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AUTOMATED SYSTEM FOR CONCRETE CROSSTIE TRANSFER LENGTH MEASUREMENT

SUMMARY

This research result was part of a larger project entitled, "Quantifying the Effect of Prestressing Steel and Concrete Variables on the Transfer Length in Pretensioned Concrete Crossties," conducted by Kansas State University (KSU) and sponsored by the Federal Railroad Administration (FRA). This report documents the advances made to determine the transfer length of pretensioned concrete railroad ties using non-contact (optical) strain measurement and digital image correlation. The full technical report can be downloaded from the K-State Research Exchange.

The work produced two, fully functional, longitudinal strain measurement and transfer length assessment devices that address specific needs of the industry. The devices are: (1) an automated computer-controlled traversing device (Figure 1) and (2) a 6-camera stationary strain field measurement system (Figure 2). In addition to controlled laboratory testing, KSU researchers extensively field-tested both devices in actual tie plants. Performance results are compared here both in terms of longitudinal strain profile measurement capability and in the devices' ability to accurately assess transfer length.

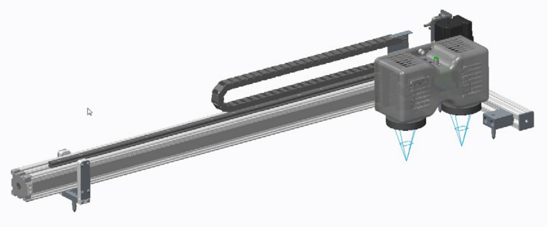


Figure 1: The automated laser-speckle imaging (LSI) strain sensor

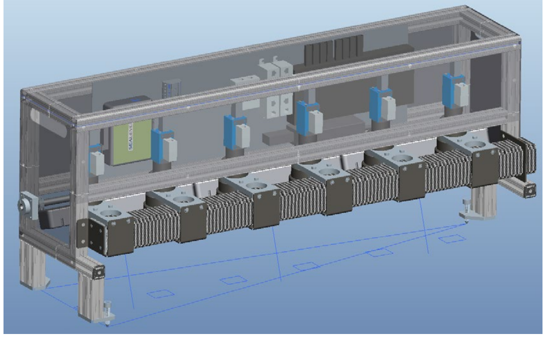


Figure 2: 6-camera strain measurement system

BACKGROUND

Prestressed concrete railroad ties are fabricated by casting concrete around pretensioned steel wires or strands. After the casting process is complete and the concrete has sufficiently cured, a de-tensioning procedure takes place. Transfer length is defined as the distance required to fully develop (or transfer) the prestressing force into the concrete.

Figure 3 shows an idealized, bi-linear crosstie strain profile superimposed above a section of track. For a prestressed concrete tie to function adequately over its expected service life, the prestressing force must fully transfer before reaching the rail seat. The transfer length should be less than the distance from the rail seat to the end of tie – approximately 21 inches. This transfer length parameter is key to ensuring the load-bearing capacity of the tie in track.

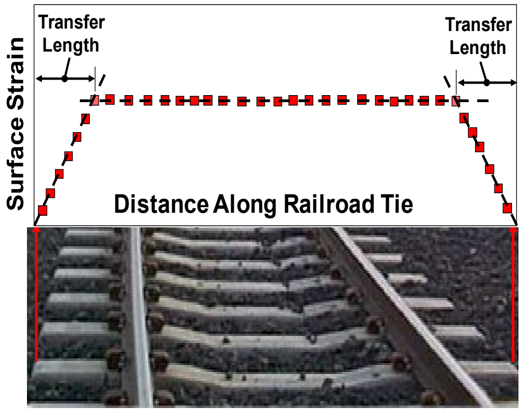
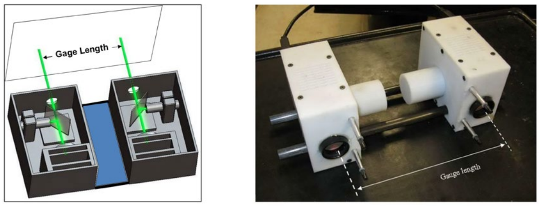


Figure 3: Schematic of transfer length

Determining transfer length requires (1) measuring the longitudinal surface strain profile along a pretensioned concrete railroad tie and (2) calculating the transfer length from the measured surface strain profiles using some prescribed computational algorithm. Traditionally, these measurements were made using a manual mechanical device known as a Whittemore gage.

Under prior work, KSU researchers developed a non-contact method to measure surface strains using Laser-Speckle Imaging (LSI). is shown in Figure 4 shows the dual-module prototype optical strain sensor. It has two identical modules attached rigidly to each other in a mirrored setup with each module capable of detecting the surface movement independently. This unique modular design had adjustable gage length. The device was a significant improvement over the Whittemore gage method, but was not an automated system. Extensive in-plant testing validated this LSI strain measurement and transfer length method.



(a) CAD drawing (b) Modular prototype
Figure 4: The modular laser speckle strain sensor

OBJECTIVES

The objectives of this research were to automate the process of measuring transfer lengths on concrete ties in a manner suitable for production environments. The goal was to enhance the prototype 2 camera LSI and to explore the potential of a multi-camera version of the LSI to further improve the measurement speed without sacrificing accuracy.

METHODS

The research effort can be divided into two key phases. During Phase I, the key objective was to create an automated version the LSI and then apply this system to extensive in-plant testing of crossties manufactured using 15 different prestressing types (wire and strand). The Advanced Manufacturing Institute (AMI) at Kansas State University automated the hardware and software of the existing Laser Speckle Imaging (LSI) System.

Phase II of the project involved the design and in-plant testing of a multi-camera version of the LSI system to further improve the sped of measurement. This prototype system used 6 independent, fixed cameras mounted to a common support, and provided 5 independent measurements of surface strain with an equivalent 6-in. gage length (the spacing between the cameras).

Phase 1 efforts produced an automated system to determine transfer length by measuring longitudinal strain in a real-time continuously scanning/traversing (CST) manner, over the entire range of interest on the tie associated with transfer length development [1] (Figure 5). A schematic of the overall automated transfer length measurement system, with LabVIEW based traverse control and data acquisition, is shown in Figure 6.

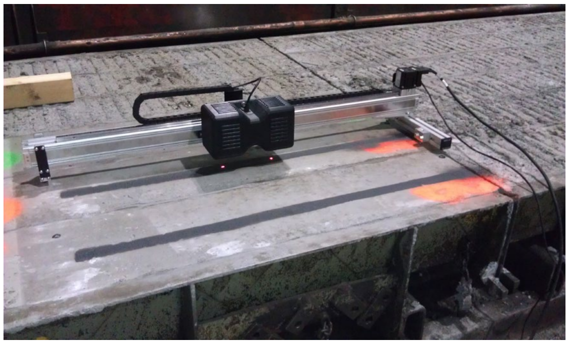


Figure 5: Automated LSI traversing system on concrete crossties in a plant facility

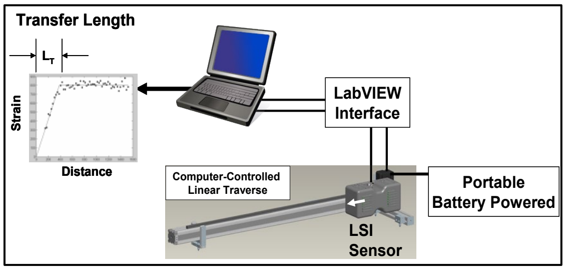


Figure 6: Overall automated LSI traversing system

The processing of transfer length from longitudinal surface strain data with the automated system is based on a new statistical method referred to as the ZL (Zhao-Lee) method. It uses a least square technique, which accounts for the shape factor variation along the length of a tie. The ZL method has been successfully applied to hundreds of transfer length measurements on real concrete railroad crossties and also on prisms and prismatic ties. In phase 2, an investigation of the effect of sampling interval using the ZL method revealed that a strain sampling interval (corresponding to a gage length) as large as 6 inches is sufficient to yield transfer length results within about ±1.5 inches. Figure 7 shows the experimental and theoretical verification of this result , which indicates that as few as 5 discrete strain measurements are needed for accurate transfer length assessment.

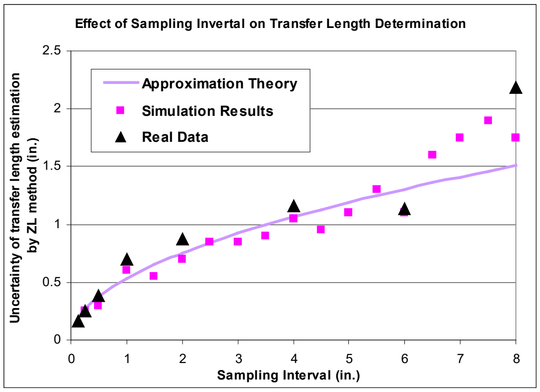


Figure 5: Effect of sampling interval on transfer length uncertainty

This led to the development of the stationary 6-camera system shown schematically in Figure 8.

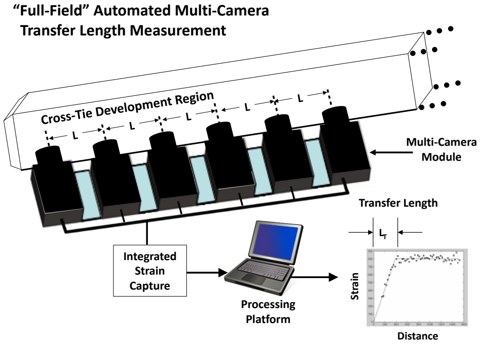


Figure 6: Schematic of a multi-camera system

RESULTS

This research succeeded in developing and testing two automated methods for determining concrete tie transfer lengths. Hundreds of in-plant transfer length measurements were made to validate performance. Both the traversing, 2-camera system and the stationary 6 camera system produce high-quality data. A sample of the current strain measurement capability is shown in Figure 9, along with results from the stationary 6-camera system. This level of measurement resolution has never before been achieved in a production plant situation. The system has a nominal strain measurement resolution of about ±20 microstrain, at traversing speeds of up to several inches per second. The device was further shown to resolve differences in the strain profiles (and associated transfer length) between crossties in adjacent rows within the same tie casting cavity.

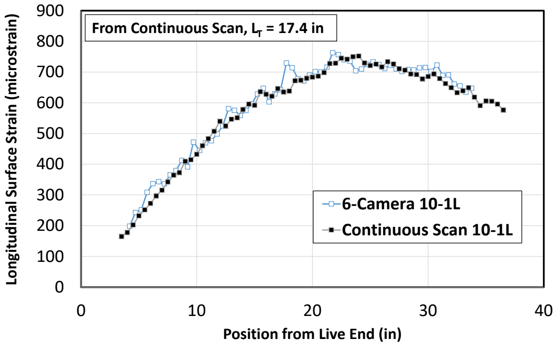
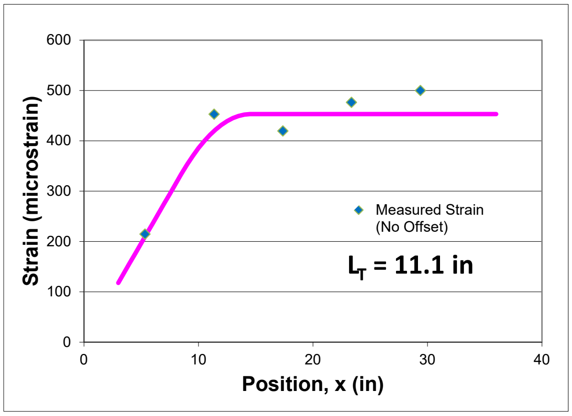
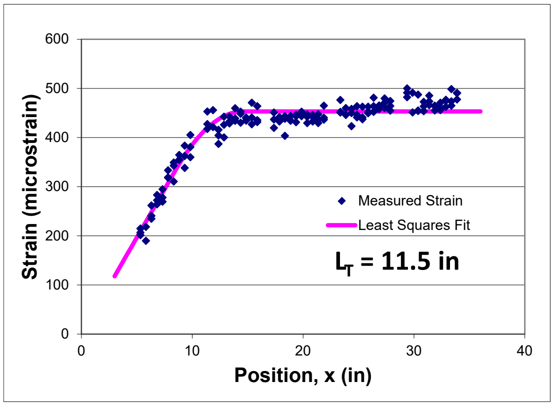


Figure 9: In-plant crosstie strain measurements

Figure 10 shows the capability of the stationary 6-camera system in resolving transfer length with as few as 5 discrete strain measurements.



(a) Single 5-point strain data with Least Squares fit (pink)



(b) 30-point grid overlay

Figure 70: Strain profile from multi-camera system

CONCLUSIONS

This research documents new non-contact technology for measurement of railroad tie strain and transfer length: (1) A 6-camera stationary system, and (2) An automated traversing system. The capability of this new technology was extensively demonstrated in the laboratory and in the tie manufacturing plant setting. It was used in conducting hundreds of in-plant transfer length measurements. Results show unprecedented resolution of strain profile shape for in-plant measurements, with capability to even resolve differences in the strain profile (and associated transfer length) between adjacent rows within the same tie casting cavity.

FUTURE ACTION

The new technology has high potential for both in-plant diagnostic testing, and practical statistical characterization of in-plant transfer length measurement for quality control.

REFERENCES

[1] Beck, B.T., Robertson, A.A., Peterman, R.J., and C. J. Wu, C-J. (2016). Performance of a Continuously Traversing 2-Camera Non-Contact Optical Strain Sensor for In-Plant Assessment of Prestressed Concrete Railroad Crosstie Transfer Length. *JRC2016-5751*.

[2] Beck, B.T., Peterman, R.J., Wu, C-J., and Bodapati, N.N. (2015). In-Plant Testing of a New Multi-Camera Transfer Length Measurement

System for Monitoring Quality Control of Railroad Crosstie Production. *JRC2015-5749*.

[3] Beck, B.T., Robertson, A.A., Peterman, R.J., and Wu, C-J. (2019). Automated Optical Surface Strain Measurement System for Concrete Railroad Crosstie Transfer Length Measurement. Manhattan: Kansas State University.

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KEYWORDS

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