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Prestress Loss Distributions along Simply Supported Pretensioned Concrete Beams

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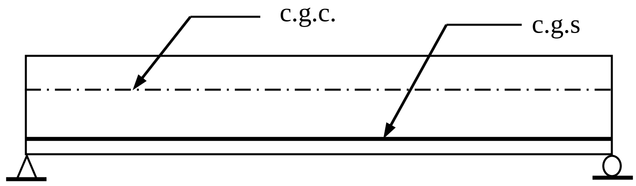
ABSTRACT: The prestressing forces in prestressed tendons undergo a process of reduction over a period of time. A common assumption is that prestress loss is constantly distributed throughout the span of a simply supported pretensioned concrete beam. The purpose of this work is to investigate the accuracy of this assumption. The types of prestressed concrete beams investigated in this work include the following three typical types of tendon profile: (I) straight strands, (II) single-point depressed, and (III) two-point depressed. The major findings derived from this work are: (1) The total prestress loss is not constantly distributed throughout the span of a simply supported pretensioned concrete beam with any of the three types of tendon profiles, (2) The variation of prestress loss along the span of a pretensioned beam caused by elastic shortening of concrete or creep of concrete is much more significant than that caused by shrinkage of concrete or relaxation of tendons, and (3) The type of tendon profile in a simply supported pretensioned concrete beam has significant effects on the pattern of prestress loss distribution along the beam.

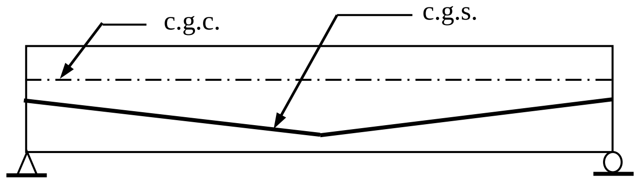
1 INTRODUCTION

A pretensioned concrete beam is a prestressed concrete beam in which the tendons are tensioned prior to casting the concrete. Structural engineers typically use the following three typical tendon profiles for the design of pretensioned concrete beams: (1) straight strands, (2) single-point depressed, and (3) two-point depressed, as shown in Figures 1(a), (b), and (c), respectively (PCI 2004). Note that "c.g.s." shown in Figure 1 represents the center of gravity of prestressing steel and "c.g.c." represents the center of gravity of a concrete section.

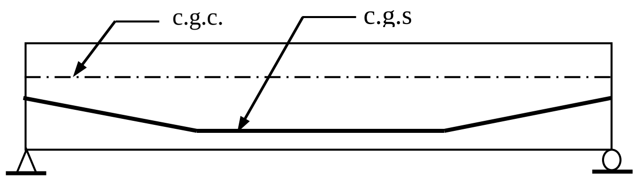
The prestressing forces in prestressed tendons undergo a process of reduction over a period of time. The four major losses of prestress for pretensioned concrete beams (Lin 1963; Nawy 2010) are: (1) Elastic shortening of concrete (ES), (2) Creep of concrete (CR), (3) Shrinkage of concrete (SH), and (4) Relaxation of tendons (RE). Elastic shortening of concrete (EC) occurs when the prestress in tendon is transferred to the concrete beam, which causes the beam to shorten and the tendon to shorten with it, resulting in a prestress loss in the tendon. Creep of concrete (CR) is defined as time-dependent deformation in the concrete element resulting from the presence of stress, which in turn results in a prestress loss in the tendon. Shrinkage of concrete (SH) occurs when the concrete element contracts due to drying shrinkage in concrete (decrease in the volume of a concrete element due to drying that is dependent on time and on moisture conditions), which results in a prestress loss in the tendon. Relaxation of tendons (RE) refers to stress relaxation in prestressing steel, which is the loss of stress when prestressing steel is prestressed and maintained at a constant strain for a period of time.



(a) Straight strands



(b) Single-point depressed



(c) Two-point depressed

Figure1. Typical prestressing tendon profiles for simply supported pretensioned concrete beams

2 LOSS OF PRESTRESS

The following addresses each of the four major losses (PCA 2008):

1) Elastic shortening of concrete (ES):
For members with bonded tendons,

$$ES = K_{es} E_{ps} \frac{f_{cir}}{E_{ci}} \tag{1}$$

where K_{es} = a factor (= 1.0 for pretensioned members); E_{ps} = the modulus of elasticity of prestressing steel; E_{ci} = the modulus of elasticity of concrete at the time of initial prestress; and f_{cir} = the net compressive stress in concrete at the center of gravity of prestressing steel immediately after the prestress has been applied to the concrete, that is,

$$f_{cir} = K_{cir}\, f_{cpi} - f_g \tag{2}$$

where K_{cir} = a factor (= 0.9 for pretensioned members); f_g = the stress in concrete at the center of gravity of prestressing steel due to the weight of the structure at time the prestress is applied; and f_{cpi} = the stress in concrete at the center of gravity of the prestressing steel due to P_{pi}, that is,

$$f_{cpi} = \frac{P_{pi}}{A_c} + \frac{P_{pi} e^2}{I_c} \tag{3}$$

where P_{pi} = prestressing force in tendons before reduction for elastic shortening of concrete, creep of concrete, shrinkage of concrete, and relaxation of the tendons; A_c = gross area of the concrete section, neglecting reinforcement; I_c = moment of inertia of the gross concrete section about the centroidal axis, neglecting reinforcement; and e = the eccentricity of cgs with respect to cgc at the cross-section considered.
From Eqs. (2) and (3), one has:

$$f_{cir} = K_{cir}\left[\frac{P_{pi}}{A_c} + \frac{P_{pi} e^2}{I_c}\right] - \frac{M_d e}{I_c} \tag{4}$$

where M_d = the moment due to the weight of the member at the time of prestressing.

2) Creep of concrete (CR):
The creep of concrete (CR) can be computed using Eq. (5):

$$CR = K_{cr}\left(\frac{E_{ps}}{E_c}\right)\left(f_{cir} - f_{cds}\right) \tag{5}$$

where K_{cr} = a factor (= 2.0 for pretensioned members); E_c = the modulus of elasticity of concrete at 28 days; and f_{cds} = the stress in concrete at the center of gravity of prestressing steel due to all superimposed permanent dead loads that are applied to the member after it has been prestressed.

3) Shrinkage of concrete (SH):
The shrinkage of concrete (SH) can be computed using Eq. (6):

$$SH = 8.2 \times 10^{-6} K_{sh} E_{ps}\left[1 - 0.06\left(\frac{V}{S}\right)\right]\left(100 - RH\right) \tag{6}$$

where K_{sh} = a factor (= 1.0 for pretensioned members); V/S = the volume to surface ratio of the concrete member, usually approximately taken as the gross cross-sectional area of concrete member divided by its perimeter [note that Eq. (6) uses the unit “inch” for the computation of V/S]; and RH = the average relative humidity surrounding the concrete member.

4) Relaxation of tendons (RE):
The relaxation of tendon stress (RE) can be computed using Eq. (7):

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

where K_{re} = 34.48 MPa (5000 psi) for 270 Grade low-relaxation strand; J = 0.040 for 270 Grade low-relaxation strand, and C = a factor which is related to the ratio of f_{pi}/f_{pu} (where f_{pi} is the prestressing stress in tendons before reduction for elastic shortening of concrete, creep of concrete, shrinkage of concrete, and relaxation of prestressing steel and f_{pu} is the specified tensile strength of prestressing steel) and is used to determine RE.

3 LOSS OF PRESTRESS COMPUTATION EXAMPLES

Three examples are demonstrated for the computation of prestress losses. These three examples include: (1) a concrete beam with straight strands, (2) a concrete beam with single-point depressed tendons, and (3) a concrete beam with two-point depressed tendons.

Example 1: A simply supported concrete beam with a span length of 12.2 m (40 ft.), as shown in Figure 2, is pretensioned using 6-12.7 mm (0.5 in.) diameter low-relaxation strands with a modulus of elasticity, E_{ps}, of 196,510 MPa (28,500 ksi). Compute the prestress losses along the span of the beam. Assume that (1) f_{pu} (specified tensile strength of prestressing steel) = 1862 MPa (270 ksi), (2) f_{pi} (prestressing stress in tendons before reduction for elastic shortening of concrete, creep of concrete, shrinkage of concrete, and relaxation of prestressing steel) = $0.74f_{pu}$, (3) f'_{ci} (the compressive strength of concrete at the time of initial prestress) = 26.90 MPa (3,900 psi.), (4) f'_c (the specified 28-day compressive strength of concrete) = 37.93 Mpa (5,500 psi.), (5) the average relative humidity surrounding the concrete member is 75 (in %), (6) the superimposed permanent dead load that is applied to the girder after it has been prestressed is 2.04 kN/m (0.14 kips/ft), and (7) the prestress transfer point located within 0.61 m (2 ft.) from the support.

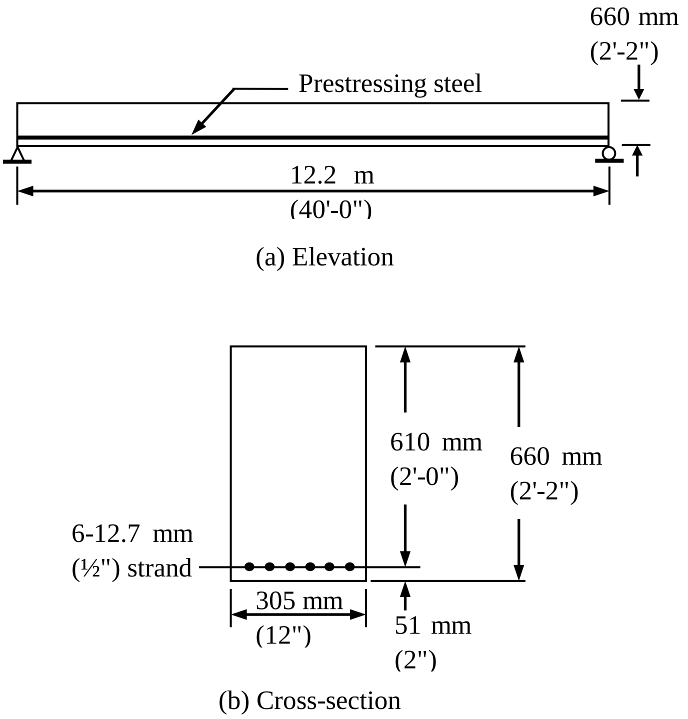


Figure 2. Pretensioned beam with straight strands for Example 1

Loss of Prestress at Midspan (6.1 m from the support)

(1) Computation of ES:

Referring to Figure 2, the moment at the midspan due to the weight of the beam [the weight of the beam is estimated to be 23.55 kN/m^3 (0.15 kips/ft^3)] at the time of prestressing can be computed to be:

$$M_d = \left[(660\text{mm})(305\text{mm})(23.55\text{kN/m}^3)\right]\left[\frac{(12.2\text{m})^2}{8}\right]$$

$$= 88.20 \text{ kN·m}$$

Since the area of 12.7 mm (½") Grade 270 strand, A_{ps} = 98.7 mm^2 (0.153 in.^{2}) (Nawy 2010), $P_{pi} = 0.74f_{pu}A_{ps}$ = 0.74(1862 MPa)(6)(98.7 mm^2) = 816 kN.

Also, referring to Figure 2(b), A_c = (305mm)(660 mm) = 201,300 mm^2, e = (660mm / 2) - 51mm = 279mm and I_c = (305mm)(660mm)^3/12 = 7.307×10^9 mm^4.

From Eq. (4), one has:

$$f_{cir} = 0.9\left[\frac{816\text{kN}}{201{,}300\text{mm}^2} + \frac{(816\text{kN})(279\text{mm})^2}{7.307\times10^9\text{mm}^4}\right] - \frac{(88.20\text{kN}\cdot\text{m})(279\text{mm})}{7.307\times10^9\text{mm}^4} = 8.104\text{MPa}$$

For normal-weight concrete, the modulus of elasticity of concrete at time of initial prestress, E_{ci}, can be computed to be (AASHTO 2007):

$$E_{ci} = 4800\sqrt{f'_c} = 4800\sqrt{26.90} = 24{,}900\text{MPa}$$

From Eq. (1), one has:

$$ES = (1.0)(196{,}510\text{MPa})\left(\frac{8.104\text{MPa}}{24{,}900\text{MPa}}\right) = 63.96\text{MPa}$$

(2) Computation of CR:

The modulus of elasticity of concrete at 28 days can be computed to be:

$$E_c = 4800\sqrt{f'_c} = 4800\sqrt{37.93} = 29{,}560\text{MPa}$$

The moment at the midspan due to superimposed permanent dead load that is applied to the beam after it has been prestressed can be computed to be:

$$M_{ds} = (2.04\text{kN/m})\left[\frac{(12.2\text{m})^2}{8}\right] = 37.954\text{kN}\cdot\text{m}$$

Therefore,

$$f_{cds} = \frac{(37.954\text{kN}\cdot\text{m})(279\text{mm})}{7.307\times10^9\text{mm}^4} = 1.449 \text{ MPa}$$

From Eq. (5), one has:

$$CR = 2.0\left(\frac{196{,}510}{29{,}560}\right)(8.104 - 1.449) = 88.48 \text{ MPa}$$

(3) Computation of SH:
Referring to Figure 2, one has:

$$\frac{V}{S} = \frac{(12\text{in.})(26\text{in.})}{2(12\text{in.}) + 2(26\text{in.})} = 4.11$$

Note that Eq. (6) uses the unit "inch" for the computation of V/S.

From Eq. (6), one has:

$$SH = 8.2 \times 10^{-6}\ (1.0)\ (196{,}510\text{MPa}) \left[1 - 0.06(4.11)\right](100 - 75) = 30.35\ \text{MPa}$$

(4) Computation of RE:
From Eq. (7), one has:

$$RE = [34.48 - 0.04(30.35 + 88.48 + 63.96)](0.95) = 25.81\ \text{MPa}$$

Note that C = 0.95 for $f_{pi} / f_{pu} = 0.74$ (PCA 2008).

The computations shown above result in the total prestress losses at the midspan = ES + CR + SH + RE = 63.96 + 88.48 + 30.35 + 25.81 = 208.60 MPa

Loss of Prestress at a Distance of 3.05 m (10 ft.) from the Support

(1) Computation of ES:
Referring to Figure 2, the moment at a distance of 3.05 m (10 ft.) from the support due to the weight of the beam can be computed to be:

$$M_d = \left[(660\text{mm})(305\text{mm})(23.55\text{kN/m}^3)\right] \left[(6.1\text{m})(3.05\text{m}) - (3.05\text{m})(1.525\text{m})\right] = 66.15\text{kN}\cdot\text{m}$$

Substituting P_{pi} = 816 kN, e = 279 mm, and M_d = 66.15 kN·m into Eq. (4), one has:

$$f_{cir} = 0.9\left[\frac{816\text{kN}}{201{,}300\text{mm}^2} + \frac{(816\text{kN})(279\text{mm})^2}{7.307\times10^9\text{mm}^4}\right] - \frac{(66.15\text{kN}\cdot\text{m})(279\text{mm})}{7.307\times10^9\text{mm}^4} = 8.946\text{MPa}$$

From Eq. (1), one has:

$$ES = (1.0)(196{,}510\text{MPa})\left(\frac{8.95\text{MPa}}{24{,}900\text{MPa}}\right) = 70.60\ \text{MPa}$$

(2) Computation of CR:
The moment at a distance of 3.05 m from the support due to the superimposed permanent dead load that is applied to the beam after it has been prestressed can be computed to be:

$$M_{ds} = (2.04\text{kN/m})\left[(6.1\text{m})(3.05\text{m}) - (3.05\text{m})(1.525\text{m})\right] = 28.466\text{kN}\cdot\text{m}$$

Therefore,

$$f_{cds} = \frac{(28.466\text{kN}\cdot\text{m})(279\text{mm})}{7.307\times10^9\text{mm}^4} = 1.087\ \text{MPa}$$

From Eq. (5), one has:

$$CR = 2.0\left(\frac{196{,}510}{29{,}560}\right)(8.946 - 1.087) = 104.49\ \text{MPa}$$

(1) Computation of SH:
SH = 30.35 MPa (SH remains the same for the entire length of the span.)

(2) Computation of RE:
From Eq. (7), one has:

$$RE = [34.48 - 0.04(30.35 + 104.49 + 70.60)](0.95) = 24.95\ \text{MPa}$$

The computations shown above result in the total prestress losses at a distance of 3.05 m (10 ft.) from the support = ES + CR + SH + RE = 70.60 + 104.49 + 30.35 + 24.95 = 230.39 MPa

Loss of Prestress at a Distance of 0.61 m (2 ft.) from the Support

(1) Computation of ES:
Referring to Figure 2, the moment at a distance of 0.61 m (2 ft.) from the support due to the weight of the beam can be computed to be:

$$M_d = \left[(660\text{mm})(305\text{mm})(23.55\text{kN/m}^3)\right] \left[(6.1\text{m})(0.61\text{m}) - (0.61\text{m})(0.305\text{m})\right] = 16.758\text{kN}\cdot\text{m}$$

Substituting P_{pi} = 816 kN, e = 279 mm and M_d = 16.758 kN·m into Eq. (4), one has:

$$f_{cir} = 0.9\left[\frac{816\text{kN}}{201{,}300\text{mm}^2} + \frac{(816\text{kN})(279\text{mm})^2}{7.307\times10^9\text{mm}^4}\right] - \frac{(16.758\text{kN}\cdot\text{m})(279\text{mm})}{7.307\times10^9\text{mm}^4} = 10.832\text{MPa}$$

From Eq. (1), one has:

$$ES = (1.0)(196{,}510\text{MPa})\left(\frac{10.832\text{MPa}}{24{,}900\text{MPa}}\right) = 85.49\ \text{MPa}$$

(2) Computation of CR:
The moment at a distance of 0.61 m (2 ft.) from the support due to the superimposed permanent dead load that is applied to the beam after it has been pre-stressed can be computed to be:

$$M_{ds} = (2.04\text{kN/m})[(6.1\text{m})(0.61\text{m}) - (0.61\text{m})(0.305\text{m})]$$
$$= 7.211\text{kN}\cdot\text{m}$$

Therefore,

$$f_{cds} = \frac{(7.211\text{kN}\cdot\text{m})(279\text{mm})}{7.307\times10^9\,\text{mm}^4} = 0.275 \text{ MPa}$$

From Eq. (5), one has:

$$CR = 2.0\left(\frac{196{,}510}{29{,}560}\right)(10.832 - 0.275) = 140.36 \text{ MPa}$$

(3) Computation of SH:
SH = 30.35 MPa (SH remains the same for the entire length of the span.)

(4) Computation of RE:
From Eq. (7), one has:

$$RE = [34.48 - 0.04(30.35 + 140.36 + 85.49)](0.95)$$
$$= 23.02 \text{ MPa}$$

Therefore, the total prestress losses at a distance of 3.05 m (10 feet) from the midspan = ES + CR + SH + RE = 85.49 + 140.36 + 30.35 + 23.02 = 279.22 MPa.

Using the same computation procedure, the prestress losses at the cross-sections at an interval of 0.61 m (2 ft.) along the span of the beam are computed and are summarized in Table 1.

As shown in Table 1, the prestress loss at the section close to the ends of the beam is about 34 % larger than that at the midspan.

Table 1. Prestress losses at the cross-sections at an interval of 0.61 m (2 ft.) along the span of the beam in Example 1

location (distance from the support) (m)	ES (MPa)	CR (MPa)	SH (MPa)	RE (MPa)	total losses ES+CR+SH +RE (MPa)
6.1	63.96	88.48	30.35	25.81	208.60
5.49	64.22	89.12	30.35	25.78	209.47
4.88	65.02	91.04	30.35	25.67	212.08
4.27	66.35	94.25	30.35	25.50	216.45
3.66	68.21	98.73	30.35	25.26	222.55
3.05	70.60	104.49	30.35	24.95	230.39
2.44	73.53	111.54	30.35	24.57	239.99
1.83	76.98	119.86	30.35	24.12	251.31
1.22	80.97	129.47	30.35	23.61	264.40
0.61	85.49	140.36	30.35	23.02	279.22

Example 2: Repeat of Example 1 for a concrete beam of 12.2 m (40 ft.) simple span with single-point depressed tendons, as shown in Figure 3.

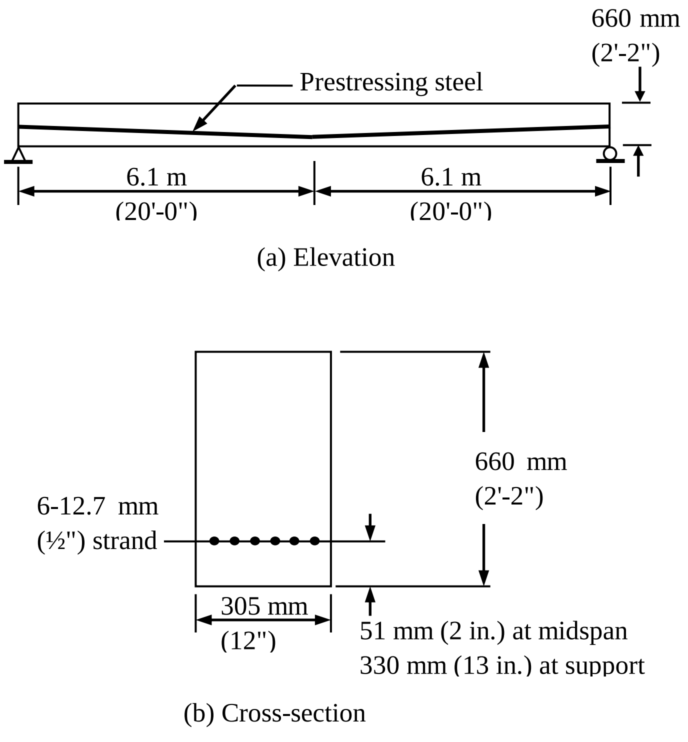


Figure 3. Pretensioned beam with single-point depressed strands for Example 2

Loss of Prestress at Midspan

Referring to Example 1, the total prestress losses at the midspan = ES + CR + SH + RE = 63.96 + 88.48 + 30.35 + 25.81 = 208.60 MPa.

Loss of Prestress at a Distance of 3.05 m (10 ft.) from the Support

(1) Computation of ES:
Referring to Example 1, the moment at a distance of 3.05 m (10 ft.) from the support due to the weight of the beam can be computed to be M_d = 66.15 kN·m.

Substituting P_{pi} = 816 kN, e = 139.5 mm, and M_d = 66.15 kN·m into Eq. (4), one has:

$$f_{cir} = 0.9\left[\frac{816\text{kN}}{201{,}300\text{mm}^2} + \frac{(816\text{kN})(139.5\text{mm})^2}{7.307\times10^9\text{mm}^4}\right] - \frac{(66.15\text{kN}\cdot\text{m})(139.5\text{mm})}{7.307\times10^9\text{mm}^4} = 4.341\text{MPa}$$

From Eq. (1), one has:

$$ES = (1.0)(196{,}510\text{MPa})\left(\frac{4.341\text{MPa}}{24{,}900\text{MPa}}\right) = 34.26\text{ MPa}$$

(2) Computation of CR:
Referring to Example 1, the moment at a distance of 3.05 m from the support due to superimposed permanent dead load that is applied to the beam after it has been prestressed can be computed to be M_{ds} = 28.466 kN·m.

Therefore,

$$f_{cds} = \frac{(28.466\text{kN}\cdot\text{m})(139.5\text{mm})}{7.307\times10^9\text{mm}^4} = 0.543\text{ MPa}$$

From Eq. (5), one has:

$$CR = 2.0\left(\frac{196{,}510}{29{,}560}\right)(4.341 - 0.543) = 50.50\text{ MPa}$$

(3) Computation of SH:
SH = 30.35 MPa (SH remains the same for the entire length of the span.)

(4) Computation of RE:
From Eq. (7), one has:

RE = [34.48 – 0.04(30.35 + 50.50 +34.26)](0.95)
= 28.38 MPa

The computations shown above result in the total prestress losses at a distance of 3.05 m (10 ft.) from the support = ES + CR + SH + RE = 34.26 + 50.50 + 30.35 + 28.38 = 143.49 MPa

Loss of Prestress at a Distance of 0.61 m (2 ft.) from the Support

(1) Computation of ES:
Referring to Example 1, the moment at a distance of 0.61 m (2 ft.) from the support due to the weight of the beam can be computed to be M_d = 16.758 kN·m.

Substituting P_{pi} = 816 kN, e = 27.9 mm and M_d = 16.758 kN·m into Eq. (4), one has:

$$f_{cir} = 0.9\left[\frac{816\text{kN}}{201{,}300\text{mm}^2} + \frac{(816\text{kN})(27.9\text{mm})^2}{7.307\times10^9\text{mm}^4}\right] - \frac{(16.758\text{kN}\cdot\text{m})(27.9\text{mm})}{7.307\times10^9\text{mm}^4} = 3.663\text{MPa}$$

From Eq. (1), one has:

$$ES = (1.0)(196{,}510\text{MPa})\left(\frac{3.663\text{MPa}}{24{,}900\text{MPa}}\right) = 28.91\text{ MPa}$$

(2) Computation of CR:
Referring to Example 1, the moment at a distance of 0.61 m (2 ft.) from the support due to superimposed permanent dead load that is applied to the beam after it has been prestressed can be computed to be M_{ds} = 7.211 kN·m.

Therefore,

$$f_{cds} = \frac{(7.211\text{kN}\cdot\text{m})(27.9\text{mm})}{7.307\times10^9\text{mm}^4} = 0.028\text{ MPa}$$

From Eq. (5), one has:

$$CR = 2.0\left(\frac{196{,}510}{29{,}560}\right)(3.663 - 0.028) = 48.33\text{ MPa}$$

(3) Computation of SH:
SH = 30.35 MPa (SH remains the same for the entire length of the span.)

(4) Computation of RE:
From Eq. (7), one has:

RE = [34.48 – 0.04(30.35 + 48.33 +28.91)](0.95)
= 28.67 MPa

Therefore, the total prestress losses at a distance of 3.05 m (10 ft.) from the midspan = ES + CR + SH + RE = 28.91+48.33+30.35+28.67 = 136.26 MPa.

Following the same computation procedure, the prestress losses at the cross-sections at an interval of 0.61 m (2 ft.) along the span of the beam are computed and are summarized in Table 2.

As shown in Table 2, the prestress loss at the section close to the ends of the beam is about 35 % smaller than that at the midspan.

Table 2. Prestress losses at the cross-sections at an interval of 0.61 m (2 ft.) along the span of the beam in Example 2

location (distance from the support) (m)	ES (MPa)	CR (MPa)	SH (MPa)	RE (MPa)	total losses ES+CR+SH +RE (MPa)
6.1	63.96	88.48	30.35	25.81	208.60
5.49	55.12	75.70	30.35	26.63	187.80
4.88	47.90	65.89	30.35	27.28	171.42
4.27	42.12	58.68	30.35	27.77	158.92
3.66	37.62	53.68	30.35	28.13	149.78
3.05	34.26	50.50	30.35	28.38	143.49
2.44	31.87	48.75	30.35	28.54	139.51
1.83	30.28	48.07	30.35	28.63	137.33
1.22	29.35	48.06	30.35	28.66	136.42
0.61	28.91	48.33	30.35	28.67	136.26

Example 3: Repeat of Example 1 for a concrete beam of 12.2 m (40 ft.) simple span with two-point depressed tendons, as shown in Figure 4.

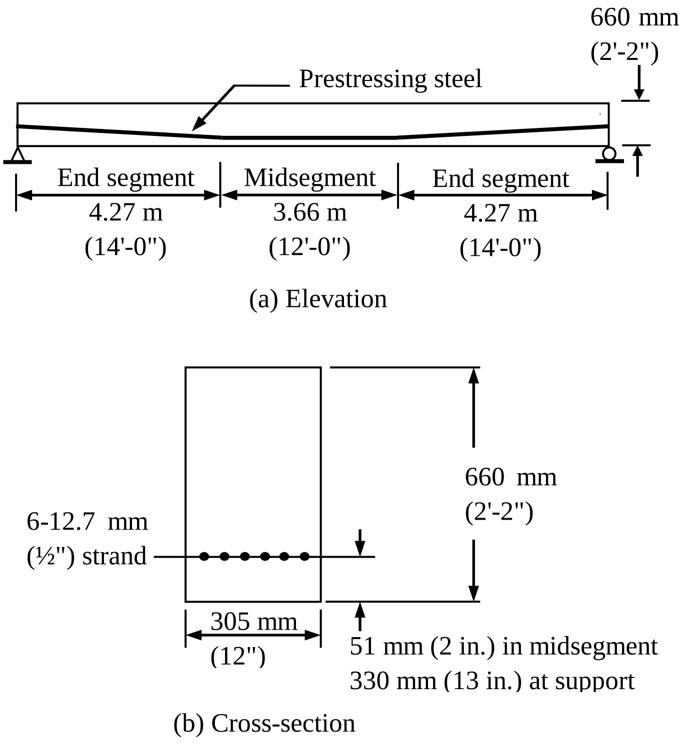


Figure 4. Pretensioned beam with two-point depressed strands for Example 3

Using the same computation procedure shown in Examples 1 and 2, the prestress losses at the cross-sections at an interval of 0.61 m (2 ft.) along the span of the beam shown in Example 3 are computed and are summarized in Table 3.

As shown in Table 3, the prestress loss at the section close to the ends of the beam is about 34 % smaller than that at the midspan.

Table 3. Prestress losses at the cross-sections at an interval of 0.61 m (2 ft.) along the span of the beam in Example 3

location (distance from the support) (m)	ES (MPa)	CR (MPa)	SH (MPa)	RE (MPa)	total losses ES+CR+SH +RE (MPa)
6.1	63.96	88.48	30.35	25.81	208.60
5.49	64.22	89.12	30.35	25.78	209.47
4.88	65.02	91.04	30.35	25.67	212.08
4.27	66.35	94.25	30.35	25.50	216.45
3.66	55.01	78.80	30.35	26.52	190.68
3.05	46.06	67.27	30.35	27.30	170.98
2.44	39.23	59.04	30.35	27.87	156.49
1.83	34.33	53.62	30.35	28.26	146.56
1.22	31.10	50.41	30.35	28.51	140.37
0.61	29.33	48.89	30.35	28.63	137.20

4 RESULTS AND DISCUSSION

Table 1 summarizes the variation of prestress losses along the span of a simply supported pretensioned concrete beam with straight tendons. The table indicates that: (1) The ES loss is the lowest at the midspan and gradually increases towards the ends of the beam; (2) The CR loss is the lowest at the midspan and gradually increases towards the ends of the beam; (3) The SH loss remains the same throughout the entire span of the beam; and (4) The RE loss is the highest at the midspan and slightly decreases towards the ends of the beam.

Table 2 summarizes the variation of prestress losses along the span of a simply supported pretensioned concrete beam with single-point depressed tendons. The table indicates that: (1) The ES loss is the highest at the midspan and gradually decreases towards the ends of the beam; (2) The CR loss is the highest at the midspan and gradually decreases towards the ends of the beam; (3) The SH loss remains the same throughout the entire span of the beam; and (4) The RE loss is the lowest at the midspan and slightly increases towards the ends of the beam.

Table 3 summarizes the variation of prestress losses along the span of a simply supported pretensioned concrete beam with two-point depressed tendons. The table indicates that: (1) The ES loss slightly increases from the midspan towards both ends in the midsegment and then sharply decreases towards both ends of the beam; (2) The CR loss slightly increases from the midspan towards both ends in the midsegment and then sharply decreases towards both ends of the beam; (3) The SH loss remains the same throughout the entire span of the beam; and (4) The RE loss slightly decreases from the midspan towards both ends in the midsegment and then slightly increases towards both ends of the beam.

Summaries of the total prestress loss distributions (ES + CR + SH + RE) for a Type I beam (a prestressioned beam with straight tendons, as shown in Example 1) in Table 1, a Type II beam (a prestressioned beam with single-point depressed tendons, as shown in Example 2) in Table 2, and a Type III beam (a prestressioned beam with two-point depressed tendons, as shown in Example 3) in Table 3 are graphically presented in Figure 5.

Figure 5 graphically describes the variations of the total prestress losses along the spans of the three types of pretentioned concrete beams with a straight tendon profile, a single-depressed tendon profile, and a two-depressed tendon profile, respectively. The figure signifies that: (1) the total prestress loss in a Type I beam (with a straight tendon profile) gradually increases from the midspan towards both ends of the beam; (2) the total prestress loss in a Type II beam (with a single-depressed tendon profile) gradually decreases from the midspan towards both ends of the beam; and (3) the total prestress loss in a Type III beam (with a two-depressed tendon profile) slightly increases from the midspan towards the both ends in the midsegment of the beam and then sharply decreases towards both ends of the beam.

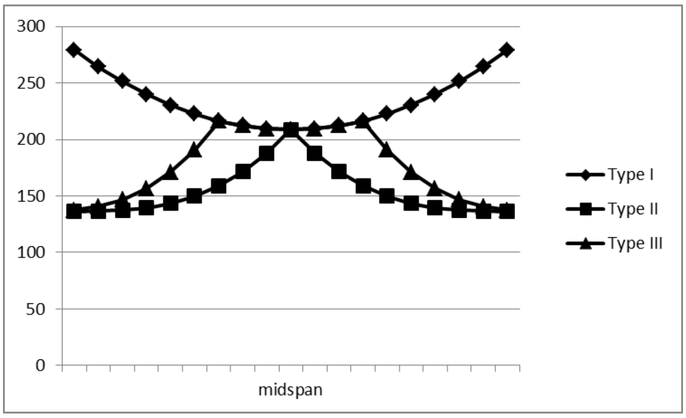


Figure 5. Prestress loss distributions along the beams in Examples 1, 2, and 3

5 CONCLUSIONS

A common assumption is that prestress loss is constantly distributed throughout the span of a simply supported pretensioned concrete beam. This work investigates the accuracy the assumption for the following three typical types of tendon profiles: (I) straight strands throughout the beam, (II) single-point depressed with the c.g.s. and the c.g.c. located at the same elevation at the ends of the beam, and (III) two-point depressed with the c.g.s. and the c.g.c. located at the same elevation at the ends of the beam. The findings derived from this work are summarized as the following:

(1) None of the three typical types of tendon profiles have a prestress loss constantly distributed throughout the span of the beam;

(2) The variation in the prestress loss along the span of a pretensioned beam caused by the elastic shortening of concrete or the creep of concrete is much more significant than that caused by the shrinkage of concrete or the relaxation of tendons;

(3) The type of tendon profile in a simply supported pretensioned concrete beam has significant effects on the pattern of prestress loss distribution along the span of the beam;

(4) The total prestress loss close to the ends of the beam is larger than that at the midspan for a Type I pretensioned beam; and

(5) The total prestress loss close to the ends of the beam is smaller than that at the midspan for both Type II and Type III pretensioned beams.

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