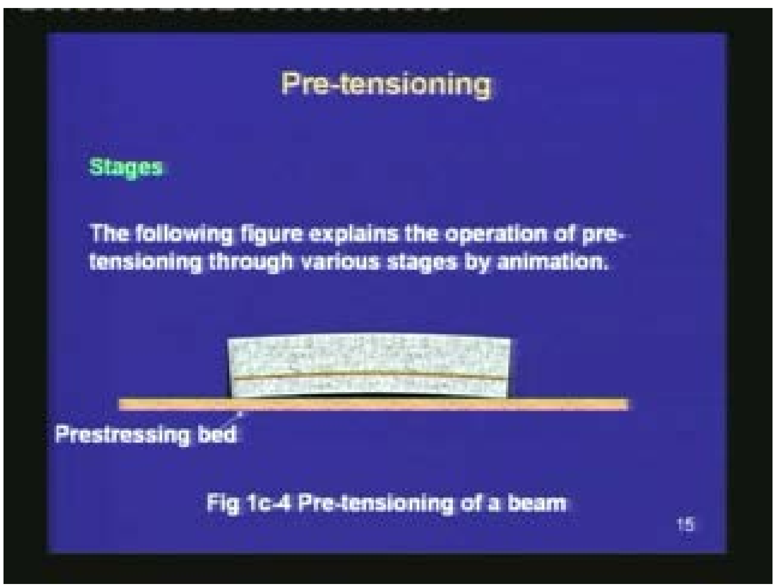

Once the tendons are cut, the member undergoes elastic shortening as well as cambering, that means it deflects upwards. Let us review this process once again. First, the tendon is placed in the prestressing bed. Next, the jacks are placed which applies the tension in the tendons. The concrete is cast in the mould. It is allowed to cure and gain its strength. Then the tendons are cut at the two ends. The member undergoes elastic shortening and cambering in case of eccentric tendons. Now, the member is ready to be transported to the site.

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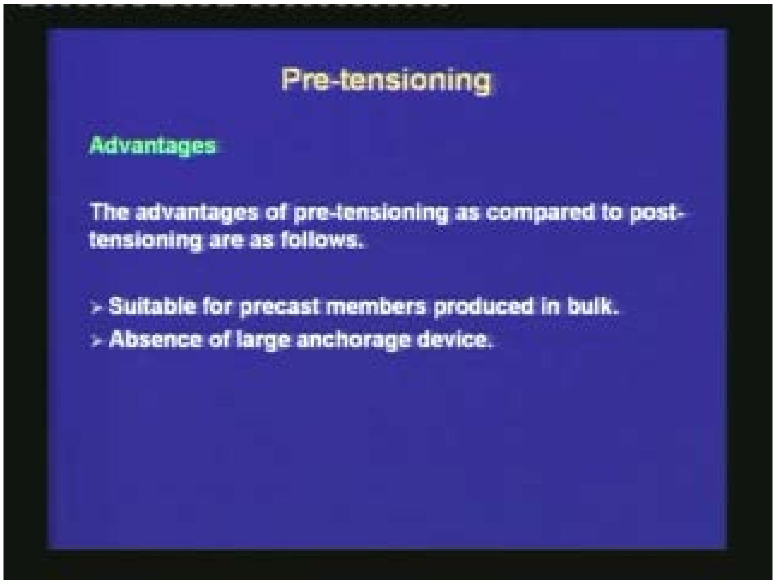

Next, let us discuss the advantages of pre-tensioning as compared to post-tensioning.

First, the pre-tensioning operation is suitable for precast members produced in bulk. That means, the member is cast somewhere else, and then they are shipped to their respective sites. When mass production is necessary, then the pre-tensioning system is advantageous. The second advantage is that the pre-tensioning does not need too much of anchorage device. It means that there is an absence of large anchorage device, which is present in the post-tensioning system.

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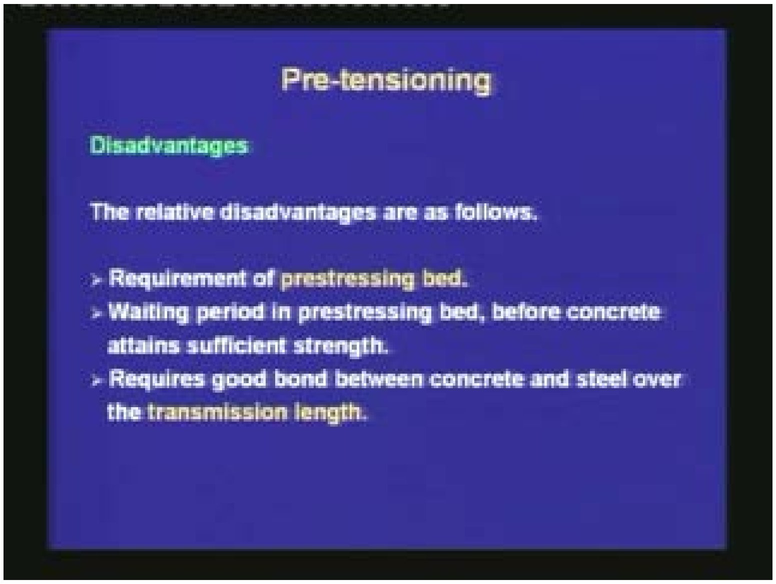

There are some relative disadvantages of pre-tensioning as compared to post-tensioning.

First, there is a requirement of prestressing bed. That means there has to be a place where the concrete will be cast and steel will be tensioned. Next, there is a waiting period in the prestressing bed, before concrete attains sufficient strength. This waiting period can be a problem, if there is a large demand of mass production at a rapid rate. Finally, the pre-tensioning requires good bond between the concrete and the steel, to transfer the prestress from the steel to the concrete.

In the post-tensioned system, we have good anchorage devices at the end which transfers the prestress from the tendons to the concrete; but for pre-tensioned members, their prestress is transferred over a certain length called the transmission length. The transmission occurs due to the bond between the concrete and the steel.

Next, we move onto the devices of pre-tensioning systems in more detail. The essential devices that are used for pre-tensioning are as follows:

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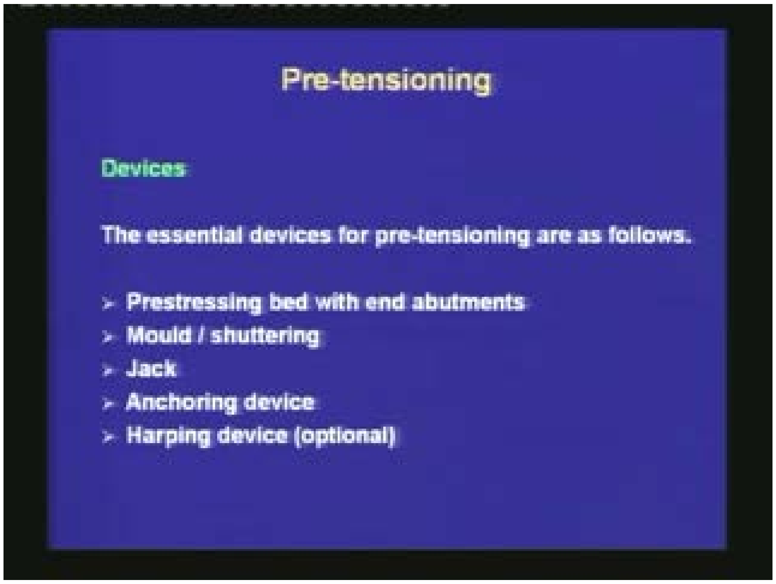

First is the prestressing bed with end abutments; next, the mould or the shuttering; third, the jack; fourth, the anchoring device; fifth, the harping device, which can be optional.

That means, first we need a prestressing bed with proper end abutments. Then we need the mould and the shuttering to cast the concrete. We need a jack to apply the tension to the tendons. We need some anchorage device to hold the tendons at the end abutments and finally, we may need a harping device which gives an eccentricity to the tendon.

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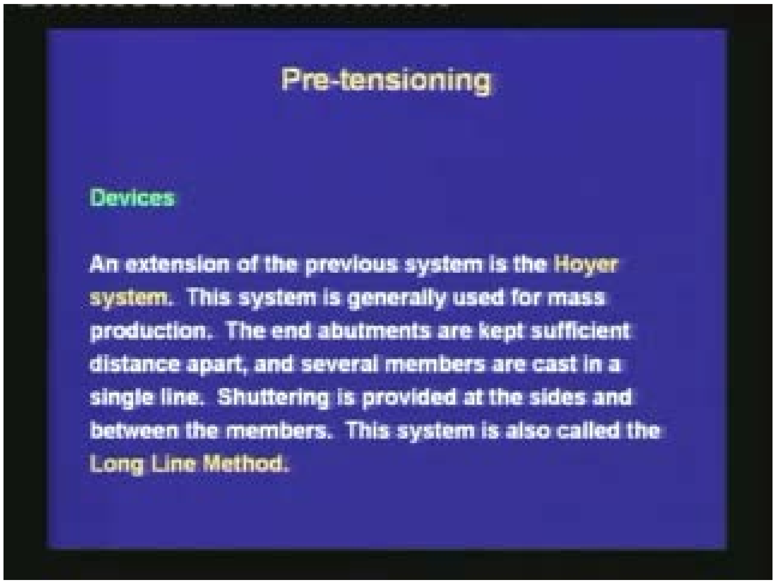

An extension of the prestressing system is the Hoyer system. This system is generally used for mass production. The end abutments are kept sufficient distance apart, and several members are cast in a single line. Shuttering is provided at the sides and between the members. This system is also called the Long Line Method.

Instead of producing individual members at a time, the Hoyer system or the Long Line system can produce several members at a time. The end abutments are sufficiently spaced apart and several members can be cast at a time. In this way, we can increase the production of the pre-tensioned members.

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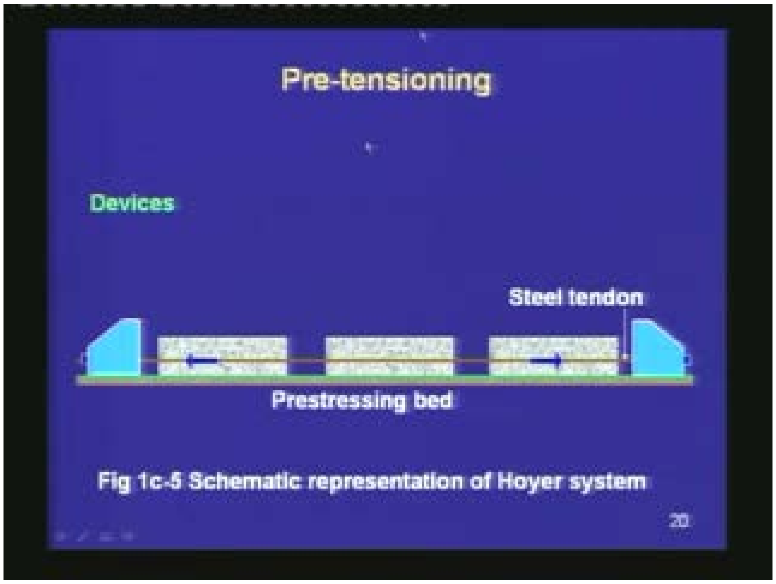

This sketch shows the Hoyer system, where we can see that the end abutments are quite widely spaced in the prestressing bed. The steel tendon is quite long, and then there are separate moulds for the separate members. Once this concrete is cast, the tendons are cut and the members are ready for shipment.

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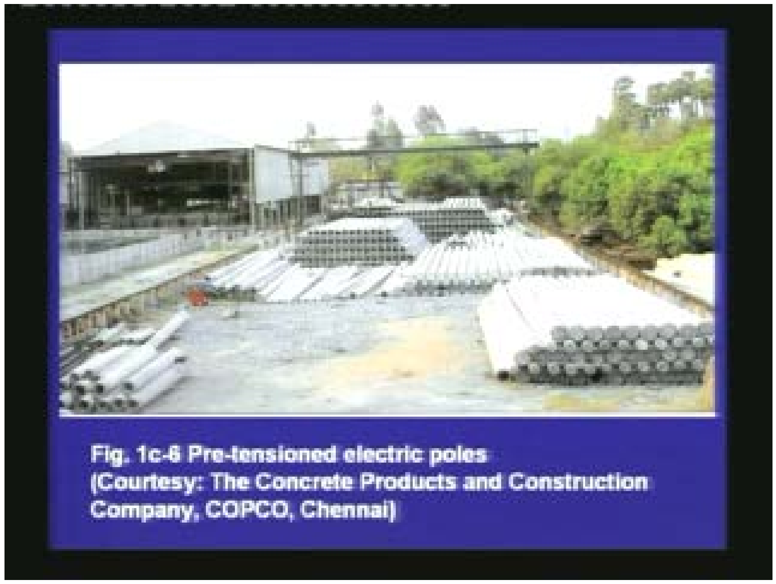

Fig. 1c-6 Pre-tensioned electric poles
(Courtesy: The Concrete Products and Construction Company, COPCO, Chennai)

In this photograph, we can see the production of pre-tensioned electric poles. In the shed, they have the pre-tensioning system. Once the concrete is cast, the members are moved onto the left, which is the curing chamber. After the member has sufficiently cured, the tendons are cut. The members are taken out from the moulds and they are stacked. These poles can be used in various applications, like in transmission lines or it can be used for street lighting. Once they are stacked under different categories, they are ready for shipment.

Next, we are seeing another location showing pre-tensioned railway sleepers.

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In our last lecture, we had seen the manufacturing of the railway sleepers. First, the steel is tensioned, the concrete is cast, then the moulds are taken to the curing chamber. Once the concrete has cured, the tendons are cut, and the prestress is transferred to the concrete. Then the members are taken out, and again they are cured till they are ready for shipment. In the above photograph, we can see that the railway sleepers have been stacked for shipment to the railways.

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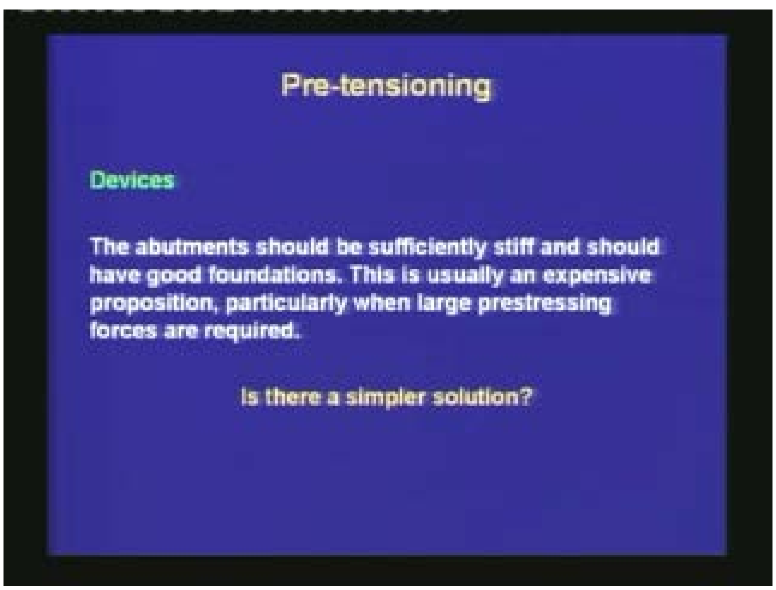

In pre-tensioning systems, the abutments should be sufficiently stiff and should have good foundations. This is usually an expensive proposition, particularly when large prestressing forces are required. As we have seen that the prestressing bed needs two end abutments, which have to be very stiff and anchored down. But this can be quite an expensive system if the prestressing forces are very high, and we need very rapid production.

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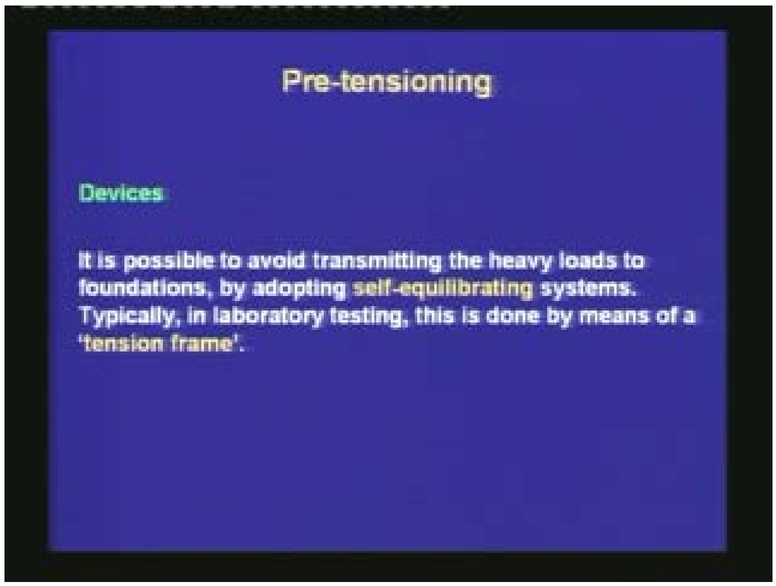

It is possible to avoid transmitting the heavy loads to foundations by adopting self-equilibrating systems. Typically, in laboratory testing, this is done by means of a tension frame. Without having abutments which are strongly fixed to the prestressing bed, we can have a system which is similar to what we have observed in laboratories of testing specimens. This system is called the self-equilibrating system. Let us first understand the principle of a self-equilibrating system through the example of a test frame, which is used in a laboratory.

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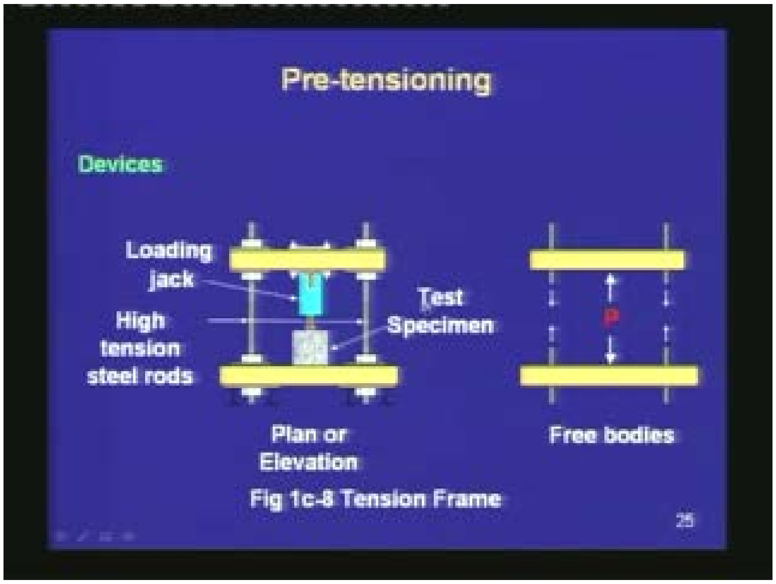

In this sketch on the left hand side, we can see a test frame which can be located either horizontally or vertically. The test frame has two reaction beams which are held together by high tension steel rods. A jack is placed against one beam and it can apply a force to a test specimen. This system is a self-equilibrating system, in the sense, that we are not transferring the force to the foundation. The compression that is applied by the jack generates tension in the tension rods, and each part is shown with the respective forces. This system is under self-equilibrium. Thus, no force is transferred to the foundation and hence, the cost of this system is relatively cheap as compared to the end abutments as we had seen before.

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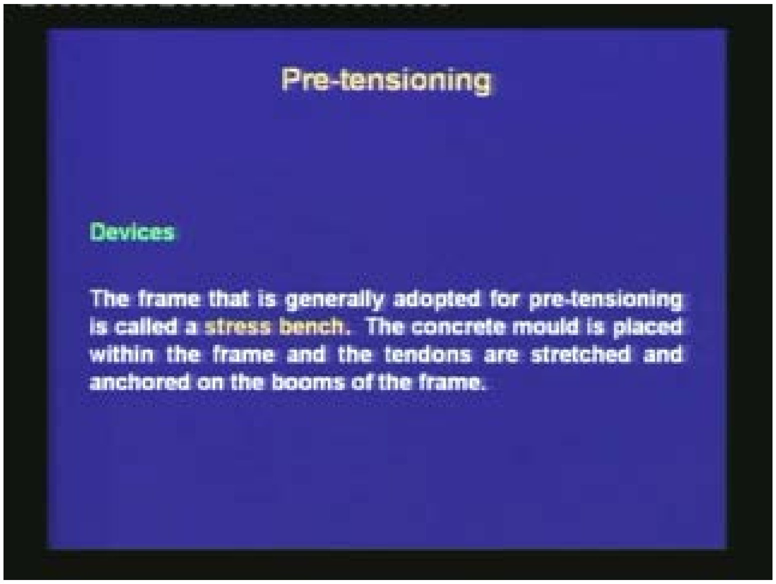

The frame that is generally adopted for pre-tensioning is called a stress bench. The concrete mould is placed within the frame and the tendons are stretched and anchored on the booms of the frame. As we had seen the photograph for the test frame that is used in the laboratory, a similar concept is used in pre-tensioning systems to avoid building end abutments and strong foundations. This system is called a stress bench, which is also a self-equilibrating system. Moulds are placed within the stress bench. The concrete is cast and then cured in the moulds.

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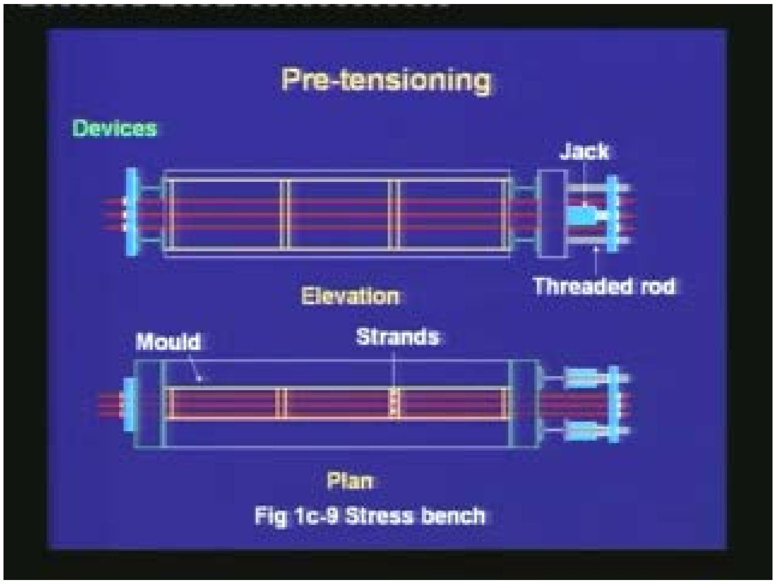

The stress bench is shown schematically by the sketches. We have some end beams to which a frame is fixed. Within the frame, there is a mould which is shown by the yellow lines. On the other side, there are beams and against an end beam, jacks are fixed. First, the tendons are anchored at the left side which is called the dead end, and then the other ends of the tendons are fixed on a moving end plate. The end plate move over some threaded rods. The jack pushes the end plate outside and since the tendons are anchored at the end plate, the tendons are stretched as the jack moves out. The top figure shows the elevation and the bottom figure shows the plan, where we can see that the individual moulds are used to cast several concrete members at a time.

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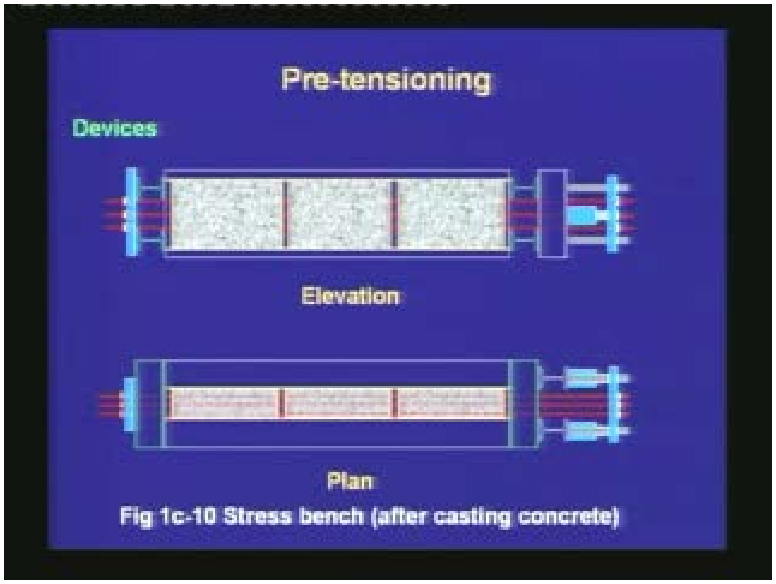

Fig 1c-10 Stress bench (after casting concrete)

In the same sketch, after the placement of the concrete, it appears like the above figure. The concrete has been placed in the moulds, and they are cured till it gets sufficient strength. Then the tendons are cut at the gaps, and the members are ready for shipment.

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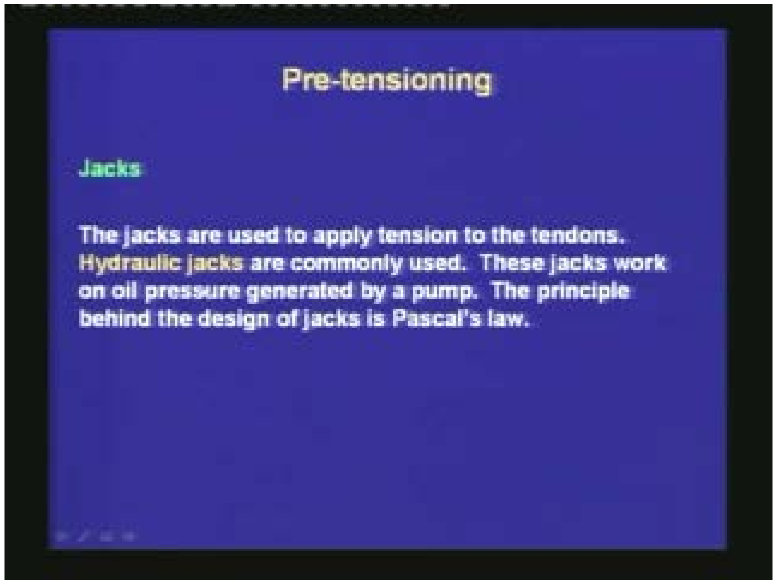

Next, we are moving on to a very important part of the pre-tensioning system: the jacks. The jacks are used to apply tension to the tendons. Hydraulic jacks are commonly used. These jacks work on oil pressure generated by a pump. The principle behind the design of jacks is Pascal's law.

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This figure shows some jacks. Some of the jacks can be single acting, where the piston can move only in one direction while applying the force. Again it has to be retracted back before it can be used to apply force again. The other type of hydraulic jacks is the double acting jacks, where the piston can apply both a pushing force as well as a pulling force. In that type of jack, we have two ports for the oil to move: One port for the oil to enter while the piston moves in one direction and another port for the oil to enter when the piston moves in the other direction. Whether a single acting jack or a double acting jack is selected, that depends upon the situation.

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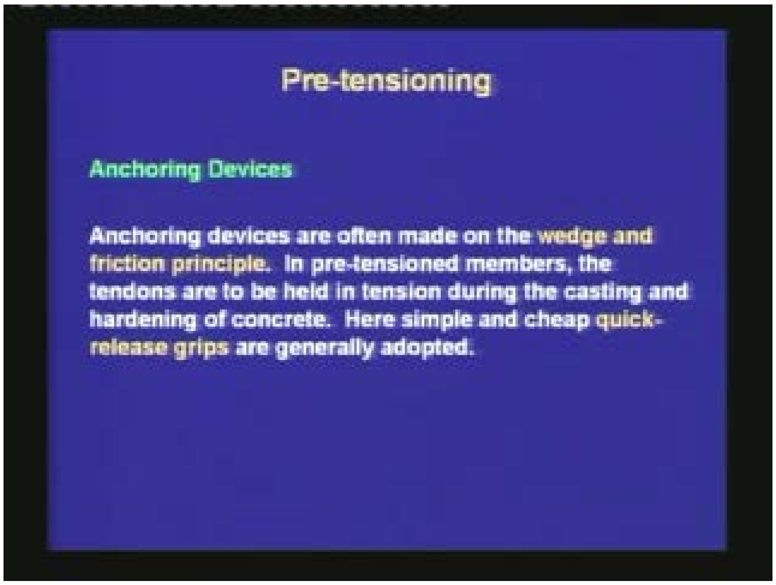

The next important device is the anchoring device. The anchoring devices are often made on the wedge and friction principle. In pre-tensioned members, the tendons are to be held in tension during the casting and the hardening of concrete. Here, simple and cheap quick-release grips are generally adopted.

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Fig 1c-12 Original anchoring device patented by Freyssinet

As compared to post-tensioning, the anchorage device for pre-tensioning is simple. It functions based on the principle of the wedge. The tendons are fixed at the dead end and they are also fixed at the other end to the end plate, which moves due to the pushing of the jack. The fixing is done by wedges. A typical example is shown in the above photograph, where the wedge sits in the barrel gripping the wires; and as the wires are stretched, the wedge holds them in their place.

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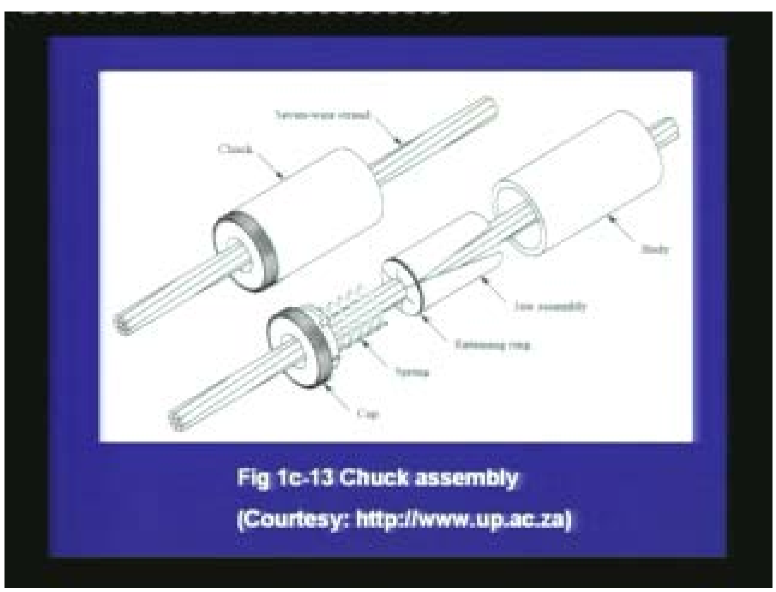

Fig 1c-13 Chuck assembly

(Courtesy: http://www.up.ac.za)

This is another photograph which shows a more complicated anchorage device. This is called the chuck assembly. The strand is held at place by wedges, which is pushed by a spring, and the whole thing is placed inside a body. This type of chuck assembly can be used to anchor the tendons at the dead end or at the stretching end.

The next important device is the harping device. The harping device means that the tendons will be pushed down from its axis, in order to provide some eccentricity to the profile of the tendons.

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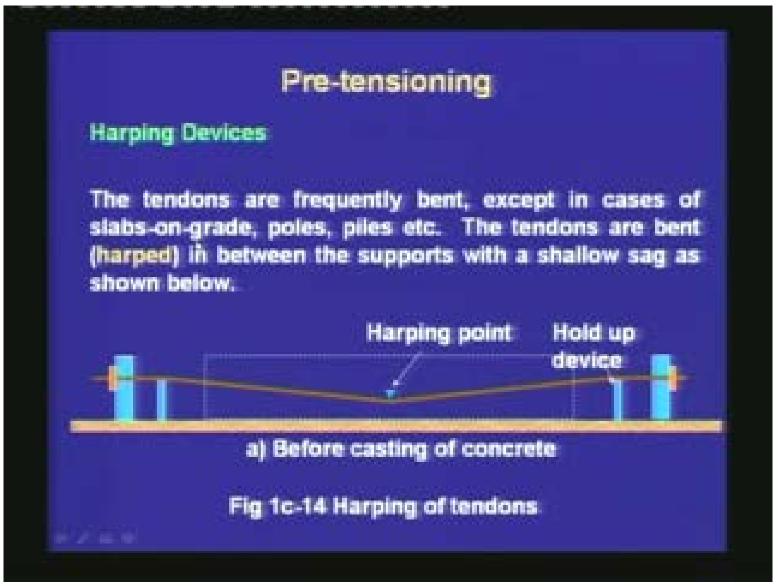

The tendons are frequently bent, except in cases of slabs-on-grade, poles or pipes. The tendons are bent in between the supports with a shallow sag, as shown. In the conventional system without any eccentricity, the tendon runs straight in between the two abutments. But when do we need an eccentricity? For example, in beams the profile of the tendon is altered by a harping device. This device pushes down the tendon, and thus gives a bent profile to the tendon. This bent profile is used to counteract the bending moment that comes later during the service life of the beam. The harping is done by a device which also acts on a jack principle, and it pushes down the tendon at the suitable points.

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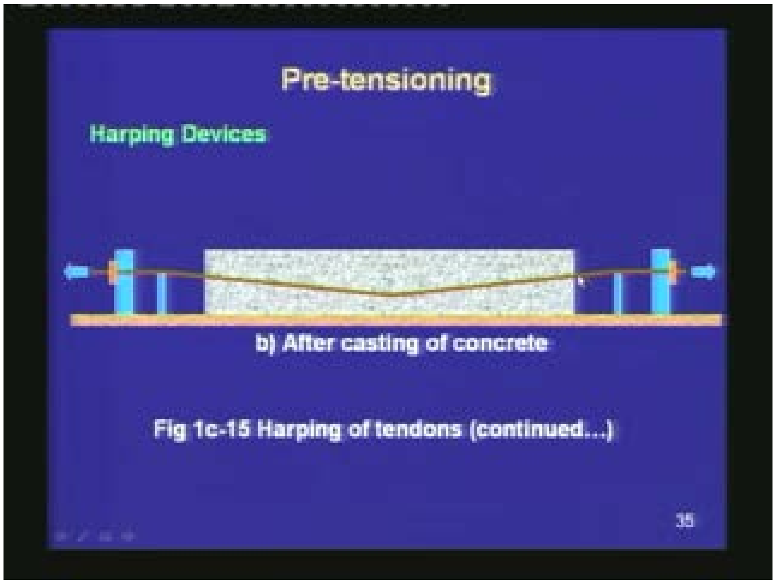

Once the concrete is cast, we can see that the tendon will have a bent profile. This will be beneficial to provide an upward moment, which will counteract the moment that comes during the service life. The harping devices are also patented devices.

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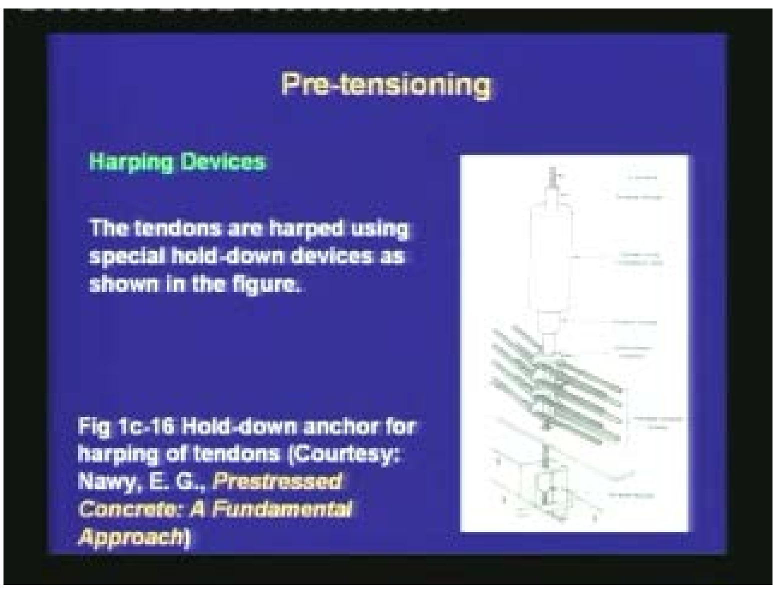

This figure shows a harping device which has some hold-down anchors, which grips the tendons. There is a hydraulic jack which pushes down these hold-down anchors. As the piston of the jack comes out, the tendons get bent at the harping point. There is a transverse tendon also to support the hold-down anchors, and the transverse tendon is fixed by a chuck on the hydraulic jack. Thus, the tendons are harped using a special hold-down device as shown in the figure.

Next, we shall understand the prestressing systems and devices as used in the manufacturing of the railway sleepers. In our last lecture, we had studied about the manufacturing of railway sleepers. I had said that, in order to expedite the process, a travelling stress bench is used.

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This photograph shows the stress bench. First of all, this is a self-equilibrating system; it does not need a foundation or an end abutment. Four sleepers can be cast at a time in this self-straining frame. The mould is placed within the frame. There are some separators which separate the four sleepers. We can see that the tendons are now fixed to the stress bench. There are some plugs which are necessary to fix the anchoring of the railway lines on to the sleepers. First, this stress bench is cleaned, the tendons are placed, and they are anchored at the dead end. Then they are pushed to the location where the concrete will be cast.

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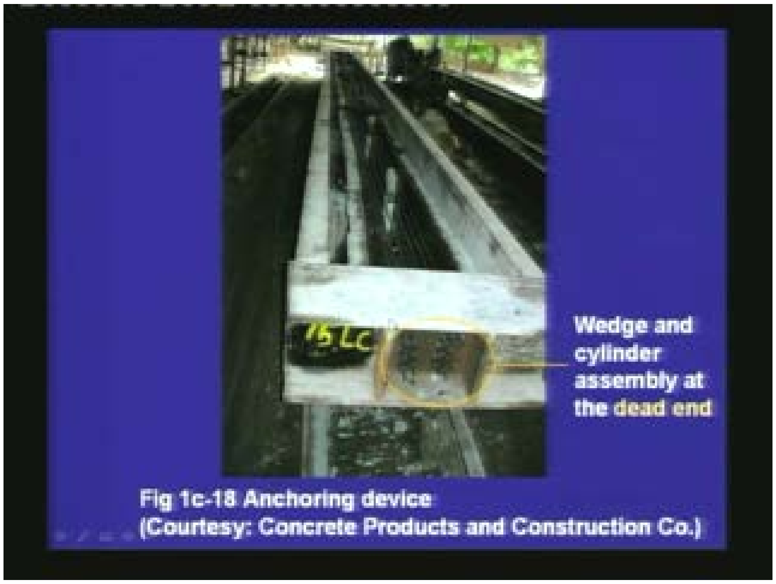

In this photograph, we see that the tendons have been anchored at the dead end; the devices that have been used are the wedges. The wedge grips the tendon at the dead end as the other end is stretched. Once the tendons are gripped at one end, then the tension can be applied at the other end.

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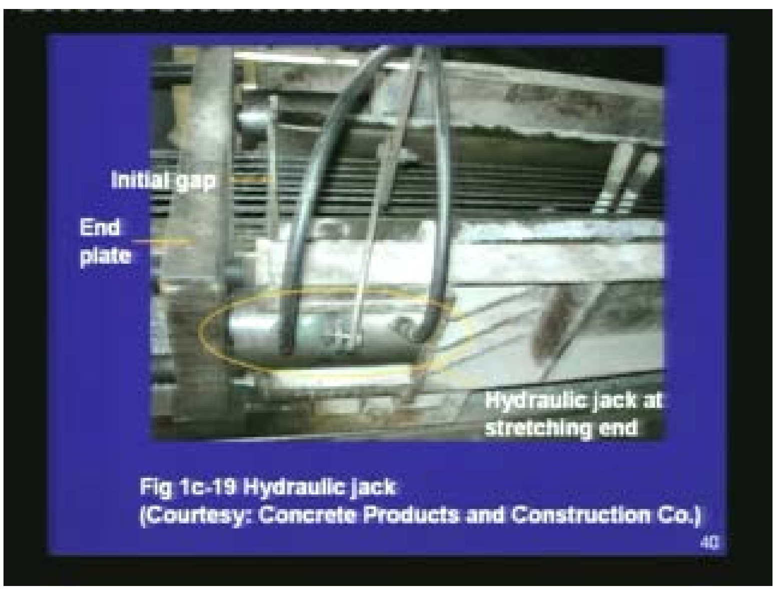

This is the photograph of the other end, where we can see that a jack has been placed. This jack gets the reaction from the self-equilibrium frame itself. This does not need an end abutment, as is necessary if we use a prestressing bed. This jack is a double acting jack. There are two ports, one for each direction of the flow of the oil. The tendons are anchored in an end plate, which can move over the threaded rods. The threaded rods act as guides for the moving of the end plate. You can see that there are two jacks at the two ends, so that the end plate can move parallel to itself as the pistons of the two jacks are pushed out. Usually, the two jacks will be controlled by the same hydraulic equipment so that the movement of the pistons is same for both the jacks. The movement of the pistons is also monitored by a scale at the top, which measures the extension of the tendons as the jacking process is undertaken.

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Once the jack is pumped and the pistons move out, then the distance between the end plate and the mould gets increased.

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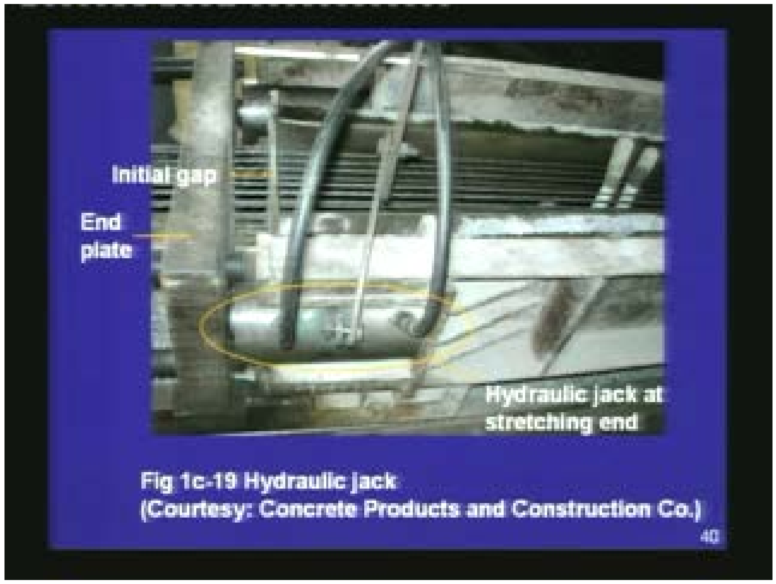

Compare this figure with the previous figure. Here, the initial gap was small. Then as the pistons of the jack are moving out the gap gets increased.

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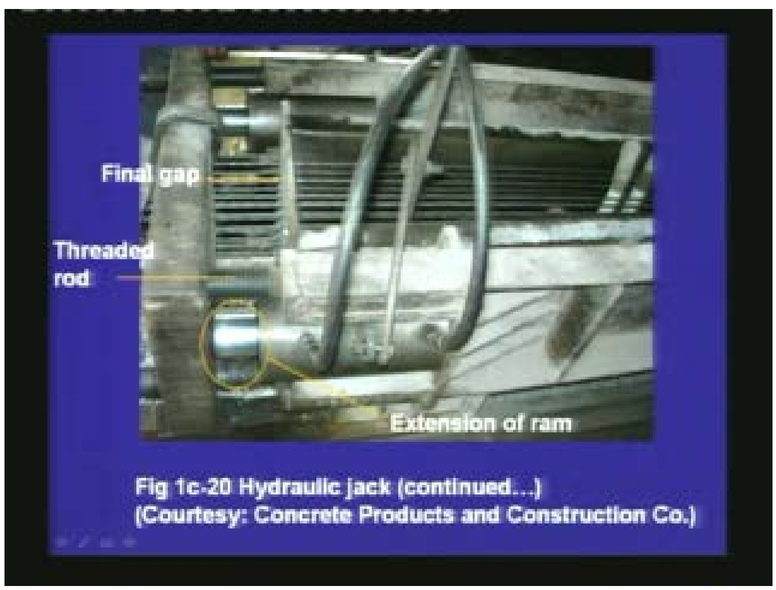

Here, we can see the extension of the ram, and the end plate has moved out; along with it, it has stretched the tendons. Thus, the prestressing has been transferred to the tendons. Once this is stretched, then the concrete can be cast. Once the concrete is compacted, the stress-bench is taken to the curing chamber where it will be cured to gain sufficient strength. Once it has gained the required strength, the tendons will be cut and each individual railway sleeper will be taken out from the mould. By this, the manufacturing process of the sleeper is much faster than a conventional process where only one member can be produced at a time.

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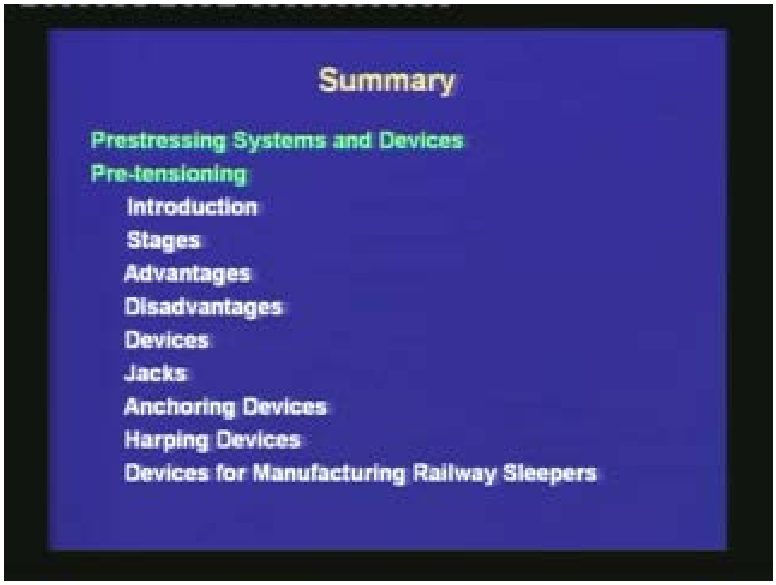

In today's lecture, we learnt about the prestressing systems and devices. As we first came to know that, the prestressing systems and devices are mostly patented by the manufacturers. The devices can be quite different for the different applications. A railway sleeper can have a different type of setup, and electric poles can have another type of setup. Each device is more described in the respective brochures and catalogues. At work, one has to get familiar with the systems and devices from the brochures. In this lecture, we have discussed the systems and devices based on the basic principles on which they function.

First, we discussed about the pre-tensioned members. The difference between a pre-tensioned member and a post-tensioned member is the sequence of the casting of the concrete and the tensioning of the steel. In a pre-tensioned member, the steel is tensioned first. Then the concrete is cast and cured, after which the tendons are cut to transfer the prestress. Whereas in a post-tensioned member, first the concrete is cast and then the steel is stretched. The transfer of prestress occurs by the anchorage device at the end of the members.

In today's lecture, we focused mostly on the pre-tensioned systems. First, we learnt about the stages of pre-tensioning. For a pre-tensioned concrete, first we need a prestressing bed with end abutments. Then, the steel tendons are fixed at one end. Subsequently they are fixed to the other end, which is the stretching end and where the jacks are placed. When the piston of the jack moves out, the tendons are stretched. Once the tendons are stretched, the concrete is ready for casting. Once the concrete is cast, it is compacted and cured to gain sufficient strength. After the curing of the concrete, the tendons are cut and the prestress is transferred to the concrete.

When the prestress is transferred, the member undergoes an elastic shortening. If the tendon has a curved profile or bent profile, then the member will undergo an upward deflection which is called camber. For each stage of the pre-tensioning process, there has to be appropriate control, so that the tension applied is proper. The concrete casted should be without any honeycomb. It should be properly compacted and cured. When the tendons are cut, it is to be made sure that the concrete is having the prestress properly. Thus, the manufacturing of pre-tensioned concrete members has to be monitored adequately for quality control.

Next, we studied about the advantages of pre-tensioning as compared to post-tensioning. In pre-tensioning, we can produce many prestressed members at a time. Thus, pre-tensioning is suitable for mass production of members like railway sleepers, poles or piles. As compared to a post-tensioned member, the pre-tensioning is done at a particular site and it is done in a very rapid process, so that we can produce these structural components in a much faster rate. Another advantage of pre-tensioned members is that we need less anchorage device as compared to a post-tensioned member. In pre-tensioned members, the prestress is transferred by bond over the transmission lengths at the ends of the members. We need some anchorage device for the steel when it is tensioned, but within the member we do not have any anchorage device. Thus, the anchorage devices that are used for one cycle of operation can be reused in the next cycle. Whereas in a post-tensioned member, we need much more anchorage device; the anchorage block stays within the member itself after the prestress has been transferred.

The disadvantages of pre-tension as compared to post-tension is that in pre-tension, we are restricted to have certain equipments like a prestressing bed and the end abutments for the manufacturing process. In post-tensioned member, we do not need these equipments as such because the post tensioning can be done at the site itself.

Next, we moved onto the devices that are used for the pre-tensioning systems. First, we had talked about the stress bed with end abutments. But this system can be costly especially if we have large prestressing force. One way to go about is to use a self-equilibrating system which is called a stress-bench. The idea is analogous to test frames that we see in the laboratories. The frame itself is self-equilibrating, in the sense that the force is not transferred to the foundation. In a stress-bench, the jack gets the reaction from the frame itself. Hence, we do not need end-abutment which reduces the cost.

Another improvement that can be done in the pre-tensioning process is the Long Line or the Hoyer method. There, several members can be cast in one line such that, the same pre-tensioning operation and the casting of the concrete can be done for several members at a time, instead of one member sequentially. Hence, the Long Line method or the Hoyer method is used for the production of sleepers and poles which can be done in a much faster production rate.

Next, we talked about the jacks. The jacks are the equipment that are used for applying the tension in the tendons. Most of the jacks are hydraulic jacks which apply the force based on the principle of oil pressure. It can be a single acting jack or a double acting jack depending upon the application.

The anchorage devices are necessary to hold the prestressing steel at its place. At the dead end, we have one anchorage device and at the stretching end, we have another anchorage device. The anchorage device acts on the principle of wedges which grip the tendons, and retain their position by friction. The other type of device that can be used is the harping device. The harping device is used when we need to provide a bent in the tendons. The tendons can be bent by a push down mechanism, which gives the bends at preferred locations along the length. The harping device can also act on the principle of the jacks. Once the hold-down device moves down, a tendon gets a bend. After the concrete is cast, the profile of the tendon is retained and when the tendon is cut, the member undergoes an upward deflection which is called camber, along with elastic shortening.

We had also seen the manufacturing of railway sleepers. To repeat it once again, let us see the manufacturing which is based on the Long Line Method, using a self-equilibrating system.

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In this photograph, we are seeing the stress bench which is a self-equilibrating system, in the sense that it does not need any foundation. It is a traveling stress bench that is it is placed on wheels which can move over tracks, so that the stress bench can be taken anywhere in the shop. Within the frame there is a mould for casting the concrete; four sleepers will be cast in one line and the sleepers are separated by some separator plates. There are plugs which are subsequently used to fix the railway lines on to the sleepers. For the sleepers, the three-wire prestressing strand has been used. Once the strands are fixed in place, the bench is moved in to the casting yard.

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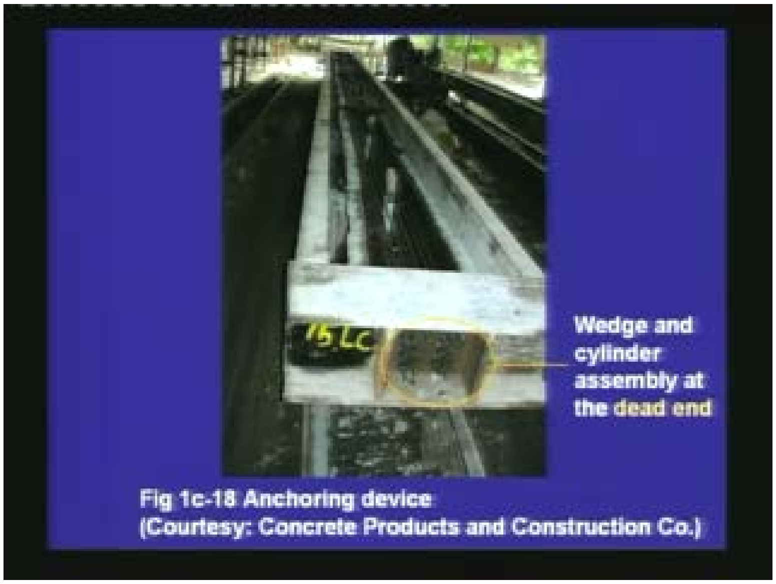

In this photograph, we can see that the anchorage device at the dead end. The anchorage device consists of the chucks, or it can be the simple wedge device. Once the anchorage is fixed at one end, on the other end the jacks are placed and the tendons are stretched.

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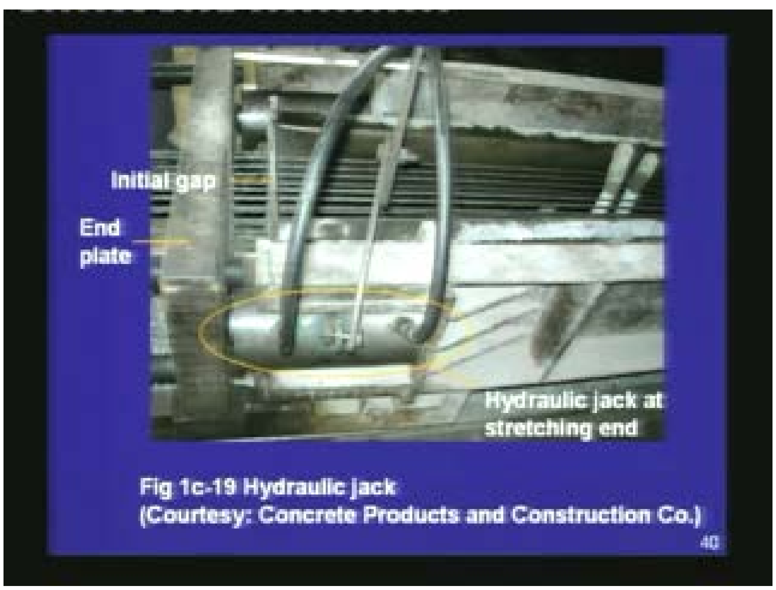

In this photograph, we can see the stretching end where hydraulic jacks have been placed on two sides. Each of the jacks is a double acting jack which is controlled by a single unit, so that the pistons of both the jacks can move together. Now the tendons are fixed at an end plate whose movement is monitored by a scale. Also, how much pressure is being applied by the jacks is monitored by a pressure gauge. The end plate moves over the guide of threaded rods and as the end plate moves out, the tendons are stretched and the prestress is applied to the tendons.

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Fig 1c-20 Hydraulic jack (continued…)
(Courtesy: Concrete Products and Construction Co.)

We can see that the end plate has moved and the gap has increased. Thus, the tension has been transferred to the prestressing strands. Once the prestress is applied to the tendons, the stress bench is ready for the casting of the concrete.

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Fig 1c-21 Material storage
(Courtesy: Concrete Products and Construction Co.)

In this photograph, we can see that the ingredients of concrete are stacked. On the left, we can see the fine aggregate which is the sand. On the right, we see the coarse aggregate which is the gravel. These materials are collected and batched in a plant.

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Fig 1c-22 Batching of materials
(Courtesy: Concrete Products and Construction Co.)

We can see that the batching of the material is being done by an automatic batching system by weight. The cement, water and any admixture are added, and the concrete is mixed in a mixer.

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Fig 1c-23 Pouring of concrete
(Courtesy: Concrete Products and Construction Co.)

Once the concrete is mixed, it is poured onto the mould by a hopper; by this time the two processes of the stretching of the tendons and the mixing of the concrete go simultaneously. The stress bench is brought beneath the hopper and then the concrete is poured in the mould. Here, you can see that the concrete is being poured into the mould within the stress bench, from the hopper which is below the concrete mixer.

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Once the concrete is poured, the mould is vibrated. This vibration can be done externally or there can be internal needle vibrators till the concrete is completely compacted and there are no voids. For prestressed concrete, the concrete has to be of very good quality to sustain the prestress, and hence the compaction of concrete has to be done extremely carefully. After the concrete is compacted, the top of the concrete is finished by a trowel and then the member is ready for curing.

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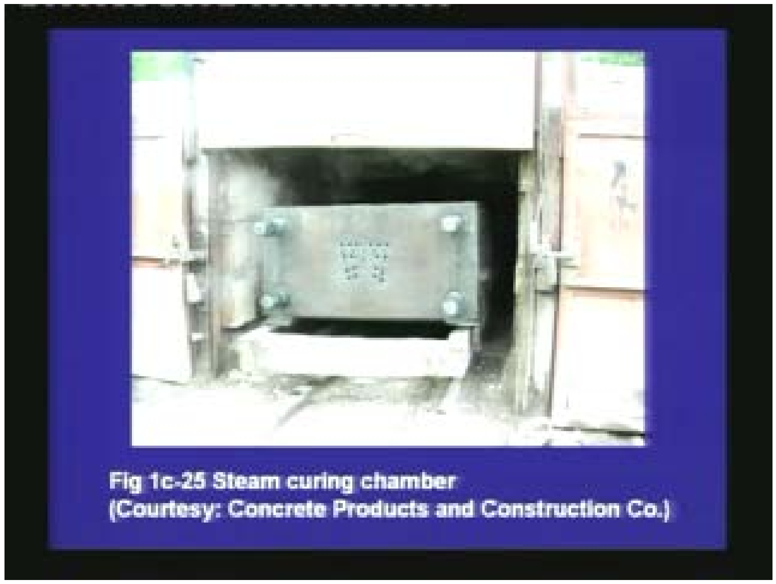

Fig 1c-25 Steam curing chamber
(Courtesy: Concrete Products and Construction Co.)

The mould is taken to a steam curing chamber for controlled curing. Here, you can see that the mould has been placed within the steam chamber for a controlled and accelerated curing. Within 24 hours, the concrete gains sufficient strength for the prestress to be transferred.

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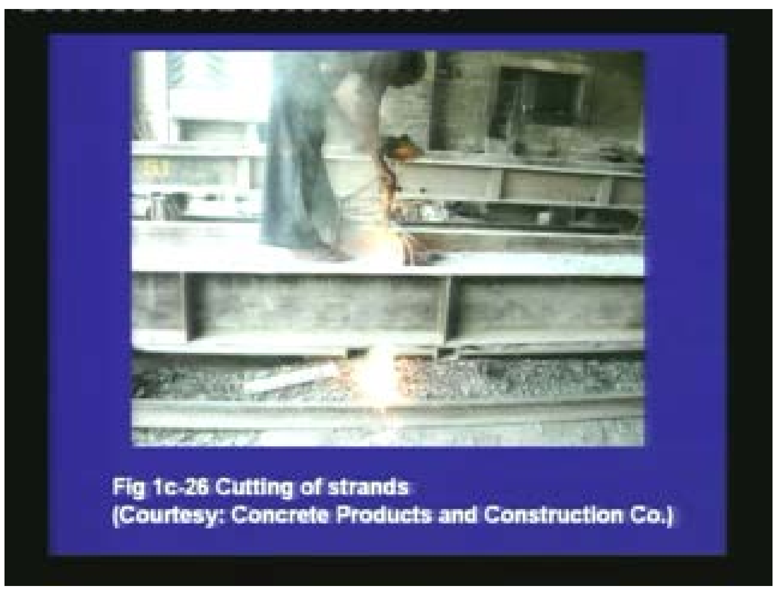

Fig 1c-26 Cutting of strands
(Courtesy: Concrete Products and Construction Co.)

Once the concrete has gained the strength, the mould is taken out and the tendons are cut. From each stress bench, we can get four sleepers because there are four moulds inside the bench. Once the tendons are cut, each individual sleeper can be taken out from the mould.

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Fig 1c-27 Demoulding of sleeper
(Courtesy: Concrete Products and Construction Co.)

In this photograph, we can see that a sleeper is being taken out from the mould. The prestress has been transferred, and the sleeper is now ready for stacking and further curing.

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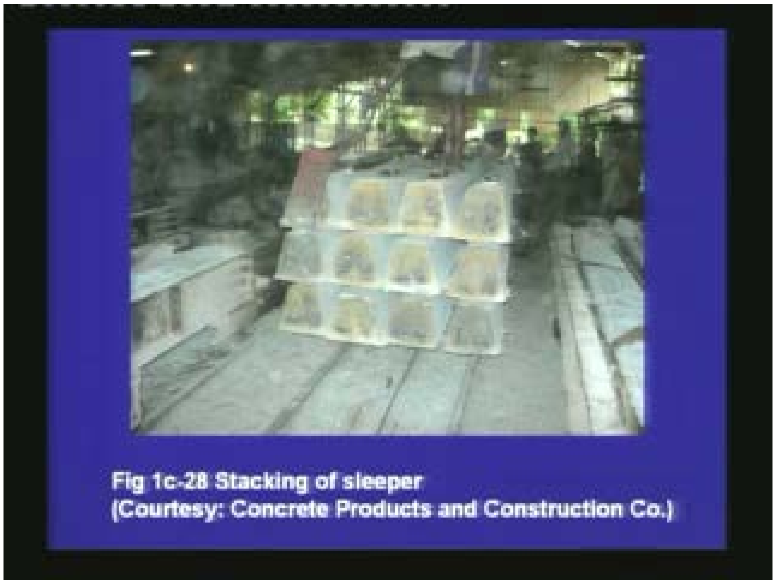
Fig 1c-28 Stacking of sleeper
(Courtesy: Concrete Products and Construction Co.)

The sleepers are now stacked in a conveyer. We can observe that the prestressed tendons have been cut at the end. Thus, the prestress have been transferred to the sleepers. Once these are de-moulded, they are taken for water curing.

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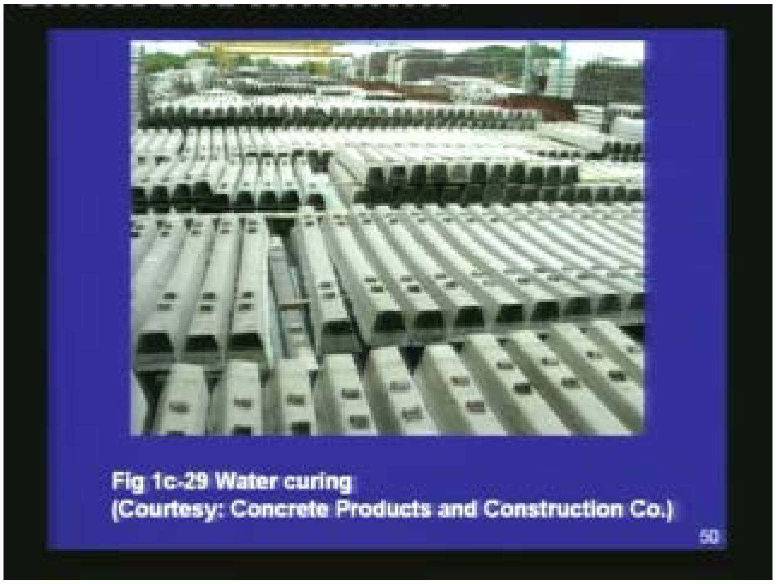

Fig 1c-29 Water curing
(Courtesy: Concrete Products and Construction Co.)

Again, to repeat, the curing of the specimens has to be done in a controlled manner, so that the concrete is of good quality and it attains the desired design strength. In a water tank, they can be cured for a sufficient period that is required to gain the designed strength. Once the curing is over, they are taken out and stacked for shipment.

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Fig 1c-30 Storage and dispatching of sleepers
(Courtesy: Concrete Products and Construction Co.)

In this photograph, we can see that the sleepers have been taken out from the curing tank and have been stacked. From the stack, the crane is picking up the sleepers and placing them on the railway wagons. They are being dispatched to the railways. A prestressed sleeper has a much-extended life as compared to the conventional wooden sleepers.

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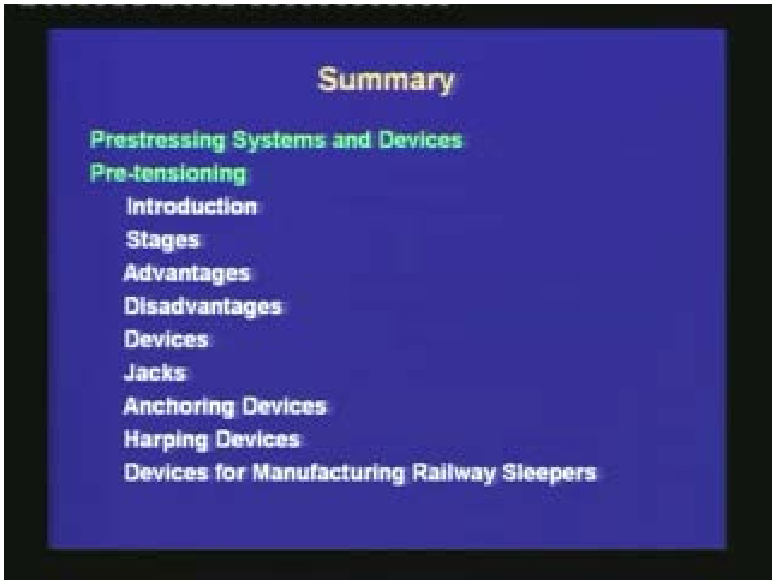

To summarise today's lecture, we have studied in detail the prestressing systems and devices for pre-tensioned concrete. We have learnt that the pre-tensioning system has several advantages as compared to a post-tensioned system. It has certain disadvantages as well. The stages of pre-tensioning system are: fixing the steel tendons, applying tension to the tendons, casting of the concrete, curing of the concrete, cutting the tendons during which the prestress is transferred; then de-moulding the specimens, which can be further cured, and then they are ready for shipment.

The devices that are used are a prestressing bed with end abutments. But this is a more difficult setup if the prestressing force is large. In that case, we can go for a self-equilibrating stress bench. Even to expedite the process, it can be a travelling stress bench that means it can move on rollers. Many members can be cast in one line, which is called the Long Line system or the Hoyer system. The other devices that are required are the jacks. It is the hydraulic jacks which are mostly used for applying the tension on the tendons. Whether it is single acting or double acting, depends upon the situation. We also need anchorage devices to grip the tendons at the ends. The anchorage devices for a pre-tensioned system are simple as compared to the post-tensioned system. They consist of wedges or chuck assemblies; they can be reused for the next set of the members.

We can also have harping devices, which give a bent profile to the tendons. Once the tendons are cut, the members tend to have an elastic shortening and a deflection upwards. We also saw the detailed manufacturing process of railway sleepers, from which we have got an overview of the pre-tensioning process.

In our next lecture, we shall discuss about the systems and devices that are used for post-tensioned members. Then we will be able to appreciate the differences between pre-tensioning and post-tensioning.

Thank you.