Ce 572: Loss of Prestress

Loss of prestress is the reduction of tensile stress in prestressing tendons due to shortening of the concrete around the tendons, relaxation of stress within the tendons and other time dependent deformations in the concrete, shrinkage and creep, related to external factors which reduce the total initial force applied to the concrete (see Figure 1). ACI 318 in Chapter 18 identifies the sources of loss of prestress discussed next.

Accurate determination of losses is more important in some prestressed concrete members than in others. Losses have no effect on the ultimate strength of a flexural member unless the tendons are unbonded or if the final stress after losses is less than 0.50 f_{pu}. Underestimation or overestimation of losses can affect service conditions such as camber, deflection and cracking.

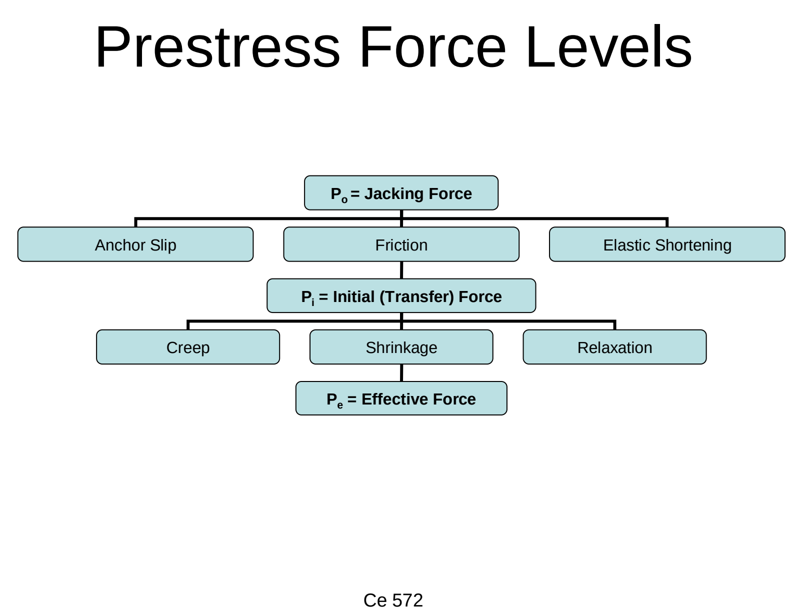

Figure 1. Effects of Losses on Prestressing Force

Sources of Stress Loss

1. Anchorage Seating Loss and Friction

Anchorage seating loss and frictionloss due to intended or unintended curvature in post-tensioning tendons are two mechanical sources of loss. They represent the difference between the tension applied to the tendon by the jacking unit and the initial tension available for application to the concrete by the tendon. Their magnitude can be determined with reasonable accuracy and, in many cases, they are fully or partially compensated for by overjacking.

2. Elastic Shortening of Concrete

The concrete around the tendons shortens as the prestressing force is applied to it. Those tendons which are already bonded to the concrete shorten with it such as in the case of post-tensioned applications with multiple tendons.

3. Shrinkage of Concrete

This is the loss of stress in the tendon due to shrinkage of the concrete surrounding it. It is proportional to that part of the shrinkage that takes place after the transfer of prestress force to the concrete.

4. Creep of Concrete and Relaxation of Tendons

Creep of concrete and relaxation of tendons complicate stress loss calculations. The rate of loss due to each of these factors changes when the stress level changes. The stress level is changing constantly throughout the life of the structure. Therefore, the rates of loss due to creep and relaxation are constantly changing.

Range of Values for Total Loss

Total loss of prestress in typical members will range from about 25,000 to 50,000 psi for normal weight concrete members and from about 30,000 to 55,000 psi for sand-lightweight members. The load tables in Chapter 2 of the PCI handbook have a lower limit on loss of 30,000 psi.

Estimating Prestress Loss

This section is based on the report of a task group sponsored by ACI-ASCE Committee 423, Prestressed Concrete[1]. That reference gives simple equations for estimating losses of prestress which would enable the designer to estimate the various types of prestress loss rather than using a lump sum value. It is believed that these equations, intended for practical design applications, provide fairly realistic values for normal design conditions. For unusual design situations and special structures, more detailed analyses may be warranted and procedures based on time-step estimates of the prestress force are available. It must be noted that all loss estimates are for a given cross section along the member length.

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[1] Zia, P., Preston, H.K., Scott, N.L., and Workman, E.B., “Estimating Prestress Losses,” Concrete International, V.1., No. 6, June 1979.

Estimating Total Losses

$$T.L. = ES + CR + SH + RE \qquad \text{(Eq. 1)}$$

where

$T.L.$ = total loss (psi), and other terms are losses due to:

ES = elastic shortening
CR = creep of concrete
SH = shrinkage of concrete
RE = relaxation of tendons

Elastic Shortening

$$ES = K_{es} E_{ps} f_{cir} / E_{ci} \qquad \text{(Eq. 2)}$$

where

K_{es} = 1.0 for pretensioned members. More guidance in C.I. article.

E_{ps} = modulus of elasticity of prestressing tendons (about 28.5×10^6 psi)

E_{ci} = modulus of elasticity of concrete at time prestress is applied

f_{cir} = net compressive stress in concrete at center of gravity of prestressing force immediately after the prestress has been applied to the concrete. Compression is positive.

$$f_{cir} = K_{cir}\left(\frac{P_i}{A_g} + \frac{P_i e^2}{I_g}\right) - \frac{M_g e}{I_g} \qquad \text{(Eq. 3)}$$

where

K_{cir} = 0.9 for pretensioned members

P_i = initial prestress force (after anchorage seating loss)

e = eccentricity of center of gravity of tendons with respect to center of gravity of concrete at the cross section considered

A_g = area of gross concrete section at the cross section considered

I_g = moment of inertia of gross concrete section at the cross section Considered

M_g = bending moment due to self-weight of prestressed member and any other permanent loads in place at time of prestress

In pretensioned members P_i typically is the prestress force level reflecting anchorage slip because any friction losses are usually compensated by overstressing the tendons and it does not include the elastic shortening effect.

Creep Losses

$$CR = K_{cr}\left(\frac{E_s}{E_c}\right)(f_{cir} - f_{cds}) \qquad \text{(Eq. 4)}$$

where

K_{cr} = 2.0 normal weight concrete and 1.6 for sand-lightweight

f_{cds} = stress in concrete at center of gravity of prestressing force due to all superimposed permanent deadloads that are applied to the member after it has been prestressed (see Eq. 5)

E_c = modulus of elasticity of concrete at 28 days

$$f_{cds} = M_{sd}(e)/I_g \qquad \text{(Eq. 5)}$$

where:

M_{sd} = moment due to all superimposed permanent dead and sustained loads applied after prestressing

Shrinkage Loss

$$SH = (8.2 \times 10^{-6})K_{sh}E_s(1 - 0.06V/S)(100 - R.H.) \qquad \text{(Eq. 6)}$$

where:

K_{sh} = 1.0 for pretensioned members

V/S = volume to surface ratio

R.H. = average ambient relative humidity (see Figure 2)

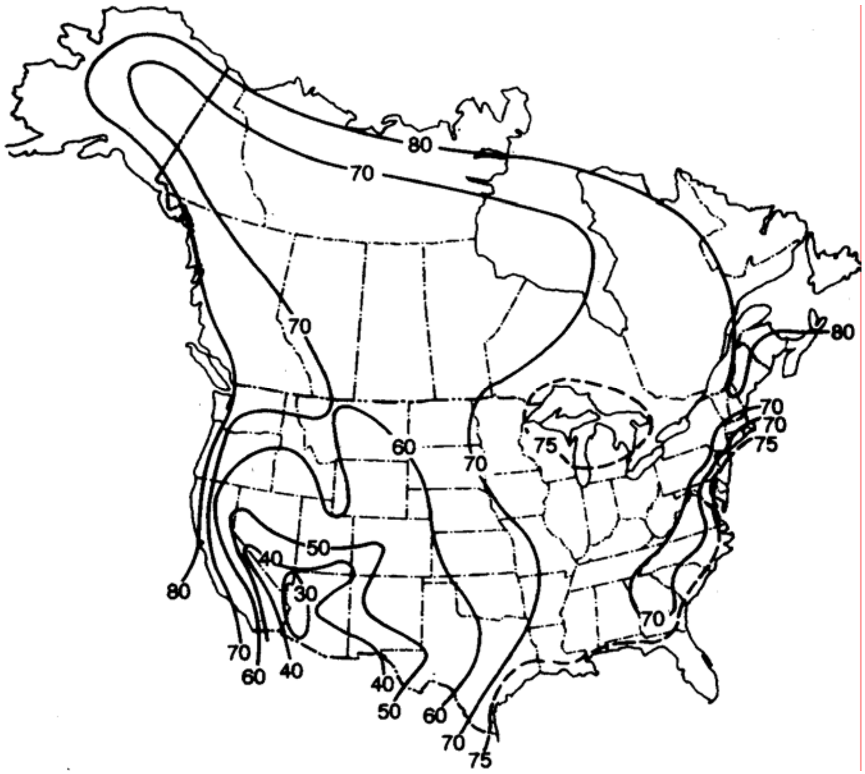

Figure 2. Annual Average Ambient Relative Humidity, %

Relaxation Losses

$$RE = [K_{re} - J(SH + CR + ES)]C \qquad \text{(Eq. 7)}$$

where

SH, CR, and ES are the estimates of individual losses. Values for K_{re} and *J* are taken from Table 1. For values of coefficient **C**, see Table 2.

Table 1 Values of K_{re} and J for Relaxation Loss Estimate

Type of tendon	K_{re}	J
270 Grade stress-relieved strand or wire	20,000	0.15
250 Grade stress-relieved strand or wire	18,500	0.14
240 or 235 Grade stress-relieved wire	17,600	0.13
270 Grade low-relaxation strand	5,000	0.040
250 Grade low-relaxation wire	4,630	0.037
240 or 235 Grade low-relaxation wire	4,400	0.035
145 or 160 Grade stress-relieved bar	6,000	0.05

Table 2. Values of Coefficient *C*

f_{pi}/f_{pu}	**Stress-relieved strand or wire**	**Stress-relieved bar or low-relaxation strand or wire**
0.80		1.28
0.79		1.22
0.78		1.16
0.77		1.11
0.76		1.05
0.75	1.45	1.00
0.74	1.36	0.95
0.73	1.27	0.90
0.72	1.18	0.85
0.71	1.09	0.80
0.70	1.00	0.75
0.69	0.94	0.70
0.68	0.89	0.66
0.67	0.83	0.61
0.66	0.78	0.57
0.65	0.73	0.53
0.64	0.68	0.49
0.63	0.63	0.45
0.62	0.58	0.41
0.61	0.53	0.37
0.60	0.49	0.33

4.7.2 Critical Locations

Computations for stress losses due to elastic shortening and creep of concrete are based on the compressive stress in the concrete at the center of gravity (CGS) of the prestressing force.

For bonded tendons, stress losses are computed at that point on the span where flexural tensile stresses are most critical. In members with straight, parabolic or approximately parabolic tendons this is usually mid-span. In members with tendons deflected at mid-span only, the critical point is generally near the 0.4 point of the span. Since the tendons are bonded, only the stresses at the critical point need to be considered. Stresses or stress changes at other points along the member do not affect the stresses or stress losses at the critical point. For design examples of loss estimates see Reference 1 and example 4.7.1 in the Fifth Edition of the PCI Design Handbook.