Implementation of 0.7 in. diameter strands at 2.0 × 2.0 in. spacing in pretensioned bridge girders

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- This paper presents the application of 0.7 in. (18 mm) diameter strands at 2 × 2 in. (50 × 50 mm) spacing to the Oxford South Bridge in Oxford, Neb.
- Twenty-six strand samples were tested for breaking strength, yield strength, and modulus of elasticity and met the requirements of ASTM A416-07.
- Transfer length measurements at three locations on two girders at release and after 14 days indicated that transfer lengths can be conservatively estimated using the *AASHTO LRFD Bridge Design Specifications*.
- End zone cracking and camber growth were in compliance with production tolerances specified by PCI and the Nebraska Department of Roads.

For several years 0.7 in. (18 mm) diameter strands have been used in cable bridges and mining applications in the United States and for posttensioning tendons in Europe and Japan. The 0.7 in. diameter strand has a cross-sectional area of 0.294 in.^{2} (190 mm^2) and weighs 1 lb/ft (1.5 kg/m). Prestressing one 0.7 in. diameter strand to 75% of its ultimate strength results in a force of 59.5 kip (265 kN), which is 35% higher than that of 0.6 in. (15 mm) diameter strand and 92% higher than that of 0.5 in. (13 mm) diameter strand. For a given prestressing force, use of 0.7 in. diameter strand results in fewer strands to jack and release, fewer chucks, and more efficient prestressing due to a lower center of gravity of the strands.

Russell et al. performed a detailed study on optimized sections for high-strength concrete bridge girders.[1] Despite the limited availability of 0.7 in. (18 mm) diameter strands in the U.S. market at the time of the study (1997), its cost-effectiveness compared with other strand sizes was evaluated. This study indicated that using 0.7 in. diameter strands at 2 in. (50 mm) in a 10 ksi (69 MPa) bulb-tee girder that is 72 in. (1.83 m) deep (known as BT-72) results in the longest girder span and most cost-effective superstructure compared with 0.5 in. (13 mm) and 0.6 in. (15 mm) diameter strands. Another analytical study conducted by Vadivelu and Ma showed that the span capacity of a BT-72 with 0.6 in. diameter strands can be achieved by using a bulb-tee girder that is 54 in. (1.37 m) deep (known as BT-54) with 0.7 in. diameter strands.[2]

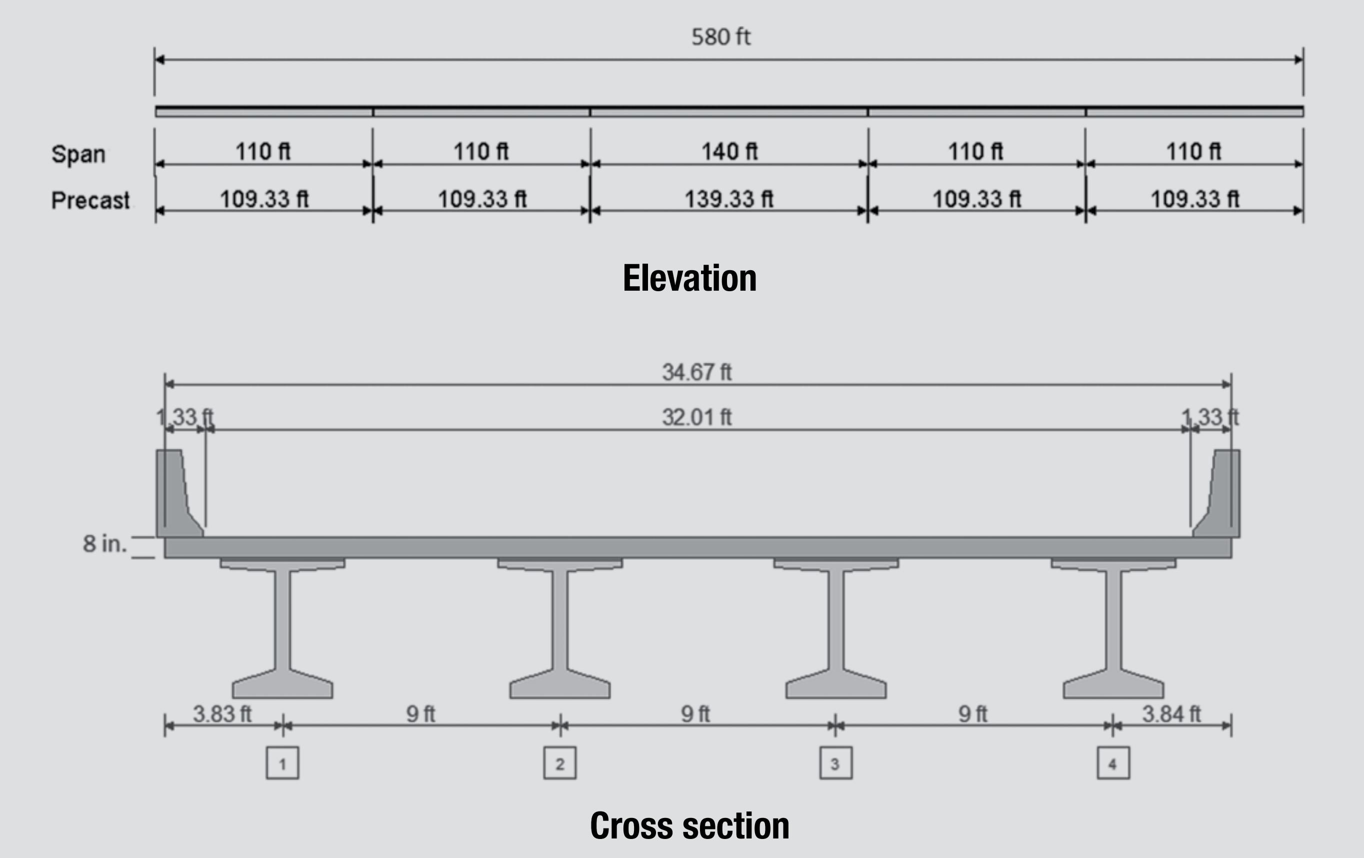
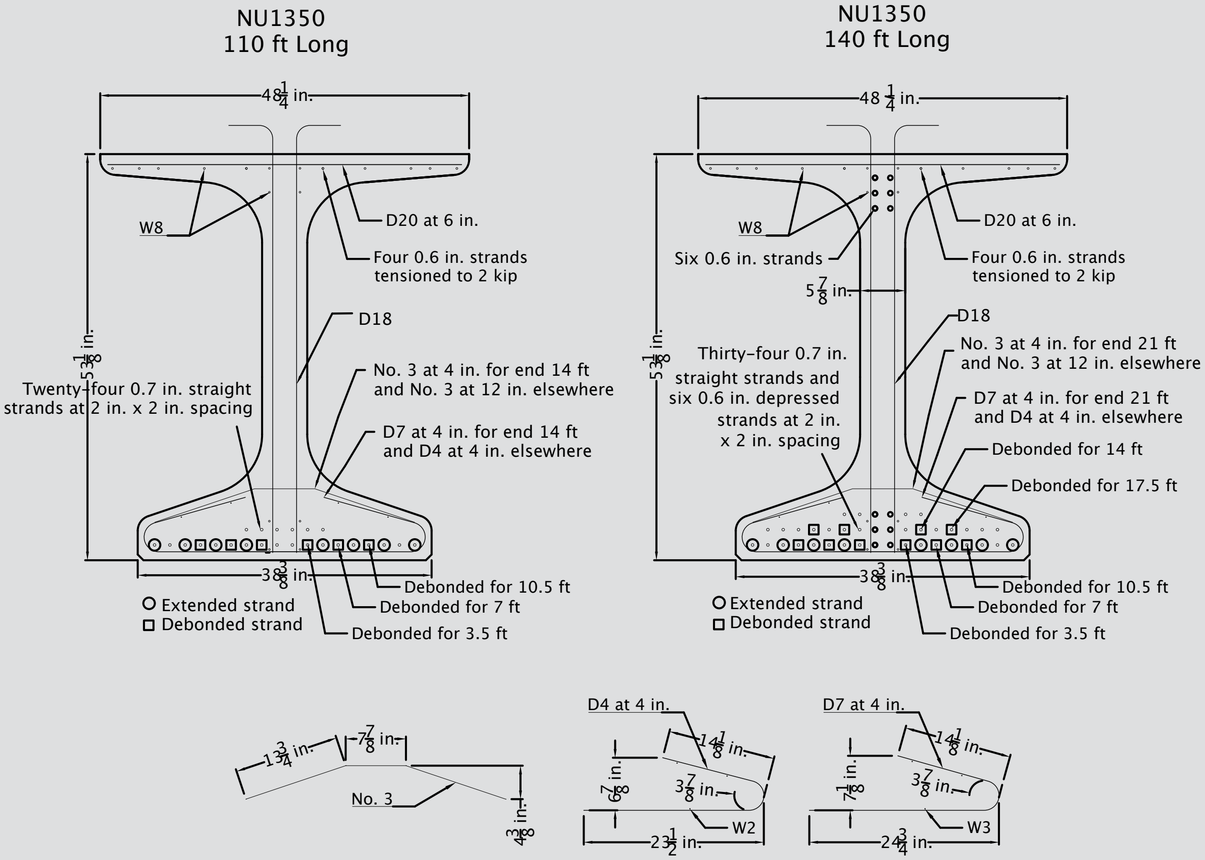


Figure 1. Elevation and cross-section views of Oxford South Bridge in Oxford, Neb. (not to scale). Note: 1 in. = 25.4 mm; 1 ft = 0.305 m.

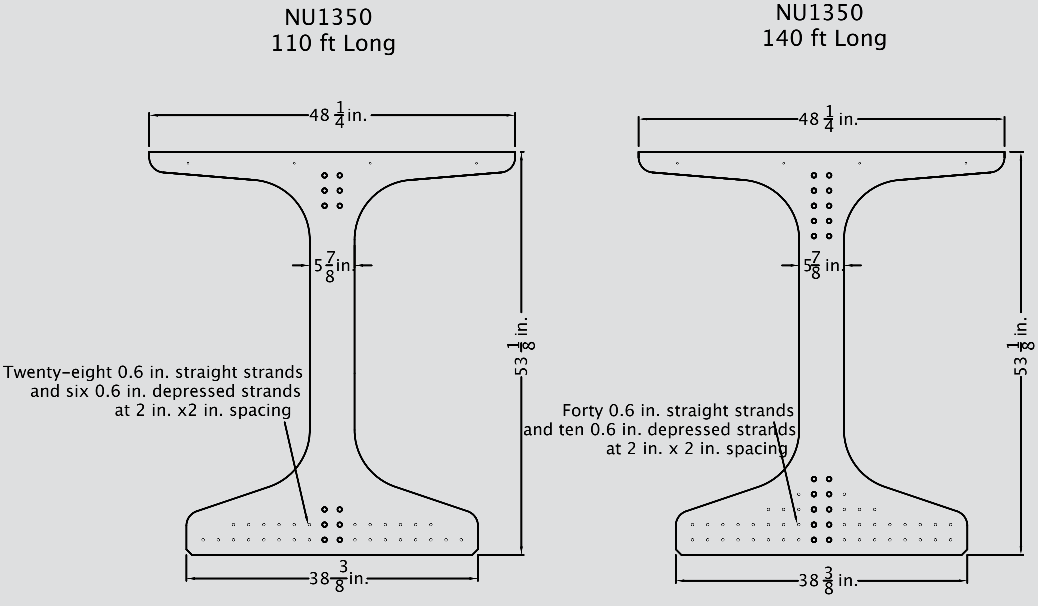
The Pacific Street Bridge over Interstate 680 (I-680) in Omaha, Neb., is the first bridge to use 0.7 in. (18 mm) diameter prestressing strands in precast, pretensioned concrete girders.[3] Based on the results of the experimental investigation on the bond of 0.7 in. diameter strands with concrete while designing the Pacific Street Bridge, strands were spaced 2 in. (50 mm) horizontally and 2.5 in. (64 mm) vertically and tensioned at 64% of the ultimate strength, which does not fully use the advantage of 0.7 in. diameter strands. Since then, experimental investigations have been conducted to evaluate the bond strength of 0.7 in. diameter strands with different concrete strengths and degrees of bottom flange confinement.[4,5] These investigations showed that 0.7 in. diameter strands can be tensioned up to 75% of their ultimate strength and spaced at 2 × 2 in. (50 × 50 mm), while satisfying the transfer length and development length provisions of the sixth edition of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*.[6] The investigations have also addressed the challenges associated with handling, jacking, and depressing 0.7 in. diameter strands.[3,4] Bridge producers need to retool their facilities to accommodate 0.7 in. diameter strands.[7]

The objective of this paper is to present the implementation of 0.7 in. (18 mm) diameter strands at 2 × 2 in. (50 × 50 mm) spacing in the Oxford South Bridge in Oxford, Neb. We believe this is the first application in the United States with 0.7 in. diameter strands tensioned at 75% of the ultimate strength at 2 in. (50 mm) spacing horizontally and vertically.

In this project, a new two-lane bridge was constructed approximately 82 ft (25 m) east (downstream) of an existing bridge. Construction began in the fall of 2012 and was open to traffic in the fall of 2013. The roadway width of the new bridge is 32 ft (9.8 m), and its skew angle is 0 degrees. The bridge is 580 ft (177 m) long and consists of five spans (110, 110, 140, 110, and 110 ft [34, 34, 43, 34, and 34 m]). The bridge was initially designed as a reinforced concrete deck on four NU1600 precast, prestressed concrete girders spaced at 9 ft (2.7 m). The prestressing of these girders was forty-two 0.6 in. (15 mm) diameter strands per girder for the 140 ft span and twenty-six 0.6 in. (15 mm) diameter strands per girder for the 110 ft (34 m) span assuming that the girders were simply supported for dead loads and continuous for live loads and superimposed dead loads. The design was revised to four NU1350 spaced at 9 ft (**Fig. 1**). The prestressing of these girders was thirty-four 0.7 in. (18 mm) diameter straight strands and six 0.6 in. (15 mm) diameter depressed strands for the 140 ft span and twenty-four 0.7 in. diameter straight strands with no depressed strands for the 110 ft spans (**Fig. 2**). For comparison, Fig. 2 also shows the same NU1350 girders designed using 0.6 in. diameter strands. For the same girder depth, using 0.7 in. diameter strands significantly reduces the number of strands to install, jack, and release, which results in economical production.



Design of NU1350 using 0.7 in. strand



Design of NU1350 using 0.6 in. strand

Figure 2. Cross sections of 110 ft girder and 140 ft girder. Note: D4 = MD25; D7 = MD45; D18 = MD120; D20 = MD130; no. 3 = 10M; W2 = MW15; W3 = MW20; W8 = MW50. 1 in. = 25.4 mm; 1 ft = 0.305 m; 1 kip = 4.448 kN.

Table 1. ASTM A416 requirements for 0.7 in. diameter strand

Steel area	0.294 in.^{2}
Minimum breaking strength	79,400 lb
Minimum load at 1% extension	71,500 lb
Minimum extension	3.5%

Note: 1 in. = 25.4 mm; 1 lb = 4.448 kN.

Figure 2 also shows the reinforcement details and the location of debonded and extended strands for the 140 ft (43 m) and 110 ft (34 m) NU1350 girders. Confinement reinforcement (welded-wire reinforcement [WWR] D7 [MD 45] at 4 in. [100 mm] spacing) was equivalent to those required by AASHTO LRFD specifications section 5.10.10.2. (no. 3 [10M] bars at 6 in. [10M at 150 mm]) (Fig. 2).[4] This reinforcement was extended from each girder end to the end of the debonded length plus one transfer length. Additional confinement reinforcement (WWR D4 [MD 25] at 4 in.) was added to the remaining length of the girder in accordance with the policies and procedures of the Nebraska Department of Roads.[8] Debonded strands were staggered at 3.5 ft (1.1 m) increments, which is the predicted transfer length of 0.7 in. (18 mm) diameter strands based on AASHTO LRFD specifications. Extended strands were bent in 90-degree hooks and embedded in the cast-in-place concrete diaphragms. The 0.7 in. (18 mm) diameter strands were not depressed due to the unavailability of hold-down devices for 0.7 in. diameter strands. Six 0.6 in. (15 mm) diameter strands were depressed instead.

Twenty-six 0.7 in. (18 mm) diameter prestressing strand samples were tested to verify that the currently produced strands conform to ASTM A416-06.[9] Testing was performed according to ASTM A370-05 Annex A7.[10] The requirements for 0.7 in. diameter strands include minimum breaking strength, load at 1% extension, and extension at failure (**Table 1**). All tested strand samples were received in ideal condition free of lubricants, rust, and any visible defects. Two groups of strands obtained from separate production runs were tested: group 1 was tested on August 9, 2012, and group 2 on August 17, 2012. **Tables 2** and **3** list test results for the two groups.

All strand samples were tensioned until they reached the minimum required breaking strength and then released

Table 2. Test results for strand group 1

Strand identification	Area, in.^{2}	Tangent modulus, psi	Load at 1% strain, lb	Stress at 1% strain, psi	Maximum load, lb	Maximum stress, psi
PSS12-116	0.2920	28,379,300	73,600	252,055	79,600	272,603
PSS12-117	0.2920	28,384,900	73,600	252,055	79,600	272,603
PSS12-118	0.2920	28,506,200	73,600	252,055	79,600	272,603
PSS12-119	0.2920	28,279,000	73,600	252,055	79,600	272,603
PSS12-120	0.2920	28,795,300	74,000	253,425	80,000	273,973
PSS12-121	0.2920	28,407,400	73,800	252,740	79,800	273,288
PSS12-122	0.2920	28,520,100	73,600	252,055	79,600	272,603
PSS12-123	0.2920	28,396,900	73,800	252,740	79,800	273,288
PSS12-124	0.2920	28,626,600	74,000	253,425	79,800	273,288
PSS12-125	0.2920	28,876,600	72,400	247,945	79,800	273,288
PSS12-126	0.2920	28,776,800	72,400	247,945	79,800	273,288
PSS12-127	0.2920	28,988,600	73,600	252,055	79,800	273,288
PSS12-128	0.2920	28,615,500	73,600	252,055	79,800	273,288
PSS12-129	0.2920	28,561,100	73,800	252,740	79,800	273,288
Mean	0.2920	28,579,593	73,529	251,810	79,743	273,092
Coefficient of variation, %	0.0	0.7	0.7	0.7	0.2	0.2
Maximum	0.2920	28,988,600	74,000	253,425	80,000	273,973
Minimum	0.2920	28,279,000	72,400	247,945	79,600	272,603

Note: 1 in. = 25.4 mm; 1 lb = 4.448 kN; 1 psi = 6.895 kPa.

Table 3. Test results for strand group 2

Strand identification	Area, in.^{2}	Tangent Modulus, psi	Load at 1% strain, lb	Stress at 1% strain, psi	Maximum load, lb	Maximum stress, psi
PSS12-130	0.2945	28,198,700	72,000	244,482	80,000	271,647
PSS12-131	0.2934	28,227,100	72,200	246,080	80,000	272,665
PSS12-132	0.2934	28,404,800	74,000	252,215	80,000	272,665
PSS12-133	0.2945	28,115,400	72,400	245,840	79,600	270,289
PSS12-134	0.2934	28,472,500	73,250	249,659	82,000	279,482
PSS12-135	0.2938	28,691,400	73,714	250,899	79,600	270,933
PSS12-136	0.2934	28,649,600	73,667	251,080	79,600	271,302
PSS12-137	0.2934	28,325,200	73,667	251,080	79,600	271,302
PSS12-138	0.2938	28,331,600	74,000	251,872	79,600	270,933
PSS12-139	0.2938	28,528,200	73,000	248,468	79,600	270,933
PSS12-140	0.2941	28,515,600	73,800	250,935	79,600	270,656
PSS12-141	0.2938	28,162,200	72,600	247,107	79,600	270,933
Average	0.2938	28,385,192	73,192	249,143	79,900	271,978
Coefficient of variation, %	0.1	0.6	1.0	1.0	0.8	0.9
Maximum	0.2945	28,691,400	74,000	252,215	82,000	279,482
Minimum	0.2934	28,115,400	72,000	244,482	79,600	270,289

Note: 1 in. = 25.4 mm; 1 lb = 4.448 kN; 1 psi = 6.895 kPa.

before rupture to avoid damage to the testing apparatus. Therefore, the actual ultimate load and extension were not determined. The extensometer used for the strand tension testing had a gauge length of 24 in. (610 mm) in accordance with ASTM A370 A7.5.2 and an accuracy of at least 0.01% in accordance with ASTM A416 6.3.1. For more details on testing setup and procedures, refer to Morcous et al.[11] Tables 2 and 3 indicate that all strand samples from both groups consistently met the minimum load at 1% strain and minimum breaking strength requirements in Table 1 with a coefficient of variation equal to or less than 1%.

Concrete properties

The specified minimum compressive strengths for the Oxford South Bridge girders were 6000 psi (41 MPa) at release and 8000 psi (55 MPa) at 28 days for the 110 ft (34 m) girders; and 7000 psi (48 MPa) at release and 9000 psi (62 MPa) at 28 days for the 140 ft (43 m) girders. **Table 4** lists the self-consolidating concrete mixture proportions that were used for all the girders. The nominal maximum size of the aggregate was ½ in. (13 mm), and the water–cementitious material ratio was approximately 0.35. Due to the low water–cementitious material ratio, special attention was given to the mixing sequence. Also, a large dosage of high-range water-reducing admixture was used to achieve a mean spread of 27 in. (690 mm).

Table 5 lists mean concrete compressive strengths at release, at 7 days, and at 28 days in the plant and at the laboratory for the 110 ft (34 m) girders and 140 ft (43 m) long girders. Results indicate that the 28-day compressive strength of all girders exceeded 9000 psi (62 MPa). The release compressive strength of all 110 ft (34 m) girders exceeded 6000 psi (41 MPa) and for all 140 ft (43 m) girders (shaded rows) exceeded 7000 psi (48 mm) by keeping the girders in the bed longer while using the same mixture. **Figure 3** shows the girder numbering and location in the bridge.

Strand transfer length

Transfer length is the length of the strand measured from the end of the prestressed concrete member over which the effective prestress is transferred to the concrete. The transferred force along the transfer length is assumed to increase linearly from zero at the end of the member to the effective prestress at the end of the transfer length. Transfer length is important for shear design and concrete stresses at release at girder ends. An overestimated transfer length might result in inefficient shear design and higher-

Table 4. Mixture proportions of concrete

Girder	Casting date	Type III portland cement, lb/yd^3	Class C fly ash, lb/yd^3	Water, lb/yd^3	Fine aggregate, lb/yd^3	Coarse aggregate, lb/yd^3	*w/cm*	Air content, %	Spread, in.	Unit weight, lb/ft^3
G-1	29-Oct	704	123	258	1540	1257	0.348	4.6	28.0	142.9
G-1	1-Nov	695	123	255	1528	1248	0.349	5.4	26.5	142.1
G-2	23-Oct	704	124	241	1552	1266	0.347	4.5	25.5	144.0
G-2	25-Oct	705	123	245	1556	1264	0.349	4.3	27.0	144.0
G-2	2-Nov	701	124	255	1539	1255	0.347	4.8	28.0	141.8
G-2	5-Nov	690	121	251	1522	1240	0.348	6.0	28.0	141.5
G-3	7-Nov	709	125	250	1558	1273	0.346	3.8	28.0	145.4
G-3	9-Nov	697	124	247	1543	1256	0.347	5.0	29.0	142.7
G-4	20-Nov	709	125	257	1560	1273	0.347	3.6	26.5	145.9
G-4	21-Nov	710	125	256	1561	1270	0.347	3.6	26.5	146.6
G-4	26-Nov	710	124	259	1567	1271	0.351	3.3	26.5	146.8
G-4	29-Nov	717	124	264	1572	1274	0.349	2.9	27.5	147.6
G-5	12-Nov	716	126	255	1577	1283	0.347	2.8	28.5	145.2
G-5	14-Nov	712	125	251	1570	1274	0.346	3.4	29.0	145.1
G-5	16-Nov	713	126	260	1559	1272	0.347	3.4	27.5	146.3
G-5	19-Nov	708	125	256	1559	1274	0.348	3.6	28.5	146.2
G-6	29-Oct	698	123	256	1532	1252	0.348	5.1	25.0	142.2
G-6	31-Oct	701	124	255	1539	1255	0.347	4.8	25.5	143.4
G-7	29-Oct	698	123	256	1532	1252	0.348	5.1	25.0	142.2
G-7	31-Oct	701	124	255	1539	1255	0.347	4.8	25.5	143.4
Average		705	124	254	1550	1263	0.348	4.2	27.1	144.3
Coefficient of variation, %		1.0	0.9	2.1	1.0	0.9	0.3	21.1	4.8	1.3
Minimum		690	121	241	1522	1240	0.346	2.8	25.0	141.5
Maximum		717	126	264	1577	1283	0.351	6.0	29.0	147.6

Note: *w/cm* = water–cemetitious material ratio. 1 in. = 25.4 mm; 1 lb/yd^3 = 0.593 kg/m^3

than-predicted stresses at release, while an underestimated transfer length might result in inadequate shear design and lower-than-predicted stresses at release.

According to the AASHTO LRFD specifications, the transfer length l_t of a fully bonded prestressing strand is calculated as follows:

$$l_t = 60 d_b$$

where

d_b = nominal strand diameter

Because this equation was developed for prestressing strands of 0.6 in. (15 mm) diameter or less, the transfer length of 0.7 in. (18 mm) diameter strands used in this project was measured to ensure that the previous equation is applicable. Before prestress release, detachable mechanical (DEMEC) gauges were glued on the side of the bottom flange at the elevation of the centroid of prestressing strands at both ends of one 110 ft (34 m) long girder and one end of another 110 ft long girder.

Twenty DEMEC gauges were used on each side at 4 in. (100 mm) spacing to ensure accurate readings and cover the predicted transfer length of 3.5 ft (1.1 m). DEMEC readings were taken at release and at 14 days using a caliper gauge. The change in the measured distance between DEMEC gauges was used to calculate the strain in the concrete.

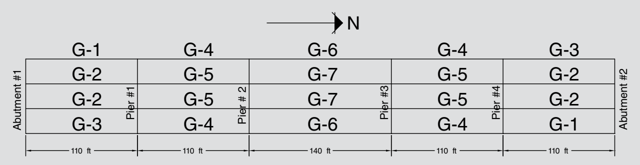


Figure 3. Girder numbering and location in bridge. Note: 1 ft = 0.305 m.

Table 5. Compressive strength testing results of 110 ft long girders and 140 ft long girders

Girder	Casting date	Average release strength, psi	Average 7-day strength, psi	Average 28-day strength, psi	NDOR average 28-day strength, psi
G-1	29-Oct	6845	n.d.	9437	n.d.
G-1	1-Nov	6286	10,390	10,242	9994
G-2	23-Oct	6269	n.d.	10,800	10,752
G-2	25-Oct	7650	10,838	11,054	9640
G-2	2-Nov	9045	8980	9873	n.d.
G-2	5-Nov	7067	9232	9139	10,051
G-3	7-Nov	6223	10,318	10,874	11,506
G-3	9-Nov	8300	9897	9998	10,246
G-4	20-Nov	6177	9467	10,679	n.d.
G-4	21-Nov	10,212	9732	9841	10,583
G-4	26-Nov	6643	9534	10,263	10,341
G-4	29-Nov	7991	10,341	10,896	11,272
G-5	12-Nov	7741	n.d.	10,661	9915
G-5	14-Nov	6307	9840	9926	10,003
G-5	16-Nov	9041	10,407	9943	n.d.
G-5	19-Nov	6258	9306	10,495	9915
Average		7378	9868	10,258	10,352
Coefficient of variation, %		7.0	5.7	5.4	5.6
Minimum		6177	8980	9139	9640
Maximum		10,212	10,838	11,054	11,506
G-6	29-Oct	7318	9491	10,021	10,291
G-6	31-Oct	7753	8202	9656	10,391
G-7	29-Oct	7318	9491	10,021	10,291
G-7	31-Oct	7753	8202	9656	10,391
Average		7536	8847	9839	10,341
Coefficient of variation, %		3.3	8.4	2.1	0.6
Minimum		7318	8202	9656	10,291
Maximum		7753	9491	10,021	10,391

Note: n.d. = no data; NDOR = Nebraska Department of Roads. 1 psi = 6.895 kPa.

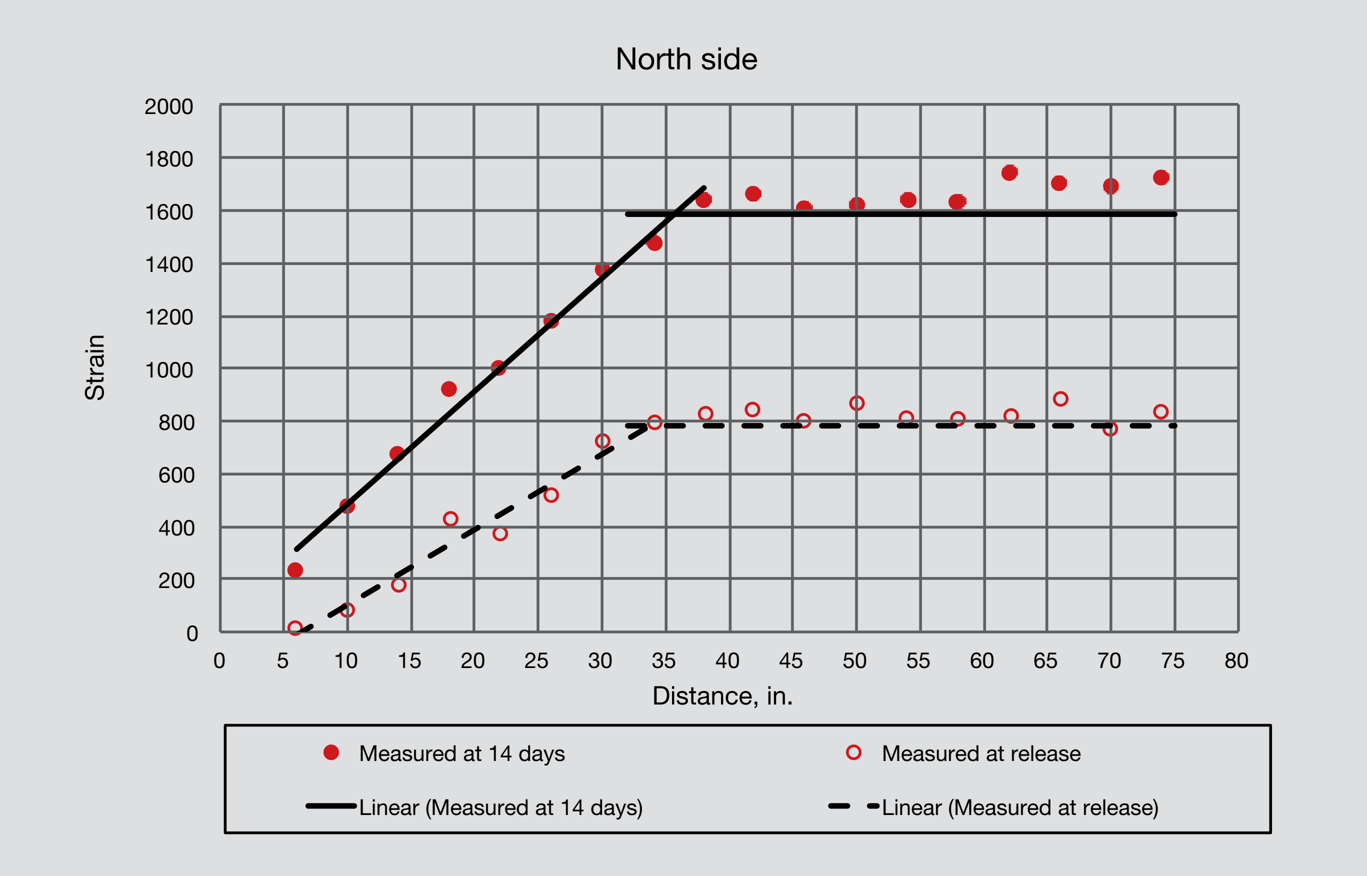


Figure 4. Strain measurements on north side of girder released on October 24, 2012. Note: 1 in. = 25.4 mm.

The transfer length was determined using the 95% average maximum strain method.[12] After prestress release, the concrete strain is zero at the girder ends, then increases with distance from the girder end. The point where the strain becomes constant indicates where all of the prestressing force has been transferred to the concrete. The transfer length was determined by measuring the distance from the end of the girder to the point where 95% of the maximum concrete strain is measured. **Figures 4**, **5**, and **6** show the strain profiles obtained from DEMEC gauge readings at the north and south ends of the girder released on October 24, 2012, and at the south end of the girder released on November 8, 2012, respectively.

According to Fig. 4, 5, and 6, the average transfer length at release of 0.7 in. (18 mm) diameter strands calculated using the average maximum strain method was approximately 32 in. (810 mm). This value increased after 14 days to approximately 36 in. (910 mm), which is close to the value predicted using the American Concrete Institute's (ACI's) *Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary (ACI 318R-11)*[13] ($l_t = 50d_b$ = 35 in. [890 mm]) and slightly less than the value predicted using AASHTO LRFD specifications (42 in. [1070 mm]). These transfer lengths are consistent with earlier research.[14] The change in strain with time is due primarily to the shrinkage and creep of the concrete. The measured strain was close to that calculated at release after considering the elastic shortening losses (790 $\mu\varepsilon$).

Girder camber

Camber is the upward deflection that occurs in prestressed concrete members due to bending resulting from the eccentricity of the prestress force. Camber is a function of the girder cross section, prestress force, strand location, concrete properties, girder age, and environmental factors, which leads to variability from predicted values and from one girder to another. According to the *Quality Control for Plants and Production of Structural Precast Concrete Products*,[15] for members with span-to-depth ratios less than 25, the tolerance for camber variation at release (within 72 hours of prestress transfer) from design camber is ± $^1/_8$ in. per 10 ft (3.2 mm per 3 m) of girder length with a maximum of ± $^1/_2$ in. (13 mm) for girders up to 80 ft (24 m) long and ±1 in. (25 mm) maximum for girders over 80 ft long. This rule applies only to the 110 ft (34 m) girders, as their span-to-depth ratio is approximately 25, while the 140 ft (43 m) girder has span-to-depth ratio of approximately 32.

Table 6 lists the camber measured at release and on January 8, 2013, (before shipping) for the sixteen 110 ft (34 m) girders. This table indicates that the camber measured at release varied from 1.5 to 2.25 in. (38 to 57 mm), and the camber at erection varied from 3.75 to 5.25 in. (95 to

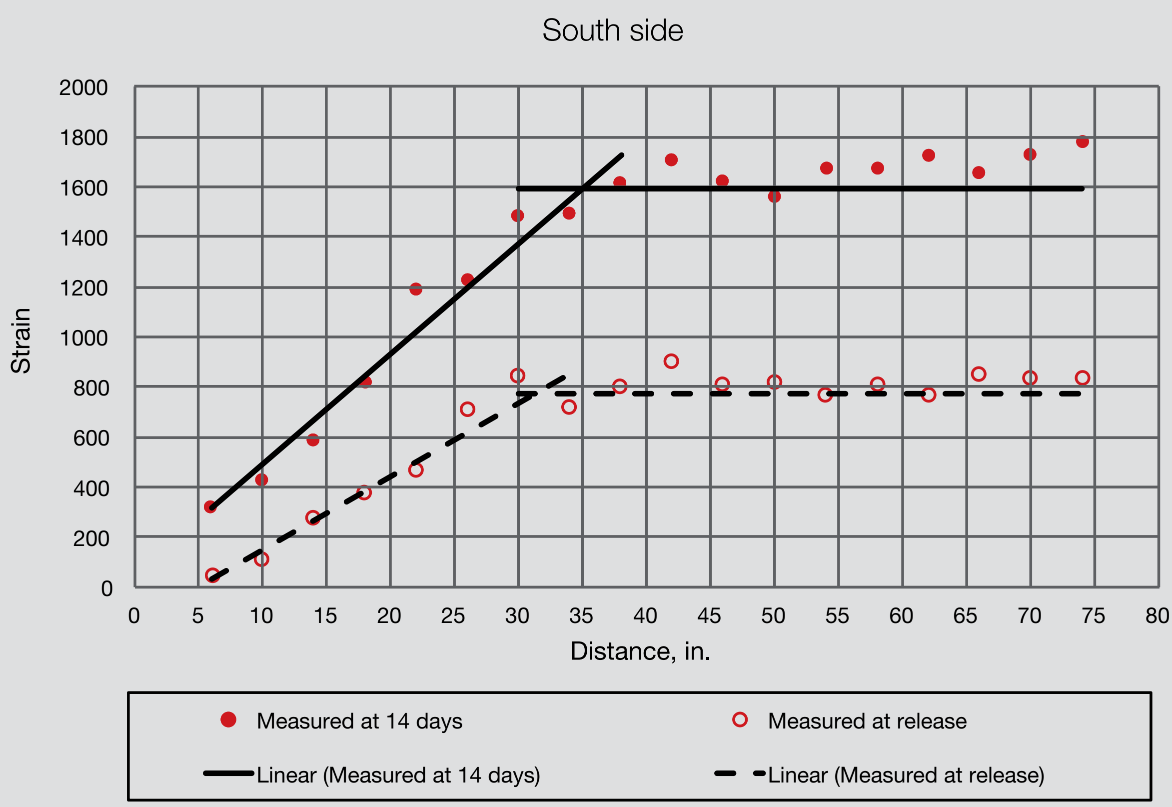


Figure 5. Strain measurements on south side of girder released on October 24, 2012. Note: 1 in. = 25.4 mm.

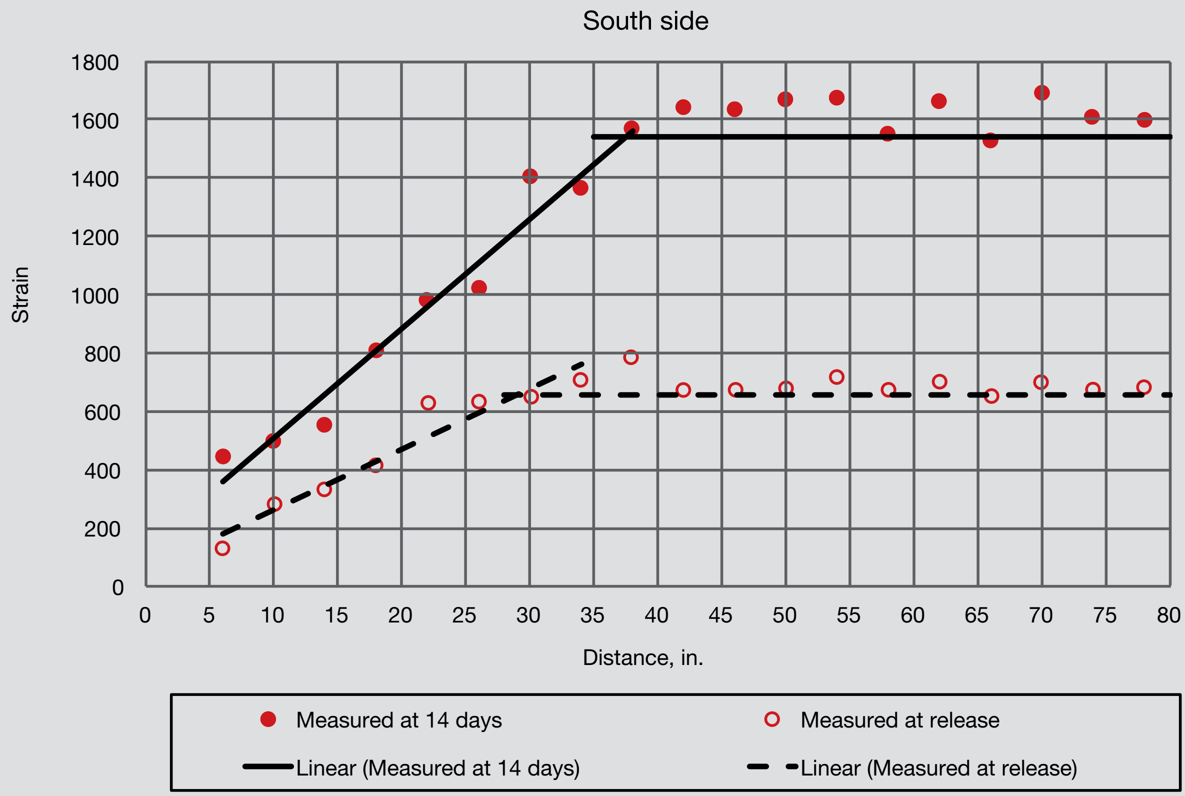


Figure 6. Strain measurements on south side of girder released on November 8, 2012. Note: 1 in. = 25.4 mm.

Table 6. Measured camber for 110 ft long girders

Girder	Casting date	Girder length, ft	Measured camber at release, in.	Age at erection, days	Measured camber at erection, in.
G-1	29-Oct	110.2	1.75	71	3.75
G-1	1-Nov	110.2	1.50	68	5.25
G-2	23-Oct	110.2	1.63	77	5.00
G-2	25-Oct	110.2	1.63	75	5.25
G-2	2-Nov	110.2	1.50	67	4.25
G-2	5-Nov	110.2	1.62	64	5.00
G-3	7-Nov	110.2	1.62	62	4.00
G-3	9-Nov	110.2	1.75	60	4.13
G-4	20-Nov	109.4	2.25	49	4.13
G-4	21-Nov	109.4	2.25	48	4.25
G-4	26-Nov	109.4	2.00	43	4.00
G-4	29-Nov	109.4	1.75	40	4.00
G-5	12-Nov	109.4	2.00	57	3.75
G-5	14-Nov	109.4	1.85	55	5.00
G-5	16-Nov	109.4	2.00	53	4.13
G-5	19-Nov	109.4	2.00	50	5.00
Average		109.8	1.82	59	4.43
Coefficient of variation, %		0.4	13.3	19.1	12.3
Minimum		109.4	1.50	40	3.75
Maximum		110.2	2.25	77	5.25

Note: 1 in. = 25.4 mm; 1 ft = 0.305 m.

Table 7. Measured camber for 140 ft girders

Girder	Casting date	Girder length, ft	Measured camber at release, in.	Age at erection, days	Measured camber at erection, in.
G-6	29-Oct	139.4	3.00	71	8.63
G-6	31-Oct	139.4	2.75	69	8.88
G-7	29-Oct	139.4	2.87	71	9.13
G-7	31-Oct	139.4	2.75	69	8.50
Average		139.4	2.84	70	8.78
Coefficient of variation, %		0.0	4.2	1.6	3.2
Minimum		139.4	2.75	69	8.50
Maximum		139.4	3.00	71	9.13

Note: 1 in. = 25.4 mm; 1 ft = 0.305 m.

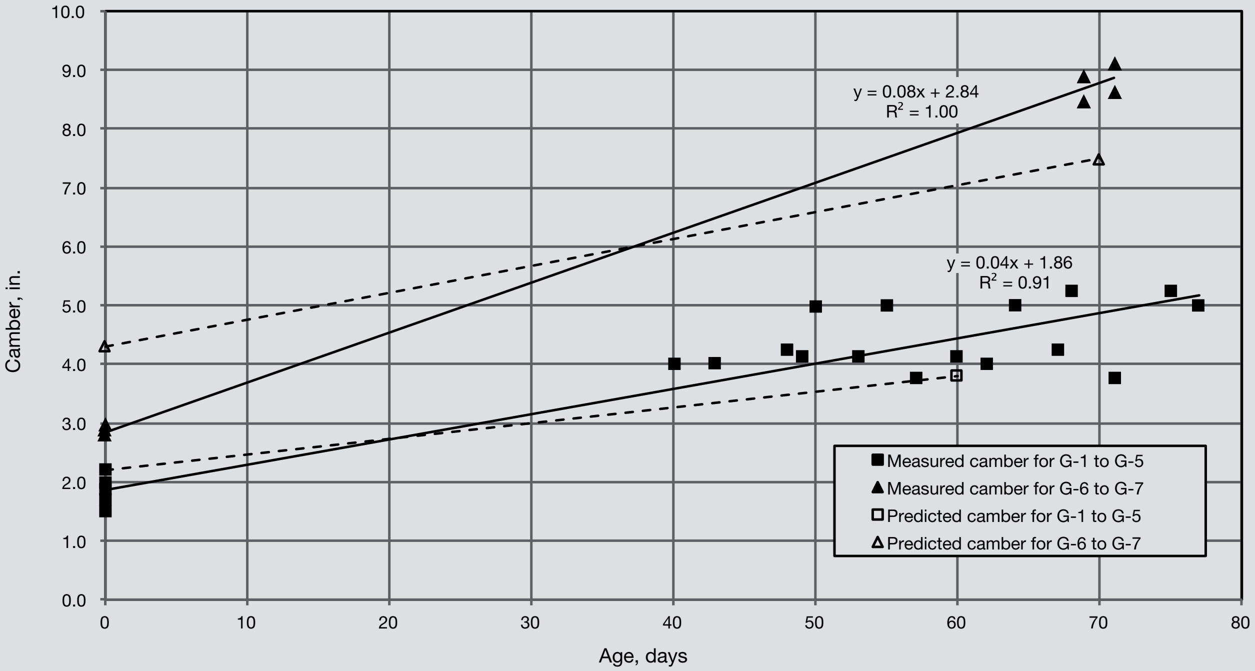


Figure 7. Camber growth with time in different girders. Note: 1 in. = 25.4 mm.

133 mm). The camber at release was within tolerance (±1 in. [25 mm]) from the 2.2 in. (56 mm) calculated using the PCI method,[16] while the camber at erection was slightly higher than the predicted value of 3.8 in. (97 mm) in some girders.

Table 6 lists the camber measured at release and on January 8, 2013, for the four 140 ft (43 m) girders. This table indicates that the measured camber at release varied from 2.75 to 3.0 in. (70 to 76 mm), while the camber at erection varied from 8.5 to 9.1 in. (216 to 231 mm). The cambers at release were below the predicted value of 4.3 in. (110 mm), and the cambers at erection were higher than the 7.5 in. (190 mm) calculated using the PCI method. These deviations from predicted values can be considered acceptable given the length of the girders, span-to-depth ratio of 32, and variations in concrete strength.

Figure 7 plots the cambers measured at release and on January 8, 2013, versus the predicted release and erection cambers to evaluate camber growth. This plot indicates the consistency in camber growth among girders of the same length. It also shows the significantly higher rate of camber growth in longer girders than in shorter ones and the effect of girder age on the camber. Special attention should be given to the rate of camber growth and girder age at the time of deck construction. **Figure 8** shows a photo of the 140 ft (43 m) girder and its camber shortly after release, while **Fig. 9** shows the girders directly before deck forming. Camber growth is not linear with time; however, straight lines were used in Fig. 7 to simplify the plot.

End zone cracking

End zone cracking was evaluated by visual examination immediately after release and a few days later. **Figure 10** shows photos of the ends of a 110 ft (34 m) girder and a 140 ft (43 m) girder. These photos indicate that no cracks were observed by the naked eye at the girder ends or between strands due to bursting stresses or to the 2 in. (50 mm) spacing between strands, which indicate that current AASHTO LRFD specifications for bursting and confinement reinforcement were adequate for designing these girders with 0.7 in. (18 mm) diameter strands.

Figure 8. Camber of 140 ft (43 m) girders at release.

Figure 9. Girders directly before deck forming.

110 ft (34 m) girder

140 ft (43 m) girder

Figure 10. End zones of girders.

Conclusion

This paper presented the first application of 0.7 in. (18 mm) diameter strands in prestressed concrete bridge girders at 2 × 2 in. (50 × 50 mm) spacing for the Oxford South Bridge. Tests of 26 strand samples indicated that they all conformed to ASTM A416. Transfer length measurements in three girder ends indicated that the transfer length of 0.7 in. diameter strands can be conservatively estimated using AASHTO LRFD specifications and are close to the value calculated using ACI 318-11. Also, measurements of girder camber indicated that camber variability at release was within the specified tolerance. No end zone cracking was observed due to the use of 0.7 in. diameter strands at 2 × 2 in. spacing.

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Abstract

Use of 0.7 in. (18 mm) diameter strands at 2 × 2 in. (50 × 50 mm) spacing in pretensioned concrete girders results in an approximately 35% increase in the prestressing force compared with the same number of 0.6 in. (15 mm) strands and a 92% increase in the prestressing force compared with the same number of 0.5 in. (13 mm) strands, allowing for longer spans, shallower depths, and/or wider girder spacing.

This paper presents the application of 0.7 in. (18 mm) diameter strands at 2 × 2 in. (50 × 50 mm) spacing to the Oxford South Bridge in Oxford, Neb. Twenty-six strand samples were tested for breaking strength, yield strength, and modulus of elasticity. The strands met the requirements of ASTM A416-07.Transfer lengths were measured at three locations on two girders at release and after 14 days. Measurements indicated that the transfer length of 0.7 in. diameter strands can be conservatively estimated using the *AASHTO LRFD Bridge Design Specifications*. All girders were monitored for end zone cracking and camber growth and were found in compliance with current production tolerances, as specified by PCI and the Nebraska Department of Roads.

Keywords

Bridge, camber, cracking, girder, strand, transfer length.

Review policy

This paper was reviewed in accordance with the Precast/Prestressed Concrete Institute's peer-review process.

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