A test program was undertaken to determine the spacing and concrete cover requirements of 0.5 in. (12.7 mm) diameter seven-wire prestressing strand coated with a grit impregnated epoxy. Spacing and concrete cover requirements were studied by varying the parameters of strand spacing, concrete cover and number of strands. These requirements were then compared with the AASHTO Specifications. The transfer length of epoxy-coated prestressing strand was also investigated. It is concluded that strand spacing and concrete cover requirements should be increased somewhat in prestressed concrete members without confinement reinforcement. However, in bridge girders and other prestressed concrete members that typically carry confinement reinforcement in the form of stirrups and end zone reinforcement, increased strand spacing and concrete cover may not be warranted.

Today, prestressed concrete is widely used in the construction industry. With the continuous improvement in design methods and production techniques, precast, prestressed concrete is recognized as a durable material with low maintenance costs. In the large majority of applications, high quality concrete and proper cover are sufficient to protect the reinforcement from possible corrosion.

As with all materials, when prestressed concrete elements are exposed to particularly harsh environments, adequate...
measures must be taken to protect the prestressing steel and mild steel reinforcement. The consequences of corrosion to the reinforcement in concrete structures subjected to harsh environmental exposures, such as in very salty coastal regions, may be severe enough to warrant special corrosion resistant materials. Under these conditions, epoxy-coated strand can be beneficial in providing corrosion protection and in ensuring long-term durability of the structure.

Florida Wire and Cable, Inc. (FWC), a major prestressing steel manufacturer, has developed an epoxy-coated strand which has proven to be effective in preventing the corrosion of prestressing steel. Recently, PCI’s Ad Hoc Committee on Epoxy-Coated Strand published guidelines for using epoxy-coated strand. The epoxy coating is impregnated with grit to improve its bonding capabilities in prestressed concrete members.

Studies conducted in the past decade have indicated splitting of concrete at stress transfer in single strand specimens. Splitting of concrete was not observed in uncoated single strand specimens with similar dimensions. The splitting was attributed to the shorter transfer length of epoxy-coated strand causing higher bond stresses, which could be even more severe in members with multiple strands at closer spacings.

The main objective of this research program was to investigate the spacing and cover requirements of epoxy-coated prestressing strand. This was done using test specimens with varying strand spacings and concrete covers. Another objective was to determine the transfer length of epoxy-coated strand.

TEST PROGRAM

Forty specimens were fabricated and tested at the Structural Engineering Research Laboratory of Auburn University. The specimens were designed to study the influence of three parameters: strand spacing, strand configuration and concrete cover. The effect of these parameters on transfer length was also investigated.

Parameters were varied to determine the minimum concrete cover and strand spacing requirements to prevent specimens from splitting at stress transfer. Nine companion specimens were fabricated with uncoated strand to serve as a control. This experimental program generated a large amount of data on the transfer length of epoxy-coated strand, a summary of which is given in this paper. Full details of the test program are given in the final project report.

Table 1. Specimen dimensions and strand details.

<table>
<thead>
<tr>
<th>Number of strands</th>
<th>Overall dimensions (in.)</th>
<th>Center-to-center strand spacing (in.)</th>
<th>Minimum cover (in.)</th>
<th>Number of specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.5 x 3.5</td>
<td>n/a*</td>
<td>1.5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4.0 x 4.0</td>
<td>n/a*</td>
<td>1.75</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>3.75 x 3.75</td>
<td>n/a*</td>
<td>1.625</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>4.0 x 8.0</td>
<td>2.0</td>
<td>1.75</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4.0 x 8.5</td>
<td>2.25</td>
<td>1.75</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4.5 x 9.0</td>
<td>2.5</td>
<td>1.75</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4.0 x 9.0</td>
<td>2.25</td>
<td>1.75</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4.5 x 9.5</td>
<td>2.5</td>
<td>2.0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4.5 x 10.0</td>
<td>2.75</td>
<td>2.0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>5.0 x 10.5</td>
<td>3.0</td>
<td>2.0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>5.0 x 11.0</td>
<td>3.0</td>
<td>2.25</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>7.0 x 9.5</td>
<td>2.5</td>
<td>2.0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>7.25 x 10.0</td>
<td>2.75</td>
<td>2.0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>7.5 x 10.0</td>
<td>2.5</td>
<td>2.25</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>7.75 x 10.5</td>
<td>2.75</td>
<td>2.25</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>8.0 x 11.0</td>
<td>3.0</td>
<td>2.25</td>
<td>3</td>
</tr>
</tbody>
</table>

* n/a: not applicable.

Note: 1 in. = 25.4 mm.

Specimen Description

As shown in Fig. 1, beam specimens were fabricated using three types of strand configuration:

- Single strand
- Three strands placed in one layer
- Six strands placed in two layers

Specimen dimensions are listed in Table 1. All specimens were rectangular in cross section with one, three or six concentric strands. No confinement reinforcement was used.

Beam lengths for the first set of specimens were 9 and 11 ft (2.73 and 3.34 m) for the uncoated and coated strand specimens, respectively. The beam lengths were increased for the second set of specimens to ensure full transfer length within the length of specimens. The lengths of specimens with coated and uncoated strand were increased to 10 and 12 ft (3.05 and 3.65 m), respectively.

Materials

The concrete mix was designed to yield a compressive strength of 4500 psi (31.1 MPa) in six to seven days and a minimum strength of 5500 psi (38.0 MPa) in 28 days to simulate conditions of a prestressing plant.

Fig. 1. Specimen cross sections showing arrangement of single and multiple strands.
ready-mixed concrete was provided by a local supplier with super-plasticizer added to obtain a minimum slump of 6 in. (154 mm) at casting.

The original mix design proportions per cubic yard were:

- Cement ............ 705 lbs (3136 N)
- Water ............... 30.5 gallons (0.115 m³)
- Sand ................. 1160 lbs (5160 N)
- Coarse aggregate .......... 1926 lbs (8567 N)
- Water-reducing admixture .................. 21.2 ounces (627 cm³)
- Super-plasticizer .......... 56 ounces (1656 cm³)

This mix was used for the first three batches. Since the concrete strength for these specimens was less than desired, the mix design was changed slightly for Batches 4 through 7. Compressive strengths obtained from the seven batches of concrete at transfer and at 28 days are listed in Table 2. Tables 3, 4 and 5 match the specimens cast with their appropriate batch number.

All the coated and uncoated prestressing steel was manufactured by FWC. The prestressing strand was low-relaxation, 0.5 in. (12.7 mm) diameter, seven-wire strand with an ultimate tensile strength of 270 ksi (1862 MPa). The coating thickness averaged 0.036 in. (0.91 mm).

The uncoated strand was used as a control to ensure satisfactory testing. A few specimens were made with uncoated strand at spacings ranging from the AASHTO minimum to the largest used in the specimens with coated strand. The epoxy coating was imbedded with an aluminum oxide grit to improve bonding with concrete.

Some coated strand sections had noticeably less grit than others, with some sections having no grit. These sections, when used, were placed in the middle of the beams to minimize interference with the transfer of the prestressing force.

**Specimen Fabrication**

Two 46 ft (14.0 m) long stressing beds were constructed in the Structural Engineering Research Laboratory of Auburn University so that two lines of specimens could be cast simultaneously. Two post-tensioned reinforced concrete end blocks were used to form the stressing bed.
The strand was pulled through an 8 in. (203 mm) diameter hole in the blocks and held in place at the ends by chucks and steel plates. Formwork was fabricated such that the strands could be stressed before placing the formwork and the beam dimensions could be changed with minimal adjustments.

Stressing was accomplished with a hydraulic jack and hand pump. The force in each strand was monitored using load cells at the dead end chucks. A pressure gauge attached to the jack was used to estimate the strand stress and to check that the dead end load cell was operating properly.

The strand stress immediately before construction averaged 74.4, 76.3 and 77.7 percent of 270 ksi (1862 MPa) for the single-, three- and six-strand beams, respectively. Based on calculated elastic shortening losses, this yielded an average strand stress immediately after transfer of 67.6, 69.9 and 70.7 percent of 270 ksi (1862 MPa) for the single-, three- and six-strand specimen, respectively.

The average concrete compressive stresses at transfer were 2210, 2380 and 2460 psi (15.2, 16.4 and 17.0 MPa), for single-, three- and six-strand specimens, respectively. However, the standard deviation of these stresses was fairly high due to the significant change in the cross-sectional dimensions.

It was decided to transfer a force per strand as used typically in a prestressing plant despite the resulting variation of \( P/A \) stresses. This was believed to be more critical for transfer length and crack propagation.

The prestressing force was transferred instantaneously (with no preheating) by acetylene torch to simulate procedures used in prestressing plants. The strands were flame cut in sequence so as not to exceed the allowable stresses in the beam at transfer. The specimen ends adjacent to flame cuts are noted in Tables 3, 4 and 5.

The average transfer length for ends adjacent to flame cuts was 38 in. (965 mm) while the average transfer length of all other ends was 31 in. (787 mm). It appears that the transfer lengths of ends adjacent to the flame cuts were substantially larger than the transfer lengths of all other ends.

### Table 5. Transfer length results for six strand specimens.

<table>
<thead>
<tr>
<th>Specimen No. (Batch No.)</th>
<th>Size (in.)</th>
<th>Spacing (in.)</th>
<th>Minimum clear cover (in.)</th>
<th>( f_{pl} ) (ksi)</th>
<th>Transfer length (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (6)</td>
<td>8 x 11</td>
<td>3</td>
<td>2.25</td>
<td>192</td>
<td>22/22 28/23 30/24</td>
</tr>
<tr>
<td>2 (6)</td>
<td>8 x 11</td>
<td>3</td>
<td>2.20</td>
<td>191</td>
<td>24/34 24/34 26/36</td>
</tr>
<tr>
<td>3 (7)</td>
<td>7.25 x 10</td>
<td>2.75</td>
<td>2.25</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>4 (7)</td>
<td>7.75 x 10.5</td>
<td>2.75</td>
<td>2.25</td>
<td>190</td>
<td>18/12 21/13 22/16</td>
</tr>
<tr>
<td>5 (7)</td>
<td>7.75 x 10.5</td>
<td>2.75</td>
<td>2.25</td>
<td>190</td>
<td>32/21 32/21 32/21</td>
</tr>
<tr>
<td>6 (7)</td>
<td>7 x 9.5</td>
<td>2.25</td>
<td>2.00</td>
<td>190</td>
<td>32/21 32/21 32/21</td>
</tr>
<tr>
<td>7 (7)</td>
<td>7.5 x 10</td>
<td>2.5</td>
<td>2.25</td>
<td>193</td>
<td>18/23 21/34 24/37</td>
</tr>
</tbody>
</table>

* End adjacent to flame cut.
† No data available due to computer malfunction.

Note: 1 in. = 25.4 mm; 1 ksi = 6.895 MPa.

**Fig. 2.** Formwork in place with threaded inserts prior to casting specimens.

### Instrumentation and Test Procedure

The transfer length is the length over which the force in the prestressing strand is transferred to the concrete. Within this length, the stress in the prestressing strand varies from zero to the effective stress, \( f_{pl} \).

The transfer length for each end of a member is the distance from the beam end to the point where the concrete strain becomes uniform and reaches its maximum. The transfer length of each specimen was measured so that the transfer of prestressing force could be determined.

Immediately after transfer, and at seven and 28 days after transfer, the strain in the concrete and, hence, the transfer length was determined. Measurements were taken prior to release with an extensometer so that the distance between gauge points before transfer could be determined.

The distance between gauge points was also measured immediately after transfer and at seven and 28 days. By subtracting the initial distance from the final distance, the change in length between gauge points was determined. The concrete surface strain due to prestress was calculated by dividing the change in length by the gauge length.

The gauge points were set at 2 in. (50.8 mm) intervals along each side of each specimen. An extensometer measured the distance between gauge points over a predetermined gauge length. Threaded inserts embedded in the concrete were used for the gauge points. Fig. 2 shows the threaded inserts screwed to the forms before the concrete was cast.

For the first batch, a gauge length of 6 in. (152 mm) was specified; however, the accuracy of these results was suspect.

For all succeeding batches, a 10 in. (254 mm) gauge length was used to decrease the relative error. The extensometer provided a digital record of readings to 0.0001 in. (0.00254 mm) over a 10 in. (254 mm) gauge length. This corresponds to a concrete surface strain of 0.00001 in. per inch.

In addition to strain readings, end slip readings were recorded using a depth micrometer and end slip brackets as shown in Fig. 3. End slip readings were taken to measure the distance each strand slipped into the concrete following transfer. The end slip brackets were attached to each strand prior to transfer.

The distance from the end of the bracket to the specimen was measured by placing the shaft of the depth micrometer through the two small holes in the end slip bracket until the body of
the micrometer was flush with the bracket. The shaft was then moved up against the specimen. End slip measurements and concrete strain readings were made before and after stress transfer. End slip measurements were taken from a digital readout measuring to the nearest 0.00005 in. (0.00127 mm).

TEST RESULTS AND ANALYSIS

Analysis of Transfer Length Results

Surface strain readings from all the beams were recorded in a spreadsheet program. The readings were used to determine the concrete strain immediately following transfer, and at seven and 28 days after transfer. These data were used to plot the concrete strain along the length of each beam.

The transfer length was determined by first drawing the best fit horizontal line through the points forming the strain plateau. Note that the transfer length of each beam was defined as the distance from the end of the beam to the point where the concrete strain reaches the strain plateau. Therefore, the transfer length is the distance required for 100 percent of the effective steel stress ($f_{te}$) to be transferred to the concrete.

A representative plot of strain vs. specimen length for three-strand Specimen 6 (see Table 4) is illustrated in Fig. 4. A strain plateau of $6.8 \times 10^{-4}$ at transfer and an average transfer length of 32.0 in. (813 mm) can be seen in this figure. The right end of this specimen was adjacent to a flame cut.

Fig. 3. Depth micrometer and end slip brackets.

Fig. 4. Typical concrete surface strain plot.
The transfer length results [at transfer (TR), and seven and 28 days after transfer] for single-, three-, and six-strand specimens with epoxy-coated strand are presented in Tables 3, 4 and 5, respectively. The transfer lengths shown are the average for each side of a member with the transfer lengths for each end of a member separated by a slash (/).

The transfer length results from Tables 3, 4 and 5 are summarized in Table 6. The average transfer lengths from different specimen types are calculated and presented in Table 8. The ratio of measured transfer length to AASHTO calculated transfer lengths, as listed in Table 7, is 1.19 for the coated cracked specimens and 0.76 for the coated uncracked specimens. The AASHTO equation overestimates transfer length for the uncracked coated strand specimens.

As expected, the transfer lengths for the cracked specimens were longer than for the uncracked specimens. When cracking occurred at prestress transfer, the transfer lengths increased because the bond between the concrete and strand was weakened within the cracked area. Cracked specimens developed cracks between strands (spacing cracks) and cracks from the strand to the outside edge of the cross section (cover cracks).

The longest crack lengths measured at each end of the specimens are listed in Tables 3 and 4. These crack lengths are the longest occurring on any of the four beam faces. Only one end of one specimen (Specimen 11 in Table 4) had just spacing cracks. These being internal cracks, no crack lengths are given. No cracking was found in any specimen containing six strands. It can be seen from the crack lengths listed in Tables 3 and 4 that following a rough correlation, transfer length increases with crack length. The transfer length of cracked specimens using epoxy-coated strand appears to approach the average transfer length of uncracked specimens [24.0 in. (610 mm)] with increased cover and spacing.

Average transfer lengths of coated strand for various concrete covers are listed in Table 8. For cracked specimens, as cover increases the transfer

### Table 6. Average and standard deviation of strand transfer length results.

<table>
<thead>
<tr>
<th>Specimen type</th>
<th>Number in sample</th>
<th>Average transfer length (in.)/Std. Dev.*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Transfer 7 days 28 days</td>
</tr>
<tr>
<td>Coated (cracked)</td>
<td>27</td>
<td>37/10 40/9 42/8</td>
</tr>
<tr>
<td>Coated (not cracked)</td>
<td>23</td>
<td>24/5 26/5 28/5</td>
</tr>
</tbody>
</table>

* Standard Deviation.
Note: 1 in. = 25.4 mm; 1 ksi = 6.895 MPa.

### Table 7. Measured and calculated transfer lengths.

<table>
<thead>
<tr>
<th>Specimen type</th>
<th>Transfer length (in.)</th>
<th>Ratio Measured AASHTO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured AASHTO Eq.</td>
<td>50d*</td>
</tr>
<tr>
<td>Coated (cracked)</td>
<td>37</td>
<td>31</td>
</tr>
<tr>
<td>Coated (not cracked)</td>
<td>24</td>
<td>32</td>
</tr>
</tbody>
</table>

* 50 strand diameters.
Note: 1 in. = 25.4 mm.

### Table 8. Effect of concrete cover on transfer length for coated strand.

<table>
<thead>
<tr>
<th>Cover (in.)</th>
<th>Average transfer length (in.) / No. of samples</th>
<th>Cracked</th>
<th>Not cracked</th>
<th>Both</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.625</td>
<td>n/a*</td>
<td>26/2</td>
<td>26/2</td>
<td></td>
</tr>
<tr>
<td>1.750</td>
<td>39/16</td>
<td>22/4</td>
<td>36/20</td>
<td></td>
</tr>
<tr>
<td>2.000</td>
<td>37/8</td>
<td>27/6</td>
<td>33/14</td>
<td></td>
</tr>
<tr>
<td>2.25</td>
<td>28/3</td>
<td>23/11</td>
<td>24/14</td>
<td></td>
</tr>
</tbody>
</table>

* No data available.
Note: 1 in. = 25.4 mm.

### Table 9. Effect of strand spacing on transfer length for coated strand.

<table>
<thead>
<tr>
<th>Spacing (in.)</th>
<th>Average transfer length (in.) / No. of samples</th>
<th>Cracked</th>
<th>Not cracked</th>
<th>Both</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.000</td>
<td>47/4</td>
<td>n/a*</td>
<td>47/4</td>
<td></td>
</tr>
<tr>
<td>2.25</td>
<td>39/8</td>
<td>n/a*</td>
<td>39/8</td>
<td></td>
</tr>
<tr>
<td>2.50</td>
<td>34/7</td>
<td>22/5</td>
<td>29/12</td>
<td></td>
</tr>
<tr>
<td>2.75</td>
<td>33/4</td>
<td>24/6</td>
<td>28/10</td>
<td></td>
</tr>
<tr>
<td>3.00</td>
<td>35/4</td>
<td>26/6</td>
<td>29/10</td>
<td></td>
</tr>
</tbody>
</table>

* No data available.
Note: 1 in. = 25.4 mm.
Concrete Cover (in.)

Number of cracked specimen ends
Number of uncracked specimen ends

length decreases, whereas for uncracked specimens, a relationship between cover and transfer length is not discernable. The average transfer lengths for various strand spacings are listed in Table 9. Transfer length appears to decrease and level out with an increase in strand spacing in specimens that cracked. For specimens listed in Table 8, strand spacing is not constant; for those listed in Table 9, concrete cover is not constant.

As shown in Fig. 5, the smallest concrete cover in multi-strand specimens which resulted in no cracking in some specimens was 2.0 in. (50.8 mm). At a cover of 2.0 in. (50.8 mm), eight of the 12 specimen ends cracked, while at a cover of 2.25 in. (57.2 mm), only three of 16 specimen ends cracked. As cover was increased, cracking significantly decreased. Both of these covers are larger than the minimum cover required by AASHTO 9.25.1.1.6

The smallest center-to-center strand spacing of 2.5 in. (63.5 mm) that caused no cracking is larger than the minimum 2.0 in. (50.8 mm) specified by AASHTO 9.25.2.1.6 At strand spacings of 2.5, 2.75 and 3 in. (63.5, 69.9 and 76.2 mm), approximately 58, 33 and 40 percent of the specimen ends cracked, respectively. Also, for groups of specimens with the same cover and increased strand spacings, there were no discernable improvements in crack prevention.

**Calculated vs. Measured End Slips**

End slip is the distance an individual strand slips into the concrete after transfer of prestress. End slip of each strand was determined by taking measurements before and after transfer. The difference of these measurements constituted the end slip.

End slip measurements were taken immediately following transfer, and at seven and 28 days after transfer. Some end slip brackets were not installed or were damaged during specimen fabrication; thus, no data were obtained at those locations. A complete listing of the end slip data is available in the project final report.5

The end slip of each strand can be calculated based on the concrete and steel strain data within the transfer length of each specimen.3 The calculated end slip can then be compared to the measured end slip to verify the calculations. Fig. 6 shows an idealized plot of steel strain immediately after transfer ($\varepsilon_c$) and concrete strain due to $P/A$ stresses ($\varepsilon_{se}$) along the transfer length.

The value $\varepsilon_{se}$ is the strain at the strain plateau and is derived from the following equation:

$$\varepsilon_{se} = \varepsilon_{pp} - \varepsilon_c$$

where

$\varepsilon_{pp}$ = steel strain prior to concrete placement

$\varepsilon_c$ = average change in concrete strain from before concrete placement to immediately following transfer of prestress

Note that $\varepsilon_c$ is the estimated strain loss and is assumed to be the value of the concrete strain plateau at this time. The shape of the steel strain plot within the transfer length and in the strain plateau region is assumed to be a straight line. The relationship is proportionally the same as the concrete strain plot due to equilibrium of forces through any beam section. It is assumed that a perfect bond exists between the concrete and steel within the strain plateau.

This assumption results in a steel strain plot approximately 10 times greater than the concrete strain plot but of the same shape. The elastic shortening (El. Sh.) over the transfer length (T.L.) of a specimen is the area under $\varepsilon_c(x)$:

$$\text{El. Sh.} = \int_0^{\text{T.L.}} \varepsilon_c(x) \, dx$$

The area between the $\varepsilon_c(x)$ curve and the initial steel strain plateau, $\varepsilon_{pp}$,
within the transfer length of the beam is the sum of the elastic shortening and the end slip (E.S.):  
\[ \text{E.S.} + \text{El. Sh.} = \varepsilon_{pp}(T, L) - \int_0^{T, L} \varepsilon_1(x)dx \]  
(4)

By rearranging Eq. (4), the end slip (E.S.) can be determined:  
\[ \text{E.S.} = \varepsilon_{pp}(T, L) - \int_0^{T, L} \left( \varepsilon_1(x) + \varepsilon_c(x) \right) dx \]  
(5)

The average slip was calculated for each specimen end from the measured transfer length. Average ratios of measured to calculated end slips are given in Table 9.

From the data provided in Table 10, it is clear that the measured transfer lengths are in good agreement with the calculated values since the average ratio of the measured end slips to calculated end slips is 0.98. This gives a standard deviation of 0.29, which can be expected as the variables of concrete strength, strand surface condition and effective stress can affect these calculations.

Cracking of Specimens

When cracking occurred at prestress transfer, the transfer lengths increased because the bond between the concrete and strand was weakened within the cracked area. Cracked beams developed either spacing cracks or both spacing and cover cracks. Spacing cracks were defined as cracks occurring between strands while cover cracks were those which propagated from the strands to the outside edge of the specimen as shown in Fig. 7.

Cracking began at the specimen end and cover cracks sometimes extended along the beam as much as 4.5 ft (1.4 m). The occurrence of cover cracks in specimens using epoxy-coated strands has been previously observed by Cousins,3 and Dorsten, Hunt and Preston.4

Cracking occurred in 31 coated strand specimen ends, with 27 of these being three-strand ends. Of the cracked specimens using three strands, all but a single specimen (one end of Specimen 11 had spacing cracks) experienced cover and spacing cracks. No specimen with six strands experienced cracking. As expected, cracking increased the transfer length of specimens with coated strand (see Table 6).

It appears that the addition of a layer from the three- to six-strand arrangement reduces the possibility of cracking and thus improves the prestress transfer characteristics. A comparison of specimens with three and six strands is provided in Table 11. Six-strand epoxy-coated specimens with spacings and covers identical to those with three strands did not crack while their three-strand counterparts did. This improvement may be due to confinement provided by the addition of another layer of coating.

Two single, uncoated strand specimens had concrete spall off the end adjacent to flame cutting at transfer. It is believed that the spalling ended resulted from flame cutting too close to the beam ends and not from lack of concrete cover. No specimen with uncoated strands experienced spacing and cover cracking. Therefore, as expected, the cover and spacing required by AASHTO was sufficient for specimens with uncoated strand.

Of the specimens which developed cracks, most experienced cover cracks in line with the strand layer on the faces containing gauge points (Fig. 7). From these observations, there was some concern that the gauge points may have induced crack propagation by weakening this area of the beam. However, this concern was unwarranted because thorough consolidation was obtained and the gauge points were of very small volume. Also, specimens with uncoated strands did not experience this type of cracking.

It appeared that cover cracks in some specimens with three-coated strands were an extension of horizontal spacing cracks. Few specimens that cracked experienced spacing cracks in combination with cover cracks extend-
ing only to the top and bottom of the cross section. Thus, insufficient spacing may develop spacing cracks, which in turn propagate outward to form a cover crack.

This type of crack can be seen in Fig. 7. Cracking typically occurred so quickly that it was difficult to determine where a crack originated, what caused it and what influence other cracks might have had.

**CONCLUSIONS AND RECOMMENDATIONS**

The following conclusions are based on the results of this experimental program:

1. Grit impregnated epoxy-coated strand causes spacing and cover cracks at prestress transfer in the transfer zone in multistrand specimens at spacings and covers less than those recommended by the AASHTO Specifications.

2. The cracked specimens using coated strands resulted in transfer lengths about 50 percent greater than those measured in specimens that did not crack.

3. A second layer of epoxy-coated strand improves prestress transfer characteristics and diminishes the likelihood of concrete cracking.

4. The AASHTO equation for transfer length overestimates the measured transfer length for coated strand specimens that did not crack.

5. The AASHTO requirements for concrete cover and strand spacing are unconservative for the epoxy-coated strand specimens to transfer the prestressing force without cracking. Spacing and cover requirements should be increased somewhat in pretensioned, prestressed concrete members with no confinement. However, for bridge girders and other pretensioned, prestressed concrete members that typically have a significant amount of confinement reinforcement in the form of stirrups and end zone reinforcement, increased strand spacing and concrete cover may not be necessary.

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The contents of this paper reflect the views of the authors, who are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the supporting agencies. This paper does not constitute a standard, specification or regulation.

**REFERENCES**


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