CE 414
Prestressed Concrete (PC)

Lesson 4
Loss of Prestress

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Loss of Prestress

- ***Prestress does not remain constant (reduces) with time. Even during prestressing of tendons, and transfer of prestress, there is a drop of prestress from the initially applied stress.***

- ***Prestress loss is nothing but the reduction of initial applied prestress to an effective value. In other words, loss in prestress is the difference between initial prestress and the effective prestress that remains in a member.***

- ***Loss of prestress is a great concern since it affects the strength of member and also significantly affects the member's serviceability including Stresses in Concrete, Cracking, Camber and Deflection.***

Loss of Prestress

Loss of prestress is classified into two types:

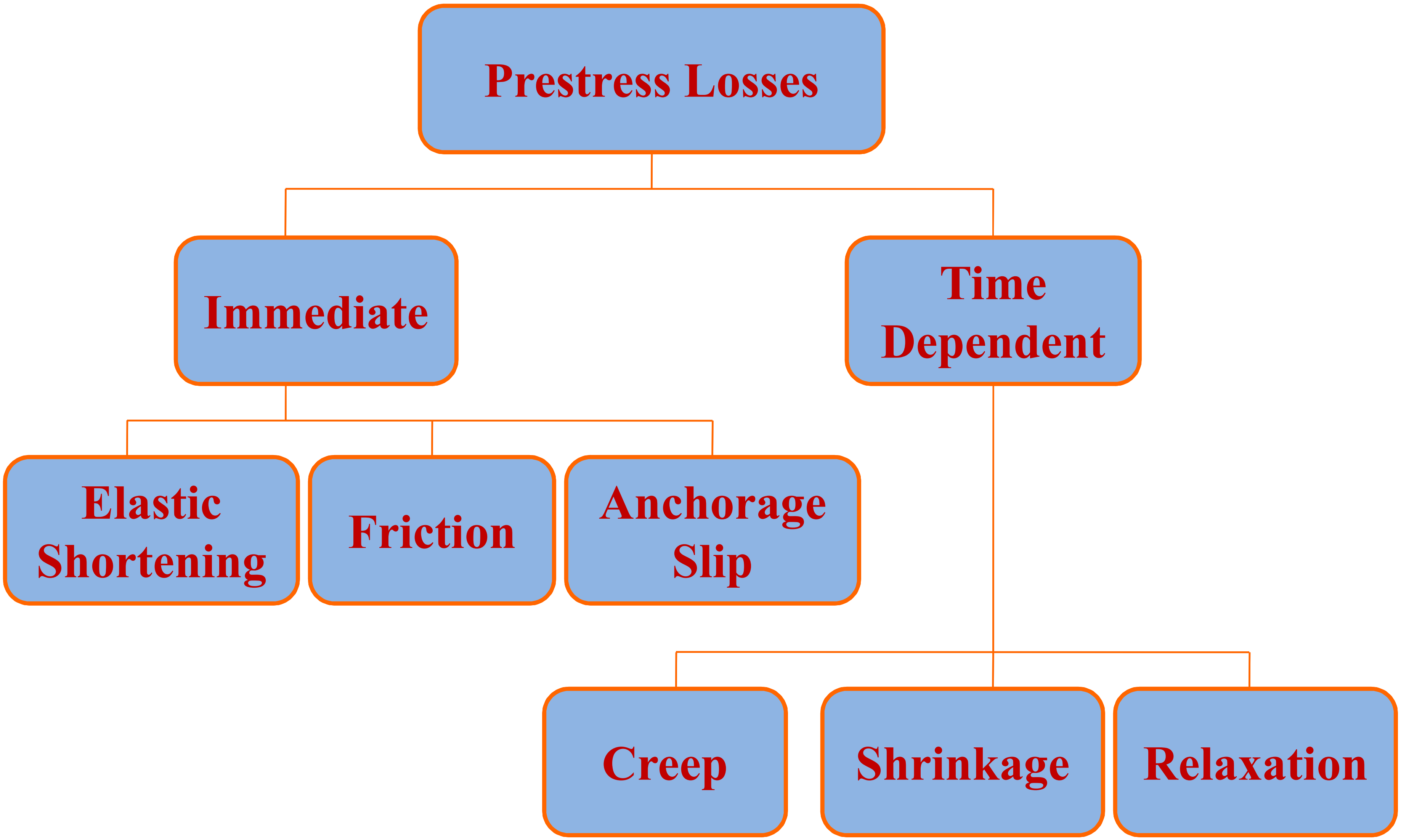
1. **Short-Term or Immediate Losses**
   - **immediate losses occur during prestressing of tendons, and transfer of prestress to concrete member.**

2. **Long-Term or Time Dependent Losses**
   - **Time dependent losses occur during service life of structure.**

Loss of Prestress

1. ***Immediate Losses include***
   - i. ***Elastic Shortening of Concrete***
   - ii. ***Slip at anchorages immediately after prestressing and***
   - iii. ***Friction between tendon and tendon duct, and wobble Effect***
2. ***Time Dependent Losses include***
   - i. ***Creep and Shrinkage of concrete and***
   - ii. ***Relaxation of prestressing steel***

Loss of Prestress



Losses in Various Prestressing Systems

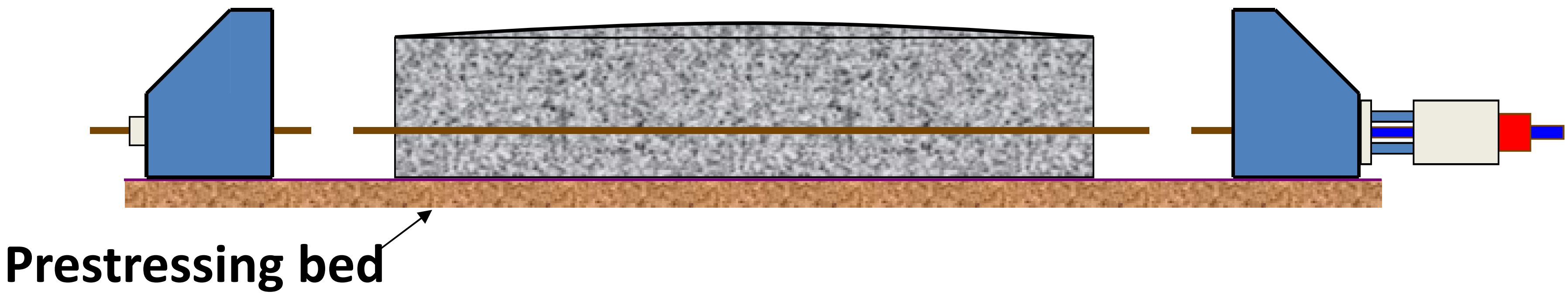
Type of Loss	Pre-tensioning	Post-tensioning
1. Elastic Shortening	Yes	i. No, if all the cables are simultaneously tensioned. ii. Yes, if the wires are tensioned in stages.
2. Anchorage Slip	No	Yes
3. Friction Loss	No	Yes
4. Creep and Shrinkage of Concrete	Yes	Yes
5. Relaxation of Steel	Yes	Yes

Elastic Shortening

1. ***Pre-tensioned Members:* When the tendons are cut and the prestressing force is transferred to the member, concrete undergoes immediate shortening due to prestress.**
2. ***Tendon also shortens by same amount, which leads to the loss of prestress.***

Elastic Shortening

Pre-tensioned Members: **operation of pre-tensioning through various stages by animation.**



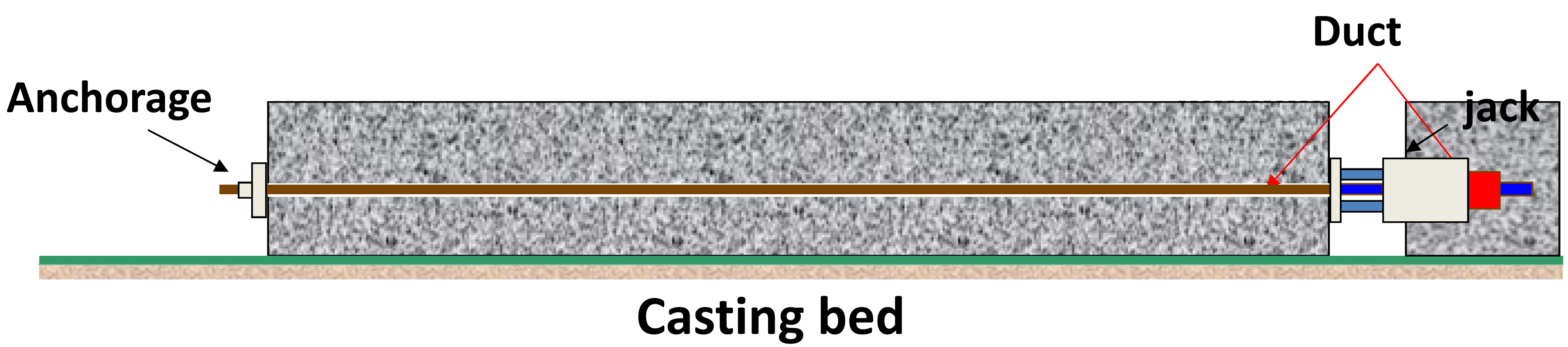
Pre-tensioning of a member

Elastic Shortening

1. ***Post-tensioned Members:*** ***If there is only one tendon, there is no loss because the applied prestress is recorded after the elastic shortening of the member.***
2. ***For more than one tendon, if the tendons are stretched sequentially, there is loss in a tendon during subsequent stretching of the other tendons.***

Elastic Shortening

Post-tensioned Members: complete operation of post-tensioning through various stages by animation



Post-tensioning of a member

Elastic Shortening of Concrete

Strain compatibility

- **Loss due to elastic shortening is quantified by the drop in prestress (Δf_s) in a tendon due to change in strain in tendon ($\Delta \delta_s$).**
- **Change in strain in tendon is equal to strain in concrete (δ_c) at the level of tendon due to prestressing force, which is called strain compatibility between concrete and steel.**
- **Strain in concrete at the level of tendon is calculated from the stress in concrete (f_c) at the same level due to the prestressing force.**
- **A linear elastic relationship is used to calculate the strain from the stress.**

Elastic Shortening

- ***Linear elastic relationship is used to calculate the strain from the stress.***
- ***Quantification of the losses is explained below.***

$$\Delta f_s = E_s \Delta\delta_s \quad = E_s \delta_c$$

$$= E_s (f_c / E_c)$$

$$\Delta f_s = n f_c$$

- ***For simplicity, the loss in all the tendons can be calculated based on the stress in concrete at the level of CGS.***
- ***This simplification cannot be used when tendons are stretched sequentially in a post-tensioned member.***

Elastic Shortening

4-3 Elastic Shortening of Concrete

This section begins the consideration of losses by each individual source. Let us first consider pretensioned concrete. As the prestress is transferred to the concrete, the member shortens and the prestressed steel shortens with it. Hence there is a loss of prestress in the steel. Considering first only the axial shortening of concrete produced by prestressing (the effect of bending of concrete will be considered later), we have

$$\text{Unit shortening } \delta = \frac{f_c}{E_c}$$

$$= \frac{F_0}{A_c E_c}$$

where F_0 is the total prestress just after transfer, that is, after the shortening has taken place. Loss of prestress in steel is

$$ES = \Delta f_s = E_s \delta = \frac{E_s F_0}{A_c E_c} = \frac{nF_0}{A_c} \tag{4-1}$$

Elastic Shortening

The value of F_0, being the prestress after transfer, may not be known exactly. But exactness is not necessary in the estimation of F_0, because the loss due to this shortening is only a few per cent of the total prestress, hence an error of a few per cent in the estimation will have no practical significance. It must be further remembered that the value of E_c cannot be precisely predicted either. However, since the value of the initial prestress F_i is usually known, a theoretical solution can be obtained by the elastic theory. Using the transformed-section method, with $A_t = A_c + nA_s$, we have

$$\delta = \frac{F_i}{A_c E_c + A_s E_s}$$

$$ES = \Delta f_s = E_s \delta = \frac{E_s F_i}{A_c E_c + A_s E_s}$$

$$ES = \frac{nF_i}{A_c + nA_s}$$

$$ES = \frac{nF_i}{A_t} \qquad (4\text{-}2)$$

From (4-1) and (4-2) above, we observe that the change in steel stress at transfer is simply the concrete stress at the level of steel multiplied by $n = E_s/E_c$.

Elastic Shortening

EXAMPLE 4-1

A straight pretensioned concrete member 40 ft. long, with a cross section of 15 in. by 15 in., is concentrically prestressed with 1.2 sq. in. of steel wires which are anchored to the bulkheads with a stress of 150,000 psi (Fig. 4-1). If $E_{ci} = 4{,}800{,}000$ psi and $E_s = 29{,}000{,}000$ psi compute the loss of prestress due to the elastic shortening of concrete at the transfer of prestress. ($L = 12.2$ m, $E_{ci} = 33.1$ kN/mm^2, and $E_s = 200$ kN/mm^2)

Solution

$$F_i = 150{,}000 \times 1.2 = 180{,}000 \text{ lb}$$

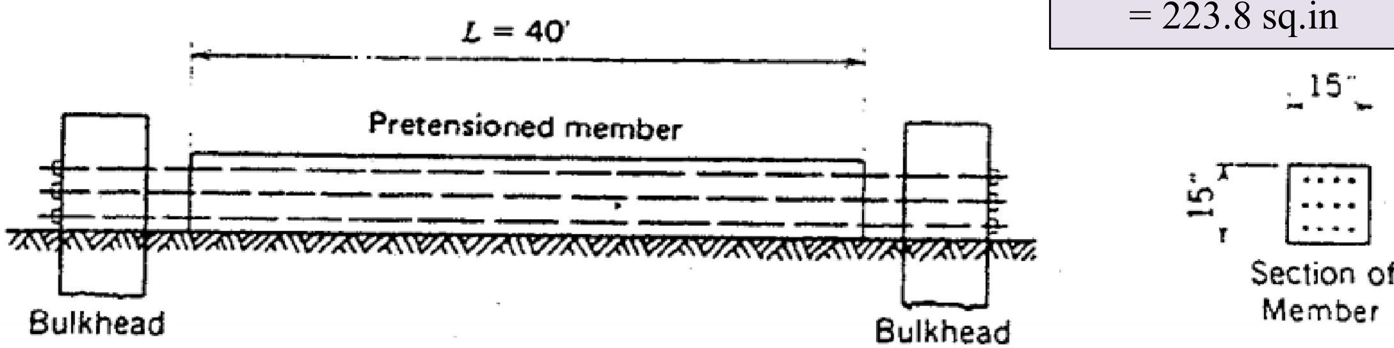
(a) Using elastic analysis with transformed section estimate the change in steel stress at transfer:

n = Es / Ec = 6.04 = 6

$$ES = \Delta f_s = \frac{nF_i}{A_c + nA_s} = \frac{6 \times 180{,}000}{223.8 + 6 \times 1.2} = 4660 \text{ psi} \qquad (4\text{-}2)$$

$$\text{Steel stress} = 150{,}000 - 4660 = 145{,}340 \text{ psi}$$

Ac = (15 x 15)-1.2
= 223.8 sq.in



Elastic Shortening

(b) Using (4-4) with estimate of $F_0 \approx 0.9\ F_i$ we find $F_0 = (0.9)(180{,}000) = 162{,}000$ lb, thus for this member with $e = 0$ and $M_G = 0$:

$$ES = \Delta f_s = \frac{E_s}{E_{ci}}(f_{cir}) = n\,\frac{F_0}{A} = \frac{6 \times 162{,}000}{225} = 4320 \text{ psi} \qquad (4\text{-}5)$$

$$\text{Steel stress} = 150{,}000 - 4{,}320 = 145{,}680 \text{ psi}$$

Note that theoretically the remaining stress immediately following transfer is 145,340 psi while our approximation equation (4-5) estimated 145,680 psi, which is very adequate for design.

EXAMPLE 4-1

A straight pretensioned concrete member 40 ft. long, with a cross section of 15 in. by 15 in., is concentrically prestressed with 1.2 sq. in. of steel wires which are anchored to the bulkheads with a stress of 150,000 psi (Fig. 4-1). If $E_{ci} = 4{,}800{,}000$ psi and $E_s = 29{,}000{,}000$ psi compute the loss of prestress due to the elastic shortening of concrete at the transfer of prestress. ($L = 12.2$ m, $E_{ci} = 33.1$ kN/mm^2, and $E_s = 200$ kN/mm^2)

- prestressed with 12 steel wires of 0.1 sq.in. Then, As = 12 x 0.1 = 1.2 sq.in
- prestressed with 12 steel wires of 0.357 in. diameter. Then, As = 12 x $\frac{\pi(0.357)^2}{4}$ = 1.2 sq.in
- prestressed with 12 steel wires of 9 mm diameter. Then, As = 12 x $\frac{\pi(9/25.4)^2}{4}$ = 1.2 sq.in

Elastic Shortening

For posttensioning, the problem is different. If we have only a single tendon in a posttensioned member, the concrete shortens as that tendon is jacked against the concrete. Since the force in the cable is measured after the elastic shortening of the concrete has taken place, no loss in prestress due to that shortening need be accounted for.

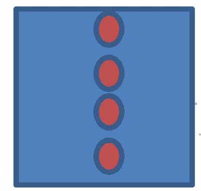
If we have more than one tendon and the tendons are stressed in succession, then the prestress is gradually applied to the concrete, the shortening of concrete increases as each cable is tightened against it, and the loss of prestress due to elastic shortening differs in the tendons. The tendon that is first tensioned would suffer the maximum amount of loss due to the shortening of concrete by the subsequent application of prestress from all the other tendons. The tendon that is tensioned last will not suffer any loss due to the elastic concrete shortening, since all that shortening will have already taken place when the prestress in the last tendon is being measured. The computation of such losses can be made quite complicated. But, for all practical purposes, it is accurate enough to determine the loss for the first cable and use half of that value for the average loss of all the cables. This is shown in example 4-2.

Elastic Shortening

EXAMPLE 4-2

Consider the same member as in example 4-1, but posttensioned instead of pretensioned. Assume that the 1.2 sq in. of steel is made up of 4 tendons with 0.3 sq in. per tendon. The tendons are tensioned one after another to the stress of 150,000 psi. Compute the loss of prestress due to the elastic shortening of concrete.

Solution The loss of prestress in the first tendon will be due to the shortening of concrete as caused by the prestress in the other 3 tendons. Although the prestress differs in the 3 tendons, it will be close enough to assume a value of 150,000 psi (1,034 N/mm^2) for them all. Hence the force causing the shortening is



$$3 \times 0.3 \times 150{,}000 = 135{,}000 \text{ lb (600 kn)}$$

The loss of prestress is given by formula 4-1

$$\Delta f_s = \frac{nF_0}{A_c} = \frac{6 \times 135{,}000}{225} = 3600 \text{ psi } (24.8 \text{ N/mm}^2)$$

(3600/3) x 2

Note that it is unnecessary to use the more exact formula 4.2.

Similarly, the loss due to elastic shortening in the second tendon is 2400 psi, in the third tendon 1200 psi, and the last tendon has no loss. The average loss for the 4 tendons will be

(3600/3) x 1

$$\frac{3600 + 2400 + 1200}{4} = 1800 \text{ psi } (12.4 \text{ N/mm}^2)$$

Remaining prestress = 150,000 – 1800 = 148,200 psi

Elastic Shortening

Note that it is unnecessary to use the more exact formula 4.2.

Similarly, the loss due to elastic shortening in the second tendon is 2400 psi, in the third tendon 1200 psi, and the last tendon has no loss. The average loss for the 4 tendons will be

$$\frac{3600+2400+1200}{4}=1800 \text{ psi } (12.4 \text{ N/mm}^2)$$

indicating an average loss of prestress of $1800/150{,}000=1.2\%$, which can also be obtained by using one-half of the loss of the first cable,

$$3600/2=1800 \text{ psi } (12.4 \text{ N/mm}^2)$$

Elastic Shortening

The above method of computation assumes that the tendons are stretched in succession and that each is stressed to the same value as indicated by a manometer or a dynamometer. It is entirely possible to jack the tendons to different initial prestresses, taking into account the respective amount of loss, so that all the tendons would end up with the same prestress after deducting their losses. Considering the above example, if the first cable should be tensioned to a stress of 153,600 psi (1059 N/mm^2), the second to 152,400 (1051), the third to 151,200 (1,042) and the last to 150,000 (1034), then, at the completion of the prestressing process, all the tendons would be stressed to 150,000 psi (1034 N/mm^2). Such a procedure, although theoretically desirable, is seldom carried out because of the additional complications involved in the field. When there are many tendons and the elastic shortening of concrete is appreciable, it is sometimes desirable to divide the tendons into three or four groups; each group will be given a different amount of over-tensioning according to its order in the jacking sequence.

Elastic Shortening

In actual practice, either of the following two methods is used.

1. Stress all tendons to the specified initial prestress (e.g., to 150,000 psi = 1,034 N/mm^2 in example 4-2), and allow for the average loss in the design (e.g., 1800 psi = 12 N/mm^2 in example 4-2).
2. Stress all tendons to a value above the specified initial prestress by the magnitude of the average loss (e.g., to 150,000 + 1800 = 151,800 psi = 1046 N/mm^2 in example 4-2). Then, when designing, the loss due to the elastic shortening of concrete is not to be considered again.

If the loss due to this source is not significant, the first method is followed. If the steel can stand some overtensioning, and if a high effective prestress is desired, the second procedure can be adopted.

Bending of Member

4-9 Loss or Gain Due to Bending of Member

Loss of prestress due to a uniform shortening of the member under axial stress was discussed in section 4-3. When a member bends, further changes in the prestress may occur: there may be either a loss or a gain in prestress, depending on the direction of bending and the location of the tendon. If there are several tendons and they are placed at different levels, the change of prestress in them will differ. Then it may be convenient to consider only the centroid of all the tendons (the c.g.s. line) to get an average value of the change in prestress.

This change in prestress will depend on the type of prestressing: whether pre- or posttensioned, whether bonded or unbonded. Before the tendon is bonded to the concrete, bending of the member will affect the prestress in the tendon.

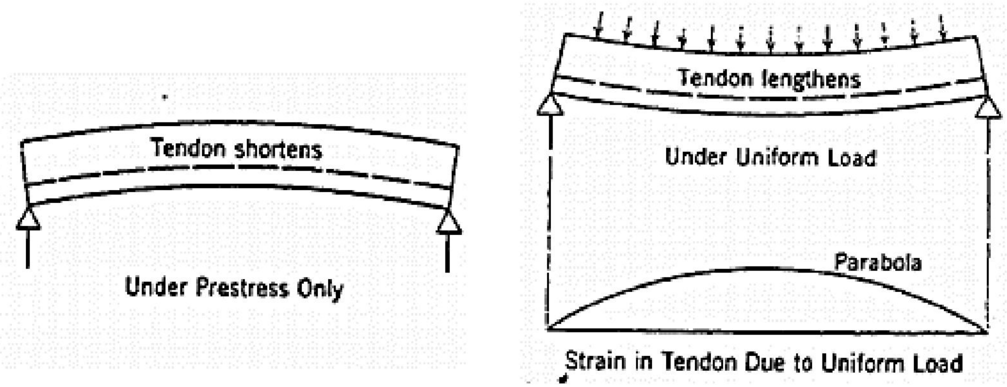


Fig. 4-3. Variation of strain in bonded tendon.

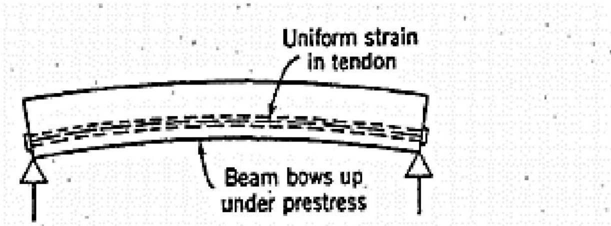


Fig. 4-4. Posttensioned member before grouting.

Bending of Member

EXAMPLE 4-3

A concrete beam 8 in. by 18 in. deep is prestressed with an unbonded tendon through the lower third point, Fig. 4-5, with a total initial prestress of 144,000 lb. Compute the loss of

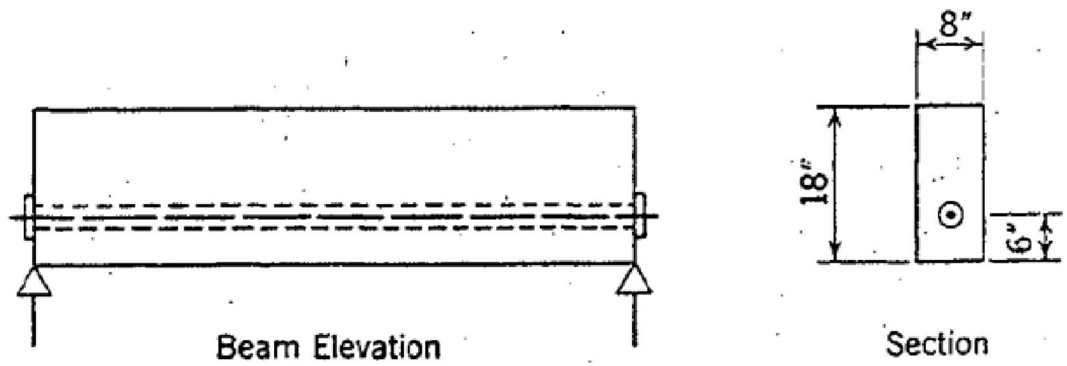


Fig. 4-5. Example 4-3.

prestress in the tendon due to the bowing up of the beam under prestress, neglecting the weight of the beam itself. $E_s = 30{,}000{,}000$ $E_c = 4{,}000{,}000$ psi. Beam is simply supported ($F_0 = 640.5$ KN, $E_s = 207$ KN/mm^2, and $E_c = 27.6$ KN/mm^2).

Bending of Member

Solution Owing to the eccentric prestress, the beam is under a uniform bending moment of

$$144{,}000 \times 3 \text{ in.} = 432{,}000 \text{ in.-lb } (48{,}816 \text{ N-m})$$

e = (18/2) - 6 = 3 in

The concrete fiber stress at the level of the cable due to this bending is

$$f = \frac{My}{I} = \frac{432{,}000 \times 3}{(8 \times 18^3)/12} = 333 \text{ psi } (2.30 \text{ N/mm}^2) \text{ compression}$$

Here, y = e

(Note that stress due to the axial prestress of 144,000 lb is not included here; also, the gross area of the concrete is used for simplicity.)

Unit compressive strain along the level of the tendon is therefore

$$333/4{,}000{,}000 = 0.000083$$

Here, strain = f /Ec

Corresponding loss of prestress in steel is

$$0.000083 \times 30{,}000{,}000 = 2500 \text{ psi } (17.2 \text{ N/mm}^2)$$

Here, $\Delta fs = \delta \times Es$

However, if the beam is left under the action of prestress alone, the creep of concrete will tend to increase the camber and will result in further loss of prestress. On the other hand, if the prestress in the tendon is measured after the bowing of the beam has taken place, this loss due to bending of beam need not be considered.

Anchorage Slip

- *In most Post-tensioning systems when the tendon force is transferred from the jack to the anchoring ends, the friction wedges slip over a small distance.*
- **Anchorage block also moves before it settles on concrete.**
- **Loss of prestress is due to the consequent reduction in the length of the tendon.**
- **Certain quantity of prestress is released due to this slip of wire through the anchorages.**

– **Amount of slip depends on type of wedge and stress in the wire.**

Anchorage Slip

- **The magnitude of slip can be known from the tests or from the patents of the anchorage system.**
- **Loss of stress is caused by a definite total amount of shortening.**
- **Percentage loss is higher for shorter members.**
- **Due to setting of anchorage block, as the tendon shortens, there develops a reverse friction.**
- **Effect of anchorage slip is present up to a certain length, called the setting length l_{set}.**

Anchorage Slip

- **Anchorage loss can be accounted for at the site by over-extending the tendon during prestressing operation by the amount of draw-in before anchoring.**
- **Loss of prestress due to slip can be calculated:**

$$\left(\frac{P}{A}\right) = \frac{E_s\Delta}{L}$$

where, Δ = Slip of anchorage

L = Length of cable

A = Cross-sectional area of the cable

E_s = Modulus of Elasticity of steel

P = Prestressing Force in the cable.

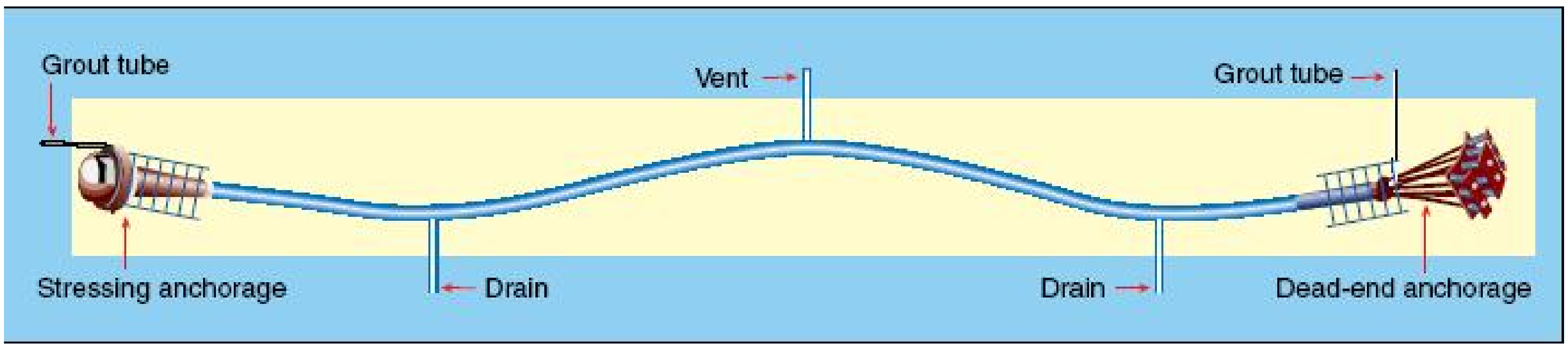
Frictional Loss

- *In Post-tensioned members, tendons are housed in ducts or sheaths.*
- *If the profile of cable is linear, the loss will be due to straightening or stretching of the cables called Wobble Effect.*
- *If the profile is curved, there will be loss in stress due to friction between tendon and the duct or between the tendons themselves.*

Frictional Loss

Post-tensioned Members

- **Friction is generated due to curvature of tendon, and vertical component of the prestressing force.**



A typical continuous post-tensioned member

(Courtesy: VSL International Ltd.)

Elongation of Tendon

Elongation of Tendons

It is often necessary to compute the elongation of a tendon caused by prestressing. When fabricating the anchorage parts in some systems, the expected amount of elongation must be known approximately. For the Prescon and other button-head, wire-type systems it must be known rather accurately. For all systems the measured elongation is compared to the expected value, thus serving as a check on the accuracy of the gage readings or on the magnitude of frictional loss along the length of the tendon. The computation of such elongation is discussed in two parts as follows.

Elongation of Tendon

Neglecting Frictional Loss along Tendon. If a tendon has uniform stress f_s along its entire length L, the amount of elongation is given by

$$\Delta_s = \delta_s L = f_s L / E_s = FL / E_s A_s \tag{4-23}$$

For prestress exceeding the proportional limit of the tendon, this formula may not be applicable, and it may be necessary to refer to the stress-strain diagram for the corresponding value of δ_s.

It is not easy to determine the slack in a tendon accurately, hence the usual practice is to give the tendon some initial tension f_{s1} and measure the elongation Δ_s thereafter. Then, neglecting any shortening of the concrete, the total elastic elongation of the tendon can be computed by

$$\text{Elastic elongation} = \frac{f_s}{f_s - f_{s1}} \Delta_s \tag{4-24}$$

Elongation of Tendon

EXAMPLE 4-6

A Prescon cable, 60 ft long, Fig. 4-12, is to be tensioned from one end to an initial prestress of 150,000 psi immediately after transfer. Assume that there is no slack in the cable, that the shrinkage of concrete is 0.0002 at time of transfer, and that the average compression in concrete is 800 psi along the length of the tendon. $E_c = 3{,}800{,}000$ psi; $E_s = 29{,}000{,}000$ psi. Compute the length of shims required, neglecting any elastic shortening of the shims and any friction along the tendon (span = 18.3 m, initial prestress = 1034 N/mm^2, $E_c = 26.2\ kN/mm^2$, and $E_s = 200\ kN/mm^2$).

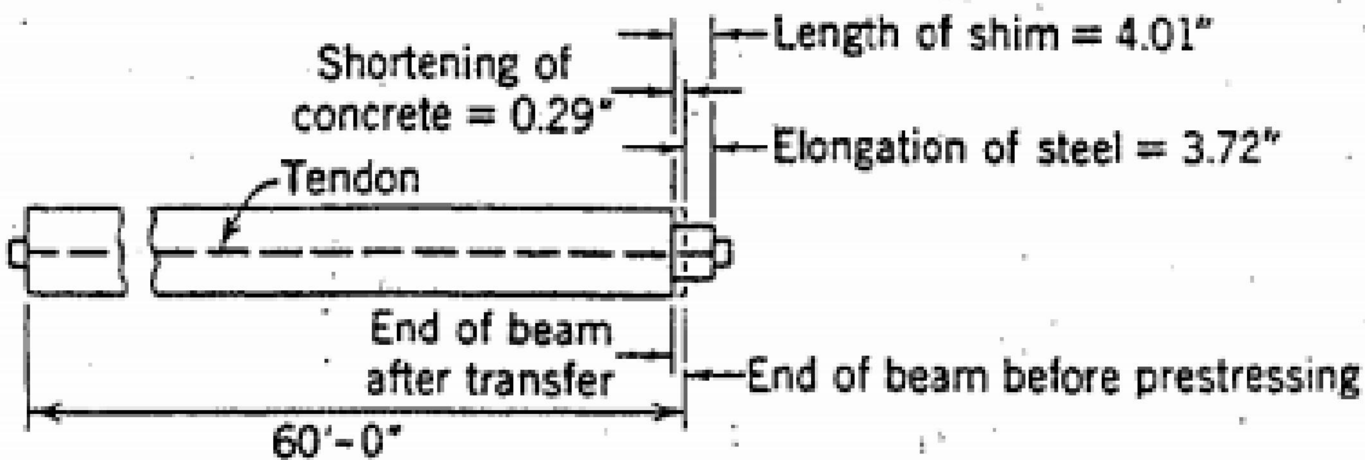


Fig. 4-12. Example 4-6.

Elongation of Tendon

Solution From equation 4-10, the elastic elongation of steel is

$$\Delta_s = f_s L / E_s = 150{,}000 \times 60 \times 12 / 29{,}000{,}000 = 3.72 \text{ in. } (94.5 \text{ mm})$$

Shortening of concrete due to shrinkage is

$$0.0002 \times 60 \times 12 = 0.14 \text{ in. } (3.6 \text{ mm})$$

Elastic shortening of concrete is

$$800 \times 60 \times 12 / 3{,}800{,}000 = 0.15 \text{ in. } (3.8 \text{ mm})$$

Length of shims required is

$$3.72 + 0.14 + 0.15 = 4.01 \text{ in. } (101.9 \text{ mm})$$

If shims of 4.01 in. (101.9 mm) are inserted in the anchorage, there should remain an initial prestress of 150,000 psi (1034 N/mm^2) in the steel immediately after transfer.

Elongation of Tendon

EXAMPLE 4-7

Eighteen 0.196-in. wires in a Freyssinet cable, 80 ft (24.4 m) long, are tensioned initially to a total stress of 3000 lb. What additional elongation of the wires as measured there-from is required to obtain an initial prestress of 160,000 psi (1103 N/mm^2)? $E_s = 28{,}000{,}000$ psi (193 kN/mm^2). Assume no shortening of concrete during the tensioning process and neglect friction.

Solution

$$A_s = 18 \times 0.03 = 0.54 \text{ sq in. } (348 \text{ mm}^2)$$

$$f_{s1} = 3000/0.54 = 5500 \text{ psi } (37.9 \text{ N/mm}^2)$$

Total elastic elongation of tendon from 0 to 160,000 psi (1103 N/mm^2) is

$$f_s L/E_s = 160{,}000 \times 80 \times 12/28{,}000{,}000 = 5.48 \text{ in. } (139 \text{ mm})$$

From equation 4-11,

$$5.48 = \frac{f_s}{f_s - f_{s1}} \Delta_s$$

$$= \frac{160{,}000}{160{,}000 - 5500} \Delta_s$$

$$\Delta_s = 5.28 \text{ in. } (134 \text{ mm})$$

Thus, with zero reading taken at a total stress of 3000 lb (13.3 kN), an elongation of 5.28 in. (134 mm) must be obtained for a prestress of 160,000 psi (1103 N/mm^2).

Elongation of Tendon (Considering Frictional Loss)

Considering Frictional Loss along Tendon. It was shown in section 4-11 that, for a curved tendon with a constant radius R, the stress at any point away from the jacking end is

$$F_2 = F_1 e^{-(\mu\alpha + KL)}$$

The average stress F_a for the entire length of curve with stress varying from F_1 to F_2 can be shown to be

$$F_a = F_2 \frac{e^{\mu\alpha+KL} - 1}{\mu\alpha + KL} \tag{4-25}$$

This equation is solved graphically in Fig. 4-14, where the dotted lines give the values of $f_a = F_a / A_s$.

The total lengthening for length L is given by

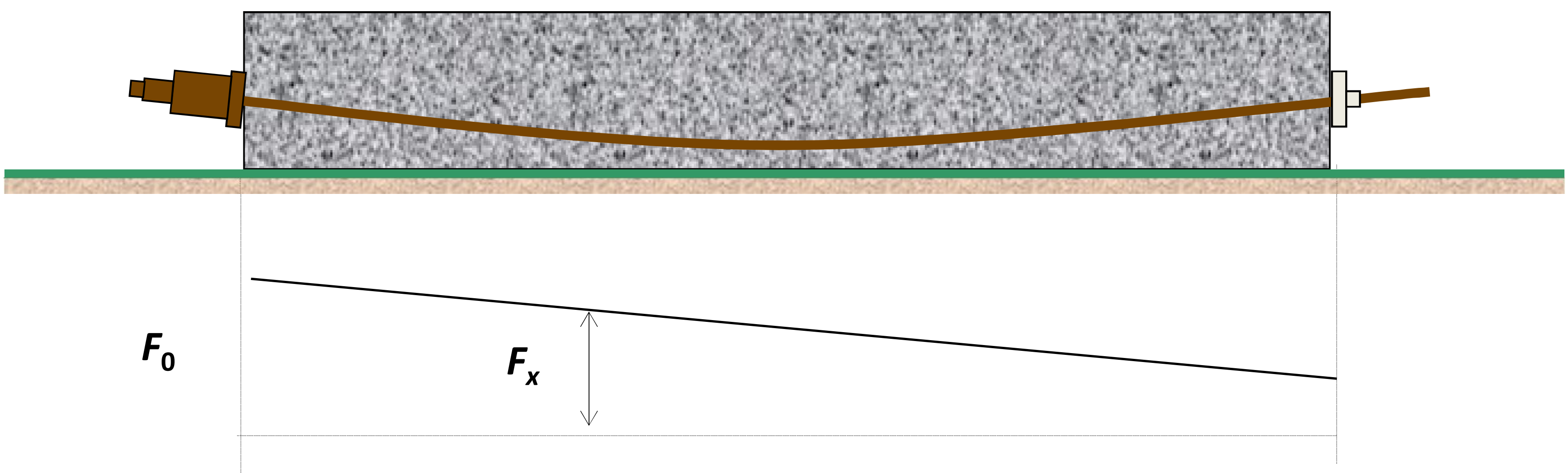
$$\Delta_s = \frac{F_a L}{E_s A_s} = \frac{F_2 L}{E_s A_s} \frac{e^{\mu\alpha+KL} - 1}{\mu\alpha + KL} \tag{4-26}$$

If only an approximate solution is desired, the medium value of F_1 and F_2 can be used in computing the elongation; thus

$$\Delta_s = \frac{F_1 + F_2}{2} \frac{L}{E_s A_s} \tag{4-27}$$

Elongation of Tendon (Considering Frictional Loss)

Post-tensioned Members



Variation of prestressing force after stretching

Elongation of Tendon

EXAMPLE 4-8

A tendon 80 ft (24.4 m) long is tensioned along a circular curve with $R = 102$ ft (31.1 m), Fig. 4-13. For a unit stress of 180,000 psi (1,241 N/mm^2) applied at the jacking end, a total elongation of 4.80 in. (122 mm) is obtained. $E_s = 30{,}000{,}000$ psi (207 kN/mm^2). Compute the stress f_2 at the far end of the tendon.

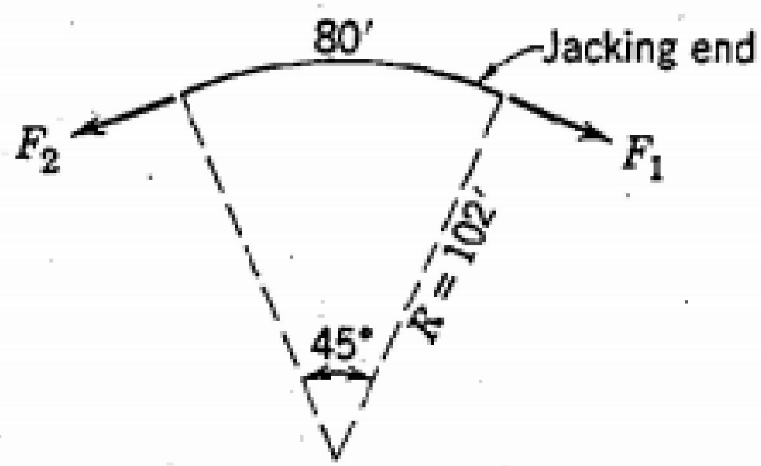


Fig. 4-13. Example 4-8.

Elongation of Tendon

Solution Approximate solution. Average stress in the tendon is given by

$$f_a = \Delta_s E_s / L = 4.80 \times 30{,}000{,}000/(80 \times 12)$$
$$= 150{,}000 \text{ psi } (1034 \text{ N/mm}^2)$$

Since the maximum stress is 180,000 psi (1241 N/mm^2), the minimum stress f_2 must be 120,000 psi (827 N/mm^2), assuming uniform decrease in the stress.

Exact solution can be shown to give $f_2 = 125$ ksi (862 N/mm^2).

Here, 180,000-150,000 = 30,000 psi

So, 150,000 – 30,000 = 120,000 psi

Time Dependent Losses

✓ **Creep of Concrete**

- **Time-dependent increase of deformation under sustained load.**
- **Due to creep, the prestress in tendons decreases with time.**

➢ **Factors affecting creep and shrinkage of concrete**

- **Age**
- **Applied Stress level**
- **Density of concrete**
- **Cement Content in concrete**
- **Water-Cement Ratio**
- **Relative Humidity and**
- **Temperature**

Creep of Concrete

- **For stress in concrete less than one-third of the characteristic strength, the ultimate creep strain ($\varepsilon_{cr, ult}$) is found to be proportional to the elastic strain (ε_{el}).**
- **The ratio of the ultimate creep strain to the elastic strain is defined as the ultimate creep coefficient or simply creep coefficient, *Cc*.**

$$Cc = \frac{\varepsilon_{cr\,ult}}{\varepsilon_{el}}$$

Creep of Concrete

- *The loss in prestress (Δf_p) due to creep is given as follows.*

$$\Delta f_s = E_s\, \varepsilon_{cr,\, ult} = E_s\, Cc\, \varepsilon_{el}$$

Since $\varepsilon_{cr, ult} = Cc\, \varepsilon_{el}$

E_s **is the modulus of the prestressing steel**

- **In special situations detailed calculations may be necessary to monitor creep strain with time.**
- ***Specialized literature or standard codes can provide guidelines for such calculations.***

Creep of Concrete

- ***Creep is due to sustained (permanent) loads only. Temporary loads are not considered in calculation of creep.***
- **Since the prestress may vary along the length of the member, an average value of the prestress is considered.**
- **Prestress changes due to creep, which is related to the instantaneous prestress.**
- **To consider this interaction, the calculation of creep can be iterated over small time steps.**

Shrinkage of Concrete

➢ Shrinkage of Concrete

- **Time-dependent strain measured in an unloaded and unrestrained specimen at constant temperature.**
- **Loss of prestress (Δf_s) due to shrinkage is as follows.**

$$\Delta f_s = E_s \, \varepsilon_{sh}$$

where **E_s is the modulus of prestressing steel.**

- **The factors responsible for creep of concrete will have influence on shrinkage of concrete also except the loading conditions.**

Shrinkage of Concrete

- **The approximate value of shrinkage strain for design shall be assumed as follows:**
- **For pre-tensioning = 0.0003**
- **For post-tensioning =** $$\frac{0.002}{Log_{10}(t+2)}$$

Where t = age of concrete at transfer in days.

Relaxation

✓ Relaxation

- Relaxation is the reduction in stress with time at constant strain.
  - decrease in the stress is due to the fact that some of the initial elastic strain is transformed in to inelastic strain under constant strain.
  - stress decreases according to the remaining elastic strain.

Relaxation

- **Factors effecting Relaxation :**
  - **Time**
  - **Initial stress**
  - **Temperature and**
  - **Type of steel.**

- **Relaxation loss can be calculated according to the any code.**

Maximum Allowable Loss

Table 4-8 Limiting Maximum Loss (ACI-ASCE Committee[2])

Type of strand	Maximum Loss psi (N/mm^2) Normal Concrete	Lightweight Concrete
Stress-relieved strand	50,000 (345)	55,000 (380)
Low-relaxation strand	40,000 (276)	45,000 (311)

The ACI-ASCE Committee[2] recommended that the values shown in Table 4-8 be considered limiting maximum loss estimates. As shown in example 4-5, this may control the loss assumed in design.

Any Question?