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INFLUENCE OF GRANITE AGGREGATE ON LONGITUDINAL SPLITTING IN PRESTRESSED CONCRETE MEMBERS

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Abstract

The experimental tests which were performed in this paper evaluate the effect of the concrete mixture using granite as aggregate on the longitudinal splitting behavior in prestressed concrete members. Three prisms having different edge distances were cast concurrently having different release strengths of concrete 4500-psi (31-MPa) and 6000-psi (41M-Pa). Furthermore, four different wires type were used in these experiments to evaluate the influence of all variables on the bond between steel and concrete which is highly important for transferring the stresses between the two materials.

Keywords: prestressed concrete, edge distance, wire type, longitudinal splitting, compressive strength

1 Introduction

The experimental program was performed to evaluate the influence of concrete mixture on bond performance between steel and concrete in prestressed concrete members. Three sets of prisms were cast at a time to understand the effect of the type of aggregate used in concrete mixture on longitudinal splitting in prestressed concrete members using different maturity of concrete, the different indentation of wire, and different cross-sections.
Aref et al. [11] investigated the Evaluation of splitting crack propagation in prestressed concrete ties made with a different type of coarse aggregate. It has been observed that concrete properties and components can highly affect crack formation and propagation. According to this research angularity and coarseness of aggregate increase the fracture toughness of concrete by 20 %. It was concluded that increasing angularity can significantly improve splitting cracks resistance.
Naga Bodapati et al. [2] investigated the variation of transfer length in pre-tensioned prestressed concrete railroad ties with varying prestressing steel types and concrete parameters. This experimental program included eighteen different prestressing reinforcement types that are employed in concrete railroad ties worldwide. It was concluded that transfer length is highly dependent on the reinforcing type and indentation pattern. The concrete compression strength at the time of prestress transfer is a primary factor influencing the transfer length in pre-tensioned concrete members utilizing both wires and strands. The transfer length is significantly important to ensure that pre-stressed forcing is introduced well before the rail seat where the high impact load is applied. A consistent decrease in the transfer length was observed for both wires and strands when the release strength was increased from 3500 psi (24 MPa) to 4500 psi (31 MPa).

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The research was conducted at Kansas State University to understand the effect of the concrete mixture on longitudinal splitting in prestressed concrete railroad ties. Three prisms were cast at a time having different cross-sections. Four wires having different indentations and 5.32 mm (0.21 in) diameter was embedded into each cross-section. Each wire was pulled to 7000 lbs (31.13 kN) and gradually de-tensioned when the maturity of concrete reached 4500 psi (31 MPa) and 6000-psi (41 MPa). The same water/cement ratio of 0.32 was used for all experiments.

2 Material

For this experimental program, four different types of wires were used for each individual set of prisms. All wires had a diameter of approximately 5.32 mm (0.21 in). Wire types were denoted using the following nomenclature: “WB”, “WF”, “WM”, and “WQ”. Indented Wire Measurements are given in the following table.
The indentation types tested included shallow and deep chevron wire types. Figure 1 shows the wires’ main characteristics, including indent depth, indent volume, indent sidewall area, and indent sidewall angle. Shown in Figure 2 are microscope images of wire and associated 3D Cad Models.

Table 1 Indented wire measurements

	Average depth [mm]	**Edge wall angle** [°]	**Sidewall area** [mm²]	**Volume** [mm³]
WB	0.119	16.45	2.92	1.696
WF	0.163	28.07	2.45	2.446
WM	0.101	16.41	2.06	1.252
WQ	0.067	11.58	2.15	0.776

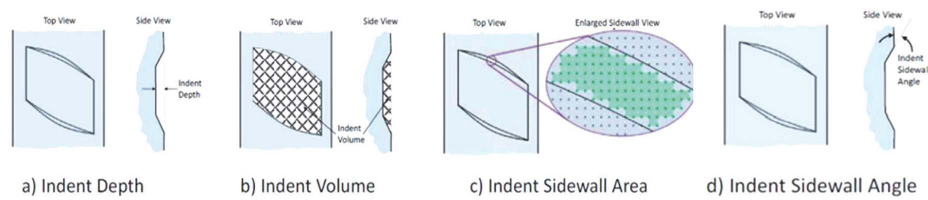

Figure 1 Wire indent geometrical features (Indent Depth, Indent Volume, Indent Sidewall Area, Indent Sidewall Angle, respectively)

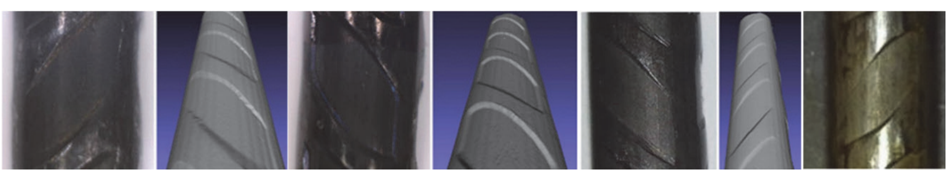

Figure 2 Microscope Image of wire type and 3D Model WB, WM, WP, and WQ respectively

Cement: Monarch Type III cement was used for the concrete mix design used in this study. The cement was obtained from Concrete Materials Inc. in Overland Park and stored in 55 gallon (250 l) drums until needed.
Aggregate: Granite was used as aggregate with 100 % passing the 3/8 in the sieve as shown in Figure 3.

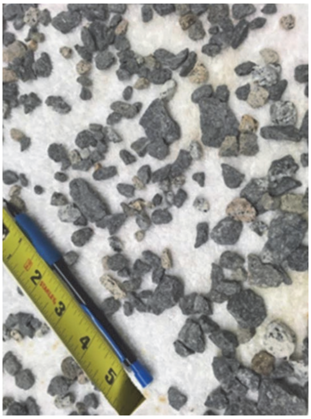

Figure 3 Granite aggregate

To achieve the desired concrete consistencies (slump) with a low water/cementitious (w/c) ratio, ADVA CAST 530 was used for all tests. Table 2 shows the material and weight of the concrete mix. In this study 0.32, water/cement ratio was used.

Table 2 Concrete mix design

Concrete Mix		
Material	**Weight (lbs.) /yd3**	**Weight** [kg/m^3]
Cement	813.8	488.3
Water	260.4	156.2
Crushed Granite	1447	868.2
Sand	1447	868.2
Adva Cast 530	81-fl.oz/yd^3	313-mL/m^3

3 Methodology

For this research study, three prisms with varying cross-sections were used which included center-to-center spacing of 2.0 in between wires with a maximum reinforcement edge distance of ¾ in (1.9 cm) and a minimum edge distance of ½ in (1.27 cm). Three concrete prisms had 3.5 in x 3.5 in (8.9 cm x 8.9 cm) square cross section, 3.25 in x 3.25 in (8.2 cm x 8.2 cm) and (7.6 cm x 7.6 cm) cross sections. The wires in the prisms were each tensioned to 7000 lbs (31.13 kN). The average initial compressive stress for edge distance ¾ in (1.9 cm) was equal to (28000 lb. / (3.5 in)^2) =2285 psi or 124 kN/8.89 cm^2 = 15.8 MPa. For prisms with a 5/8 in (1.6 cm) edge distance, the value of stress was: 28000 lb. / (3.25 in)^2 =2650 psi or 124 kN/8.25^2 = 18.27 MPa which was 59 % of the 4500 psi (31 MPa) concrete release strength. For prisms with ½ in (1.27 cm) edge distance, the average initial compressive stress was 3110 psi (21.44 MPa), which was approximately 89 % of the 4500 psi (31 MPa) concrete release strength. This value is significantly into the nonlinear range of the concrete. Figure 4 shows the square cross-section of the prism having a ¾ in (1.9 cm) edge distance with four wires embedded into the cross-section.

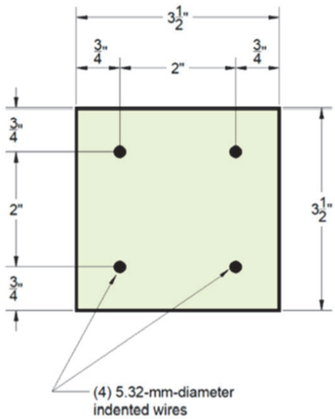

Figure 4 Prism 3.5-in x 3.5-in (8.9-cm x 8.9-cm) having ¾-in (1.9-cm) edge distance

Figure 5 shows the placement of concrete in the steel prism. Additionally, 12 4 in x 8 in (10.16 cm x 20.32 cm) compression strength cylinders were also cast simultaneously using the Sure Cure System which allowed the cylinders to have the same temperature as the prisms. Five hours after casting, cylinders were tested using the Forney machine, and tests were repeated every 45 minutes. The desired strength of 4500 psi (31 MPa) was reached approximately after 8 hours and 6000 psi (41 MPa) after 11 hours when the process of de-tensioning commenced. In this research, two maturities of concrete were investigated 4500 psi (31 MPa) and 6000 psi (41 MPa).

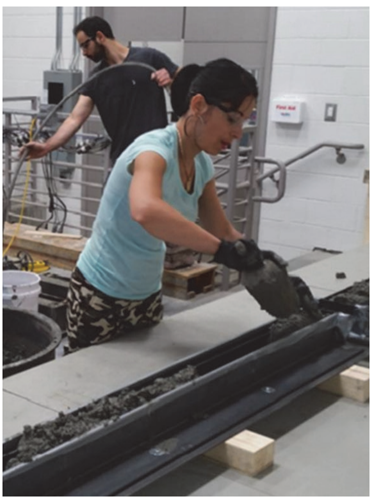

Figure 5 Placement of concrete

For prestressed concrete railroad ties to function adequately in the field and ensure safety, the prestressing force must be fully introduced into the railroad tie at a location well before the rail load is applied. The length required to transfer the prestress force into the concrete member is well known as the "Transfer length". For transfer length measurements LSI (Laser Speckle Imaging) system was used [3]. The laser-speckle device was used to scan the top surface of a concrete prism before and after de-tensioning, automatically plot the strain profile, and determine the transfer length using a least-squares algorithm [3].

Additionally, each prism provided a sample of eight different and approximately independent splitting tests of edge distance for a given compressive strength of concrete. After the de-tensioning procedure, all cracks that appeared on the prisms were marked, and photographs of all prism end surfaces were taken to identify the cracking field [4]. The crack length was measured by tracing out the path of a given crack with a piece of string and measuring the overall path (string) length including branches. In cases where spalling was observed, the crack width was assigned an arbitrary width value of 0.20 in (0.50 cm). The crack area was defined as the total crack length multiplied by the maximum crack width [4]. Figure 6 shows the example of observed cracking. All prisms were investigated three months after the de-tensioning procedure. Some cracks appeared immediately after de-tensioning, but some were due to sustained lateral stresses several weeks later.

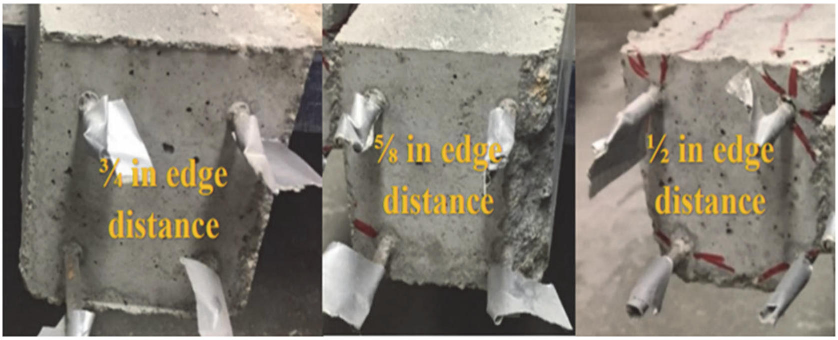

Figure 6 Observed Cracking

4 Results

For this experimental research, four-wire types were investigated having shallow chevron and deep chevron indentation. Wires WM and WQ belong to the shallow chevron type and WB and WF belong to the deep chevron type. Additionally, two compressive strengths of concrete were observed: 4500 psi (31 MPa) and 6000 psi (41 MPa) and three different edge distances ¾ in (1.9 cm), 5/8 in (1.6 cm), and ½ in (1.27 cm). Tables 3 and 4 show the values of the crack area which was defined as crack width multiplied by crack length, crack length, and the values of transfer lengths. Transfer lengths values were given only for prisms having ¾ in (1.9 cm) edge distance. In cases where transfer lengths have values over 17 in (43 cm) that indicates a significant amount of cracking. Figure 7 shows the example of the longitudinal strain profile along with the values of transfer lengths.

Shallow chevron-type wires performed very well with the concrete mixture using granite as aggregate having no cracks on all prisms using ¾ in (1.9 cm) edge distances. With increasing the maturity of concrete these wires performed better by reducing the number of crack areas on the prisms having 5/8 in (1.6 cm) edge distances.

Deep chevron wire types performed poorly with the concrete mixture using granite as aggregate. With reducing the thickness of the concrete cover, the values of crack areas and crack lengths increased as shown in Tables 3 and 4. WF wire type had a significant amount of crack areas on the prisms having 5/8 in (1.6 cm) and ½ in (1.27 cm) edge distances, and with increasing the compressive strength of concrete these amounts are higher. High values of crack areas suggest an almost complete loss of bond in this region.

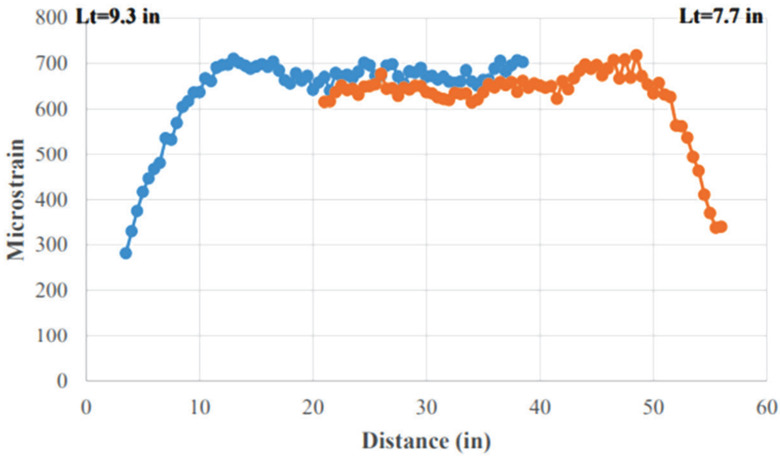

Figure 7 Longitudinal Strain Profile WQ wire Type, 6000 psi (41 MPa)

Table 3 Crack area, crack length, transfer length-4500 psi (31 MPa)

	4500 psi (31 MPa)						
	¾ in (1.9 cm)			**5/8 in (1.6 cm)**		**½ in (1.27 cm)**	
	Crack area [in²]	**Crack length** [in]	**Transfer length** [in]	**Crack area** [in²]	**Crack length** [in]	**Crack area** [in²]	**Crack length** [in]
WB	3.6	170	17.25	10	354	9.5	405
WF	1.4	64	10.8	12	293	59.4	471
WM	0	0	10.25	0.2	16	2.9	169
WQ	0	0	8.35	0.4	27	4.6	220

	4500 psi (31 MPa)						
	¾ in (1.9 cm)			**5/8 in (1.6 cm)**		**½ in (1.27 cm)**	
	Crack area [cm²]	**Crack length** [cm]	**Transfer length** [cm]	**Crack area** [cm²]	**Crack length** [cm]	**Crack area** [cm²]	**Crack length** [cm]
WB	23	432	44	64	899	61	1029
WF	9	163	27.4	77	744	383	1196
WM	0	0	26	1.3	41	19	429
WQ	0	0	21	2.6	69	30	559

Table 4 Crack area, crack length, transfer length-6000-psi (41-MPa)

	6000 psi (31 MPa)						
	¾ in (1.9 cm)			5/8 in (1.6 cm)		½ in (1.27 cm)	
	Crack area [in²]	**Crack length**[in]	**Transfer length** [in]	**Crack area** [in²]	**Crack length** [in]	**Crack area** [in²]	**Crack length** [in]
WB	2.2	202	27.5	6.0	377	8.4	395
WF	0.8	32	5.5	55.7	411	74	520
WM	0	0	8.25	0.04	4	18.8	340
WQ	0	0	8.50	0.004	0.4	14.6	248

	6000 psi (31 MPa)						
	¾ in (1.9 cm)			5/8 in (1.6 cm)		½ in (1.27 cm)	
	Crack area [cm²]	**Crack length** [cm]	**Transfer length** [cm]	**Crack area** [cm²]	**Crack length** [cm]	**Crack area** [cm²]	**Crack length** [cm]
WB	14	503	70	39	958	54	1003
WF	5.2	81	14	361	1044	477	1321
WM	0	0	21	0.26	10	121	864
WQ	0	0	22	0.026	1	94	630

5 Conclusions and recommendations

Based on the results of this study, the following conclusions are drawn:

- Prisms manufactured with shallow chevron wire type and having granite as aggregate in concrete mixture indicated particularly good performance in all two compressive strengths 4500 psi (31 MPa) and 6000 psi (41 MPa). There were no observed cracks on the prisms having ¾ in (1.9 cm) edge distance.
- Prism manufactured with deep chevron wire type had longitudinal cracks on the prisms having 5/8 in (1.6 cm) and ½ in (1.27 cm) edge distances initiating at all eight wire-end locations. Prism manufactured with deep chevron having Granite as aggregate indicated extremely poor performance. According to previous investigations, these wire types performed better using crushed aggregate with no cracks on the prisms having ¾ in (1.9 cm) edge distances. It is not recommended to use deep chevron wire types with granite.
- Based on the current research, concrete release strength of 4500 psi (31 MPa) and 6000 psi (41 MPa) and edge distances of 5/8 in (1.6 cm) and ½ in (1.27 cm) using the 5.32 mm diameter of wire are not recommended for the manufacturing of pre-tensioned concrete railroad ties. Likewise, the test results indicate that ¾ in (1.9 cm) is the minimum edge distance to achieve crack-free members with shallow chevron types of wire. In this case, a 1 in (2.54 cm) edge distance would provide a reasonable factor of safety against splitting cracks from a design standpoint. For deep chevron wire type, the minimum edge distance to achieve crack-free members is higher than ¾ in (1.9 cm), and according to the previous investigation, it is 1 in (2.54 cm). In this case, a 1.25 in (3.18 cm) edge distance would provide a reasonable safety against splitting cracks.

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