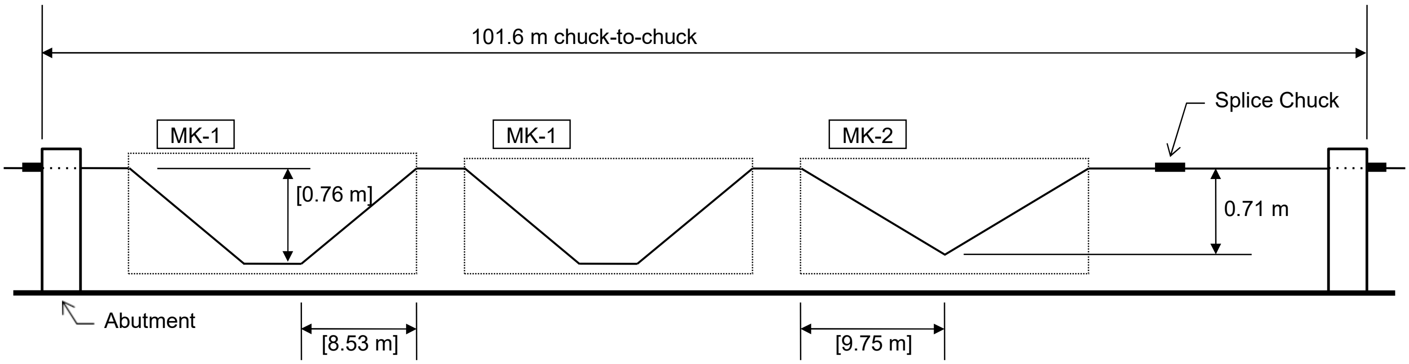
MNL 116-21 Addendum – Appendix F – Sample Tensioning Data Calculations for Draped Strand (SI Units)

Add the following examples to those already in Appendix F.

5M. Pretensioned Harped Strand - Tensioned in the Harped Position

The following example details the method for calculating the tensioning data for strand tensioned using a single strand tensioning system in the draped position in an abutment anchorage set-up. Adjustments for abutment rotation, anchor wedge seating loss, splice chuck seating, and temperature variation are shown.



Material Data and Bed Set-Up Information:

1. Size and type of strand: 12.7 mm diameter,1860 MPa, low-relaxation.

2. Physical characteristics of strand:
   The average values being used by the plant are,
   $A = 98.71\ mm^2$
   $E = 197,190\ MPa$
   See note in Example 1 regarding strand properties.

3. Initial load of 13,344 N (13.344 kN) has proven adequate on strand in this bed in the past.

4. Strand is to be tensioned to 75% of ultimate,
   $1860\ MPa \times 98.71\ mm^2 \times 0.75$
   $= 137.7\ kN = 137,700\ N$

Corrections to Tensioning:

a. Abutment Rotation
   Based on ongoing monitoring of abutments under various strand patterns, the abutments are expected to rotate inward under load 6 mm each, for a total correction of 12 mm.

b. Dead End Anchor Wedge Seating Loss
   Based on ongoing monitoring, seating after initial load is applied is expected to be 3 mm.

c. Live End Anchor Wedge Seating Loss
   Expect 6 mm based on history. Over-pull of 6 mm is required.

d. Splice Chuck Anchor Wedge Seating
   Based on ongoing monitoring, slippage of 3 mm each side of splice, or 6 mm total is expected after initial tensioning.

e. Temperature Variation
   Strands will have a temperature of 4.4°C when tensioned. The concrete is expected to be at 21.1°C based on current production monitoring, giving an anticipated change of 16.7°C.

f. Friction from Hold Down Anchors
   Depending on the design of hold down anchor hardware, friction between the deflected strand and hold down hardware may be a significant source of friction. For this example, hardware is assumed to result in negligible friction.

5M. Pretensioned Harped Strand - Tensioned in the Harped Position (cont'd)

Tensioning Computations:

$$\text{Basic Elongation} = \frac{(\text{Force required beyond initial tension})(\text{Length of strand between anchorages})}{(\text{Area of strand})(\text{Modulus of elasticity})}$$

Calculate the overall length of stand addition due to sloped length increases due to depression points:

Added strand length in two MK-1 set-ups;

$$\left(\sqrt{(8.53\text{ m})^2 + (0.76\text{ m})^2} - 8.53\text{ m}\right)\text{ x }4 = 0.135\text{ m}$$

Added strand length in one MK-2 set-up;

$$\left(\sqrt{(9.75\text{ m})^2 + (0.71\text{ m})^2} - 9.75\text{ m}\right)\text{x }2 = 0.052\text{ m}$$

Total strand length = $101.6\text{ m} + 0.135\text{ m} + 0.052\text{ m} = 101.787\text{ m} = 101{,}787\text{ mm}$

$$\text{Basic Elongation} = \frac{(137{,}700\text{ N} - 13{,}344\text{ N})\text{ x }101{,}787\text{ mm}}{98.71\text{ mm}^2\text{ x}197{,}190\text{ MPa}} = 650.3\text{ mm}$$

Theoretical Elongation = Basic Elongation combined with appropriate corrections.

Computations of Corrections to Tensioning:

Based on the assumption that elongation will be measured relative to the abutment or live end chuck bearing on the abutment, the following will be required.

a. Abutment Rotation: Correct for ½ of the total abutment rotation by adding 6 mm to elongation. Adjust force accordingly.

$$F_{AR} = \frac{6\text{ mm x }(137{,}700\text{ N} - 13{,}344\text{ N})}{650.3\text{ mm}} = 1147\text{ N}$$

Note that the amount of abutment rotation will vary with the force applied to the abutment and the location of the strands relative to the abutment anchorage. In addition, the layout of the strands will determine the necessity and magnitude of force and elongation adjustments for individual strands.

b. Dead End Anchor Wedge Seating: Add 3 mm to elongation. No adjustment to force is required.

c. Live End Anchor Wedge Seating: Over-pull by 6 mm. Adjust force accordingly.

$$F_{LE} = \frac{6\text{ mm x }(137{,}700\text{ N} - 13{,}344\text{ N})}{650.3\text{ mm}} = 1147\text{ N}$$

d. Splice Chuck Anchor Wedge Seating Loss: Add 6 mm to elongation. No adjustment to force is required.

5M. Pretensioned Harped Strand - Tensioned in the Harped Position (cont'd)

e. Temperature Adjustment (required for variations of 14°C or greater): Adjust 1% per 5.5°C variation. Since the strand will be warmed as the concrete is placed, an over-pull is required.

$$F_{temp} = 137{,}700 \text{ N x } \left(\frac{0.01}{5.5°C} \text{ x } 16.7°C\right) = 4{,}181 \text{ N}$$

$$\text{Elongation Adjustment} = \frac{4{,}181 \text{ N x } 101{,}787 \text{ mm}}{98.71 \text{ mm}^2 \text{ x } 197{,}190 \text{ MPa}} = 21.9 \text{ mm}$$

Note that if only a portion of the bed is used, and only that portion is covered and heated during the curing cycle, a proportional decrease in the over-pull force and elongation adjustment required for temperature should be used.

Total Force Required = 137,700 N + 1,147 N + 1,147 N + 4,181 N = 144,175 N

Tolerance Limits: -5% = 136,966 N
+5% = 151,384 N
Note that this value exceeds the allowable force allowed to be placed on the strand (80% of ultimate strength). The maximum force that should be applied to the strand is (1860 MPa x 98.71 mm^2) x 0.8 =146,880 N.

Elongation Computation Summary:

	Gross Theoretical Elongation		Net Theoretical Elongation
Basic Elongation		650.3 mm	650.3 mm
Abutment Rotation		6	6
Dead End Seating		3	3
Live End Seating		6	0
Splice Chuck Seating		6	6
Temperature Adjustment		21.9	21.9
Total Elongation		693.3 mm	687.3 mm
Rounded		693 mm	687 mm
Tolerance Limits	-5% =	659 mm	-5% = 653 mm
	+5% =	728 mm	+5% = 721 mm

Use Gross Theoretical Elongation for monitoring travel of strand tensioning jack ram and compare the final gauge reading to the target final force of 144,175 N. Compare Net Theoretical Elongation for comparison, (strand elongation after seating of live end anchorage) against the distance the strand's reference mark moved since initial force was applied.

Check Anchor Load At Deflected Strand Points:

The anchor force at the deflect points should always be checked against the safe working capacity of the hardware being used. Note that the total anchor load (the sum for all strand in the set-up) needs to be checked.

For angles of less than 10 degrees, the sine and tangent functions are nearly equal. Therefore, it is common practice to use the tangent in calculating the anchor resistance required rather than computing the deflected strand length.

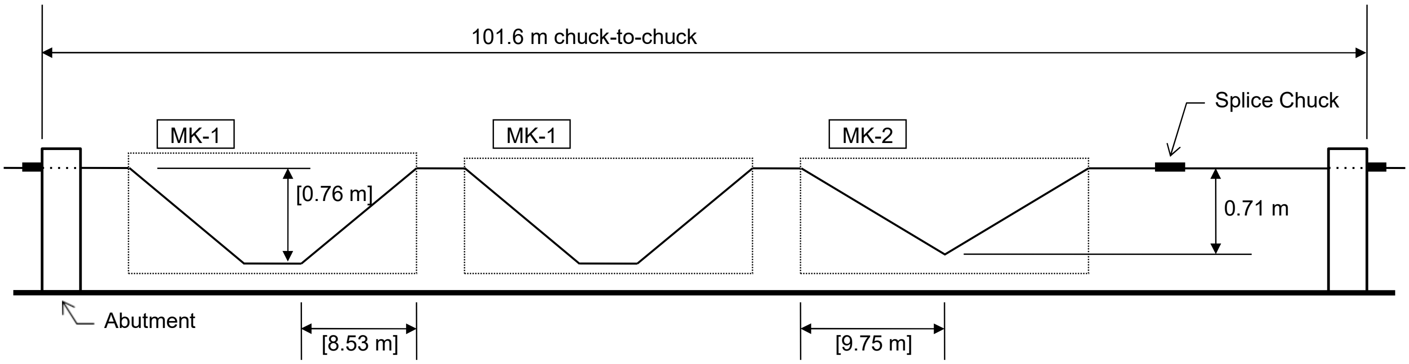
$$\text{MK1 setup: End Anchor Load} = \frac{0.76 \text{ m}}{8.53 \text{ m}} \text{ x } 144{,}175 \text{ N} = 12{,}846 \text{ N}$$

$$\text{MK2 setup: End Anchor Load} = \frac{0.71 \text{ m}}{9.75 \text{ m}} \text{ x } 144{,}175 \text{ N} = 10{,}499 \text{ N}$$

$$\text{Center Anchor Load} = 2 \text{ x } 10{,}499 \text{ N} = 20{,}998 \text{ N}$$

6M. Pretensioned Harped Strand - Straight Strand Lifted or Deflected into Final Position

The following example details the method of calculating the tensioning data for a straight strand subsequently realigned to a draped position. Adjustments for abutment rotation, anchor wedge seating loss, splice chuck seating, and temperature variation are shown.



Material data and bed set-up information are the same as in Example 5M.

Tensioning Computations:

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$$\text{Basic Elongation} = \frac{(\text{Force required beyond initial tension})\ (\text{Length of strand between anchorages})}{(\text{Area of strand})(\text{Modulus of elasticity})}$$

$$\text{Basic Elongation} = \frac{(137{,}700\ \text{N}\ -\ 13{,}344\ \text{kN})\ \text{x}\ 101{,}600\ \text{mm}}{98.71\ \text{mm}^2 \text{x}\ 197{,}190\ \text{MPa}} = 649.1\ \text{mm}$$

Determine added length of strand due to depressing into final position (see Example 5M for calculation): Added strand length in two MK-1 set-ups; 135 mm

Added strand length in one MK-2 set-up; 52 mm

$$\text{Required Measured Elongation}\ = 649.1\ \text{mm}\ -\ 135\ \text{mm}\ -\ 52\ \text{mm}\ =\ 462.1\ \text{mm}$$

$$\text{Required Measured Tensioning Force} = \frac{462.1\ \text{mm x}\ 98.71\ \text{mm}^2 \text{x}\ 197{,}190\ \text{MPa}}{101{,}600\ \text{mm}} = 88{,}530\ \text{N}$$

Theoretical Elongation = Required Measured Elongation combined with appropriate corrections.

D6. Pretensioned Harped Strand - Straight Strand Lifted or Deflected into Final Position (cont'd)

Computations of Corrections to Tensioning:

Based on the assumption that elongation will be measured relative to abutment or live end chuck bearing on the abutment, the following will be required.

a. Abutment Rotation: Add 6 mm to elongation. An adjustment to force is required. (Same as Example 5M.)

b. Dead End Anchor Wedge Seating: Add 3 mm to elongation. No adjustment to force is required. (Same as Example 5M.)

c. Live End Anchor Wedge Seating: Over-pull by 6 mm. Adjust force accordingly. (Same as Example 5M)

$$\frac{6\text{mm} * 88{,}530\text{ N}}{462\text{ mm}} = 1{,}150\text{ N}$$

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d. Splice Chuck Anchor Wedge Seating Loss: Add 6 mm to elongation. No adjustment to force is required. (Same as Example 5M.)

e. Temperature Adjustment (required for variations of 14 °C or greater): Adjust 1% per 5.5 °C variation. Since the strand will be warmed as the concrete is placed, over-pull is required.

$$\text{Force Adjustment} = 88{,}530\text{ N x}\left(\frac{0.01}{5.5°\text{C}}\text{ x } 16.7°\text{C}\right) = 2{,}688\text{ N}$$

$$\text{Elongation Adjustment} = \frac{2688\text{ N x } 101{,}787\text{ mm}}{98.71\text{ mm}^2\text{ x } 197{,}190\text{ MPa}} = 14.1\text{ mm}$$

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Total Force Required = 88,530N + 1,150N + 1,150N + 2,688N = 92,368 N

Note that if only a portion of the bed is used, and only that portion is covered and heated during the curing cycle, a proportional decrease in the over-pull force and elongation adjustment required for temperature should be used.

Elongation Computation Summary:

	Gross Theoretical Elongation	Net Theoretical Elongation
Basic Elongation	462.1 mm	462.1 mm
Abutment Rotation	6 mm	6 mm
Dead End Seating	3 mm	3 mm
Live End Seating	6 mm	0 mm
Splice Chuck Seating	6 mm	6 mm
Temperature Adjustment	14 mm	14 mm
Total Elongation	497.1 mm	491.1 mm
Rounded	497 mm	491 mm
	-5% = 473 mm	-5% = 467 mm
Tolerance Limits	+5% = 522 mm	+5% = 515 mm

6M. Pretensioned Harped Strand - Straight Strand Lifted or Deflected into Final Position (cont'd)

Use Gross Theoretical Elongation for monitoring travel of strand tensioning jack ram and compare the final guage reading to the target final force of 92,368 N. Compare Net Theoretical Elongation (strand elongation after seating of live end anchorage) against the distance the strand's reference mark moved since initial force was applied.

Check Anchor Load at Deflected Strand Points:

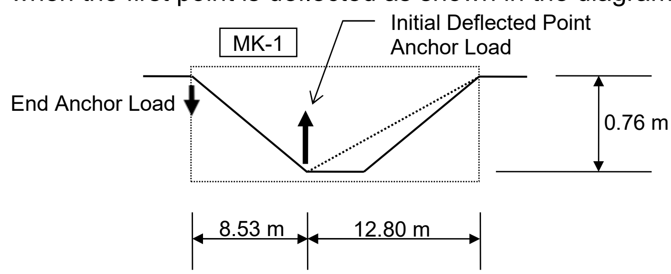
The anchor load at the harping points should always be checked against the safe working capacity of the hardware being used. Note that the total anchor load (the sum for all strands in the set-up) needs to be checked.

As the strand is forced into its final position (usually with a hydraulic ram) the force in the strand increases due to the increased strain. The maximum anchor load should therefore be calculated based on the final force in the strand.

Final strand force = 137,700 N + 1,150 N + 1,150 N + 2,688N = 142,688 N

For angles of less than 10 degrees, the sine and tangent functions are nearly equal. Therefore, it is common practice to use the tangent in calculating the anchor resistance required rather than computing the deflected strand length.

MK-1 set-up: In a "2-point" deflected pattern, as shown in the diagram for the "MK-1" set-up, the strand is usually deflected at each point independently. The maximum load occurs when the first point is deflected as shown in the diagram below.



$$\text{End Anchor Load} = \frac{0.76\text{ m}}{8.53\text{ m}} \text{ x } 142{,}981\text{ N} = 12{,}739\text{ N}$$

$$\text{Initial Deflect Point Anchor Load} = \left(\frac{0.76\text{ m}}{8.53\text{ m}} + \frac{0.76\text{ m}}{12.80\text{ m}}\right) \text{x } 142{,}981\text{ N} = 21{,}229\text{ N}$$

MK-2 set-up:

$$\text{End Anchor Load} = \frac{0.71\text{ m}}{9.75\text{ m}} \text{ x } 142{,}980\text{ N} = 10{,}412\text{ N}$$

$$\text{Center Anchor Load} = 2 \text{ x } 10{,}412\text{ N} = 20{,}824\text{ N}$$