The Influence of Different Type of Aggregate, Fly Ash and Fiber Reinforced Polymer on Splitting Resistance in Pretensioned Concrete Railroad Ties

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This research evaluates the influence of the different types of concrete mixture, using a shallow type of indentation of wire, having the different edge distance and compressive strength of concrete on splitting resistance in pre-tensioned concrete railroad sleepers. The investigated compressive strength of concrete was 4500psi. The research was experimental, and the part of this research was formally adapted in Arema Standards for Railway Engineering Chapter 30 section 4.2.4.

Keywords: Heavy machinery, Mechanical engineering, Civil engineering

1. INTRODUCTION

This research is focused on longitudinal splitting which occurs in prestressed concrete members due to different variables such as concrete mixture, wire type, and release strength of concrete. The goal is to find the best possible design parameters to diminish longitudinal splitting in prestressed concrete members. Different prestressed concrete prisms were examined having different cross-sections using different concrete mixture and compressive strength. The examined wire type which will be described in this paper is denoted as “WB” wire type, which belongs to the chevron type of wire. The research which was conducted at Kansas State University used this wire type having 1in edge distance and experiments with this wire were successful without longitudinal splitting in prestressed concrete members. The influence of variables was presented in the research of Bodapati [1], Savic et al [2], [3], [4], [5], [6]. They investigated the influence of edge distance and wire type indentation on longitudinal splitting. According to their research, the minimum edge distance depends on the wire type and for shallow wire type, it will be 0.75 in.

2. METHODOLOGY

2.1. Splitting Crack Evaluation

Three prisms having different cross-sections were cast at a time. The values of edge distances were 3/4in, 5/8in, and 1/2in. Different concrete mixes were designed so that the most effective factors were included. These factors are angularity, coarseness, the volume of coarse aggregate, class F fly ash, and w/cm ratio. In addition, 5 mixes were designed to assess the effect of transverse reinforcement on splitting cracks. The compressive strength of concrete was 4500psi for each prism and the water/cement ratio was 0.32. Adva Cast 530 was used as a water reducer.

2.2. WB Wire Type

WB wire Type belongs to chevron type of wires, but during this research and after all experimental investigation this wire had performance remarkably similar to wires which belong to deep chevron wire type. The physics behind this splitting is still unknown and the VOLPE center is working on a numerical approach to find the reason for such behaviour. The geometry of the prestressing wire indents is a significant variable in the formation of longitudinal splitting cracks in pre-tensioned concrete members. Longitudinal splitting along prestressing tendons can result in severe splitting and complete tie failure in the field under normal train loading over time. Features of interest for each wire type are indent depth, indent volume, indent sidewall area, indent sidewall angle, indent length, indent pitch period, indent width, indent distance, and indent orientation angle. Figure 1 shows graphically the indent features of wires [2].

Figure 1: The indent Features of wires

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Table 1: Indented wire Measurements

	Average depth (mm)	Edge Wall angle (degree)	Side Wall Area (mm ²)	Volume (mm ³)
WB	0.119	16.45	2.92	1.696

Figure 2 presents WB Wire Type Microscope Image and 3D Model [8].

Figure 2: WB Wire Type- Microscope Image and 3D Model (8)

2.3. Sample preparation

Three prisms having different edge distances were cast at a time. The edge distance is defined as a distance from the tendon center to the edge of the prism. Four prisms were embedded into each cross-section having a common distance of 2 in. Three different values of edge distances were examined $\frac{3}{4}$ in, $\frac{5}{8}$ in, and $\frac{1}{2}$ in.

Before the casting procedure, each wire was pulled to 7000 lbs. The average initial compressive stress for edge distance $\frac{3}{4}$ in was equal to $28000 \text{ lb.} / (3.5 \text{ in})^2 = 2285 \text{ psi}$. For prisms with a $\frac{5}{8}$ in edge distance, the value of stress was: $28000 \text{ lb.} / (3.25 \text{ in})^2 = 2650 \text{ psi}$ which was 59 % of the 4500-psi concrete release strength. For prisms with $\frac{1}{2}$ in edge distance, the average initial compressive stress was it was 3110 psi, which was approximately 89 % of the 4500-psi concrete release strength. This value is significantly into the nonlinear range of the concrete. In the pre-tensioning frame, wires within each prism were tensioned between two abutments before the casting of concrete. A jacking assembly was created at Kansas State University and used for this study. The mechanical gear jack was attached to the metal frame which allowed

gradual tensioning and release operations. Jacking of the steel prestressing wires occurred at the end of the steel frame referred to as the “Live End” as shown in Figure 4. Figure 5 shows a prestressed concrete bed with three sets of prisms having differentiated edge distances.

Figure 3: Cross-section of three prisms for each set of prisms

Figure 4: Prestressed Jacking Arrangement at the Live End

Figure 5: Prestressed Concrete Bed

Figure 6: Casting the Prestressed Concrete Prisms

2.4. Test Procedure

After casting specimens, temperature-match cured cylinders were tested at periodic intervals to determine the compressive strength. As soon as the cylinders reached 4500 psi (approximately after eight hours, depending on the lab temperature), the prisms were gradually de-tensioned. For prestressed concrete railroad ties to function sufficiently in the field, and to guarantee safety, the prestressing force must be fully introduced into the railroad tie at a location well before the rail load is applied. The length needed to transfer the prestress force into the concrete member is well known as the “Transfer length”. The laser-speckle device was used to scan the top surface of a concrete prism before and after de-tensioning, and automatically plot the strain profile and determine the transfer length using a least-squares algorithm [9].

Figure 7. Measuring the Transfer Lengths

Two scans are required for transfer length measurement one before de-tensioning and one after the cutting operation after the de-tensioning procedure. The surface strain was calculated and plotted automatically after the raw images are captured.

Each prism provided two measurements of transfer lengths (live and dead-end) and provided approximately eight independent splitting tests of edge distance (four-wire cover tests on each end) for a given release strength. [2]

The length and width of cracks were measured using a ruler and concrete crack comparator respectively, after 90 days. This time delay was used to evaluate long term creep behavior of splitting cracks. In some cases, the longitudinal splitting occurred immediately after the de-tensioning procedure but due to lateral sustained stresses, some cracks appeared after several weeks. All cracks were marked using a permanent red marker. For further investigations crack length for each prism was determined along with the values of Crack Areas. The crack area was defined as crack width multiplied with crack length. In the case where spalling occurred the arbitrary value of crack width was used as 2in.

3. RESULTS

3.1. WB wire type 4500psi using Crushed Gravel as aggregate.

WB wire type which belongs to the chevron type of wire was examined using different concrete mixtures to understand which variable is most important in transferring the stresses between steel and concrete. Mix#1 used Crushed Gravel as aggregate, Adva Cast 530 as High Range Water Reducer, and water/cement ratio was 0.32 for all set of prisms. Table 2 shows the concrete mix ingredients.

Table 2: Concrete Mix Design Using Crushed Gravel as Aggregate

Material	Weight (lbs./yd ³)
Cement	813.8
Water	260.4
Large Crushed Gravel	897.8
Small Crushed Gravel	538.7
Sand	1436.5
Adva Cast 530	81 fl.oz./yd ³

Figure 8 shows a set of prisms after the de-tensioning procedure on the dead-end of the prestressed bed (Dead end stress operations did not occur). Spalling was noticed on the prism having 1/2in edge distance.

Figure 8: Observed Cracking

Figures 9 and 10 present Crack Area and Crack Length respectively as a function of the edge distance of the prisms. With reducing the values of edge distance more cracks appeared, and crack lengths are higher.

Figure 8: Crack Area (in²)

Figure 9: Crack Length

3.2. WB wire Type using Mix#2

Mix design number 2 used Granite as aggregate and Table 3 shows the mix properties.

Table 3: Concrete Mix Design Used Granite as Aggregate

Material	Weight Lbs/yd ³
Cement	813.8
Water	260.4
Crushed Granite	1447
Sand	1447
Adva Cast 530	81 fl.oz/yd ³

Figure 11 shows the longitudinal strain profile for the prism having 3/4 in edge distance. The values for transfer lengths are enormous. This results from the large magnitudes of longitudinal surface strain that go along with longitudinal splitting of the prism. The values of transfer lengths imply that wire type WB exhibits poor performance.

Figure 11: Longitudinal Strain Profile

The average crack width was 0.02in and the average crack length was approximately 15 in.

Figure 12: Crack Area

Figure 13: Crack length

According to Figures 12 and 13 WB wire type performed better using Granite in comparison to crushed gravel.

3.3. WB wire Type using Mix #3

Mix Design #3 had uncrushed local Pea Gravel and had poor performance resulting in high values of crack areas and crack lengths as shown in Figures 14 and 15.

Material	Weight (lbs./yd ³)
Cement	780
Water	249.6
Uncrushed Gravel	1526
Sand	1526
Adva Cast 530	81 fl.oz/yd ³

The maximum crack width on the live end of the prism with a 3/4 in edge distance was 0.05in and the maximum crack length was 32in. On the other side, the maximum crack width was 0.04in and the maximum crack length was 27 in.

Figure 14: Crack Area

Figure 15: Crack Length

3.4. WB wire Type using Mix #4

To diminish the crack lengths and crack areas in prisms using WB wire type in Mix#1 25% fly ash replacement was added. According to the results shown in Figure 16, adding fly ash into the mixture has a slight effect on 3/4in.-edge distance prisms. Overall, the substitution of fly ash negatively affects prisms in terms of splitting cracks.

Figure 16: Crack length measurements for prisms with 0 and 25% Fly ash

3.5. Effect of Fiber Reinforcement

During the years of research, it was well-established that reinforcing concrete can lead to a greater crack resistance [10], [11]. To improve the mechanical properties of concrete material, polymer fibers have been widely used with different percentages.

To increase the mechanical properties of the concrete a monofilament polypropylene micro-fiber was also added to the concrete of a select number of

prestressed prisms. This Fiber complied with ASTM C 1116, Standard Specification for Fiber Reinforced Concrete and Shotcrete.

Figure 17: Polymer Fiber [10]

Polymer Fiber of 5% was added to Mix#3 and according to experimental investigation, it was concluded that better results were achieved. The number of detectable cracks declined by more than 30% when polymer fiber was used. However, the number of splitting cracks was reduced at 1/2-in. edge distance.

There is a significant improvement in crack propagation resistance when polymer fiber is used.

Figure 18: Crack length measurements for prisms with 0% and 5% polymer fiber

Figure 18 shows the crack length measurements using WB wire type and concrete mixture #3 with fiber polymer.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this study, the following four primary conclusions are drawn.

- The edge distance is the most significant parameter to prevent longitudinal splitting in prestressed concrete members. According to previous research conducted at Kansas State University by Naga Bodapati, WB wire type did not split having 1 in tendon edge distance.
- The second significant parameter is the wire indent characteristics. According to research conducted by A. Savic [3], [4], [5] the shallow chevron type of wires did not split on the prisms having 3/4in edge distance. The indent wire type affects the edge distance, according to all results the minimum edge distance for WB wire type and deep chevron wire types is 1.25in.
- The third important parameter which affects longitudinal splitting is a concrete mixture. Concrete mix using fiber polymer showed the best performance and increase splitting resistance. Fly ash in concrete mixture had a negative impact on splitting resistance.

- The fourth important parameter is concrete maturity at the time of the de-tensioning procedure. In this research 4500psi compressive strength was examined since that all prestressed concrete tie manufacturer de-tensioning procedure commenced at that time. Higher compressive strengths at the transfer of prestressing also correspond to a higher Modulus of Elasticity (MOE). The higher MOE causes increased lateral stresses and serve to diminish much of the benefit aspect of the increased tensile strength.

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Uticaj različitih vrsta agregata, letećeg pepela i polimera ojačanog vlaknima na otpornost na kidanje u prethodno zategnutim betonskim železničkim vezama

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Ovim istraživanjem procenjuje se uticaj različitih tipova betonske mešavine, korišćenjem plitkog tipa udubljenja žice, različitog rastojanja ivica i čvrstoće betona na granicu kidanja u prednapregnutim betonskim železničkim pragovima. Ispitana čvrstoća betona bila je 4500 psi. Istraživanje je bilo eksperimentalno, a deo ovog istraživanja je formalno adaptiran u Arema Standards for railway Engineering Chapter 30 section 4.2.4.

Ključne reči: Teške mašine, Mašinstvo, Građevinarstvo