CHAPTER 9 - PRESTRESSING

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9.1 SCOPE

This chapter covers the supply and installation of prestressing.

Site Monitoring Staff should read and obtain a sound understanding of the relevant section of the Standard Specification and the Project Specifications before applying this section of the Manual.

This chapter contains a substantial amount of information and requirements which are contained in the specifications. This is provided to assist monitoring staff in understanding "normal requirements": note that this does not take precedence over the specifications.

This section deals mostly with grouted internal post-tensioning, the most common form of prestressing in South Africa. For any of the following systems, refer to the relevant project specifications and specialist literature:

- Pre-tensioning;
- Un-bonded tendons; and
- External prestressing.

Other useful references include:

- Prestress supplier's handbooks

This section is laid out to follow the process encountered on a construction site:

(a) Information provided by the designer;
(b) Prestressing system, materials and equipment;
(c) Contractor's prestressing drawings;
(d) Supplying and storing materials;
(e) Installing prestressing;
(f) Checks prior to prestressing;
(g) Stressing of cables; and
(h) Grouting of cables.

9.2 INFORMATION PROVIDED BY THE DESIGNER

The monitoring staff should check that the following design information is provided to the contractor, usually on the drawings:

(a) Alignment (horizontal and vertical) of each tendon or group of tendons;
(b) Prestressing system on which the design is based;
(c) Tensioning sequence including any partial tensioning;

(d) Tensioning force and force after transfer, expressed in MN and as a percentage of characteristic strength;

(e) Tendon extensions, E-modulus and wedge pull-in;

(f) Friction loss coefficients for friction and wobble;

(g) Elastic factor (This is only really relevant for simply supported structures);

(h) Creep and shrinkage factors;

(i) Relaxation of prestressing;

(j) Anchorage types and positions;

(k) Bursting reinforcement. Note that this is reinforcement supplied in terms of TMH7 Part 3 Clause 4.8.5 and does not refer to the spiral that is required by some prestressing systems to prevent concrete crushing. This latter reinforcement should be detailed by the prestressing supplier;

(l) Precamber at quarter points or closer;

(m) Concrete compressive strength at transfer; and

(n) Type/grade of prestressing steel used in the design.

9.3 PRESTRESSING SYSTEM, MATERIALS AND EQUIPMENT

The site monitoring staff should ensure that the contractor has supplied full details of his prestressing system for approval. This should be received within one month of the tender having been awarded.

For testing of prestressing steel, anchorage assemblies, couplings and grout, refer to the relevant section of the Standard Specification.

9.3.1 Proprietary Prestressing System

The contractor's system should meet the following requirements:

(a) The system should be a proprietary system with a proven track record; and

(b) It should comply with the specifications including BS EN13391. (Note that this document supersedes BS 4447).

9.3.2 Prestressing Strand

The contractor should show that the prestressing strand complies with the relevant specifications. Note that the specifications for prestressing in COLTO 6503 (b) (ii) and (iii) is not in accordance with the latest standards. (These standards have been superseded and some of the strands and bars are no longer available.) Refer to the drawings or project specifications for the latest standards.

The contractor should test the prestressing strand and keep all records of these tests for each batch of prestressing supplied.

The calculation of prestressing extensions should be based on the prestressing cross-section area and the E-modulus determined in these tests.

9.3.3 Prestressing Anchorages

Prestressing anchorages are required to distribute the prestress forces into the structural member without damage. When damage does occur it usually falls into two categories:

(a) Concrete crushing directly behind the anchor: The prestressing supplier should provide details of any reinforcing coils and minimum concrete strength required to prevent this from happening; and

(b) Concrete bursting or splitting: This typically occurs in the zone between 200 and 1000 mm from the anchor. The designer usually designs and details reinforcement to control this behaviour.

When checking the prestressing system, the site monitoring staff should check that both these forms of reinforcement have been detailed and supplied.

9.3.4 Prestressing Sheaths

Prestressing sheaths are required to meet the following requirements:

(a) They should be grout-tight;

(b) Sheaths must enable bond forces to be transferred from the prestressing tendons to the concrete. Sheathing should therefore be deformed on both the outside face and the inside face. Sheathing with only one smooth face should not be used. This applies especially to plastic sheathing;

(c) The sheathing should not react with the prestressing steel to cause a corrosion cell. Metals such as aluminum should therefore not be used. Galvanized sheathing is generally not permitted;

(d) The flexibility of the sheaths should be sufficient to form the required curvature, but should not reach levels where wobble increases friction loss beyond the design limits;

(e) The sheaths should be strong enough to resist handling and prevent damage during placing and vibrating of the concrete; and

(f) The cross-section area of the sheath should be at least twice the area of the prestressing strands. For vertical tendons, this should be increased to three times the area of the strands.

9.3.5 Prestressing Supports

The function of the prestressing supports is to provide the necessary support and secure fixing of the prestressing sheaths at the required position and level. Their design and supply is the responsibility of the contractor.

The supports should comply with the following requirements:

(a) They should be able to carry all loads imposed on them, especially during concreting, without bending or buckling; and

(b) Normal web reinforcement should not be used to support the prestressing.

Prestressing supports typically consist of R12 or R16 reinforcing stirrups with lugs welded on at the correct level. A reinforcing bar is then tied to the tops of these lugs and the prestressing duct is supported on top of the bar. It is sometimes necessary to support the ducts by hanging them under the bar, such as at locations where two ducts pass each other vertically.

9.3.6 Vent Pipes

The function of vent pipes is to release air and grout from the prestressing ducts. Good practice includes the following:

(a) Vent pipes should be provided at least at both ends and at all crests and low points of ducts of multi-span continuous ducts;

(b) The pipes at the crests should be at least 25 mm diameter;

(c) They should be able to withstand a pressure of 15 bar;

(d) They must be fitted with standpipes at least 500 mm long but preferably 1 200 mm or more above deck level. The provision of adequate height is important as it is necessary to provide a "reservoir" to accommodate the bleed water above the cable ducts. This bleed water accumulates because the heavy cement particles tend to settle and move towards the valleys of the duct profile (sedimentation) whilst water and air bubbles collect at the high points (bleeding). Considering that bleeding of 3 to 4 per cent of the volume is not uncommon, it is fairly obvious that several metres of duct at the high points will only be partially filled with grout if no "reservoirs" at a higher level have been provided.

(e) Short, thin plastic vent pipes have in many instances been proved insufficient to serve as effective bleed reservoirs; and

(f) The inclusion of expanding agents in the grout mix does not eliminate the above requirements.

9.3.7 Grout

Grout should comply with the following requirements:

(a) The relevant clauses in the Specification;

(b) Chloride ions in water should be less than 500 mg per litre;

(c) Only CEM I with 15% or less slag should be used;

(d) Aggregate, where used, should be very fine sand or finely ground limestone. Generally, aggregates are not used;

(e) Only approved additives that do not cause damage should be used;

(f) Viscosity and bleeding should be within accepted limits specified in the Standard Specification; and

(g) Cube compressive strength should exceed 20 MPa at 7 days.

Although grout mix specifications are generally performance-based, specifying viscosity, bleeding and strength, good grout usually falls into the following categories:

- The water cement ratio W/C is usually in the range of 0.36 to 0.45; and
- An approved admixture will improve fluidity and reduce bleeding. Air entrainers are often used for this. Although only chlorides are limited in the specifications, admixtures should not contain nitrates, sulphides or sulphites.

9.3.8 Unbonded and External Tendons

Refer to relevant project specifications and specialist literature.

9.3.9 Prestressing Equipment

Prestressing equipment should comply with the following requirements:

(a) Should be able to measure the prestressing force to an accuracy of +/- 2%;

(b) Force should by measured using a load cell (direct reading dynamometer). Note that the hydraulic jack is generally a form of load cell, once its internal losses such as friction are known;

(c) Pressure gauge to be at least 150 mm in diameter and should be used in the range of 50% to 90% for maximum pressure;

(d) The hydraulic circuits should have self-sealing connections;

(e) The tensioning equipment should be calibrated before use and at frequent intervals thereafter. The contractors should provide the calibration certificates; and

(f) Extension of tendons should be measured to +/- 2% or +/- 2 mm, whichever is more accurate.

9.3.10 Grouting Equipment

Grouting equipment should comply with the following requirements:

(a) The mixer should be mechanically operated;

(b) The screen should have openings not exceeding 1 mm;

(c) Where the mixer is too small to fill the duct on one mix, a mechanical agitator should be used;

(d) The grout pump should be of the positive displacement type capable of at least 10 bars of pressure;

(e) The grout pump should have a pressure gauge to ensure that the grouting pressure is at least 10 bars/1 000 kPa;

(f) There should be a safety device to prevent the grout pressure exceeding 20 bars; and

(g) The hydraulic circuits should have self-sealing connections.

9.4 CONTRACTOR'S PRESTRESSING DRAWINGS

The contractor is required to prepare and submit prestressing drawings. These should be received at least two months prior to commencing prestressing work, and should be checked for the following:

(a) Layout and alignment of individual tendons;

(b) Details of cable supports;

(c) Modifications to bursting and other reinforcement. Note that spirals directly behind the anchor to control concrete crushing are NOT bursting reinforcement. These spirals must be detailed by the prestressing supplier;

(d) Anchorage recesses;

(e) Tensioning sequence;

(f) Tensioning loads and extensions, based on the measured prestressing areas and E-modulus;

(g) Wedge pull-in; and

(h) Each tendon should be separately numbered for identification.

Photo 9.1: Reinforcement at prestressing anchor. The spiral behind the anchor is detailed by the prestressing supplier while the clips are detailed by the designer. Note that the clips should be anchored around a bar of its own diameter.

The site monitoring staff should check the contractor's prestressing drawings for any clashes of transverse and longitudinal cables with each other or with reinforcement, especially at the anchors.

9.5 SUPPLYING AND STORING MATERIALS

Prestressing supplied to site should comply with the following conditions:

- Prestressing strand is supplied to site in coils of large diameter in such a way that they are protected against damage or corrosion;
- If corrosion inhibitor is used, it should not affect the steel, grout or concrete and it should not affect the bond between steel and grout or concrete;
- The prestressing should ideally be free of rust but some light surface rust that is not flaking could be acceptable. This however may increase the friction losses;
- The depths of imperfections or pits should be less than 0.1 mm on wires and 0.2 mm on bars; and
- Prestressing should be weld-free. Where prestressing has been welded to assist in handling, the welded portions should be cut out.

Prestressing bars, wire or strand should be stored under roof and off the ground to minimize the formation of rust that can reduce the strength. In locations close to the coast, prestressing should be stored in an enclosed shed.

The contractor should provide copies of the test certificate of each cheese of prestressing strand to be used as well as the delivery note with the cheese numbers. (A cheese refers to a role of prestressing strand, usually supplied in a steel frame or on a wooden drum.) The Contractor must also provide at least a 2 meter length of strand from each cheese that will be used. This should be colour-coded and properly marked with the cheese number so that one can easily determine which strand is placed in which duct.

Photo 9.2: Storing of cheeses of prestressing strand: Prestressing should not be stored as shown in the photograph

9.6 INSTALLING PRESTRESSING

> **BEWARE**
> No welding operations should take place close to prestressing as even minor contamination from hot weld splatter may cause rupture of the wire during tensioning.

Prestressing should not be exposed to heat treatment on site. Prestressing strand or bars should be cut using cutting disks, and should not be flame-cut or cut with a welding torch.

All materials including prestressing, anchorages and sheaths should be clean and free from loose mill scale, loose rust and other harmful matter.

9.6.1 The Use of Soluble Oil

The prestressing strand should be free of sand and rust and as clean as possible before being placed in the ducts in order to minimise friction during stressing. Flushing the cable with clean water before stressing will help. However, if sand particles do get stuck in the hollows of the duct, it may be impossible to remove them. If necessary the ducts can also be flushed with soluble oil, which must then be washed out with clean water before grouting. Note that the use of a detergent for flushing should not be allowed since it is more difficult to remove than the oil. It is recommended that the ducts be flushed out twice using fresh water as it has been found that if ducts are flushed out the day before grouting occurs, more oily solution (green) will be visible in the water the next morning because more oil comes loose overnight.

9.6.2 Prestressing Hangers or Supports

Hangers and supports on which to position the prestressing ducts should be formed to the correct dimensions before being put in place. The Contractor should not be allowed to do welding on these once in place with the prestressing cables. The ducts should be securely tied to the hangers to prevent displacement during casting.

9.6.3 Pulling/Shooting Through of Strand

In some cases such as in incrementally launched bridges, the empty ducts are cast into the concrete and the strand is only inserted afterwards. Before concreting, the ducts need to be checked for holes and dents. All the joints also need to be properly sealed, and special attention paid to the connections between the ducts and anchors.

Once the concrete is cast, the ducts need to be checked to ensure that they have not been blocked by concrete paste that may have entered a hole in a damaged duct. This can be done in a number of ways including flushing the duct with water.

The strand can either be pulled into the prestressing duct as a group, or the individual strands can be shot through. For both systems, care must be taken to ensure that the strand stays absolutely clean. No sand must enter the duct as this increases friction.

Shooting strands through ducts with many low and high points has caused problems in the past. For example, when shooting strands through a three-span deck, the strands become intertwined, making shooting further strands difficult. It also gives a force-extension curve that is not straight. In these cases, it is better to pull the strands through as a group.

9.6.4 Wedges and Swages

On placement, wedges should be oil free on the inside to prevent slippages from occurring. Wedges should be clean on the outside to allow movement between the wedge and the anchor. The wedges should be knocked tightly in place with a piece of metal tubing so that they grip the strand equally.

Crimped wedges or swages are often used at dead ends and couplers. It is very important to make sure these are installed the right way around, the teeth pointing against the direction of stressing, since it is virtually impossible to rectify a swage which fails during stressing without de-tensioning the whole cable. A failed swage, if not identified during stressing, will also lead to over-stressing of the remaining strands.

Photo 9.3: Seating prestressing wedges: This is best done with a tube around the strands rather than as seen in the photograph

9.6.5 Prestressing Ducts

It is important to check that the prestressing cables are laid to the specified profile. In case of simply supported beams it is sufficient to check at midspan, at the anchorages and also at quarter-points. Between these points the cables should follow a smooth parabola which can be easily judged by eye.

In the case of skew slabs, whether simply supported or continuous, and of continuous beams or slabs, more careful checking of the profile is necessary. Here the cable positions must be checked at all supports (high points), at centre of all spans (low points), at the points of contraflexure, and at the anchorages. A few random checks at other intermediate points are advisable.

The cable profile in relatively thin slabs (150mm to 250mm), e.g. deck slabs of box girders, must be fixed and checked with the utmost care. Allowance must be made for the fact that the centroid of the wires or strands do not coincide with centre-line duct.

The permissible tolerance in placing the cables should comply with the Standard Specification.

The prestressing ducts must not move during concreting, either due to the weight of the concrete or due to buoyancy. If it is possible to push the duct around with one's foot or deflect it appreciably, the duct should be considered inadequately fixed.

Prestressing cables must enter the anchorages at right angles and approximately the last 1 000 mm of cable before the anchorage or cone (trumpet) must be straight. Therefore anchorage recess formers such as wooden wedges or boxes and polystyrene must be cut and fixed to the formwork with the utmost care.

9.6.6 Check Prestressing Ducts After Concreting

Immediately after concreting, the contractor needs to show that the ducts are clear and that concrete paste has not entered any of the ducts. This can be done by flushing the duct with water or by checking the movement of the strand within the duct. While the paste is still weak within the first two hours of hardening it is relatively easy to remove the blockage. If the blockage is left for several days, it may be necessary to break into the duct to clear it, or abandon the duct.

9.7 CHECKS PRIOR TO PRESTRESSING

Prior to prestressing, all the various details and information regarding the prestressing system should have been submitted by the contractor, as previously stated in 9.3. These must be reviewed to confirm that the contractor has shown that his system fully complies with the specifications and drawings. Prestressing may not start until the site monitoring staff have given their approval.

The contractor should provide a stressing programme so that the site monitoring staff can have the opportunity of monitoring the prestressing operation. In this, the contractor should confirm that the jacks, dial gauges and pumps are in working order and calibrated and that the pressure grouting equipment is also in working order. The programme should also state at what age of the concrete stressing should commence and that the cube-testing machine will be in working condition at the anticipated day of stressing.

> **NOTE:** Prestressing is the pre-compression of concrete, and can only be fully achieved if the concrete member is allowed to shorten.

Timber formwork does not restrain this shortening appreciably, but steel formwork can have undesirable effects. Sideforms, especially if made of steel, should therefore be stripped prior to stressing. Steel soffit formwork, particularly in case of slab superstructures, must be able to shorten without restraining the concrete excessively.

Similar considerations also apply to the staging supporting the formwork, but are generally only relevant in the case of longer superstructures.

Monitoring staff should also check that bearings are free to move in order to accommodate the movements which occur during the elastic shortening of the superstructure. This applies especially to bearings which have temporary fixity such as transportation brackets.

Additional concrete test cubes should be manufactured and tested just prior to stressing to confirm that the concrete has reached adequate strength (usually 35 MPa is required). Lower strengths may lead to concrete crushing behind the anchor and concrete cracking and splitting.

Photo 9.4: Crack in end of precast beam: The effect of the prestressing causing the beam to hog with all the self weight being carried by the ends combined with the beam not being able to slide on the casting bed has caused the end of the beam to crack. Ideally the bed supporting the end of the beam should be sufficently compressible to relieve the high end pressures.

9.8 STRESSING OF CABLES

The stressing operation should be done in increments and the calculation of results done continually to avoid over-stressing of a strand. Before starting, the strands protruding from the anchor should all be marked at the same distance from the anchor, or all cut to the same length, in order to see if slippage occurs.

During stressing the cable extension and the tensioning force should be carefully measured and recorded to check that there is acceptable agreement with the predicted values. The accuracy with which the extension should be measured should be in accordance with the specifications. The gauge pressure versus extension should be plotted on graph or squared paper during the prestressing operation in order to identify changes in slope which may indicate blockages which come free or strands breaking or slipping.

WARNING

Prestressing is a potentially dangerous operation as there is the possibility that strands or wires break, wedges fail, hydraulic hoses burst or come loose, concrete behind an anchor can burst, a curved duct can pull out of the concrete, etc. The contractor should include his prestressing operations in his Occupational Health and Safety Plan. This plan should include requirements that only the necessary personnel are allowed in the immediate vicinity of a prestressing operation and no one (including site monitoring staff) should stand behind the prestressing jack during stressing.

In the case of strange or anomalous prestressing results, the piece of strand that represents the cheese from which the prestressing strands were taken, can be sent away for testing if necessary. Note that the Contractor should keep a record of which cheese is used in which duct and provide the monitoring staff with this information. As far as possible, strand from different cheeses should not be placed together in the same cable. If this happens, the weighted averages of the modulus of elasticity and area values should be used in the calculations.

If the actual cable extension is excessively larger than the calculated value and falls outside the allowable range of variation, then the following checks should be carried out immediately:

(a) Check the accuracy of pressure gauge;

(b) Check the actual E-modulus of steel verse the assumed one in extension calculations;

(c) Check for damage or distortion of anchorages; and

(d) Check for indications of single wire or strand fracture.

The following remedial measures can be applied:

If, after correction for the first two items, the variation is within allowable limits, the prestressing can be accepted.

If on the other hand the discrepancy is still out of specification and no evidence of faulty anchorages or fractured wires can be found, then a very low friction and a minus tolerance in wire diameter is likely. In this case the cable should be released and locked off at the specified force.

If damage to anchorages or fracture of wires or strand has been established, the cable should be completely de-tensioned, the extent of damage investigated and remedial action proposed by the contractor. In the interim stressing of the remaining cables may proceed.

If the actual cable extension is much less than the calculated one (say -8% and less), then check the following:

(a) Actual and assumed E-modulus as above; and

(b) Tolerance in cross-sectional area of the wire.

The following remedial measures can be applied:

If, after correction for the above two items, the discrepancy falls outside allowable tolerances, then excessive friction or blockage in the duct must be suspected. In this case it is prohibited to increase the cable force in order to obtain the calculated extension. Instead, the cable should be completely released and re-stressed (twice if necessary) and the extension measured again. If the extension now falls within tolerance, the cable can be accepted. However, if there is no marked improvement then the duct should be flushed with water-soluble oil, the cable released and re-stressed again. If the extension now falls within tolerance, the duct should be repeatedly flushed with water to remove the oil, and then accepted.

If, after the remedial work, the extensions do not fall within allowable tolerances, they should be referred to the design office to check the implication on the structure.

Tensioning at Both Ends:

The designer's drawings often require that cables in long beams and continuous superstructures be tensioned from both ends. If both ends are stressed simultaneously, it is almost impossible to get a straight force-extension curve. This straight curve can only be achieved if both jacks start simultaneously and work at the same rate of increase of force. The stressing force diagrammes in Figure 9.1 illustrate the problem.

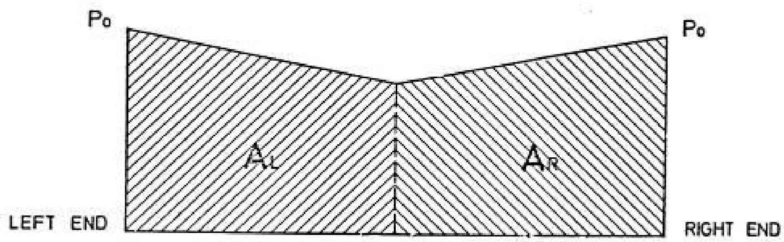


FIG.1. Identical rate of increase of force.

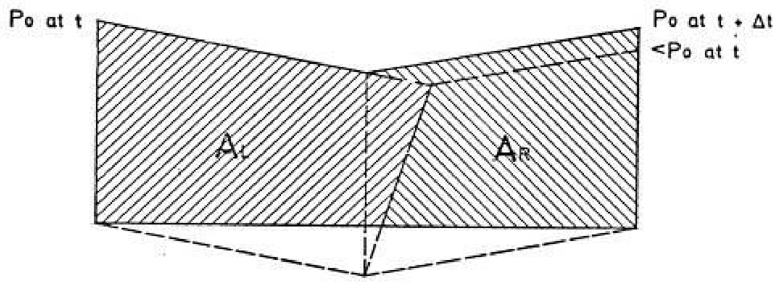


FIG.2. Right jack slower but catching up whilst left jack held.

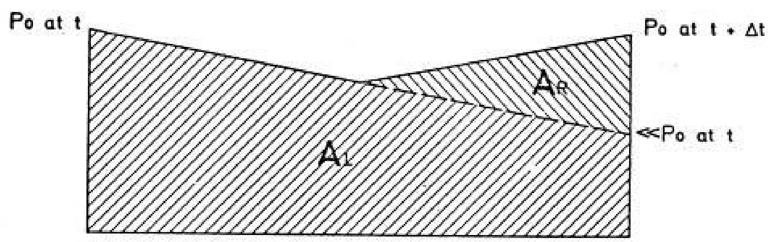


FIG.3. Stressing left end first, then right end.

Figure 9.1: Stressing tendons from both ends

In Figure 9.1, the cable extension at each end is the appropriate area (hatched AL of AR) under the force diagram divided by AS x ES, i.e.

$$\Delta\ell = \int_0^x \frac{P_x \, dx}{A_s E_s} \quad \therefore \quad \Delta\ell_L = \frac{A_L}{A_s E_s} \quad \& \quad \Delta\ell_R = \frac{A_R}{A_s E_s}$$

This does not include the additional extension due to the elastic shortening of the concrete, which has only to be considered if all cables are stressed in one operation.

In FIG.1 both ends are stressed simultaneously and exactly the same rate. This is the ideal situation but does not happen in practice.

FIG.2 shows what is more likely to happen: One jack is faster than the other and the extensions at the two ends are quite different from each other.

It could be shown that if one jack gains force about 10% faster, the extension of that end will be about 60 to 70% of the total instead of the theoretical 50% with a corresponding low value at the other jack, depending on friction loss and length of member. However, the final force diagramme will nevertheless be as assumed in design. Irregularities of friction losses are, of course, not considered in the above.

Because of this, it is recommended that stressing be done from one side at a time. This is shown in FIG.3 of Figure 9.1. The force-extension curve at the first side, plotted as the cable is stressed, will behave normally and the normal procedures for checking and calculating apply. The plot should be straight.
The extension at the second side will be quite different. Initially, only the extension in the jack will be measured. In other words, the only cable that will stretch is that length between the wedges at the anchor plate and the wedges at the back of the anchor.

The wedges at the anchor will only lift off once the force in the jack is greater than the force in the cable at the anchor caused by the first stressing plus any force needed to overcome the friction of the wedges. This wedge friction could be quite high, resulting in the dial measuring the jacking force climbing up quite quickly and then jumping down as the wedges lift off. Only after this will the cable in the deck start extending. The plot of extension will not be a straight line because initially the extension only causes an increase in cable force over a short distance from the jack, extending further along the cable as stressing progresses. The plot will therefore follow a convex curve.

The plotted readings should always follow a smooth curve. The force-extension can easily be pre-calculated using a spreadsheet and then checked on site for conformity.

Photo 9.5: Broken prestressing wires due to prestressing wedges being too hard and damaging the strand

Failure of wedges or wires:

After stressing, the monitoring staff should check that all of the cables are properly prestressed. This includes checking for:

- Broken wires: This is shown if Photo 9.5. When this happens, the other wires will slip past the broken wire as tensioning continues, leaving the end of the broken wire sticking out beyond the ends of the other wires;
- Wedges which have not seated properly: Here it can be seen that the three sections which make up each wedge have not pulled in uniformly. Instead, one section is sticking out relative to the others; and
- Wedges have not gripped the strand properly: This can be seen when looking at the ends of the strands after prestressing. Before prestressing, the strands are all marked at one spot, either with a hacksaw blade or with spray-paint. After prestressing, these marks must extend by the same amount. If one has not extended as much as the others, the wedges on this strand have slipped.

Stressing members on "Elastic" staging:

In some situations where a member is supported on high formwork, the staging shortens elastically as the member is cast. When the member is stressed, it lifts the member and transfers the weight to the bearings or piers. If the elastic shortening is greater than the amount by which the prestressing lifts the member, then under full prestressing, the full self-weight will not be acting. This has led to the member cracking due to tension.

In situations like this where members are on "elastic" staging, common practice is to partially release the props after applying about 65% of the prestressing.

9.9 GROUTING OF CABLES

The importance of the grouting operation cannot be overemphasized. The grouting of cable ducts entails the complete filling of the ducts with a suitable grout mixture to ensure bond and, above all, corrosion protection of the prestressing wire or strand.

A major problem that has affected prestressing in bridges is corrosion occurring behind the anchors, at construction joints in segmental construction and at voids in the grout. This seriously weakens the prestressing after several years. The problem was found to be so severe that some authorities in England did not allow internal prestressing for many years. This extreme action was taken because prestressing corrodes very rapidly under stress and tends to fail suddenly without prior warning. Prestressing can also fail without oxidation due to embrittlement by nascent hydrogen – this is associated mainly with galvanizing.

Cable ducts should be grouted as soon as possible after tensioning of the steel, generally within seven days. If, for structural reasons, grouting has to be delayed for more than seven days, temporary protection of the prestressing by methods or products which will not affect bond or durability, should be used, e.g. flushing of the ducts with water soluble oil.

General practice for grout mixing is as follows:

- The cement should be added to the water in the mixer drum;
- The mixing time should be at least 4 minutes.
- Admixtures should be added 2 or 3 minutes after commencement of mixing.

It has become common practice to use an admixture in prestressing grout, or even proprietary grouts. These generally contain corrosion inhibitors, plasticisers and retarders. Bleeding is also significantly less.

On completion of concreting, all cable ducts should have been flushed with water to detect and remove blockages which may have occurred due to duct leakages. The water must immediately thereafter be blown out with compressed air. Prior to grouting this procedure should be repeated, this time in order to wet the surfaces of the tendons and ducts. If this is not carried out sufficient water may be extracted from the advancing head of grout to cause thickening of the grout and blockage of the duct. Drainage or grout injection pipes at low points of ducts, if provided, should be opened to drain excess water in the ducts.

The ideal grout injection points are the low points of the duct profile. However, most prestressing systems have a grout injection nozzle hole in the anchorage. Injection should be slow enough to prevent segregation (say 6 to 12m per minute) and should be continuous. As injection proceeds, diluted grout or even clear water will first issue from successive bleeder tubes (stand-pipes) and at the far-end vent opening. This occurs due to water trapped in the corrugations of the ducts which usually cannot be entirely removed by compressed air. As soon as grout of normal consistency emerges at the intermediate vents these should be closed. When normal grout flows from the end-vent, this should also be closed and finally all vents hermetically closed and the grouting pressure increased to 10 bar prior to closing the injection nozzle.

> **NOTE**
> Vent pipes must be closed (or clamped) at the upper end of the pipe, (not near the bottom) to give space for the bleed water to migrate.

After about 1½ hours the grout level in the standpipes should be checked. If the grout has settled below deck level, regrouting or perhaps topping up is necessary. Re-grouting should commence while the grout is still fluid but not later than 2 hours after the first grouting and care must be taken that the hose from the pump does not contain any air when reconnected. The grout mix also needs to be modified to reduce bleeding.

In case of hold-ups, e.g. break down of grout mixer, the grout may be used if it is not older than ¾ hour (½ hour in hot weather) and must be remixed.

If a blockage occurs during grouting, the duct must be flushed out immediately with water and preferably in the opposite direction. Pumps developing a pressure of 10 bar are likely to be required.

Grouting During Low Temperatures:

In frosts, standing water in the cable ducts must be avoided. If the temperature is less than 5°C, grouting should be delayed. If, however, particular circumstances require that grouting be done or continued under such conditions, special precautions should be taken. The ducts should be flushed with warm water having a temperature not exceeding 50°C until it is likely that the concrete around the ducts has a temperature of at least 5°C. Thereafter the water should be blown out with compressed air. Warm water should be used in the grout mix such that the temperature of the grout prior to injection is about 25°C. Alternatively a frost-proof grout containing a certain proportion of entrained air (generally 6 to 10%) may be used.

If the temperature is likely to fall below 2°C within 48 hours after injection, the member should be protected to avoid frost effects.

After grouting, the anchorages will be enclosed to ensure that they cannot corrode.

INDEX TO APPENDICES

CONTRACTOR'S PRESTRESSING DRAWINGS CHECK LIST

CONSTRUCTION MONITORING CHECKLIST

PROJECT NO. / NAME: ....

INSPECTOR'S NAME(S): ....

STRUCTURE: .... **ELEMENT**: ....

ACTIVITY AND DETAILS	**APPROVAL**			**SIGNED**	**DATE**
	Y/N	N/A	Comment		
1 Prestressing system is a proprietary system					
2 Complies with the relevant specifications (BS EN 13391)					
3 Prestressing strand complies					
4 Prestressing supports comply					
5 Vent pipes comply					
6 Grout mix design complies					
.7 Grout equipment complies					
8 Prestressing equipment complies					
9 Contractor's drawings contain the required information					
10 Spacing and type of cable supports comply					
11 Designer has reviewed changes to the original design					
12 Prestressing bursting reinforcement, where required, is detailed and does not conflict with other reinforcement					

**PRESTRESSING CHECK LIST:
PRIOR TO CASTING CONCRETE**

CONSTRUCTION MONITORING CHECKLIST

PROJECT NO. / NAME: ....

INSPECTOR'S NAME(S): ....

STRUCTURE: .... **ELEMENT**: ....

ACTIVITY AND DETAILS	APPROVAL			SIGNED	DATE
	Y/N	N/A	Comment		
1 Prestressing system has been approved					
2 Prestressing ducts are to line and level					
3 Prestressing anchors are installed at correct angles					
4 Prestressing ducts are firmly tied and watertight					
5 Prestressing vent pipes are installed correctly and are of correct size and length					
6 Bursting reinforcement is correctly installed					

PRESTRESSING CHECK LIST:
PRESTRESSING OF TENDONS

CONSTRUCTION MONITORING CHECKLIST

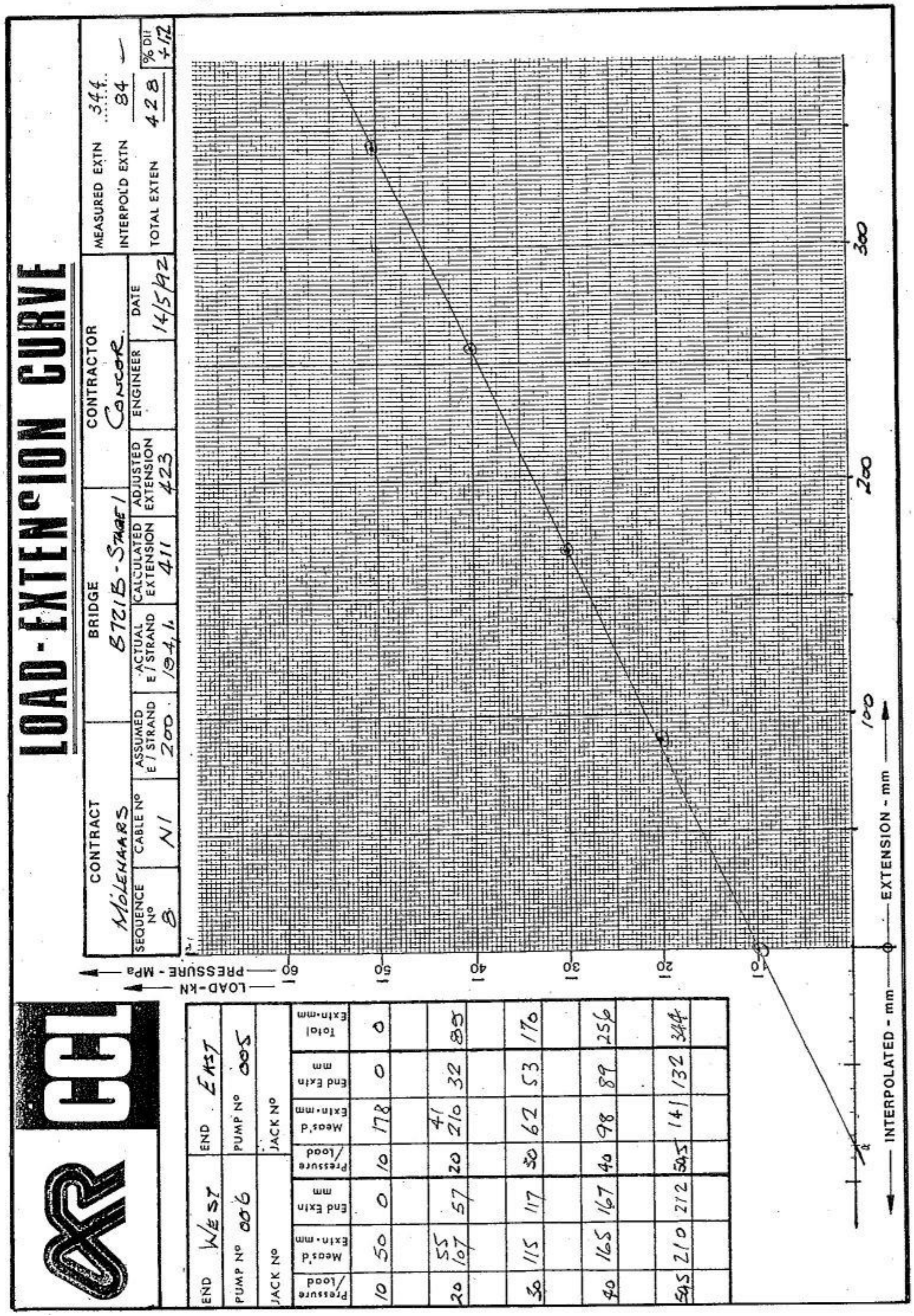
PROJECT NO. / NAME: ....

INSPECTOR'S NAME(S): ....

STRUCTURE: .... **ELEMENT**: ....

ACTIVITY AND DETAILS		**APPROVAL**			**SIGNED**	**DATE**
		Y/N	N/A	Comment		
1	Prestressing system approved					
2	Pre-concrete check approved					
3	Ducts have been checked after concreting					
4	Correct number of strands in each duct					
5	Calculated prestressing load cell readings and cables extensions approved					
6	Prestressing programme approved					
7	Structure is free to shorten under prestressing					
8	Bearing temporary fixity has been removed where required					
9	Concrete has reached the required strength					
10	Prestressing equipment complies and is calibrated					

PRESTRESSING RECORD - SAMPLE



LOAD-EXTENSION CURVE

CONTRACT		BRIDGE		CONTRACTOR		MEASURED EXTN	344
MÓLENAARS		B721B-STAGE 1		CONCOR		INTERPOL'D EXTN	84
SEQUENCE Nº	CABLE Nº	ASSUMED E / STRAND	ACTUAL E / STRAND	CALCULATED EXTENSION	ADJUSTED EXTENSION	ENGINEER	DATE
8	N1	200	194,1	411	423		14/5/92

TOTAL EXTEN	% Dif
428	+1,2

END West			END East			
PUMP Nº 006			PUMP Nº 005			
JACK Nº			JACK Nº			
Pressure /Load	Meas'd Extn-mm	End Extn mm	Pressure /Load	Meas'd Extn-mm	End Extn mm	Total Extn-mm
10	50	0	10	178	0	0
20	55 107	57	20	41 210	32	85
30	115	117	30	62	53	170
40	165	167	40	98	89	256
54,5	210	212	54,5	141	132	344

1.3 Pre-tensioning Systems and Devices

This section covers the following topics.

- Introduction
- Stages of Pre-tensioning
- Advantages of Pre-tensioning
- Disadvantages of Pre-tensioning
- Devices
- Manufacturing of Pre-tensioned Railway Sleepers

1.3.1 Introduction

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 brochures published by companies. There are general guidelines of prestressing in **Section 12** of **IS:1343 - 1980**. The information given in this section is introductory in nature, with emphasis on the basic concepts of the systems.

The prestressing systems and devices are described for the two types of prestressing, pre-tensioning and post-tensioning, separately. This section covers pre-tensioning. Section 1.4, "Post-tensioning Systems and Devices", covers post-tensioning. In pre-tensioning, the tension is applied to the tendons before casting of the concrete. The stages of pre-tensioning are described next.

1.3.2 Stages of Pre-tensioning

In pre-tensioning system, the high-strength steel tendons are pulled between two end abutments (also called bulkheads) prior to the casting of concrete. The abutments are fixed at the ends of a prestressing bed.

Once the concrete attains the desired strength for prestressing, the tendons are cut loose from the abutments.

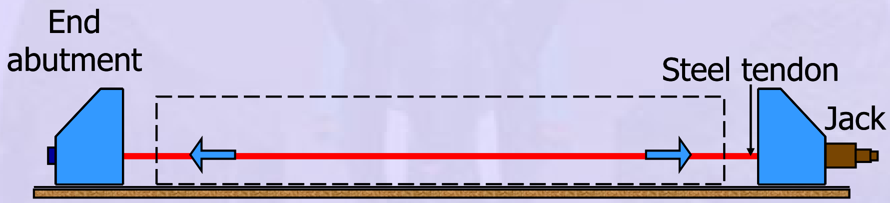
The prestress is transferred to the concrete from the tendons, due to the bond between them. During the transfer of prestress, the member undergoes elastic shortening. If the tendons are located eccentrically, the member is likely to bend and deflect (camber).

The various stages of the pre-tensioning operation are summarised as follows.

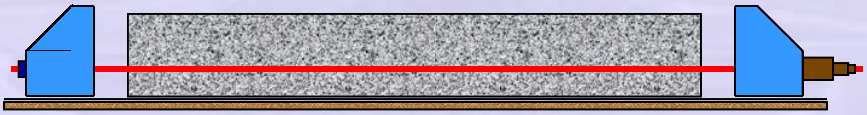
1) Anchoring of tendons against the end abutments
2) Placing of jacks
3) Applying tension to the tendons
4) Casting of concrete
5) Cutting of the tendons.

During the cutting of the tendons, the prestress is transferred to the concrete with elastic shortening and camber of the member.

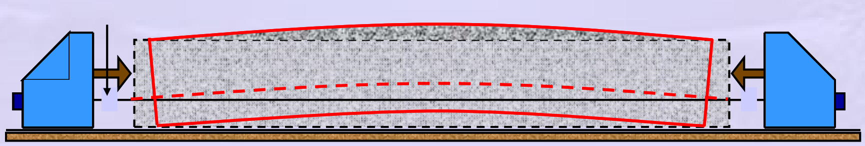
The stages are shown schematically in the following figures.



(a) Applying tension to tendons



(b) Casting of concrete



(c) Transferring of prestress

Figure1-3.1 Stages of pre-tensioning

1.3.3 Advantages of Pre-tensioning

The relative advantages of pre-tensioning as compared to post-tensioning are as follows.

- Pre-tensioning is suitable for precast members produced in bulk.

- In pre-tensioning large anchorage device is not present.

1.3.4 Disadvantages of Pre-tensioning

The relative disadvantages are as follows.

- A prestressing bed is required for the pre-tensioning operation.
- There is a waiting period in the prestressing bed, before the concrete attains sufficient strength.
- There should be good bond between concrete and steel over the transmission length.

1.3.5 Devices

The essential devices for pre-tensioning are as follows.

- Prestressing bed
- End abutments
- Shuttering / mould
- Jack
- Anchoring device
- Harping device (optional)

Prestressing Bed, End Abutments and Mould

The following figure shows the devices.

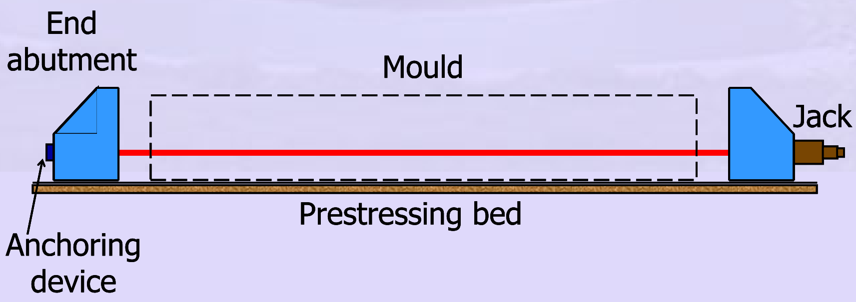


Figure1-3.2 Prestressing bed, end abutment and mould

An extension of the previous 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. The shuttering is provided at the sides and between the members. This system is also called the **Long Line Method**. The following figure is a schematic representation of the Hoyer system

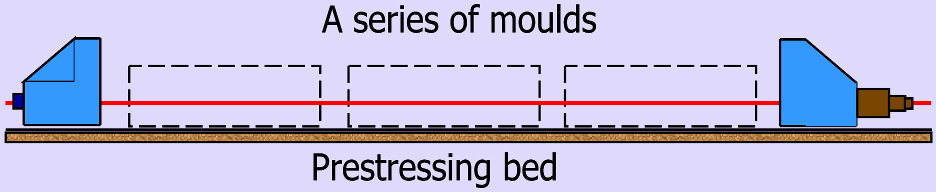


Figure 1-3.3 Schematic representation of Hoyer system

The end abutments have to be sufficiently stiff and have good foundations. This is usually an expensive proposition, particularly when large prestressing forces are required. The necessity of stiff and strong foundation can be bypassed by a simpler solution which can also be a cheaper option. It is possible to avoid transmitting the heavy loads to foundations, by adopting self-equilibrating systems. This is a common solution in load-testing. Typically, this is done by means of a 'tension frame'. The following figure shows the basic components of a tension frame. The jack and the specimen tend to push the end members. But the end members are kept in place by members under tension such as high strength steel rods.

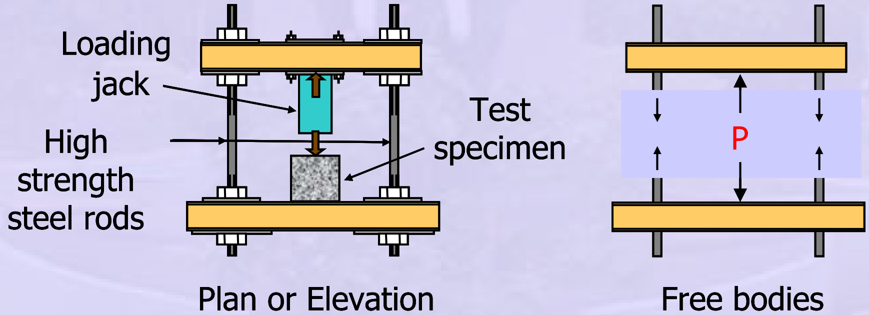


Figure 1-3.4 A tension frame

The frame that is generally adopted in a pre-tensioning system 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. The following figures show the components of a stress bench.

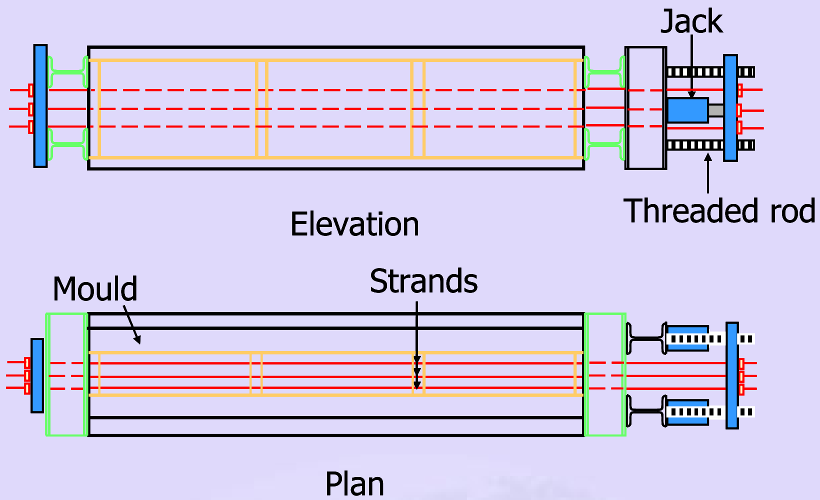


Figure 1-3.5 Stress bench – Self straining frame

The following figure shows the free body diagram by replacing the jacks with the applied forces.

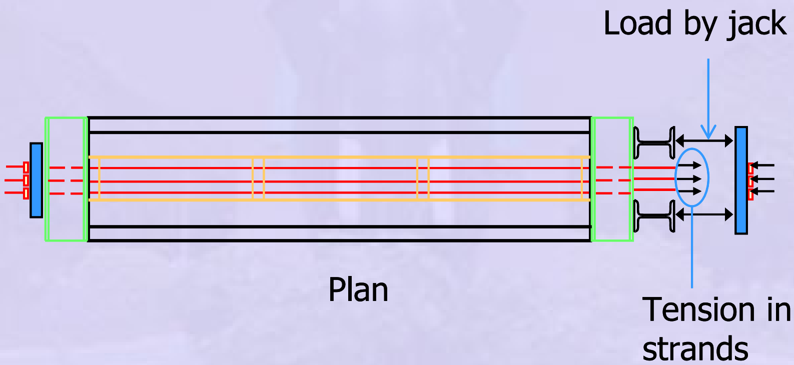


Figure 1-3.6 Free body diagram of stress bench

The following figure shows the stress bench after casting of the concrete.

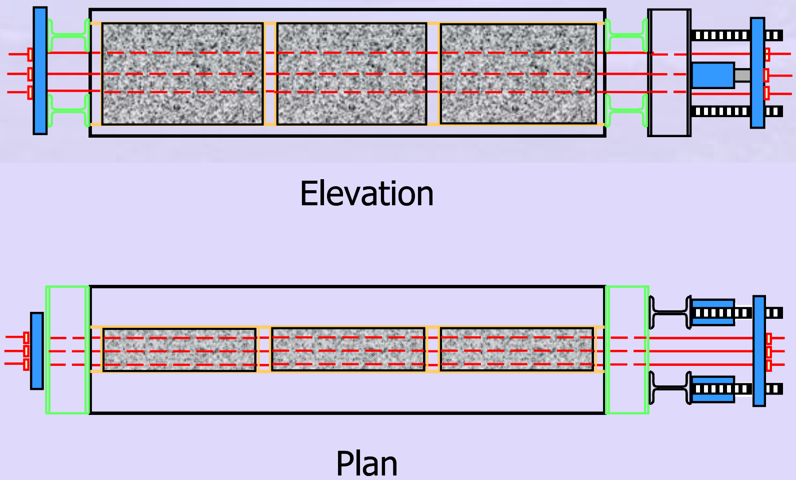


Figure 1-3.7 The stress bench after casting concrete

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. The load applied by a jack is measured by the pressure reading from a gauge attached to the oil inflow or by a separate load cell. The following figure shows a double acting hydraulic jack with a load cell.

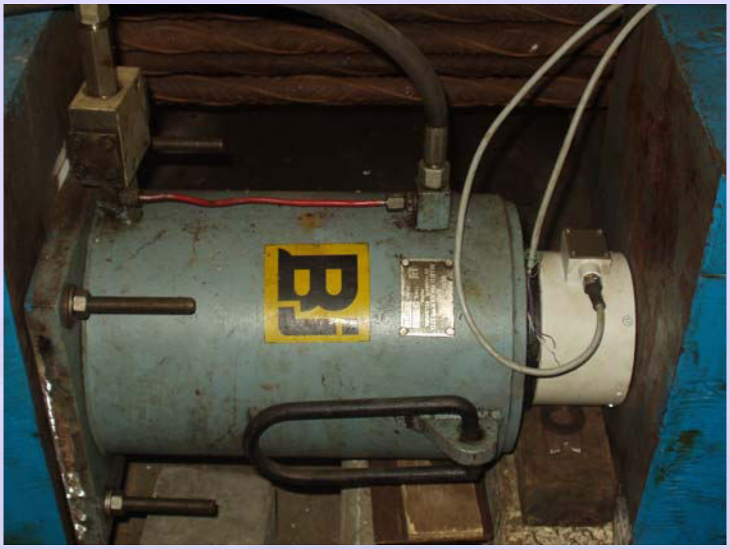


Figure 1-3.8 A double acting hydraulic jack with a load cell

Anchoring Devices

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 hardening of concrete. Here simple and cheap quick-release grips are generally adopted. The following figure provides some examples of anchoring devices.

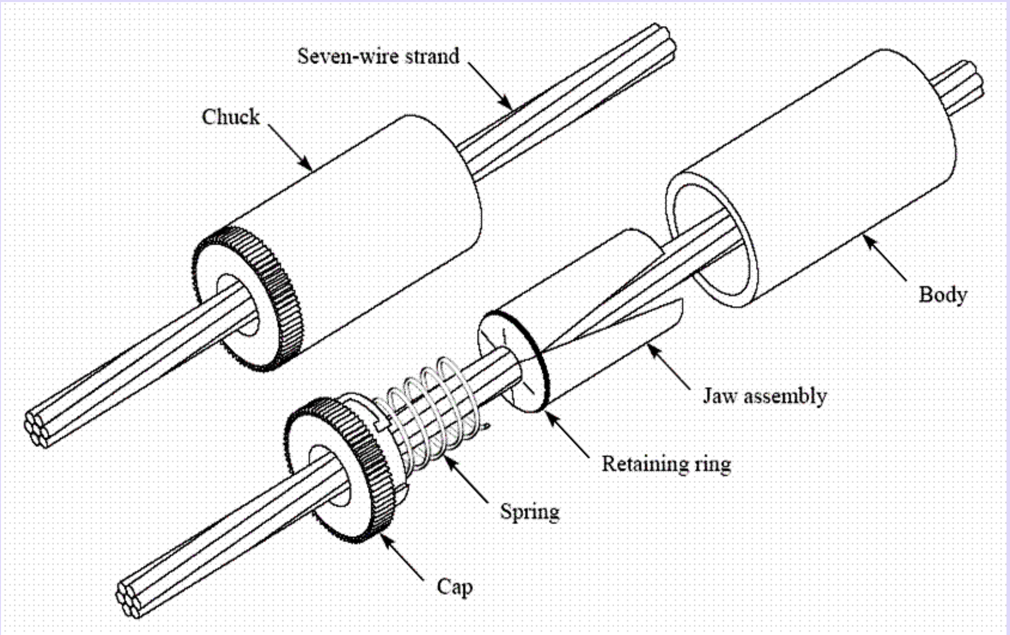


Figure 1-3.9 Chuck assembly for anchoring tendons

(Reference: Lin, T. Y. and Burns, N. H.,

Design of Prestressed Concrete Structures)

Harping Devices

The tendons are frequently bent, except in cases of slabs-on-grade, poles, piles etc. The tendons are bent (harped) in between the supports with a shallow sag as shown below.

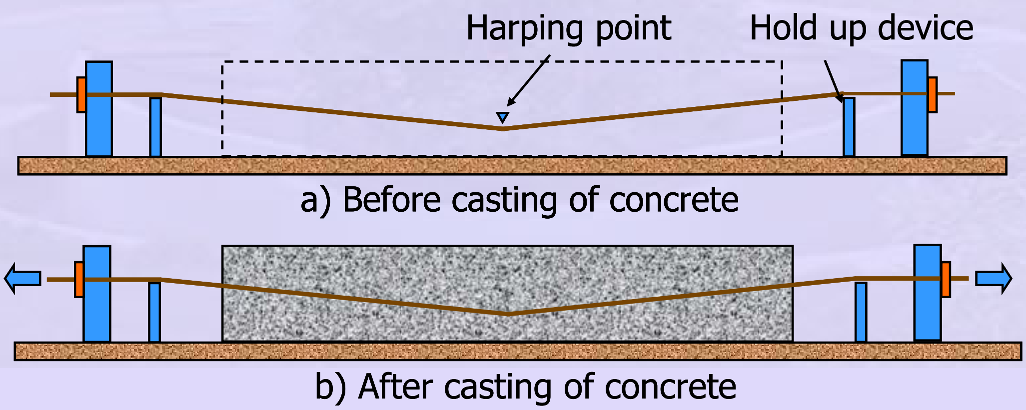


Figure 1-3.10 Harping of tendons

The tendons are harped using special hold-down devices as shown in the following figure.

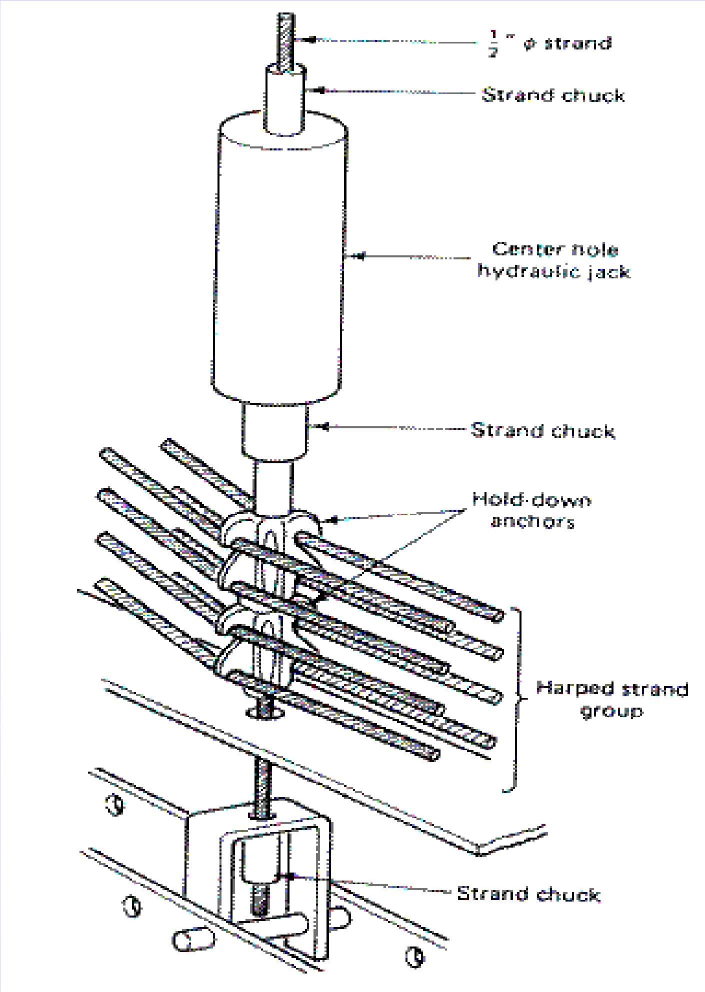


Figure 1-3.11 Hold-down anchor for harping of tendons

(Reference: Nawy, E. G., *Prestressed Concrete: A Fundamental Approach*)

1.3.6 Manufacturing of Pre-tensioned Railway Sleepers

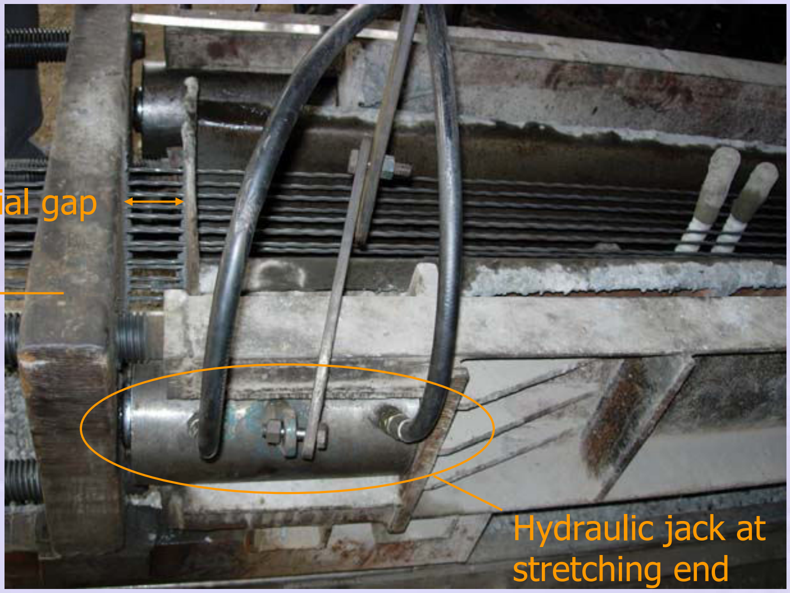
The following photos show the sequence of manufacturing of pre-tensioned railway sleepers (Courtesy: The Concrete Products and Construction Company, COPCO, Chennai). The steel strands are stretched in a stress bench that can be moved on rollers. The stress bench can hold four moulds in a line. The anchoring device holds the strands at one end of the stress bench. In the other end, two hydraulic jacks push a plate where the strands are anchored. The movement of the rams of the jacks and the oil pressure are monitored by a scale and gauges, respectively. Note that after the extension of the rams, the gap between the end plate and the adjacent mould has increased. This shows the stretching of the strands.

Meanwhile the coarse and fine aggregates are batched, mixed with cement, water and additives in a concrete mixer. The stress bench is moved beneath the concrete mixer. The concrete is poured through a hopper and the moulds are vibrated. After the finishing of the surface, the stress bench is placed in a steam curing chamber for a few hours till the concrete attains a minimum strength.

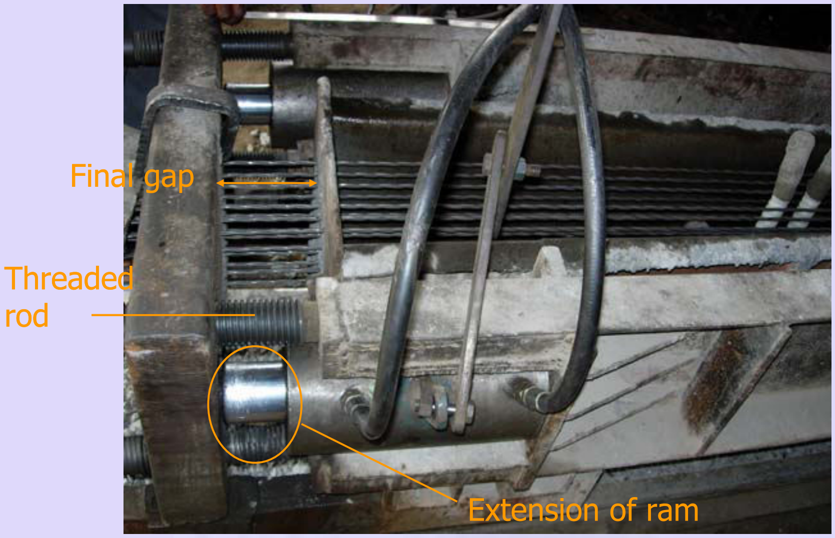
The stress bench is taken out from the chamber and the strands are cut. The sleepers are removed from the moulds and stacked for curing in water. After the complete curing, the sleepers are ready for dispatching.

(a) Travelling pre-tensioning stress bench

(b) Anchoring of strands



(c) Stretching of strands



(d) Stretching of strands

(e) Material storage

Automated batching by weight

(f) Batching of materials

(g) Pouring of concrete

(h) Concrete after vibration of mould

(i) Steam curing chamber

(j) Cutting of strands

(k) Demoulding of sleeper

(l) Stacking of sleeper

(m) Water curing

(n) Storage and dispatching of sleepers

Figure 1-3.12 Manufacturing of pre-tensioned railway sleepers