FHWA

July 8, 1988

Prestressing Strand for Pretensioning
Development Length

5144-3

Mr. Maurice Smith, Director
Arkansas State Highway and
Transportation Department
Little Rock, Arkansas

Dear Mr. Smith:

Enclosed for your information and appropriate action are copies of memorandums from our Region and Washington offices addressing the development length for prestressing strands. Recent North Carolina research has indicated that the current AASHTO formula for development lengths are extremely unconservative when applied to 270 ksi strands at 0.70 to 0.75 GUTS. In view of this information our Washington office has recommended that the development length be increased by a factor of 2.5 when AASHTO specifications are used or by a factor of 2.0 when the Zia/Mostafa equation is applied. This design change will apply to all future Federal-aid projects until further notice.

We will be happy to supply you with a copy of the North Carolina Report when it becomes available. If you should have any questions or concerns about the above requirement please let us know.

Sincerely yours.

R. G. Fairbrother
Division Administrator

Enclosure
cy: Chief Engr.
Asst. Ch. Engr. Almond
Asst. Ch. Engr. Peevy
Asst. Ch. Engr. Walters
Rdwy.
Bridge
M&R
309.110
309.111

FHWA June 28, 1988

Subject: Prestressing Strand for Pretensioning
Development Length

From: Director, Office of Structures
Fort Worth, Texas

To: Division Administrators R.G. Fairbrother
J. N. McDonald, A. L. Alonzo, G. E. Penney
And J. J. Conrado

Attached for your information and further handling is one copy of the Washington Office memorandum on the development length of prestressing strand. The information is based on a limited research conducted at the North Carolina State University. It is intended as an interim measure until a more detailed research can be undertaken.

The North Carolina research was directed at the bond strength of epoxy coated strand. In conjunction with that, several test were made on uncoated strands. The test result on all sizes indicated a development length substantially greater than required by the current AASHTO or Zia/Mostafa formulas. In view of that, the Washington Office is recommending the development length be increased by a factor of 2.5 when the AASHTO Specifications are used or 2.0 when the Zia/Mostafa equation is applied.

The development length, as given in the AASHTO Specification, is a one equation term. It applies to the ultimate strength check of prestressed concrete beam. This change could have an impact on short beam and cantilever sections where there is a rapid buildup of applied moment. It will be especially critical on beams that have blanket stands, and we would suggest any of these be reviewed in detail.

The other item, not mentioned in the Washington Office correspondence, is transfer length for the strands. The overall development length includes two components, transfer length and bond. The AASHTO equation combines them for direct application. The Zia/Mostafa equations and ACI code separate them. We are attaching a portion of the ACI code that illustrates this concept. While it makes little difference how these are handled in the ultimate strength determination, it does make a difference in determining the effect in the anchorage zone at the end of prestressed beams.

The current AASHTO provision (9.20.2.4) for checking shear at the end of beam requires a reduction in the prestressing component if the transfer length is greater than h/2. The transfer length is designated as 50 strand diameter with a linear variation from zero to maximum in that length. This 50 diameter is a simplified determination of the transfer length. The North Carolina research would also suggest that it be increased by the same ratio as the overall development length. This would mean that new value of 125 strand diameter should be used or a separate determination made based on 2.5 times that transfer length in ACI or twice the transfer length in Zia/Mostafa.

We would expect that these modifications will have an effect on computer programs and/or States' design practices. We would anticipate further research in the next couple of years that will add to our knowledge of bonding and transfer lengths on prestressing strand. In the interim, we would expect that the above would apply on Federal-aid projects.

We will have a copy of the North Carolina Research Report available within the next couple of weeks. If you or the State should have questions or concerns about the above requirements, please let us know and we will try to address them.

James R. Craig

Attachment

FHWA June 20, 1988

Subject: Prestressing Strand for
Pretension Applications - Development Length

From: Chief, Bridge Division
Office of Engineering

To: Regional Federal Highway Administrators
Direct Federal Program Administrator (DHF-1)

The purpose of this memorandum is to update you with regard to developments concerning the subject topic.

The FHWA in a memorandum dated December 16, 1987, indicated that "no strand" larger than ½ inch in diameter should be used in a pretensioned application on any Federal-aid project." At a meeting with PCI representatives, held in Washington, D.C. on January 13, 1988, the FHWA, as an interim measure, advised that those State agencies who wish to use strand sizes larger than ½ inch in diameter may request a case specific opinion from FHWA based upon project parameters.

In a memorandum dated February 11, 1988, the FHWA concurred in an interim criteria proposed by the Florida DOT as follows:

(1) no 0.6 diameter strand is to be used in a pretensioned application;

(2) strand spacing (center-to-center of strand) will be four times the nominal diameter; and,

(3) development length will be determined as twice the value determined by the Zia-Mostafa equation for ½ inch diameter (special) and 9/16 inch diameter (regular and special) strand.

It should be noted that the second item above refers to a <u>minimum</u> strand spacing. The Zia-Mostafa equation in item 3 above is given in the following reference: Zia, P. and Mostafa, T., "Development Length of Prestressing Strand," PCI Journal, September-October 1977.

A concern has been brought to our attention regarding the complexity of modifying existing computer programs, which are based upon the AASHTO (ACI-83) equation, to that of the Zia-Mostafa equation. In the spirit of the current interim criteria and in the interest of simplification, we have no objection to the use of the current AASHTO equation (9.32) increased by a factor of 2.5 in lieu of twice the Zia-Mostafa equation as stated in item 3 of the above interim criteria.

Our concern for the adequacy of the current AASHTO equation (9-32) for development length is expressed in a February 2, 1988, letter to Mr. Henry Bollmann, Chairman, AASHTO Technical Committee for Prestressed Concrete (copy attached). In reviewing our position with regard to this topic, it has come to our attention that these concerns are as valid for ½ inch diameter regular strand and smaller as they are for ½ inch diameter special strand and larger. Therefore, in pretensioned applications the bond development length for <u>all</u> size strands shall be determined by the above interim criteria and as modified by the preceding paragraph.

Stanley Gordon

Attachment

Stanley Gordon, Secretary
Subcommittee on Bridges
And Structures
Federal Highway Administration
400 7th Street, SW., Room 3113
Washington, D.C. 20590

Mr. Henry T. Bollmann
Chairman, Technical Committee
For Prestressed Concrete
Florida Department of Transportation
Haydon Burns Building, M-33
604 Suwannee Street
Tallahassee, Florida 32301

Dear Mr. Bollmann:

Recent research data [1/] has caused concern with regard to the validity of Articles 9.25.2.1 and 9.27.1 of the AASHTO Standard Specifications for Highway Bridges. These two articles are in regard to the minimum clear spacing and development length of prestressing strand in a pretensioned application.

Although the research reported in Reference 1 is directed at epoxy-coated strand, the data reported for uncoated strand control specimens are cause for concern. Data presented, for uncoated strand, in Table 8.10 of Reference 1 for 3/8-, ½-, and 0.6-inch diameter strand indicates that the ACI (AASHTO) equation for development length (AASHTO Article 9.27.1) underestimates the measured development length by 23.2, 53.0 and 44.5 percent respectively. If the Zia and Mostafa [2/] equation for development length is used (also used in the 1983 Ontario Highway Bridge Design Code), it underestimates the measured development length by 12.1, 44.6 and 36.3 percent respectively.

The current AASHTO equation for development length (Article 9.27.1) is based upon research conducted by Kaar, LaFraugh and Mass.[3/] However, this research is based on 250 ksi stress relieved strand with a steel stress immediately after transfer not exceeding 0.7 of guaranteed ultimate tensile stress (GUTS). Current practice generally used 270 ksi low-relaxation strand and the 1987 AASHTO Interim Specification allows a stress at transfer of 0.75 GUTS for this material.

The data in Reference 3 was based on specimens of ¼-, 3/8-, ½- and 0.6-inch diameter strand. Figures 9 and 10 of Reference 3 indicates a linear relationship between strand diameter and transfer length. However, Reference 3 also states:

> Whereas, the ¼-, 3/8- and ½- inch diameter strands were entirely clean and free from any sign of rust when received at the laboratory, the 6/10-inch diameter strand had been exposed to rain in transit and consequently there were rust spots on the strand when received.

Although this rust was removed as thoroughly as possible, it is thought that the surface of the strand was slightly pitted from the rusting, and that as a result of this a better bond was achieved between the concrete and this strand than was possible in the case of the other strands which were perfectly smooth and clean.

The degree that the rusted and subsequently cleaned 0.6-inch diameter strand specimens affected bond is unknown as there is no comparative data with bright strand. Therefore, the extrapolation of the linear relationship between strand diameter and transfer length for strands larger than ½-inch diameter appears to be subjective and questionable.

Another area of concern associated with development length, is the strand spacing criteria for pretensioned applications presented in AASHTO Article 9.25.2.1. This criteria appears to be somewhat empirical in that it only relates to a multiplier of the strand diameter. This is no consideration of the concrete strength or the level of stress in the strand at the time of the concrete strength or the level of stress in the strand at the time of transfer. Although Figure 1 of Reference 3 indicates that this criteria was used to develop the strand pattern configuration for the specimens tested in that research, there is no indication that the effect of strand spacing was considered as a variable parameter. The current research reported in Reference 1 only considers the embedment of a single strand. Therefore, this criteria requires evaluation of its adequacy not only with regard to smaller diameter strands and to strand material and stress levels currently being used in practice.

Based on the above, it is suggested that the AASHTO Technical Committee for Prestressed Concrete investigate the applicability of Articles 9.25.2.1 and 9.27.1 to current practice with regard to stress levels, size of strand available for potential use in pretension applications and strand spacing.

<u>References</u>:

1. Cousins, T.E.; Johnston, D. W. and Zia, P., "Bond of Epoxy Coated Prestressing Strand," Center for Transportation Engineering Studies, Department of Civil Engineering, North Carolina State University, December 1986.

2. Zia, P and Mostafa, T., "Development Length of Prestressing Strand," PCI Jounral, September-October 1977.

3. Kaar, P.; LaFraugh, R. and Mass, M., "Influence of Concrete Strength on Strand Transfer Length," PCI Journal, October 1963.

Sincerely yours,

Stanley Gordon
Secretary, subcommittee on
Bridges and Structures

Cc: Mr. Clellon L. Loveall

12.9 – Development of welded smooth wire fabric in tension

New development provisions for welded smooth wire fabric were adopted in 1976. Fig. 12-3(b) shows the development requirements for smooth wire fabric with development primarily dependent on the location of cross wires. For fabrics made with the smaller wires, an embedment of at least two cross wires 2 in. or more beyond the point of critical section is adequate to develop the full yield strength of the anchored wires. However, for fabrics made with larger closely spaced wires a longer embedment is required and a minimum development length is provided for these fabrics.

12.10 – Development of prestressing strand

The development requirements for prestressing strand are intended to provide bond integrity for the strength of the member. The provisions are based on tests performed on normal weight concrete members with a minimum cover of 2 in. These tests may not represent the behavior of strand in low water-cement ratio, no-slump concrete. Fabrication methods should insure consolidation of concrete around the strand with complete contact between the steel and concrete. Extra precautions should be exercised when low water-cement ratio, no-slump concrete is used. In general, this section will control only for the design of cantilever and short-span members. The requirement of doubled development length for strand not bonded through to the end of the member is also based on test data.[12.7]

The expression for development length ℓ_d may be rewritten as:

$$\ell_d = \frac{f_{se}}{3} d_b + (f_{ps} - f_{se}) d_b$$

where ℓ_d and d_b are in inches, and f_{ps} and f_{se} are in kips per sq in. The first term represents the transfer length of the strand, i.e., the distance over which the strand must be bonded to the concrete to develop the prestress f_{se} in the strand. The second term represents the additional length over which the strand must be bonded so that a stress f_{ps} may develop in the strand at nominal strength of the member.

The variation of strand stress along the development length of the strand is shown in Fig. 12-4.

The expressions for transfer length, and for the additional bonded length necessary to develop an increase in stress of $(f_{ps} - f_{se})$ are based on tests of

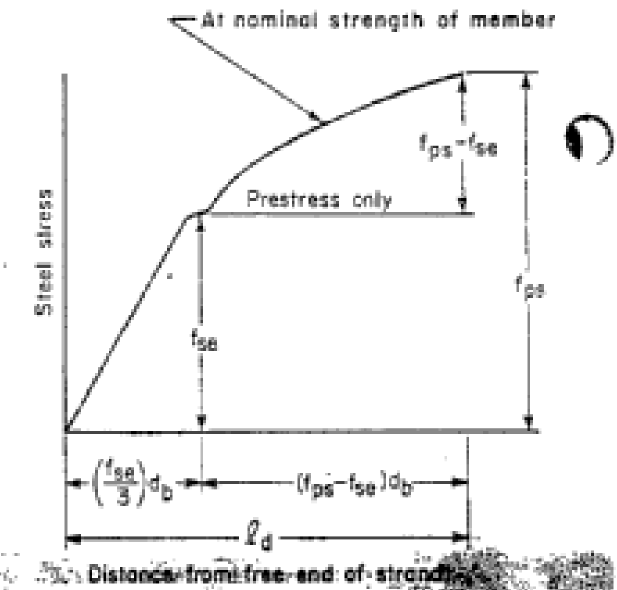

Fig. 12-4 – Variation of steel stress with distance from free end of strand

members prestressed with clean, ¼, ⅜, and ½ in. diameter strands for which the maximum value of f_{ps} was 275 kips sq in.[12.7, 12.8, 12.9]

The transfer length of strand is a function of the perimeter configuration area and surface condition of the steel, the stress in the steel, and the method used to transfer the steel force to the concrete. Strand with a slightly rusted surface can have an appreciably shorter transfer length than clean strand. Gentle release of the strand will permit a shorter transfer length than abruptly cutting the strands.

The provisions of Section 12.10 do not apply to plain wires nor to end anchored tendons. The length for smooth wire could be expected to be considerably greater due to the absence of mechanical interlock. Flexural bond failure would occur with plain wire when first slip occurred.

12.11 – Development of flexural reinforcement – General

12.11.2 – Critical sections for a typical continuous beam are indicated with a "c" or an "x" in Fig. 12-5. For uniform loading, the positive reinforcement extending into the support is more apt to be governed by the requirements of Section 12.12.3 rather than by development length measured from a point of maximum moment or bar cutoff.

12.11.3 – The moment diagrams customarily used in design are approximate; some shifting of the location of maximum moments may occur due to