Semi-Annual Progress Report

TIDC Transportation Infrastructure Durability Center AT THE UNIVERSITY OF MAINE

Project Number and Title: 3.5 Prevention of Stressed-Induced Failures of Prestressed Concrete Crossties of the Railroad Track Structure
Research Area: New Systems for Longevity and Constructibility
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Reporting Period: *10/01/2018 and 3/31/2019*
Date: *3/31/2019*

Overview:

The problem we are trying to solve is to understand and mitigate premature failures of prestressed concrete crossties. One of the failure modes is associated with the bonding mechanisms between prestressing wires and concrete. In practice, there are many types of prestressing wires with different indentations which result in different bonding mechanisms. In order to characterize the different bonding mechanisms with various prestressing wires, phenomenological methods either using a cohesive model or simplified springs have been predominantly utilized for finite element analysis due to the efficiency of the methods. During the project period, a physics-based modeling approach is used develop a detailed prestressed wire and concrete block model, and numerical analyses have been conducted based on both a direct solver method and a parallel computing algorithm. Figure 1 shows an example of two different indented wires, 3D CAD wire models, and meshed wires with detailed indentations. The parallel computing analysis involves creating indented wire models using a 3D CAD software, importing into a finite element (FE) software, properly meshing the complex-geometries, partitioning the meshed model into a number of subsections, and analyzing the model with a great number of CPUs or cores available. The prestressing wire models comply with the general dimensions provided by ASTM A881/A881M as shown in Figure 2, where a is the depth of the indentation, P is the nominal pitch, and L is the nominal length. In this project, different geometrical characteristics of indentations including a, P, and L are directly modeled and simulated. In these two models, the cut depth, a is equal to 0.0045 in., P is equal to 0.215 in, and L is equal to 0.138 in. In addition, a smooth wire with no indentations is modeled.

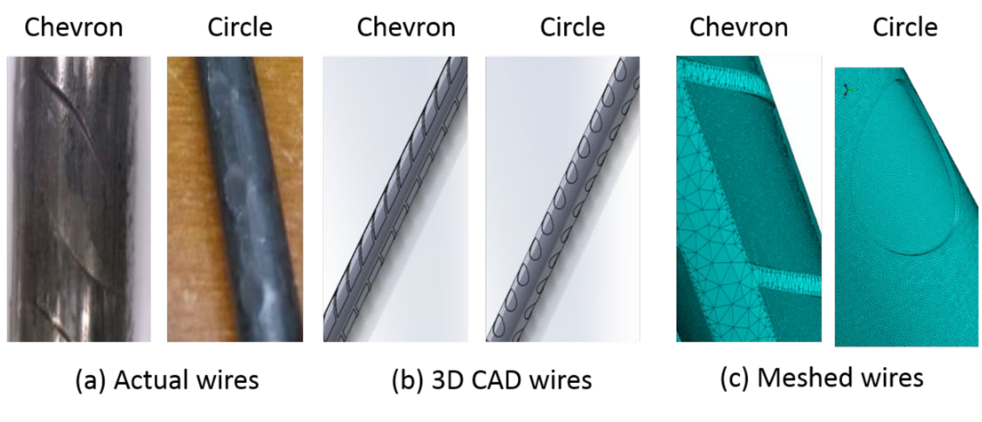


Figure 1. Actual, CAD, and Meshed Wires

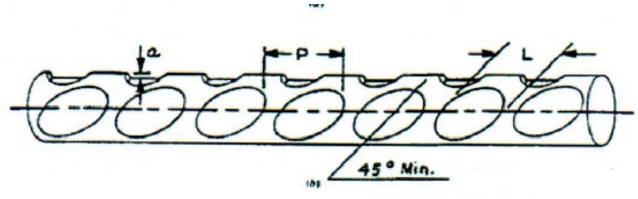
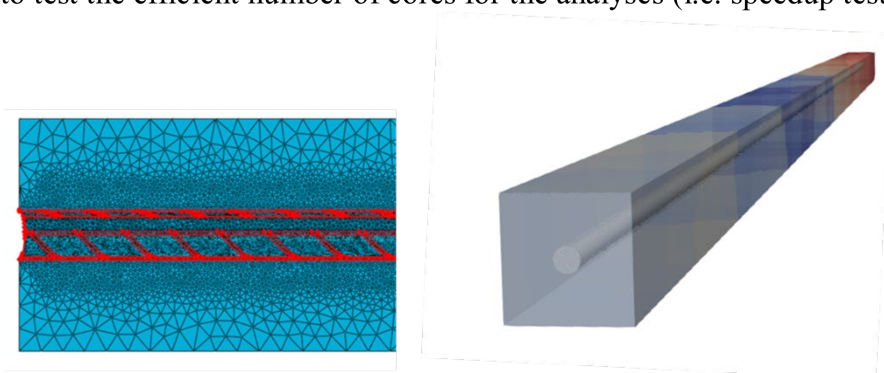


Figure 2. General Wire Dimensions (ASTM, 2016)

In order to have detailed mesh of complex geometries, the quadratic or linear tetrahedral elements are used together with the free mesh technique. This allows a user to simply assign approximate element sizes to certain regions. Because of the large number of degrees of freedom of the models, the analysis requires the high-performance computer (HPC). The high-performance computer uses node clusters. Partitioning the meshed model and then performing the analysis is done using a parallel computing algorithm, which is built around utilizing MPI library, PETSc Library, and METIS library. Figure 3 shows the detailed mesh of concrete block at the interface between concrete and a chevron pattern wire, and visualization of a prestressed concrete prism with a wire after the mesh was partitioned into 256 parts; the total number of the elements of the concrete prism with the prestressing wire is about 13 million elements due to the complex geometries at the interface. The different colors indicate each partitioned part. After the original mesh has been partitioned into 256 parts, which can be a variable depending on the size of the model, a varying number of cores (16~256) were used to perform numerical analyses to test the efficient number of cores for the analyses (i.e. speedup test).



(a) Complex meshed geometry at the interface

(b) Partitioned Single-wire prism

Figure 1. An example of the complex mesh at the interface between concrete and a prestressing wire (a) and a partitioned concrete prism with a wire (b).

WNE research team with undergraduate students has been attempting to utilize locally available resources (e.g. aggregates) to develop an engineered cementitious material (ECM). 3 in x 6 in concrete cylinders made of only cement, water, and aggregates obtained from a local aggregate quarry in the state of Connecticut were prepared and the compressive strength of the cylinders was measured. Figure 4. (a) and (b) show the compressive strength results of the cylinders, and the sieve analysis result of the aggregates, respectively. The following experiments will be performed to develop a durable ECM suitable for railroad concrete crossties: (1) changing aggregate size distribution, (2) implementation of cementitious materials and nanoparticles, and (3) addition of various fibers.

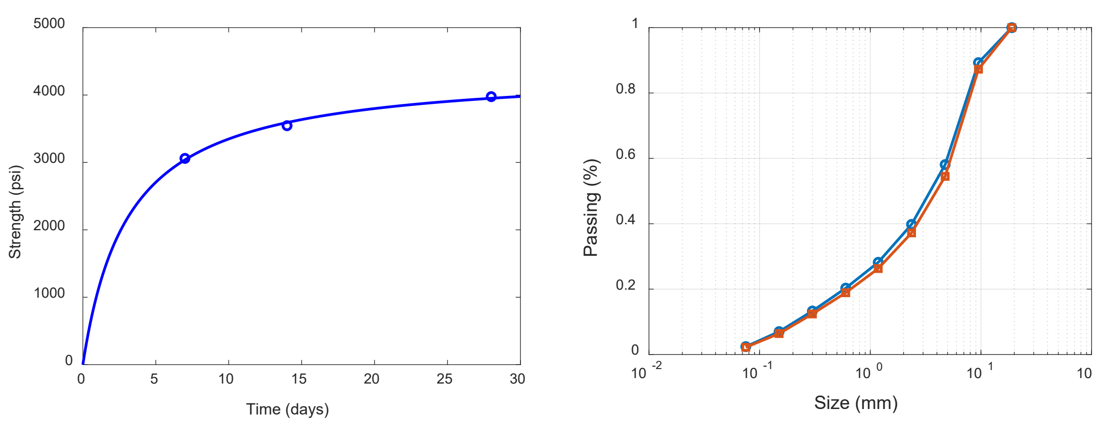


Figure 4. (a) Compressive strength test results and (b) the sieve size analysis for the local aggregates.

Participants and Collaborators:

XSEDE: University of Texas at Austin – Providing an access to their High performance computer, Stampede2 in TACC

Dr. JaeHyuk Kwack at the Argonne National Laboratory as a collaborator

Cy Riding, Master's student in Civil Engineering, building numerical models and conducting numerical simulations

Isaiah Colombani, Senior in Civil Engnieering, preparing concrete cylinders and setting-up experiments

Changes:

N/A

Planned Activities:

1. We are planning to conduct a series of a pull-out test with different indentation in order to characterize the different bond-mechanisms between prestressing wires and surrounding concrete block.
2. We will come up with an optimized concrete mix design to mitigate splitting failure
3. We will keep developing detailed prestressed concrete prism models with different parameters.

References:

ASTM A881 / A881M-16a, (2016) Standard Specification for Steel Wire, Indented, Low-Relaxation for Prestressed Concrete, ASTM International, West Conshohocken, PA