Loss of prestress

الفقد في الشد

1- loss due to Elastic shortening of concrete

الفقد فيه الـ (الإجهاد) في الكابلات بسبب الانضغاط المرن للخرسانة وذلك في

a) pre-tensioned concrete

١- يتم تثبيت الكابلات على stressing beds أو abutment

٢- يتم شد الكابلات

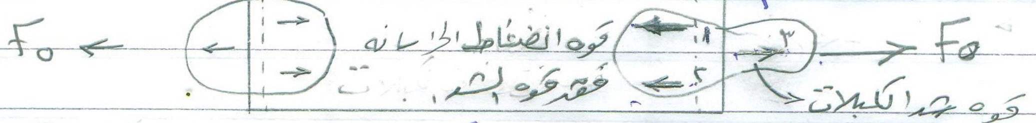
٣- يتم صب الخرسانة

٤- يتم فك الـ stressing bed أو abutment

٥- تنتقل قوة الضغط للخرسانة. (من الكابلات المشدودة)

٦- يحدث Elastic shortening للخرسانة

٧- بانضغاط الخرسانة تنكمش الكابلات معها وبالتالي يحدث فقد فيه الشد الموجود في الكابلات يساوي مقدار انضغاط الخرسانة



١- قوة انضغاط الخرسانة عند حدث الانكماش وذلك لا تنتقل قوة الشد للخرسانة

٢- بانضغاط الخرسانة تنكمش الكابلات معها وبالتالي يحدث فقد في شد الكابلات

٣- قوة شد الكابلات

٤- F_o هي محصلة ما يسمى بـ prestress Forces

- strain $\epsilon = \dfrac{f \text{ stress}}{E \text{ modulus of elasticity}}$

- Modular ratio $n = \dfrac{E_s}{E_c}$ $\dfrac{\text{modulus of elasticity of steel}}{\text{modulus of elasticity of concrete}} = (6.5 - 5)$

$E_s = (6.5 - 5)\, E_c$

- F_o : final prestress force after shortening
- ϵ_c : Concrete strain due to axial prestress (F_o)

$$\epsilon_c = \frac{f_c}{E_c} = \frac{F_o}{A_c E_c}$$

- ϵ_s : steel strain = $\boxed{\epsilon_s = \epsilon_c} = \dfrac{F_o}{A_c E_c}$

(ϵ_s ←) الفقد فيه الشد

(ϵ_c ←) مقدار الانضغاط

Loss of prestress in steel

$$\Delta f_s = \epsilon_s E_s$$ ← elasticity

stress, strain

$$= \frac{F_o E_s}{A_c E_c}$$

$$= n \frac{F_o}{A_c}$$

$$\boxed{Loss = \Delta f_s = n f_{co}}$$

max allowable concrete stress C_{28}

- مقدار الانضغاط المرن (Elastic shortening) الذي يحدث

بعد فك الاكتاف وانتقال إجهاد الشد من الكابلات للخرسانة يساوي مقدار الفقد في إجهاد الشد في الكابلات

مقدار الانضغاط = الفقد في إجهاد الشد

مثال : إذا كانت الخرسانة المستخدمة في سبق الإجهاد ذات إجهاد بعد ٢٨ يوم = ٢٤٠ كجم/سم٢
وكان الإجهاد الشد المطلوب للكابلات = ١٠ طن/سم٢
احسب كمية الفقد في إجهاد شد الكابلات الناتج عن الانضغاط المرن
(Elastic shortening)

الحل

assuming $n = 6$

$$ave\ f_{co} = \tfrac{1}{2}\ max\ f_{co}$$

$$= \tfrac{1}{2} \times 120 = 60 \quad kg/cm^2$$

$$Loss = \Delta f_s = n \cdot f_{co}$$

$$= 6 \times 60 = 360 \quad kg/cm^2$$

∴ مقدار الانضغاط المرن (Elastic shortenting) = الفقد في إجهاد الشد
= ٣٦٠ كجم/سم٢
- إذا كان إجهاد شد الكابلات = ١٠ طن/سم٢

(tensile strength) $f_s\ max = 10.000\ kg/cm^2$

$$\Delta f_s = \frac{360}{10,000} \times 100 = 3.6\%$$

مثال : إذا كانت الخرسانة المستخدمة في سبق الإجهاد ذات إجهاد بعد ٢٨ يوم = ٤٠٠ كجم/سم٢
وكان إجهاد الشد المطلوب للكابلات = ١٥ طن/سم٢
احسب كمية الفقد في إجهاد شد الكابلات الناتج عن الانضغاط Elastic shortening

الحل

assuming $n = 6$

$$ave\ f_{co} = \tfrac{1}{2}\ max = 200\ kg/cm^2$$

$$Loss = \Delta f_s = n\ f_{co} = 6 \times 200 = 1200\ kg/cm^2$$

∴ مقدار الانضغاط المرن (Elastic shortening) = الفقد في إجهاد الشد = ١٢٠٠ كجم/سم٢

- إذا كان إجهاد شد الكابلات = ١٥ طن/سم٢ $f_s\ max = 15000\ kg/cm^2$

$$\Delta f_s = \frac{1200}{15000} \times 100 = 8\%$$

b) post-tensioned concrete

- بالنسبة لل post-tensioning فإن المشكلة مختلفة

i) If we have only single tendon

١- لا يحدث فقد في إجهاد الشد ينتج من Elastic shortening وذلك لأن الكابل يكون مثبت على الخرسانة المصبوبة نفسها
ويتم قياس قوة الشد في الكابل بعد حدوث ال Elastic shortening

ii) If we have more than tendon

١- فإن قيمة الضغط (prestress) ينتقل إلى الخرسانة تدريجياً مع التدرج بشد كابل تلو الآخر
٢- shortening of concrete يزيد تدريجياً وذلك بشد كابل تلو الآخر
٣- بالتالي فإن قيمة الفقد في قوة الشد (loss) الناتجة من Elastic shortening تختلف من كابل إلى آخر.

٤- أول كابل يتم شده: يتعرض إلى أكبر قيمة فقد في الشد من Elastic sho- عن باقي الكابلات

- وذلك لأنه عند شد الكابل الثاني تتعرض الخرسانة إلى ضغط ويحدث Elastic shortening وتسبب الكابل الأول معه (مقدار الضغط = مقدار الفقد في الشد في الكابل الأول)
- وكذلك في الكابل الثالث تتعرض الخرسانة إلى ضغط ويحدث Elastic shortening وتسبب الكابل الأول والثاني معه (الضغط = الفقد في الشد في الكابل الأول والثاني)
- بالمثل في باقي الكابلات (مثل Pre-tensioned)

٥- آخر كابل يتم شده: لا يتعرض إلى فقد في الشد من Elastic shortening وذلك لأنه يتم قياس قوة الشد في الكابل بعد حدوث ال Elastic shortening (مثل single tendon)
٦- لحساب قيمة الفقد في الشد (loss) يكفي حساب قيمة الفقد في الشد للكابل الأول فقط. تقسم لنص لنعتبرها نصف متوسط الفقد في باقي الكابلات

Example: Consider that the prestressing steel stress in post-tensioned member is 10 t/cm² and carried by 4 cables which are tensioned one after anther the ultimate compressive strength is 120 kg/cm². Calculate loss due to Elastic shortening of concrete.

الحل : الفقد في إجهاد الشد في الكبل الأول بسبب شد الكبلات الثلاثة الأخرى
- يتم حساب متوسط الفقد في إجهاد الشد في الكبل الأول فقط
= نصف متوسط الفقد في باقي الكبلات

$$ave\ f_{co} = \frac{1}{2} max\ f_{co} = 60\ Kg/cm^2$$

$$Loss = \Delta f_s = n\ f_{co}$$

عدد الكبلات الباقية

$$= \frac{1}{2} \left(6 \times \frac{3}{4} \times 60\right) = 135\ Kg/cm^2$$

المتوسط ← $\frac{1}{2}$

الفقد في الشد في الكبلات الباقية

العدد الكلي ← 4

- اذا كان إجهاد شد الكبلات = ١٠ طن/سم²

$$f_{s\,max} = 10.000\ Kg/cm^2$$

$$\Delta f_s = \frac{135}{10000} \times 100 = 1.35\ \%$$

* عند التنفيذ تستخدم أحد الطريقتين
- لتحديد إجهاد شد الكبلات لتلافي الفقد في الشد الناتج عن Elastic short.

الأولى : اذا كان التصميم يسمح بإهمال قيمة متوسط الفقد في إجهاد الشد الناتج عن Elastic shortening
- يتم الشد بقيمة إجهاد الشد التصميمي فقط Intial specified prestress

الثانية : إذا كان التصميم لا يسمح بإهمال قيمة متوسط الفقد في إجهاد الشد الناتج عن E-S
- يتم إضافة متوسط الفقد في إجهاد الشد إلى إجهاد الشد التصميمي
Intial specified prestress حيث يصل الإجهاد إلى أكبر من قيمته التصميمية
مقدار الفقد الناتج عن Elastic shortening

$$10000\ kg/cm^2 + 135\ kg/cm^2 = 10135\ Kg/cm^2$$

2- Loss due to creep & shrinkage in concrete

١- قيمة الفقد في إجهاد الشد الناتج عن Creep = (١-٢) قيمة الفقد في إجهاد الشد الناتج عن Elastic shortening

٢- للفرق بينهم أن الفقد في إجهاد الشد الناتج عن creep لا يمكن تعويضه بينما الفقد في إجهاد الشد الناتج عن Elastic shortening يمكن أن يوازن في post-tensioned members

٣- الفقد في إجهاد الشد الناتج عن Creep ≃ ٥-٦٪

٤- $$\Delta f_{s_{cr}} = (1-2)\, n\, f_{co}$$

($\Delta f_{s_{cr}}$: الفقد في إجهاد الشد في الكيبلات)

Example :- Modular ratio $n = 6$
- Max allowable concrete stress $= 120\ kg/cm^2$
- prestressing steel stress $= 10\ t/cm^2$

Req: Calculate loss due to creep in concrete

Sol : $n = 6$

$av\ f_{co} = \frac{1}{2} max\ f_{co} = 60$

$$loss = \Delta f_{s_{cr}} = (1-2)\, n\, f_{co}$$

$$= 1.5 \times 6 \times 60 = 540\ kg/cm^2$$

- إذا كان إجهاد شد الكيبلات = ١٠ طن/سم²

$f_s = 10.000\ kg/cm^2$

$$\Delta f_{s_{cr}} = \frac{540}{10000} \times 100 = 5.4\ \%$$

معادله حساب الفقد في إجهاد الشد الناتج عن creep في الخرسانه

Coefficient of Creep : $C_{cr} = 2.5$

$$C_{cr} = \frac{\epsilon_t}{\epsilon_i} \qquad \frac{\text{الانفعال في الخرسانه عند التحميل بحمل ثابت لمده طويله}}{\text{الانفعال في الخرسانه عند التحميل حاليا بحمل جديد}}$$

$$\boxed{\Delta f_{s_{cr}} = (C_{cr}-1)\frac{f_{co}}{E_c} \cdot E_s = (C_{cr}-1)\, n\, f_{co}}$$

Example: assuming $C_{cr} = 2.5$ $n = 6$ $f_{co} = 60\ kg/cm^2$

slu : $loss = \Delta f_s = 1.5 \times 6 \times 60 = 540\ kg/cm^2$

Loss due to shrinkage in Concrete

ϵ_{sh} : shortening strain due to shrinkage $= 0.2 - 0.3\ mm/m$

$$\boxed{\Delta f_{s_{sh}} = \epsilon_{sh} \times E_s}$$

Example : - shrinkag strain = 0.3 mm/m
- Modulus of elastticity of steel = 2 000 000 kg/cm² مرونه الكبلات 2 مليون كجم/سم
- prestressing steel stress = 10 t/cm²

Req: Calculate loss due to shrinkage in Concrete

slou :

$\epsilon_{sh} = 0.3\ mm/m$ & $E_s = 2000\ 000\ kg/cm^2$

$$\Delta f_{s_{sh}} = \epsilon_{sh} \times E_s$$

$$= \frac{0.3}{1000} \times 2\,000\,000 = 600\ kg/cm^2$$

للتحويل إلى m (1000) — اذا كان الإجهاد = 10 طن/سم²

$$\Delta f_{s_{sh}} = \frac{6000}{10{,}000} \times 100 = 6\%$$

3- loss due to creep in steel

١- يفترض أن قيمة الفقد في الشد الناتج عن creep في الكابلات = ٣-٤ %

٢- علماً أن تقل قيمة الفقد في الشد على نوعية الأداء

أ- زيادة قيمة الشد في الكابلات عن القيمة التصميمية بمقدار ٥ - ١٠ %

ب- إذا تم الشد خلال ٢-٣ دقائق

4- loss due to Anchorage Take-Up ← فك الإكاكات

١- في معظم نظم شد الكابلات الـ Post-tensioning
التي يتم فيها شد الكابلات بكامل قوة الشد التصميمية

٢- عند إجراء فك الإكاكات تنتقل قوة الشد للـ wedge (الخابور)
وبالتالي فإن تجهيزات الـ wedge تتعرض لإجهادات ضغط
وتميل للتشكل وكذلك إزاحة طفيفة للكابلات

٣- وبالتالي فإن friction wedges (جلب الاحتكاك المخروطية) لمسك الكابلات
تنزلق مسافة قليلة قبل أن يتم تثبيت الكابلات بإحكام

٤- حيث أن مسافة الانزلاق تقدر بـ ٢-٣ مم
وتعتمد هذه المسافة على م. نوع الجلب ت. إجهاد الشد ... الخ

طريقة حساب قيمة الفقد في الشد نتيجة فك الإكاكات

Δa : Anchorage deformation

$$\Delta f_s = \frac{\Delta a \, E_s}{L}$$

(Δa in cm, L in cm)

Example : A post-tensioned concrete beam is with span length 40 m & deformation of anchorage and slippage of wires estimated at = 0.5 cm & E_s = 2000 000 kg/cm²

sol : $\Delta f_s = \frac{\Delta a \, E_s}{L} = \frac{0.5 \times 2000\,000}{4000} = 250$ kg/cm²

(cm ← Δa, cm ← L)

يكمل ←

The loss of prestress for the entire length of a tendon can onsidered from section to section, with each section consisting ither a straight line or a simple circular curve. The reduced ss at the end of a segment can be used to compute the frictional in the next segment etc..

Since, for practically all prestressed concrete members, the 1 is small compared with the length, the projected length of on measured along the axis of the member can be used when comng frictional losses. Similarly, the angular change θ is given le transverse deviation of the tendon divided by its projected ch, both referred to the axis of the member.

icients of Friction μ & k

es of μ may be taken as :

0.55 for steel moving on concrete
0.30 " " " " steel
0.25 " " " " lead.

In circular construction where circumferential tendons are oned by ~~means of jacks, the losses due to friction may be~~ lated from the formulea given before, but the values of μ may ken as :

0.45 for steel moving on smooth concrete
0.25 " " " " steel bearers fixed to concrete
0.10 " " " " " rollers.

alue of k ~~per meter length should generally be taken as not~~ than 32×10^{-4}/m length but where strong sheaths or duct formers sed closely supported so that they are not displaced during oncreting operation, the value of k may be taken as 16×10^{-4}

xample :

prestressed-concrete beam, Fig. IV-3, is continuous over 2 and its curved tendon is to be tensioned from both ends. e the percentage loss of prestress due to friction from one the centre of the beam (A to E). The coefficient of fricbetween the cable and the duct is taken as 0,4, and the averable or length effect is represented by

$$k = 32 \times 10^{-4}/m$$

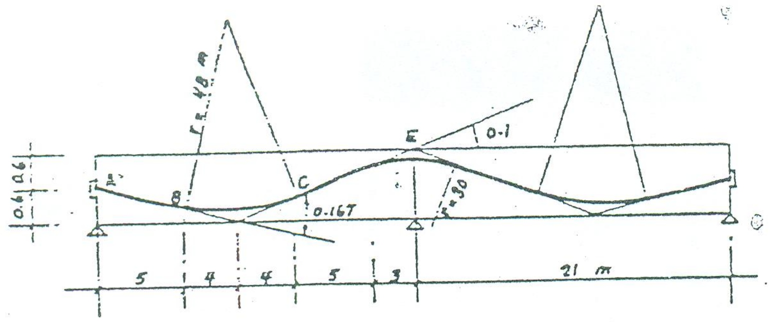


FIG. IV-3

Solution 1 : A simple approx. solution will 1st. be presented :

$$\frac{F_A - F_E}{F_A} = - kl - \mu\theta$$

$$= - 32 \times 10^{-4} \times 21 - 0.4\ (\ 0.167 + 0.1\ )$$

$$= - 0.067 - 0.107 = 0.174 \quad \text{i.e. loss} = 17.4\ \%$$

Solution 2 : The above solution does not take into account the gradual reduction of stress from A toward E. A more exact solution would be to divide the tendon into 4 portions from A to E and sonsider each portion after the loss has been reduced from the preceeding portions. Thus, for stress at A = F_1,

AB, length effect $\quad kl = 0.0032 \times 5 = 0.016$

Stress at B $\quad = 1 - 0.016 = 0.984\ F_1$

BC, length effect $\quad kl = 0.0032 \times 8 = 0.026$

Curvature effect $\quad \mu\theta = 0.4 \times 0.167 = 0.067$

total $\quad 0.026 + 0.067 = 0.093$

Using the reduced stress at B of 0.984,

the loss is $\quad 0.093 \times 0.984 = 0.091$

Stress at C $\quad = 0.984 - 0.091 = 0.893\ F_1$

CD, length effect $\quad kl = 0.0032 \times 5 = 0.016$

Using the reduced stress of 0.893 at C,

the loss is $\quad 0.016 \times 0.893 = 0.014$

Stress at D $\quad = 0.893 - 0.014 = 0.879\ F_1$

DE, length effect $\quad kl = 0.0032 \times 3 = 0.010$

Curvature effect $\quad \mu\theta = 0.4 \times 0.1 = 0.040$

total $\quad = 0.01 + 0.04 = 0.050$

loss $\quad = 0.05 \times 0.879 = 0.044$

Stress at E $\quad = 0.879 - 0.044 = 0.835\ F_1$

[illegible]

The loss according to this method is slightly less than the
t approx. method.

6 Total Amount of Losses

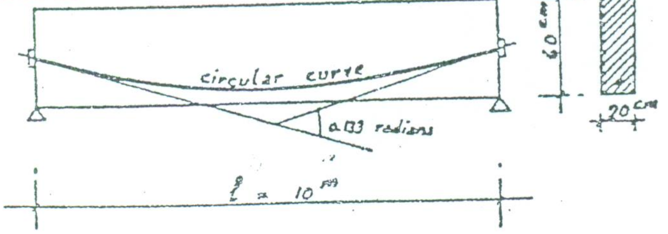
From the previous investigations we may conclude that for age steel and concrete properties, cured under average air conons, the following tabulated percentages may be taken as represative of the average losses :

	Pre-tensioning	Post-tensioning
Elastic shortening	3	1
Creep of concrete	6	5
Shrinkage of concrete	7	6
Creep in steel	2	3
Total loss	18 %	15 %

The table assumes that proper overtensioning has been applied :educe creep in steel and to overcome friction and anchorage ;es.

umple :

A post-tensioned concrete beam (fig. IV-4) with a cable of parallel wires (total steel area 7,2 cm^2) is tensioned with 2 ;s at a time. The jacking stress is to be measured by jack gage ;sure. The wires are to be stressed from one end to a vaule of to overcome frictional loss, then released to a value of f_2 so t immediately after anchorage an initial prestress of 10 t/cm^2 ld be obtained. Compute f_1 & f_2 . Then compute the final design ess in the steel after all losses have taken place.



ume the following : FIG. IV-4

Coeff. of friction $\mu = 0.55$ between steel and concrete
$k = 32 \times 10^{-4}$ for length effect.
) Deformation of anchorage and slippage of wires estimated at
1.5 mm. $E_s = 2000\ 000$ kg/cm^2
) Elastic shortening of concrete is to be computed for
E_c = 00 000 kg/cm^2

4) Creep coeff. of concrete $C_{cr} = 2.5$

5) Shrinkage of concrete $\varepsilon_{sh} = 0.2$ mm/m

6) Creep of steel $\approx$ 3% of initial steel stress

Solution :

1) Loss due to friction :

Length effect = $kl = 0.032 \times 10 = 0.032$
Curvature effect = $\mu\theta = 0.55 \times 0.133 = 0.072$
Total = $0.032 + 0.072 = 0.104$

Hence it is necessary to tension the steel to $f_1 = 10\,000/(1-0.104)$
$= 11\,160$ kg/cm^2

at one end in order to overcome the friction and obtain a stress of 10 000 kg/cm^2 at the unjacked end.

2) The anchorage slippage of $\Delta = 1.5$ mm. occurs only on one end, since the unjacked end would have its slippage taking place before the release of jack.

The loss is given by $\Delta f_s = \frac{a}{l} E_s = \frac{0.15 \times 2000\,000}{1000} = 300$ kg/cm^2

Hence, by tensioning the steel to $f_1 = 11\,160$ kg/cm^2 and then releasing it to $f_2 = 10\,300$ kg/cm^2 for anchoring, the min. stress after anchorage will be 10 000 kg/cm^2. This min. stress will occur at both ends of the beam.

3) Since the wires are tensioned two by two, the first pair will loose some stress due to the elastic shortening of concrete under the action of the subsequent 11 pairs, and the average amount of loss will be approx.

$$\frac{1}{2} \times \frac{11}{12} \times \frac{10\,000 \times 7.2}{20 \times 60} \times \frac{2000\,000}{300\,000} = 183 \text{ kg/cm}^2$$

4) The force F_o in the steel is : $10 \times 7.2 = 72$ tons
the corresponding elastic shortening is

$$\frac{72\,000}{20 \times 60 \times 300\,000} = 0.2 \times 10^{-3}$$

Creep of concrete $(2.5 - 1)\, 0.2 \times 10^{-3} = 0.3 \times 10^{-3}$

Loss due to creep $= 0.3 \times 10^{-3} \times 2000\,000 = 600$ kg/cm^2

5) For $\varepsilon_{sh} = 0.2$ mm/m

Loss due to shrinkage $= 0.2 \times 10^{-3} \times 2000\ 000 = 400$ kg/cm^2

6) Creep of steel 3%

Loss due to creep of steel $= 10\ 000 \quad 3/100 = 300$ kg/cm^2

The total loss :

Elastic shortening	183
Creep of conc.	600
Shrinkage of conc.	400
Creep of steel	300
	1483 kg/cm^2

Eventual loss of prestress $\approx$ 15 %

$$f = \frac{72000}{1200} \pm \frac{72000 \times 10}{12000} = -60 \pm 60 \text{ kg/cm}^2$$

i.e $f_{top} = -120$ and $f_{bot} = 0$ kg/cm^2 same answers as before.

I-3 Classification and Types

Prestressed concrete structures can be classified in a number of ways depending upon their features of design and construction :

1) Pre-Tensioning & Post-Tensioning. The term pre-tensioning is used to describe any method of prestressing in which the tendons are tensioned before the concrete is placed. It is evident that the tendons must be temporarily anchored against some abutments or stressing beds when tensioned and the prestress transferred to the concrete after it has set. This proceedure is employed in precasting plants or laboratories where permanent beds are provided for such tensioning; it is also applied in the field where abutments can be economically constructed. In contrast to pre-tensioning, post-tensioning is a method of pre-stressing which the tendon is tensioned after the concrete has hardened. Thus the prestressing is almost always performed against the hardened concrete, and the tendons are anchored against it immediately after prestressing. This method can be applied to members either precast or cast in place.

2) End Anchored or Non-End. Anchored Tendons. When post-tensioned , the tendons are anchored at their ends by means of mechanical devices to transmit the prestress to the concrete. Such a member is termed end-anchored. In pretensioning, the tendons generally have their prestress transmitted to the concrete by their bond action near the ends. The effectiveness of such stress transmission is limited to wires of small size .

3) Bonded or Unbonded Tendons. Bonded tendons denote those bonded throughout their length to the serrounding concrete. Nonend-anchored tendons are necessarily bonded ones; end-anchored tendons may be either bonded or unbonded to the concrete. In general, the bonding of post-tensioned tendons is accomplished by subsequent grouting; if unbonded, protection of the tendons from corrosion must be provided by galvanising , greasing, or some other means.

4) Partial or Full Prestressing: When a member is designed so that under the working load there are no tensile stresses in it, then the concrete is said to be fully prestressed. If some tensile stresses [illegible] be produced in the member under working load, then it is termed

partially prestressed. For partial prestressing additional mild s bars are frequently provided to re-inforce the portion under tensi

5) <u>Precast, Cast-in-place, Composite Construction.</u>

Precasting permits better control in mass production and is of economical. Cast-in-place requires more form and falsework per uni product but saves the cost of transportation and erections; it is a necessity for large and heavy members. Often-times, it is economic to precast part of a member, erect it, and then cast the remaining portion in place. This proceedure is called composite construction. The precast elements in a composite construction can be more easily jointed together than those in a totally precast structure. By this type of construction it is possible to save much of the form work re- quired for cast in place construction.

I-4 <u>Advantages of Prestressed Concrete as a Building Material</u>

The most outstanding advantage of prestressed concrete is the po ibility of the effective use of high strength concrete and steel pro- ducing concrete structural elements free from cracks.

In reinforced concrete, the concrete is effectively used only in the compression zone of the sections and high strength concrete cannot be fully utilized so long as we use low percentages of tension reinfor- cements. Even if it is possible to use high strength concrete, the sections will be smaller and the required reinforcement will be corres- podingly bigger giving a more costly design. Furthermore, the use of high grade steels for the tension reinforcements is limited by the al- lowed width of cracks.

In prestressed concrete, the high tensile steel is freely prest- retched to any possible desirable amount and anchored against the con- crete creating desirable strains and stresses which serve to eliminate or reduce cracks in concrete. Thus the entire section of the concrete becomes effective and the higher the strength of the concrete, the smaller is the section. Stronger concrete is also necessary to resist high stresses at the anchorages and to give strength to the thinner sec- tions frequently employed for prestressed concrete.

Prestressed concretes free from cracks possess bigger elasticity bigger stiffness, higher resistance to external and climatic actions and bigger gas and water tightness.

By convenient prestressing, it is possible to eliminate or reduce inconvenient undesirable strains and stresses as will be shown in the lowing cases in addition to what has been explained.

By prestressing the tie of an arch one can eliminate its elongation using undesirable bending moments in the arch.

The prestressing of the footing of a concrete surface of revolution (a dome or a cone) or the edge beam of a cylindrical shell, eliminates or reduces undesirable stresses and strains at the edges.

) Prestressing reduces the elastic and plastic deformations caused by hrinkage and creep of beams due to the negative deflections which take lace at transfer under the action of dead loads.

) The use of curved or inclined tendons create upward forces which counterbalance a part of the downward dead and working loads and hence reduce the shearing forces in the beam. In addition, precompression in the concrete reduces the diagonal tension. Thus it is possible in prestressed concrete to use smaller webs and in many cases to dispence with most of the web reinforcements to carry the same amount of external shear in a beam.

Prestressed-concrete design is more suitable for structures of long span and those carrying heavy loads, principally because of the higher strengths of materials employed.

Prestressed structures are more slender due to smaller dimensions. They do not crack under working loads, and what ever cracks may be developed under over loads will be closed up as soon as the load is removed, unless the load is excessive. Under dead load the deflection is reduced, owing to the cambering effect of prestress. This becomes an important consideration for such structures as long cantilevers. Under live load, the deflection is also smaller becasue of the effectiveness of the entire uncracked concrete section, which has a much bigger moment of inertia than that of the cracked section. Prestressed elements are more adaptable to precasting because of the lighter weight.

In spite of the previous advantages, it has to be noted that stronger materials will have a higher unit cost. More auxiliary materials are required for prestressing , such as end anchorages, conduits and grouts. The price of the end anchorage per cable is fixed, hence,its cost per m decreases for longer cables. Prestressed concrete projects require more elaborate design and continual engineering supervision. Such over-head charges will decrease if the same typical design is repeated many times. The use of high strength wires is more economic than the use of normal mild and high grade steels because the rate of increase of the price is smaller than that of the strength.

From the above discussion, it can be concluded that prestressed :rete design is more likely to be economical when the same unit is eated many times or when heavy loads are acting on long spans. Its lication may also be suitable for pre-cast and semi-precast compo- elements. The economy of each case must be considered individal-

Prestressed-concrete can however only be used by specialized des- ers and contractors having special pre-tensioning factories and ex- ienced executing crew.

II - MATERIALS

The most effective use of prestressing can only be obtained if the concrete and the steel are of a very high quality.

II-1 Concrete

Special care shall be given to the properties of individual materials used for the production of concrete for structural members in prestressed concrete and their effect on such properties of concrete as compressive strength,modulus of elasticity,shrinkage, creep and bond. The aim shall be produce high quality concrete not only for the sake of obtaining higher crushing strength but also in order to avoid serious reductions in the prestressing force. High quality concrete can be achieved through careful selection of aggregates, suitable granular composition, use of low water cement ratio, the eventual addition of convenient admixures, sufficient cement content and through proper mixing compaction and curing.

The minimum cement content for prestressed concrete work shall be 350 kg. per m^3 of finished concrete. The cement content shall preferably be within 500 kg/m^3. In no case shall it exeed 600 kg/m^3.

The expected crushing strength of the different mixes may be :

Cement dose	350	400	450	500	kg/m^3
Strength f_{C28}	300	400	500	600	kg/cm^2

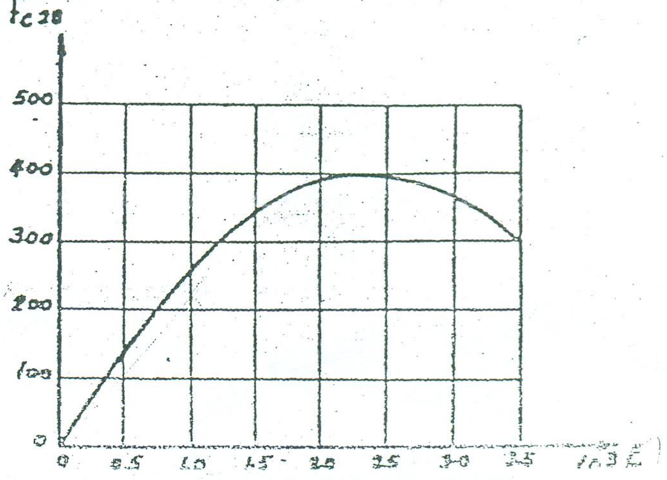
For pre-tensioned concrete min.

f_{C28} = 400 kg/cm^2

For post-tensioned concrete min.

f_{C28} = 300 kg/cm^2

The stress-strain relation for a C400 concrete (i.e concrete with a minimum crushing strength of 400 kg/cm^2 at 28 days) is shown in figure II-1.



The modulus of elasticity

nd the modular ratio $n = E_s/E_c$ for the different concrete quali-
nay be assumed as follows :

strength	f_{C28}	300	400	500	600	kg/cm^2
"	f_{cp}	240	310	380	450	" "
of elasticity	E_c	300	340	370	400	t/cm^2
ar ratio n		6.5	6	5.5	5	

c strain of concrete ε_c

$$\varepsilon_c = f_c / E_c$$

ven values of E_c may be used for $f_c \leqslant 0.3$ to $0.4\ f_{C28}$

age strain ε_{sh}

rposes of design, the shrinkage strain ε_{sh} may be assumed :

$$\varepsilon_{sh} = 0.20 \text{ to } 0.30 \text{ mm/m}$$

ε_{cr} and coefficient of creep C_{cr}

he term coefficient of creep C_{cr} is employed to indicate the of the strain ε_t after a lengthy period of constant stress to stantanious strain ε_i immediately obtained at the application of ress. Hence

$$C_{cr} = \varepsilon_t / \varepsilon_i$$

or purposes of design it is considered safe to take C_{cr} around 3. st-tensioned members, where the prestress is applied late, the cient could be a little less, for pre-tensioned members, where estress is applied at an early age, the coefficient could be a more.

or a creep coefficient of 3, the amount of creep strain is two the instantaneous elastic strain. Of this two, it can be rough- mated that about 1/4 takes place within the first two weeks, application of prestress, another 1/4 within 2 to 3 months, another thin a year or two, and last 1/4 within the course of many years.

Expansive Cement

pes of cement that expand chemically after setting and during ng are known as expansive or self-stressing cements. When these [illegible] used to make concrete with embedded steel, the steel is elongated by the expansion of the concrete. Thus the steel is prestressed in tension, which in turn produces compressive prestress in the concrete, resulting in what is known as chemical prestressing or self stressed concrete.

When concrete made with expanding cement is unstrained, the amount of expansion produced by the chemical reaction between the cement and water amount to 30-50 mm/m and the concrete would then disintigrate by itself. When restrained either internally or externally with steel or other means, the amount of expansion can be controlled.

When high-tensile steel is used to produce the prestress, say corresponding to tensile stress at 10 t/cm^2 and an E_s = 2000 t/cm^2, an expansion of

$$\frac{10}{2000} = \frac{5}{1000} = 5 \text{ mm/m}$$

is required. For other stress levels, varying amounts of expansion will be required.

Because of the expansion in all three directions, it seems difficult to use this cement for complicated structures cast in place, such as buildings.

Expanding cement has been successfully applied for many interesting projects, especially in France. However, many problems concerning the use of expanding cement for self-stressing such as the exact control of the stresses and strains are still unsolved but its extensive application in the near future is expected.

II-3 Steel

The steel to be used for the prestressing members shall be one of the 2 types described below :

a) Hard drawn wire of an ultimate strength not less than 15 t/cm^2 supplied in coils as given in the following table :

Ø of wire m/m	Ultimate Strength t/cm^2	Min. diam. of Coil cm.
7 - 5	15 - 16	180
4 - 3	18 - 20	150
2 - 1	22 - 24	90

If diam. of coil is smaller, the wires must be mechanically straightened.

b) Silicon chrome or other alloy steel of an ultimate strength of at st 10 t/cm^2 .

of stress : If the steel has no definite yield point as is general-
the case for hard drawn wires, the proof stress shall be assumed as
tensile stress producing a permanent elongation of 0.2%. The proof
ess shall not be less than 80% of the ultimate tensile strength.

The min. elongation at rupture: For hard drawn wires 4% in a 25 cm
ge and for high strength steel alloy bars 4% in a gauge of 20 diam-
rs. Wires and bars used for prestressing shall not be spliced by
ling. The stress-strain relation for hard drawn wires is shown in
ure II-2.

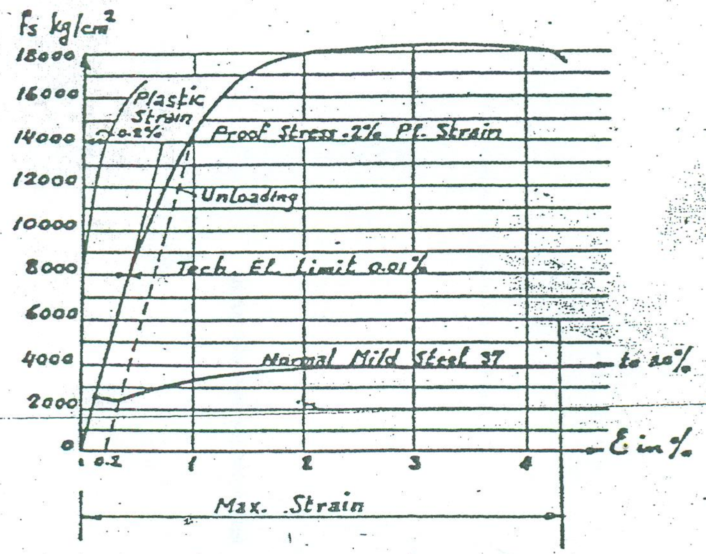


FIG. II-2

p of Steel

Creep of steel due to normal prestressing forces may be assumed
design purposes between 3 & 4% . While creep in steel is a fun-
n of time, there is evidence to show that under the ordinary work-
stress for high-tensile steel, creep takes place mostly during the
t few days. Under constant strain, creep ceases entirely after
t 2 weeks. If the steel is stressed to a few per cent above its
ial prestress and the overstress is maintained for a few minutes,
eventual creep can be greatly lessened, and it practically stops
bout 3 days.

Fiberglass Tendons

Fiberglass is manufactured by drawing fluid glass into fine fila-
s. Although this new material has not yet been commercially appli-
n prestressed-concrete construction, it has been proved by tests
it possesses certain superior qualities that indicate high promise

for prestressing. An Ultimate tensile strength of 70 t/cm^2 is quite commonly obtained. Values as high as 350 t/cm^2 have been reached for individual silica fibers 0.0003 mm. in diameter, it being known that the strength varies approximately inversily as the diameter of the fiber.

Fiberglass can be made in three formes: parallel chords, twisted strands and parallel fibers embedded in plastic. The last form in the shape of fiberglass rods is considered most suitable for prestressing because of its relative simplicity for handling, gripping and anchoring. As bonding agent in the manufacture of fiberglass rods , epoxy resin has proved to be superior. Their tensile strength is generally $>$ 16 t/cm^2 based on the gross area of the rod.

Another advantage of fiberglass is its low modulus of elasticity which ranges between 450 and 750 t/cm^2. With its high strength and low modulus, the percentage of loss of prestress would be quite small. Other advantages claimed for this material are high resistance to acids andalkalies and the ability to withstand high temperature. However some major problems must be solved before its commercial use in practice such as : its long-time ulitimate strength, its dynamic fatigue, the best method of fabricating chords giving an even distribution of stress and the design of suitable end anchorages protecting the brittle fiberglass rods from failing in the grip under the effect of stress concenterations and combined stresses.

II-5 Grout

Steel installed in holes or flexible metal tubes cast in the concrete shall be bonded, in which case the annular space between the perimeter of the hole or tube and the steel shall be pressure grouted after the prestressing process has been completed. The grout shall be made to the consistency of thick paint and shall be mixed in the proportions, by volume, of one part portland cement to 0.75 part (max.) of sand and 0.75 part (max.) of water. It may be necessary to eliminate the sand from the mix and use neat cement grout.

II-6 Sheathing

Sheathing is used when the cables are put in the form and concrete is cast around them. The sheathing shall be metallic and completely water tight specially at joints so that fine concrete mortar cannot penetrate and hinder the free movement of the wires. Sheaths shall be strong enough to maintain their shape against the forces due to handling, placing and compaction of concrete and eventual rust effect. The dimensions of the sheath must permit the easy flow of grout around

III - PRESTRESSING SYSTEMS

- 1 Pre-tensioning System

A simple way of stressing a pre-tensioned member is to pull the ions between two bulkheads anchored against the ends of a stres - ; bed. The forms are there erected around the tensioned tendons the concrete is poured and well compacted, effectively by the of vibrators. After the concrete hardens, the tendons are cut e from the bulkheads and the prestress is transferred to the con- e by bond. Such stressing beds are often used in laboratories and tressing factories.

The dependence on bond to transmit prestress between steel and rete necessitates the use of small wires to ensure good anchora- Wires greater than about 3mm. diameter are to be used only if are waved along their length or if they are corrugated. In any , a certain length of transfer is required to develop the bond. ld there be insufficient length of transfer, for example, when ks occur near the end of a beam, the bond may be broken and the s may slip. A more reliable method is to add mechanical end an- ages to the pre-tensioned wires.

- 2 Post-tensioning System

The methods used for post-tensioning can be classified under e main groups: 1) mechanical prestressing by means of jacks ; lectrical prestressing by application of heat ; 3) chemical tressing by the use of expanding cement.

Mechanical Prestressing :

In both pre-tensioning and post-tensioning, the most common meth- for stressing the tendons is jacking. In post-tensioning, jacks used to pull the steel against the hardened concrete as shown in e I-1, in pre-tensioning, to pull it against some bulkheads or . Hydraulic jacks are often used, because of their high capacity be relatively small force required to apply the ...

Pressure guages for jacks are calibrated either to read the pressure on the piston or to read directly the amount of tension applied to the tendon. It is usual practice to measure the elongation of steel to be checked against the guage indications.

In order to minimize creep in steel and also to reduce frictional loss of prestress, tendons are sometimes jacked a few per cent above their specified initial prestress. Over-jacking is also necessary to compensate for slippage and take-up in the anchorage at the release of jacking pressure. When tendons are long or appreciably curved, jacking should be done from two ends.

2) <u>Electrical Prestressing</u> :

The electrical method of prestressing dispenses with the use of jacks altogether. The steel is lengthened by heating with electricity. This electrical process is a post-tensioning method where the concrete is allowed to harden fully before the applications of prestress. It employs smooth reinforcing bars coated with thermoplastic material such as sulfur or low - melting alloys and buried in the concrete like ordinary reinforcing bars but with protruding threaded ends. After the concrete has set, an electric current of low voltage but high amperage is passed through the bars. When the steel bars heat and elongate, the nuts or the protruding ends are tightened against heavy washers. When the bars cool, the prestress is developed and the bond is restored by the resolidification of the coating.

However, this method has been found to be uneconomical in competition with prestressing using high tensile steel although it has found wide usage in the U.S.S.R. in pretensioning.

3) <u>Chemical Prestressing</u> :

As described previously, the chemical reactions which take place in expensive cements can stress the embedded steel which in turn compresses the concrete. This is often termed self-stressing , but can also be termed chemical prestressing (Refer to section II-2).